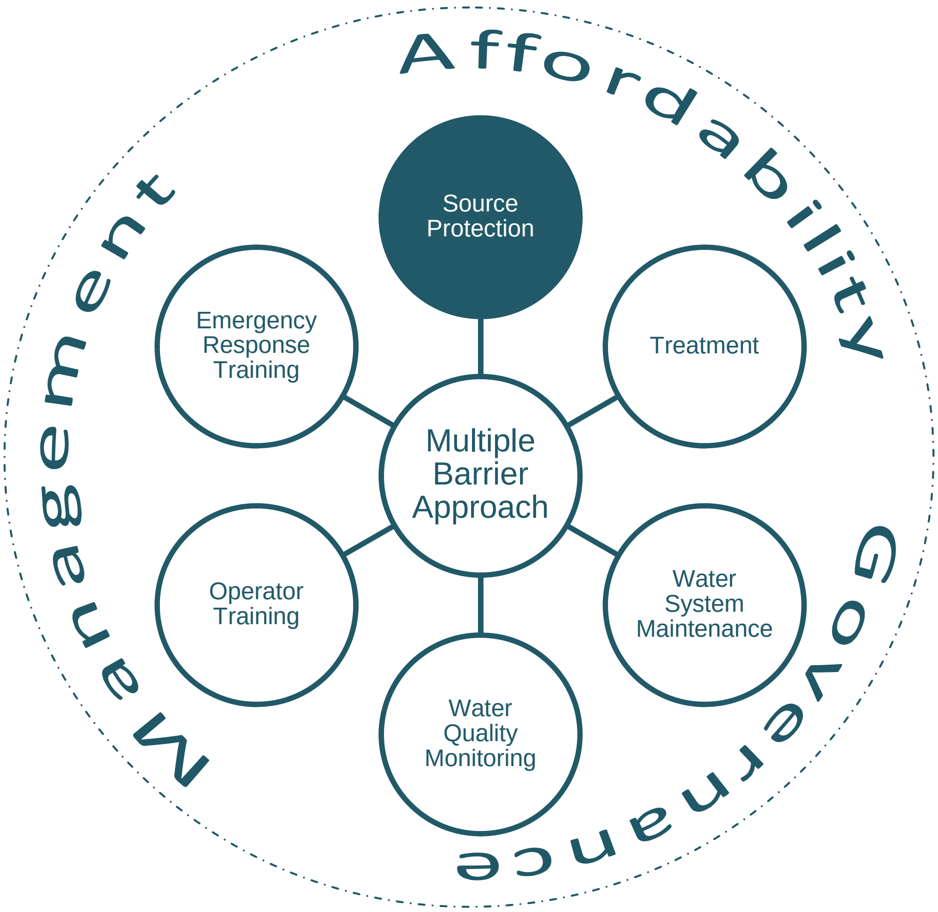
COMPREHENSIVE DRINKING WATER SOURCE-TO-TAP ASSESSMENT GUIDELINE

MODULE 1

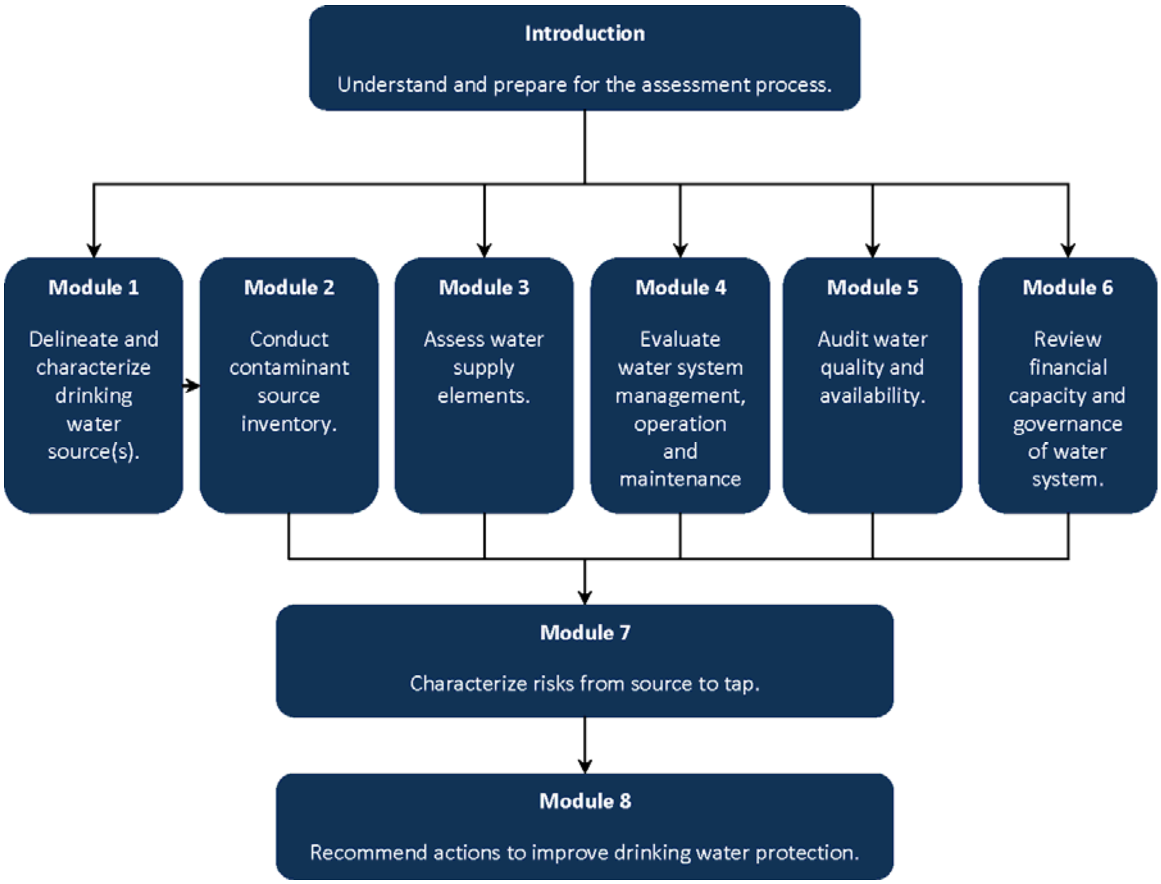
DELINEATE AND CHARACTERIZE DRINKING WATER SOURCE(S)



2010

Ministry of Healthy Living and Sport

Comprehensive Drinking Water Source-to-Tap Assessment Guideline Process



Here are the steps in the source-to-tap assessment process, through the Introduction and eight modules. Note that the Introduction should be read prior to undertaking any assessment.

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1. INTRODUCTION

Source water assessment is a crucial component of a source-to-tap assessment because it increases understanding of:

- The location and characteristics of the water source area
- Natural processes that influence source water quality and availability:
  - Source water is the primary determinant of tap water quality, and source water determines the type and level of treatment necessary to produce safe drinking water.
  - The amount of water accessible for the drinking water supply system is determined by source water availability and other water users.
- Activities and decisions in the water source area that influence the drinking water supply.
- Possible impacts of climate change on the water source.
- The impact that sanitary condition and location of water capture mechanisms (e.g., intakes and wells) can have on water quality.

Module 1 (this module) of the source-to-tap assessment involves delineating and characterizing the drinking water source area, and the extent and boundaries of the land area contributing water to the intake or well. The type of water source and its unique hydrologic setting determine the nature and size of the drinking water source area. Table 1-1 defines drinking water source areas for the four general source types: streams and rivers, lakes, springs and wells.

Table 1-1. Drinking Water Source Type and Corresponding Source Areas

Source Type	Drinking Water Source Area	How to Define Drinking Water Source Areas
Streams and Rivers Sources where water is withdrawn: • Directly from a stream or river through an intake • From a small constructed reservoir or impoundment on the stream • Through an infiltration gallery near a stream	Contributing watershed	The topographically defined area draining to the drinking water point of diversion
Lakes and Reservoirs Sources where water is withdrawn through an intake pipe directly from a lake or reservoir	Contributing watershed	The topographically defined area draining to the lake or reservoir

Source Type	Drinking Water Source Area	How to Define Drinking Water Source Areas
Springs Naturally occurring groundwater discharges collected through pipes, drainage channels or trenches	Spring source area	The land area that contributes recharge to the groundwater flow system that supplies the spring
Drinking Water Wells Drinking water wells are constructed holes or conduits extending from the surface to beneath the ground, where they are designed to penetrate water-yielding geologic deposits, making groundwater available for consumption. They include drilled wells, dug wells and wells under the influence of surface water. Aquifers are the water-saturated geologic formations that yield significant quantities of water to wells and springs.	Capture zone	The land area corresponding to the portion of the aquifer supplying water to a pumping well

Watersheds—source areas for streams, rivers, lakes and reservoirs—can be determined with certainty. However, delineation of well capture zones and spring source areas is done with much less certainty, due to the hidden nature of the groundwater resource.

This module outlines recommended methods for delineating drinking water source areas for all types of water sources. Additionally, this module provides guidance on describing the intrinsic characteristics of water source areas, and evaluating the integrity and location of the intake or well.

Figure 1-1 illustrates how to select the assessment process (and which section of this module to use) based on the type of source being assessed. The overall process for delineating and characterizing drinking water sources in Module 1 is similar for groundwater sources (wells and springs) and surface water sources (such as streams, rivers, lakes and reservoirs). However, the assessment components are conducted in a slightly different order, due to inherent differences in the water setting.

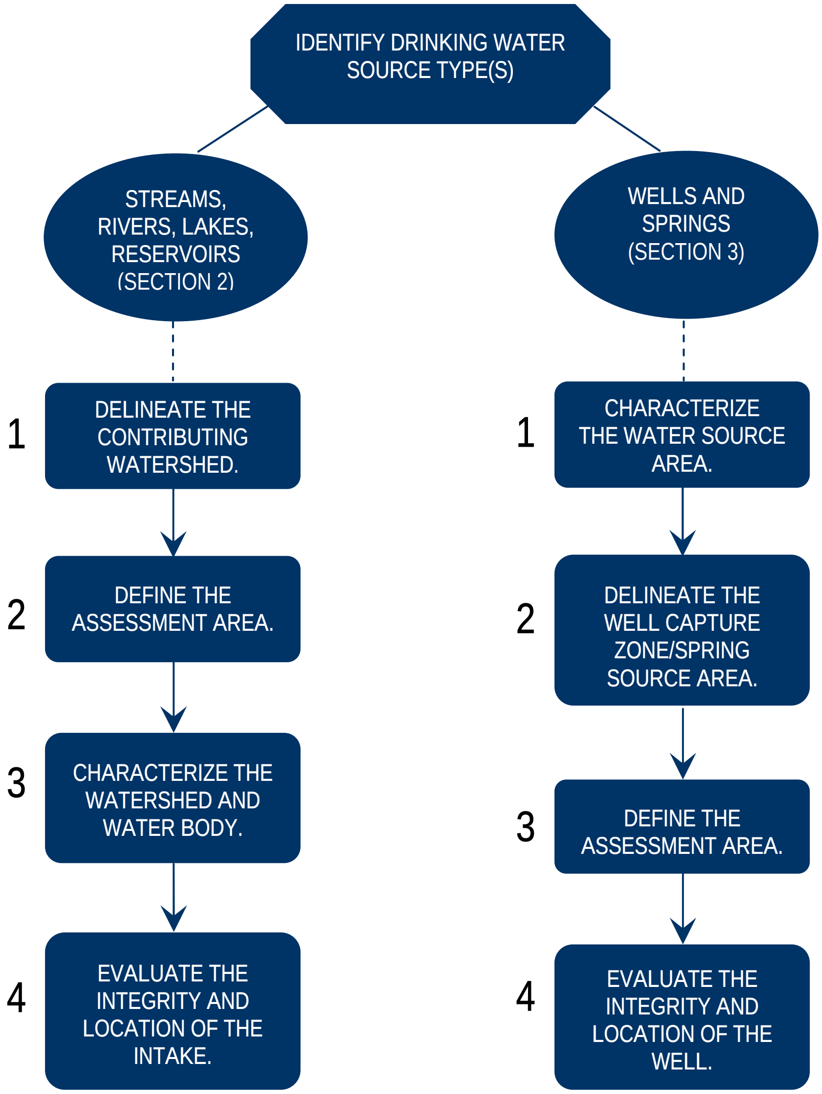


Figure 1-1. Flow Diagram of Assessment Process for Module 1, Based on Drinking Water Source Types

1.1. Module 1 Assessment Process

For surface water sources, the delineation of the contributing watershed and assessment area precedes the characterization phase, though some preliminary analysis of topographic, geological, physical, climatic or biological information may be required to define the assessment area for large watersheds.

For stream, river, lake or reservoir source, use Section 2 of Module 1 (Assessment Components for Stream, River, Lake and Reservoir Water Sources) as a guide through the following process:

1. Delineate the contributing watershed area.

2. Define the assessment area.
3. Characterize the watershed and water body.
4. Evaluate the integrity and location of the water intake.

For wells and springs, the unique aspects of the aquifer must be understood through characterizing the water source area before the capture zone can be delineated. Section 3 (Assessment Components for Well and Spring Sources) is a guide through the Module 1 assessment process for wells and springs:

1. Characterize the aquifer.
2. Delineate the capture zone/spring source area.
3. Define the assessment area.
4. Evaluate the integrity and location of the well/spring.

Delineating Water Source Areas

- Surface water: Step 1
- Groundwater: Step 2

The purpose of source area delineation is to identify the area from which water flows to the intake or well. This is the area that supplies water to the drinking water system. Activities and conditions in this area determine the quality and amount of water being supplied to the intake or well.

Defining Assessment Areas

- Surface water: Step 2
- Groundwater: Step 3

An assessment area is defined by the assessment team, in collaboration with stakeholders, for the purposes of serving as the area in which the contaminant source inventory in Module 2 is undertaken, and in some cases, the region where source area characterization in Module 1 occurs.

An assessment area may or may not be exactly the same area as the drinking water source area, depending upon a number of factors related to the type of source. Since the assessment area is defined in Module 1, it must always precede Module 2. Table 1-2 identifies the assessment areas for each source type. These are discussed further in Section 2 for surface water sources and Section 3 for groundwater sources.

The assessment area is different from the water source area because:

1. It includes an intake/well protection zone of at least 100 metres radius.
2. It may consist of a smaller subset of the contributing watershed if is too large to reasonably assess and risks are not perceived to be high.

3. It may include additional delineated areas such as for groundwater under the influence of surface water and for distant aquifer recharge areas.

The latter two circumstances are discussed in more detail where they apply. The purpose of applying an intake/well protection zone is two-fold:

1. To delineate the area closest to the intake/well where an intensive contaminant source and hazard identification takes place, based on the principle that the closer a hazard or contaminant source is to the intake or well, the greater the risk.
2. To identify potentially hazardous conditions and activities occurring immediately downstream, not otherwise captured in a source area delineation. Downstream hazards can be nonstationary or mobile sources of contaminants (e.g., residential areas: sources of domestic pets and possible vandalism, and air emissions).

Table 1-2. Assessment Areas by Drinking Water Source Type

Source Type	Assessment Area
All watersheds	Contributing watershed + Intake protection zone (min. 100 m radius around intake)
Streams with watersheds >500 km^2	Portion of contributing watershed (e.g., time of travel, corridor zones, fixed radius) + Intake protection zone (min. 100 m radius around intake)
Lakes with watersheds >500 km^2	Portion of contributing watershed (e.g, time of travel, corridor zones, fixed radius) + Intake protection zone (min. 100 m radius around intake)
Springs	Spring source area + Intake protection zone (min. 100 m radius around spring)
Wells	Capture zone + Well protection zone (min. 100 m radius around well)

Characterizing the Drinking Water Source

- Surface water: Step 3
- Groundwater: Step 1

Characterization involves an evaluation and analysis of the source water characteristics and the land within the assessment area to provide insight into the biogeophysical influences on water quality and quantity. The objectives of the characterization of the source area are not only to describe the biogeophysical and biochemical features of the drinking water source, but also to evaluate their implications for water quality and availability.

Evaluating the Integrity and Location of the Intake/Well

- Surface water: Step 4
- Groundwater: Step 4

Integrity refers to the quality of design, construction, sanitary aspects and state of repair of infrastructure. Location or siting of intakes and wells can influence water quality and should be positioned to obtain the best available source-water quality and ensure a sustainable drinking water supply.

If a water supply system uses multiple drinking water sources, Modules 1 and 2 are to be conducted for each source separately.

1.2. Hazard and Vulnerability Identification

Throughout the process of evaluating water supply elements in the source-to-tap system, assessors identify and describe hazards that pose a threat to drinking water safety or sustainability, and vulnerabilities in the multiple barrier system or other protective systems (e.g., security).

Hazards are recorded in the Hazard Identification Table (see Table 1-6), which is used to document hazards in a consistent way throughout the source-to-tap assessment process. Information on strengths and vulnerabilities in the drinking water supply system identified throughout the assessment is recorded, compiled from each module, and used to inform the multiple barrier system evaluation in Module 7.

1.3. Module 1 Assessment Team

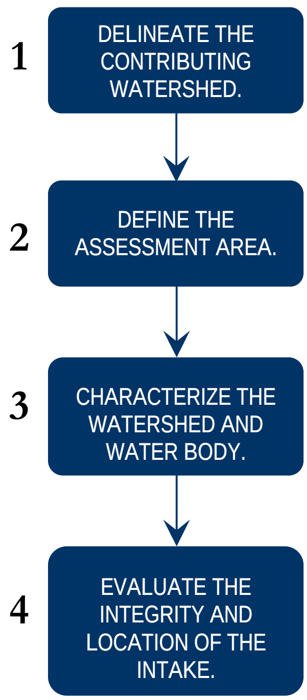
A broad range of issues can exist in a water supply system from source to tap. As a result, comprehensive drinking water assessments require a multidisciplinary assessment team rather than a single assessor. Each module of the Comprehensive Drinking Water Source-to-Tap Assessment Guideline requires some specialized skills and a unique spectrum of knowledge related to water sources and systems.

Collectively, the assessment team for Module 1 should have knowledge and experience related to:

- Hydrology and limnology (surface water sources).
- Hydrogeology (groundwater sources).
- Wells and well construction (wells).
- Spatial analysis and mapping.
- Public health issues related to drinking water.
- Water chemistry.
- Microbiology and microbes commonly found in drinking water.

- Legislation related to drinking water, surface water, groundwater risk assessment and risk management.

2. ASSESSMENT COMPONENTS FOR STREAM, RIVER, LAKE AND RESERVOIR WATER SOURCES



If a drinking water source is a stream, river, lake or reservoir, the assessment process for Module 1 is as follows:

1. Delineate the contributing watershed area.
2. Define the assessment area in which to conduct the source characterization and potential contaminant source inventory.
3. Characterize the watershed and water body.
4. Evaluate the integrity and location of the intake.

2.1. Delineate the Contributing Watershed Area

The purpose of source area delineation is to identify the land area from which water drains to the intake, also referred to as the contributing watershed area. To define the watershed area, a precise location is required for the intake or point of diversion (POD). If the intake has not previously been georeferenced using latitude and longitude coordinates, obtain lat/long or UTM coordinates so the intake can be accurately mapped.

To delineate the contributing watershed boundary and determine the size of the watershed, use a topographic map of a suitable scale, GIS platform or iMapBC (http://webmaps.gov.bc.ca/imfx/imf.jsp?site=imapbc). Mark the points of highest elevation upslope of the intake and connect them (Figure 1-2).

2.2. Define the Assessment Area

For most surface water sources, the assessment area includes the contributing watershed or portion plus an intake protection zone—a circular area surrounding the intake with a radius of at least 100 metres (Figures 1-2 and 1-3). When defining the protection zone, the assessment team should use professional judgement and experience to ensure that site specific conditions are taken into consideration. The purpose of delineating an assessment area is to define the area in which assessment activities occur, such as source characterization in Module 1 and the contaminant source inventory conducted in Module 2.

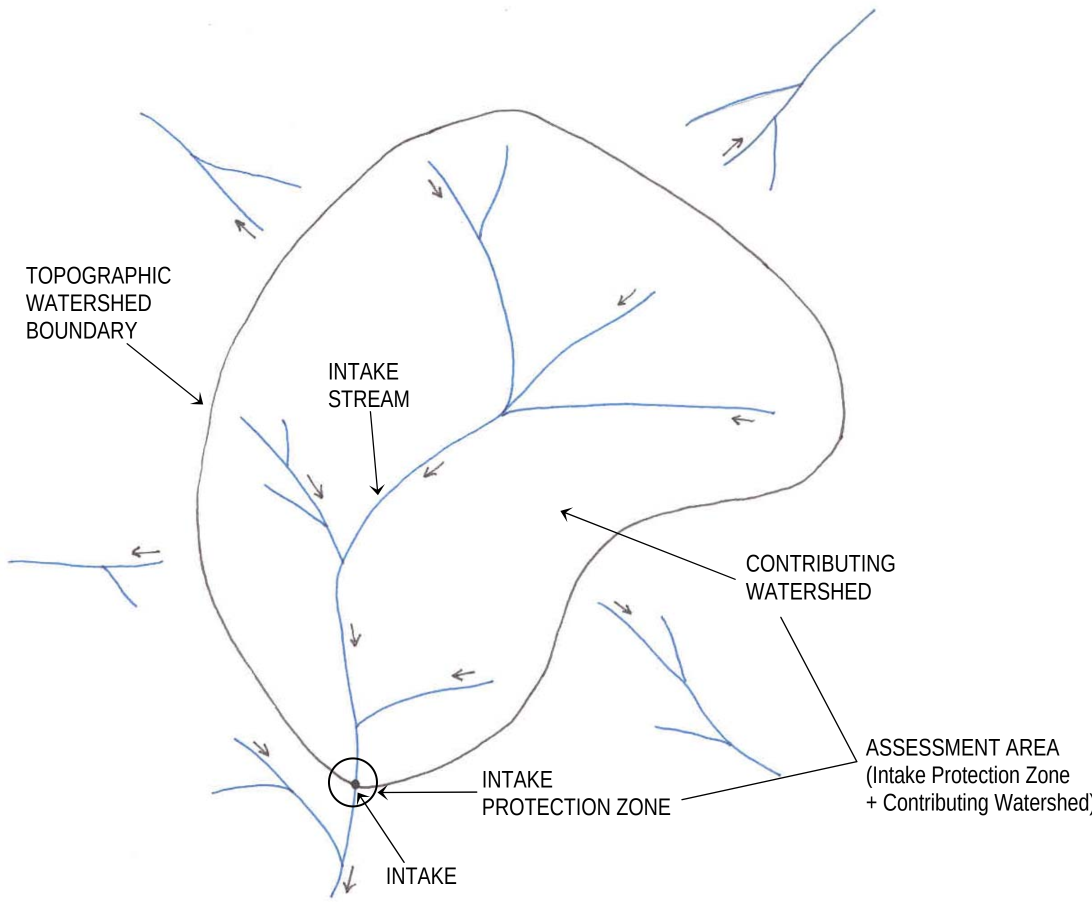


Figure 1-2. Example of Source Area and Assessment Area Delineation for a Stream Source with a Watershed 500 km^2 in Area or Less

Contributing watersheds for some water bodies are so large, however, that it would be too onerous and unnecessary for some water providers to characterize and identify all the potential hazards and contaminant sources in the entire area.

Where contributing watersheds are >500 km^2 and risks are not high, a smaller, more focused area may be delineated to characterize and carry out the contaminant source inventory in Module 2. Assessment areas of all watersheds with areas of 500 km^2 or less[1] shall include the entire contributing watershed area and the intake protection zone.

[1] A minimum watershed area of 500 km^2 was established as a sufficiently large size that assessments could become excessively onerous on small water systems. This limit is also consistent with the maximum area of *Forest and Range Practices Act* Community Watersheds. For watersheds under 500 km^2, watershed assessments are often performed and contain valuable biogeophysical information. This type of existing watershed assessment would not necessarily be available otherwise for watersheds in excess of 500 km^2.

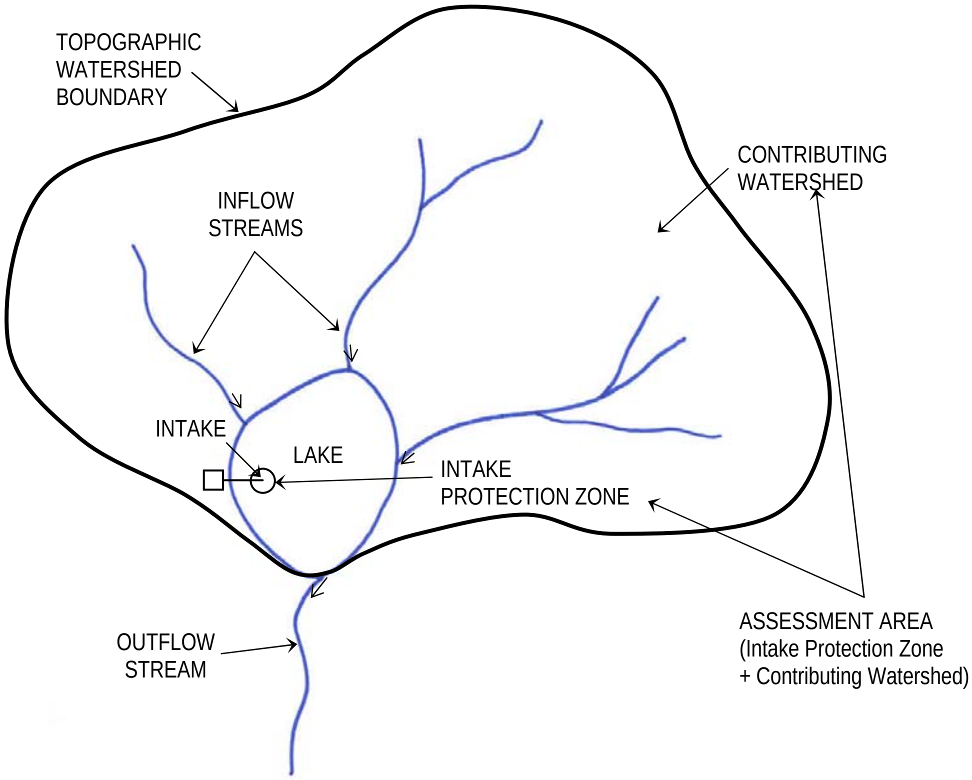


Figure 1-3. Example of Lake Watershed and Assessment Area Delineation for Watersheds 500 km^2 in Area or Less

Several methods for defining assessment areas exist, many of which produce corridor zones along water bodies (see Appendix 1D), or define other areas in the watershed perceived to have a significant influence on the water source.

Professional judgment, and available methods and tools, should determine the method used. Regardless of the approach applied, the assessment area should be designed to be conservative, include areas most susceptible to hazards, and where possible, defined based on site-specific characteristics. Supporting rationale for selecting an assessment area should be provided in the assessment report.

Some preliminary source characterization will be required in order to define the assessment area. Data elements that may be useful for delineating the assessment area for surface water sources are presented in Section 2 of Appendix 1C. Two arbitrary methods for defining assessment areas where resources do not allow for a physically defined assessment area are presented in Appendix 1D.

2.3. Characterize the Watershed and Water Body

Characterization involves an evaluation and analysis of the source water characteristics and the land within the assessment area to provide insight into the biogeophysical and biogeochemical influences on water quality and quantity. The objectives of the characterization of the source area are not only to describe the biogeophysical features of the drinking water source, but also to evaluate their implications for water quality and volume.

Box 1-1. Intrinsic Watershed Characteristics that Can Affect Source Water Quality

- Climate
- Relief/topography
- Geology
- Terrain stability; soil types, textures, drainage
- Channel stability
- Vegetation type, abundance and distribution; presences and condition of wetlands, riparian areas
- Wildlife
- Fire
- Total impervious cover

When characterizing the source area for surface water sources, identify intrinsic influences on water quality or quantity focusing on the factors with the greatest public health threat—such as sediment sources and wildlife populations acting as hosts for pathogenic organisms.

Intrinsic aspects of the watershed refer primarily to natural biogeophysical features, rather than human activities that are addressed in the Contaminant Source Inventory in Module 2 (see Box. 1.1) One exception to this is that the total impervious cover in the watershed should be identified in the source characterization because of its influence on runoff patterns and corresponding stream flows. Factors that influence lakes in particular include stratification, internal cycling, and productivity (CCME, 2004).

Some sources of data for the water source characterization step include watershed assessments, land use reports, raw water quality test results, field inspections and maps. Appendix 1C lists suggested information elements (with data sources) to review in the source characterization. This list is not exhaustive, nor is it intended to be prescriptive or inflexible.

2.3.1. Characterize Source Water Quality and Quantity Monitoring Data

Characterizing raw water quality and quantity data involves determining the status and assessing trends over time, and evaluating the effectiveness of source water protection mechanisms. Understanding the quality of raw water is important because it prescribes the treatment needed to produce potable water. Rapid, significant changes in water quality can have an impact on the ability of a water treatment plant to perform optimally. Water quality is linked to quantity when low water levels cause higher temperatures and algal growth, or when large precipitation and/or snow melt events drive sediment loading and increased turbidity.

The purpose of analyzing water quantity data is to determine if the water source will be able to sustain future demands. This evaluation is based both on projected population estimates for the water service area and a water balance for the source over the next 10 years, including groundwater recharge capacity, taking into account any trends observed in water flow and climate data. A water balance estimate is to be conducted at the discretion of the assessor, where critical water quantity issues have been identified (see Appendix 1B for resources).

For streams and rivers, analyze water quality and flow over time using available reliable data or field/laboratory measurements. For lakes/reservoirs, evaluate trends in water levels and summarize other evident seasonal or other patterns. Data should be collected at different times of the year and over multiple years to gain an understanding of the seasonal and annual variation. Where they are observed, determine the causes of water quality changes (e.g., rainfall, snowmelt, temperature, changes in the watershed).

Historical water quality and flow data for water sources may not be available. In these circumstances, raw water quality samples should be obtained from the source and analyzed for possible contaminants of concern. Otherwise, it may be necessary to use limited results, data available from nearby hydrometric stations or observation wells, or base evaluations on qualitative observations. If few raw water data are available, identify the lack of raw water quality data as an issue in the assessment report and make recommendations for action as appropriate.

2.4. Evaluate the Integrity and Location of the Intake

Integrity refers to the quality of design, construction, sanitary aspects, and state of repair of infrastructure. Location or siting of intakes can influence water quality and should be positioned to obtain the best available source water quality where turbidity is low. Ideally, lake or reservoir intakes should be able to withdraw water at multiple depths to adapt to stratification patterns that influence water quality at different depths. Intakes should also be constructed and positioned to protect against animals and vandalism. Table 1-3 lists the set of factors to consider when evaluating the integrity and locations of intakes in streams, rivers, lakes and reservoirs.

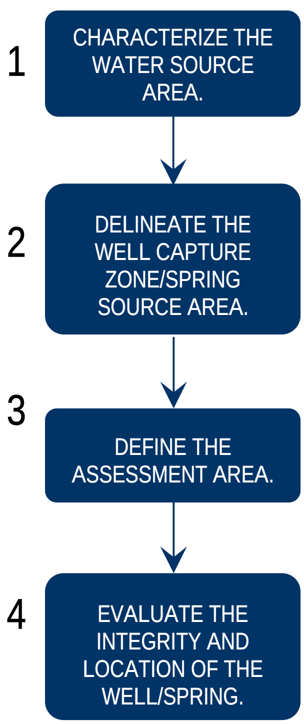
Table 1-3. Factors for Evaluating the Integrity and Location of Intakes

Streams and Rivers	Lakes and Reservoirs
• Intake location and depth • Accessibility for inspection and cleaning • Water circulation patterns • Bank stability and potential for localized erosion • Bottom sediment buildup and siltation • Protection from other uses • Potential for ice formation • Protection from animals and vandalism	• Factors influencing water flow in lakes: o lake morphology/bathymetry o inflow and outflow o lake stratification patterns (water temperature/density) o wind strength, direction, and duration • Ability to alter the depth of the intake to capture the best quality water • Protection from animals and vandalism

3. ASSESSMENT COMPONENTS FOR WELL AND SPRING SOURCES

For well and spring water sources, the approach in Module 1 of the source-to-tap assessment guideline is to conduct the hydrogeologic characterization before delineating the source area and defining the assessment area, as follows:

1. Characterize the water source area.
2. Delineate the well capture zone/spring source area.
3. Define the assessment area.
4. Evaluate the integrity and location of the well/spring.



Several terms can be applied to groundwater source areas, including **capture zone** and **well protection zone**, defined below in the context of this guideline:

A **capture zone** is the land area corresponding to the portion of the aquifer that contributes water to a pumping well. Assessment activities should be focused on the well capture zone, unless site-specific information or uncertainty in the delineation suggests that the contaminant source inventory should be conducted beyond the estimated capture zone area.

The **well protection zone** is the area within a minimum 100-metre radius of the well. This zone should be given the most scrutiny in the assessment as it is the area of highest risk.

An understanding of the hydrogeologic setting is required to estimate the location and size of the well capture zone/spring source area. Therefore, it is necessary that the source characterization be conducted before delineating the source area and assessment area.

3.1. Characterize the Water Source Area

Characterization involves an evaluation and analysis of the source water characteristics and the land within the assessment area, in order to provide insight into the biogeophysical influences on water quality and quantity. The objectives of the characterization of the source area are not only to describe the biogeophysical features of the drinking water source, but also to evaluate their implications for water quality and volume.

Characterizing raw water quality and quantity data involves determining the status and assessing trends over time, and evaluating the effectiveness of source water protection mechanisms. Understanding the quality of raw water is important because it prescribes the treatment needed to produce potable water. Rapid, significant changes in water quality can have an impact on the ability of a water treatment plant to perform optimally.

3.1.1. Wells

Understanding basic aquifer characteristics and well pumping rates is critical to delineating a more accurate capture zone area. Therefore, the source characterization must precede capture zone delineation. The information required to characterize the aquifer and to delineate the well capture zone is listed in Appendix 1E.

An understanding of a well's vulnerability to contamination from the surface is an important element of source characterization. Aquifer type (e.g., bedrock vs. sand and gravel; confined vs. unconfined) will provide an indication of this vulnerability. However, given the heterogeneity of geologic features, a measure of the vulnerability of the aquifer at the well site or in the capture zone area—such as the Aquifer Vulnerability Index (AVI) or the DRASTIC method (see Appendix 1F)—may provide a more quantifiable estimate of vulnerability, and can be used to identify areas where the aquifer is most vulnerable. Other natural hazards or vulnerabilities include arsenic-bearing minerals in an aquifer, salt water intrusion in coastal areas, and wells under the direct influence of surface water.

Analyze raw well water quality as part of the source characterization to identify the natural chemical and physical features of the water and existing contamination problems. Well pumping data, information on nearby pumping wells and aquifer levels should be evaluated for water volume concerns. See Appendix 1E for other data elements recommended to characterize aquifers and capture zones.

Groundwater under the Direct Influence of Surface Water

A well is considered to be under the direct influence of surface water when a well draws water directly from an adjacent surface water body and/or contains indicators of surface water contamination (e.g., coliforms, chlorophyll *a*, viruses and protozoan cysts).

Groundwater is usually free of harmful microbes. Wells under the influence of surface water are of special concern because a pumping well can induce surface water to flow from a stream, lake or surface runoff into the aquifer and well. Where there is minimal or undependable subsurface filtration, microbial contaminants can enter the well where they are not always expected.

Determining if a well is under the direct influence of surface water should be done using site-specific information on well construction, geology, proximity to surface water source, seasonal water table fluctuations, elevation of the well compared to surface water source and presence of water quality contaminants characteristic of surface water.

3.1.2. Springs

Springs are naturally occurring groundwater discharge features. Spring occurrence is linked to geologic setting and can be categorized into the following general spring types (Kreye et al., 1996):

- **Depression springs** occur where the water table intersects the ground surface.
- **Contact springs** occur at or near the base of the underlying confining unit.
- **Fault/fracture/joint springs** occur along faults, fractures, or joints where they intersect the land surface.
- **Karst springs** occur where solution channels in limestone and dolomite intersect the land surface.
- **Lava springs** occur where lava tubes, interbeds, or cooling joints intersect the land surface.

A spring source or catchment area is "the land area that contributes recharge to the groundwater flow system that supplies the spring" (Kreye et al., 1996). Geology, topography, and climate control the groundwater flow to springs and determine the area and extent of a spring source area. Understanding how these factors influence groundwater flow assists in defining the source area. In view of this, the spring source characterization must be performed before delineating the catchment area. Springs can be complex in their hydrogeology; therefore, the delineation and characterization of source areas for springs are not simple.

Source characterization for springs includes analyzing the topographic and geologic settings, understanding aquifer characteristics, water table elevations, precipitation discharge relationships, and water chemistry. With an understanding of its hydrogeology, a spring can be classified, its flow regime identified and its source area delineated.

Where data are available, analyze raw water quality status and trends for a spring over time to reveal information about the flow regime and geology of the aquifer, and any issues regarding raw water quality (e.g., nitrate, arsenic and bacteria). Examine spring discharge data (if available) to characterize water flows to the source and any seasonal or long-term discharge trends. See Appendix 1E for other data elements recommended to characterize spring source areas.

3.2. Delineate the Well Capture Zone/Spring Source Area

The purpose of the source area delineation is to identify the area from which water flows to the well or spring. Water source areas for wells are called *capture zones*. Source areas for springs are referred to simply as *spring source areas*.

To define a well capture zone or spring source area, a precise location is required for the well or spring. If geographic coordinates are not available for the well/spring, obtain latitude/longitude or UTM coordinates so the intake can be accurately mapped.

3.2.1. Wells

There are six recognized approaches to delineating capture zones for drinking water wells, presented here in order of increasing complexity and accuracy:

1. **Arbitrary fixed radius**: prescribing a circular area with an arbitrarily defined fixed radius around the well.
2. **Modified arbitrary fixed radius**: applying an arbitrary fixed radius plus the watershed area uphill of the well.
3. **Calculated fixed radius**: calculating an area around the well idealized from the volume of water pumped from the well.
4. **Analytical equations**: using analytical equations developed for specific hydrogeologic conditions.
5. **Hydrogeologic mapping**.
6. **Numerical modeling** of the groundwater flow.

Each of these methods is described briefly in Appendix 1G. The information required to delineate the well capture zone varies, depending on the delineation method applied. However, understanding basic aquifer characteristics and well pumping rates is critical to delineating a more accurate capture zone area. Appendix 1E lists the data elements required to delineate the capture zone.

Table 1-4 specifies the <u>minimum</u> well capture zone delineation methods for each water system type in the given hydrogeologic setting. The leftmost column (Water System Type) lists the categories of water system by size. The remaining four columns to the right list the minimum delineation method for the four general hydrogeologic settings.

Table 1-4. Suggested Well Capture Zone Delineation Methods, Based on Water System Size and Hydrogeologic Setting

Water System Type	Unconfined Sand and Gravel Aquifers	Confined Sand and Gravel Aquifers	Well in Area of High Well Density in Sand and Gravel Aquifers	Fractured Bedrock and Lava Aquifers
*** For all wells, delineate a well protection zone — 100 metre (330 foot) radius around well.**				
WS1c (20,000+ connections)	Analytical equations and hydrogeologic mapping	Analytical equations and hydrogeologic mapping	Numerical modeling	*There are no known water systems in B.C. that fall in this category.*
WS1b (10,001-20,000 connections)	Analytical equations and hydrogeologic mapping	Analytical equations and hydrogeologic mapping	Numerical modeling	
WS1a (301-10,000 connections)	Analytical equations	Analytical equations	Analytical equations and hydrogeologic mapping	Analytical equations and hydrogeologic mapping
WS2b (101-300 connections)	Analytical equations	Analytical equations	Analytical equations	Analytical equations and hydrogeologic mapping
WS2a (16-100 connections)	Calculated fixed radius	Calculated fixed radius*	Calculated fixed radius♦	Analytical equations
WS3 (2-15 connections)	Calculated fixed radius	Calculated fixed radius*	Calculated fixed radius♦	Arbitrary fixed radius (AFR) or modified AFR♦
WS4 (1 semi-public connection)	Calculated fixed radius	Calculated fixed radius*	Calculated fixed radius♦	Arbitrary fixed radius (AFR) or modified AFR♦

* Note that flow from a contaminant source is more likely to be lateral in confined aquifers as opposed to vertical as CFR method implies.
♦ Water systems in these circumstances may need regional or joint delineations.

The arbitrary fixed radius (AFR), modified arbitrary fixed radius (modified AFR), and calculated fixed radius (CFR) approaches are suggested for small water systems (WS2a or smaller) where pumping rates are typically low, and where more physically based methods may not be warranted. Analytical solutions, hydrogeologic mapping and numerical modeling are recommended for larger water systems and more complex hydrogeologic settings where more physically based delineations are needed, requiring professional hydrogeologic expertise.

Table 1-4 specifies minimum recommended delineation methods for each type of situation. However, assessors should use the most physically based method possible using available data and resources. Although generally more time consuming and costly, using a more physically based method will provide a more accurate capture zone that is technically sound.

For all water systems, if insufficient hydrogeologic data are available to use the recommended minimum capture zone delineation method and reasonable efforts have been made to obtain the data, then a method of lesser accuracy may be used **as a temporary measure**. For example, if CFR is the recommended minimum method and there is no driller's log, and the pumping rate for the well in not known, the AFR may be used until sufficient information on the pumping rate and aquifer thickness can be obtained to do a CFR delineation.

Community wells that are completed into confined aquifers may be vulnerable to contamination from distant recharge area(s)[2] for the aquifer. For this reason, the delineation of the capture zone may involve identifying and delineating the distant recharge areas so that potential contaminant sources can also be identified in those areas.

There are two important points to note about capture zone delineation. First, capture zone boundaries are not as certain as watershed boundaries by nature of the fact that they are delineated based on point-based, subsurface information. Second, unlike watersheds, capture zones can change over time because groundwater flow rates and direction, pumping rates and patterns can change over time. Otherwise, the capture zone functions the same as a watershed in that it defines the area that feeds water to the intake (well) and becomes the area on which to focus source assessment and protection efforts.

3.2.2. Wells under the Influence of Surface Water

If a well is suspected to be under the influence of surface water, capture zone delineation may not be suitable and a different approach to delineating an assessment area may be employed. One common approach to defining assessment areas for wells under the influence of surface water is to delineate the watershed for the adjacent lake or stream. Assessors will need to use professional judgement in

[2] A distant recharge area for a confined aquifer is the location where the aquifer materials become unconfined and percolation from the surface to the aquifer occurs.

delineating assessment areas for wells under the influence of surface water and may use methods not provided in this guideline.

3.2.3. Springs

Spring source area delineation is inherently less certain than delineating watershed areas for other surface water sources. Spring delineation is based on point subsurface geologic data, whereas watersheds are delineated by topography, which is defined throughout the catchment area. Spring source area boundaries can also change over time as new data become available, as water extraction rates change, or if there are significant changes in well pumping in or near the source area. Uncertainty and revisions to the source area boundaries need to be taken into account in interpreting spring source areas.

Spring-Fed Water Systems with More than 15 Connections

Water systems with more than 15 connections and relying on a spring source should follow the delineation approach outlined in *Defining the Source Area of Water Supply Springs* (http://www.env.gov.bc.ca/wat/wq/reference/springwater.pdf) (Kreye et al., 1996). This guidance document summarizes eight methods used in defining spring source areas. Methods included are based on topography, geology, water balance, water table contours, water chemistry, spring discharge hydrographs, tracers and an arbitrary delineation. *Defining the Source Area of Water Supply Springs* outlines a general approach for delineation. It includes compiling and analyzing data, developing a conceptual model, conducting a site investigation and delineating the source area.

Contrary to watershed delineation, spring source areas are not as easily definable. Most often, they require the use of more than one approach to delineate a source area with reasonable certainty. Using combined methods, the resulting source area will more accurately reflect the actual area contributing water to the spring, but using this approach requires the expertise of an individual with experience in hydrogeology. Due to the inherent uncertainty associated with spring source area delineation, it is critical that data supporting delineations and assumptions are documented in the assessment report.

Spring-Fed Water Systems with 15 Connections or Less

The physically based spring source area delineation methods outlined above will require substantial hydrogeological expertise to implement, and smaller water systems may not have adequate resources. Water systems with 15 connections or less may use a semi-arbitrary delineation approach (Figure 1-4). This approach would, at a minimum, consist of delineating a circular area with a radius of 300 metres (1000 feet) around the spring, extending the upslope boundary to the height of land (as for a watershed).

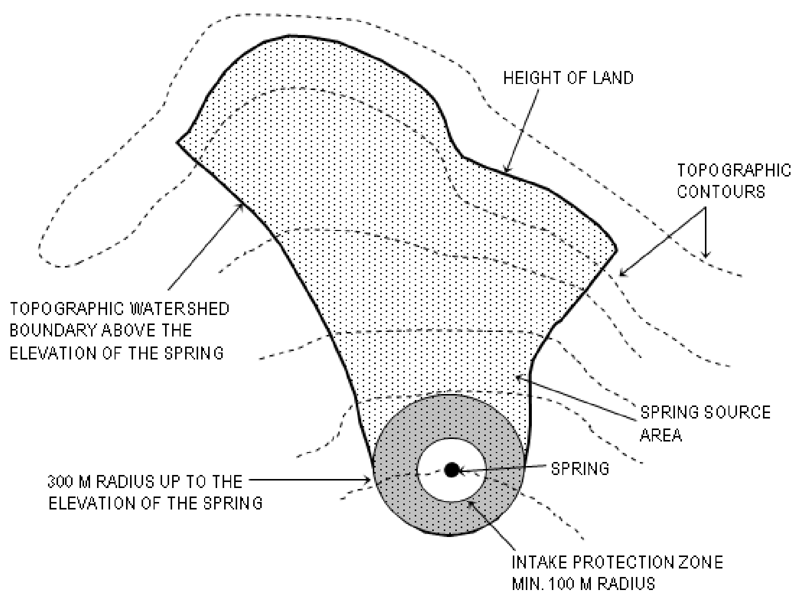


Figure 1-4. Example of Semi-Arbitrary Spring Source Area Delineation

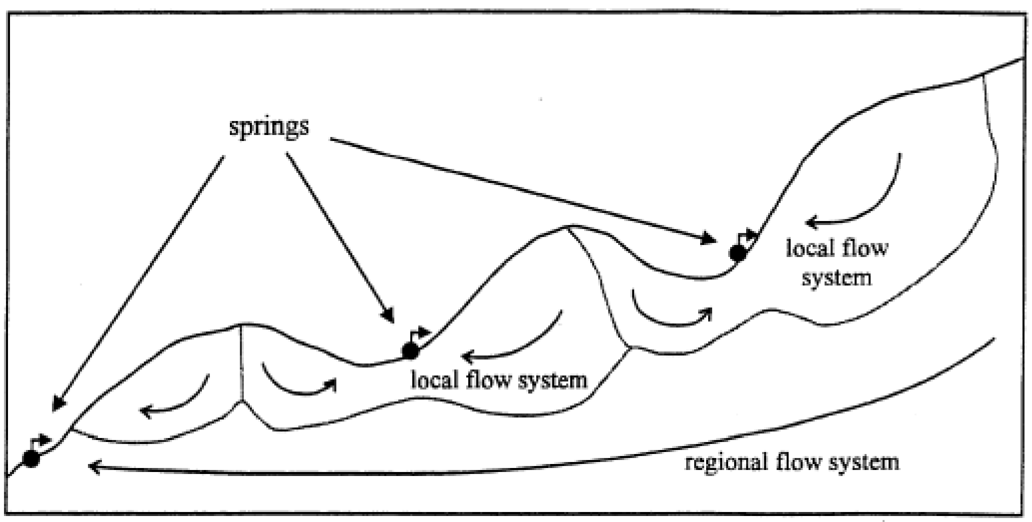


Figure 1-5. Influence of Topography on Local and Regional Groundwater Flow Systems and Locations of Source Areas for Springs
(from Kreye et al., 1996)

It is important that professional judgment be used in applying the semi-arbitrary spring source area delineation method. Understanding the nature and occurrence of the spring can assist in determining the appropriateness of this simple delineation method. Water quality and the permanence and variability of flow in the spring can indicate whether or not the spring is part of a regional flow system or a local flow system (Figure 1-5). For example, a highly mineralized spring with constant flow would indicate a regional flow system, suggesting that the arbitrary source area delineation method may not reflect the actual area contributing to the spring.

3.3. Define the Assessment Area

The purpose of the source area delineation is to identify the area from which water flows to the well or spring. The assessment area for groundwater sources includes a combination of the delineated source area and a well/spring protection zone, an area of at least 100 metres radius around the well or spring (Figure 1-6). The well/spring protection zone serves as an area of intensive scrutiny for evaluating the integrity and location of source water capture infrastructure, and for the contaminant source inventory in Module 2.

In certain situations, assessment areas may also include distant recharge areas for confined aquifers or watershed areas delineated for groundwater under the influence of surface water. Professional judgment should be used to identify these situations and define the assessment area accordingly.

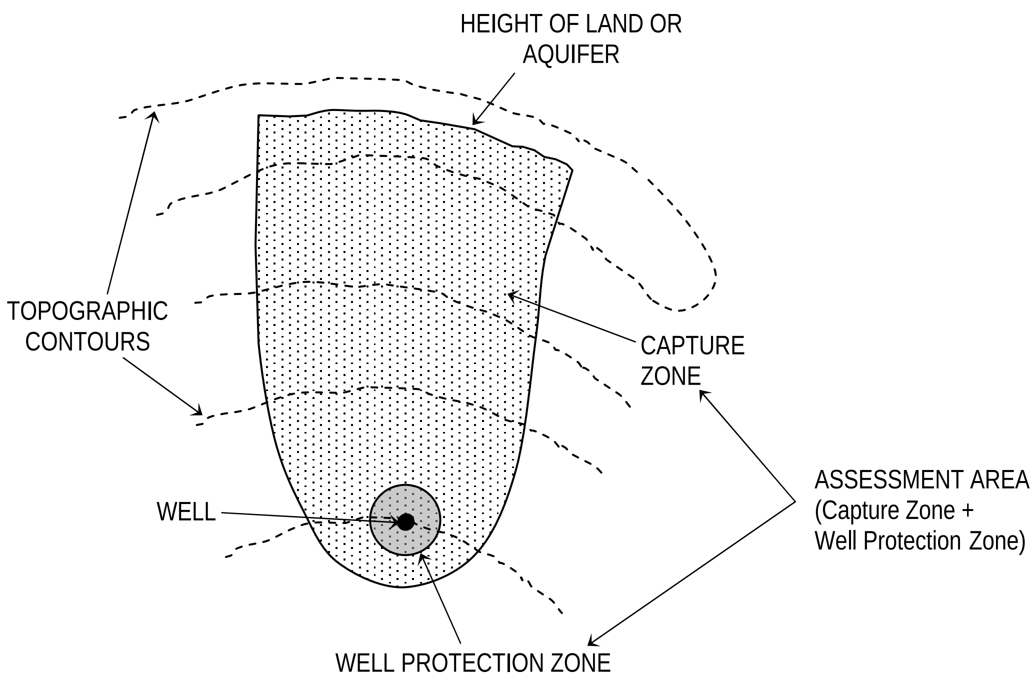


Figure 1-6. Example of Capture Zone Delineation Using Analytical Equations

3.4. Evaluate the Integrity and Location of the Spring/Well

Integrity refers to the quality of design, construction, sanitary aspects and state of repair of infrastructure. Location or siting of wells and springs can influence water quality, particularly if the area is susceptible to flooding. Springs and wells should be constructed and positioned to protect against animals, vandalism and flooding. They should also be reasonably accessible for repairs or maintenance.

One special consideration for the location of wells is determining if they are under the direct influence of surface water. If a well is deemed to be under the direct influence of surface water, the water it takes in may contain pathogens not normally expected in groundwater, and pose a hazard if the water is not disinfected. Table 1-5 lists aspects to consider when evaluating the integrity and location of wells and springs, but is not intended to be an exhaustive list. Additional site-specific factors influencing drinking water safety should also be examined.

Table 1-5. Aspects to Consider in Evaluating the Integrity and Location of Wells and Springs

Wells	Springs
• Construction method • Location • Depth (wells) • Surface completion method • Cap/cover • Sanitary grout seal that prevents surface water from flowing into or down the well • Condition of the well and its components • Siting (horizontal: distance to contaminant sources or hazard; vertical: susceptibility to flooding) • Presence, design and condition of pumphouse • Floodproofing • Protection from other uses • Protection from animals and vandalism	• Water capture infrastructure • Location • Cover/enclosure • Condition of the spring and its components • Siting (horizontal: distance to contaminant sources or hazard; vertical: susceptibility to flooding). • Presence and condition of pumphouse • Floodproofing • Protection from other uses. • Protection from animals and vandalism

4. ASSESSMENT DOCUMENTATION AND REPORTING

4.1. Assessment Report

Assessment reports should include, at minimum, the following elements from Module 1 for each water source:

- Map(s) showing:
  - Accurate location of intake, well or spring.
  - Water source area boundaries.
  - Assessment area boundaries.
  - Important biogeophysical information.
- Rationale for the source area delineation method used, including substantiating hydrogeologic data for the spring source area and well capture zone delineations. Any uncertainty associated with source delineations should also be documented.
- Description and characterization of the source area, including intrinsic hazards and vulnerabilities. Source characterization information should be presented in map, graphical, and/or tabular form, where possible.
- Completed hazard identification table for Module 1 (see Table 1-6 for an example).

4.2. Hazard Identification Table

Drinking water hazards identified in Module 1 should be entered into the Hazard Identification Table as shown in Table 1-6. Hazards are numbered to indicate the module in which they are identified and use a sequential numbering system for the hazards within a module.

Hazard numbering is slightly more complicated when there are multiple drinking water sources for one water supply system: a letter can be assigned to each source to differentiate among hazards. If two sources are being assessed, a stream and a well, hazards identified for the stream can be identified with an “a” after the hazard number, and hazards associated with the well can be designated with a “b”. See the examples shown in Table 1-6.

Table 1-6. Sample Module 1 Hazard Identification Table

Hazard No.	Drinking Water Hazard	Possible Effects	Existing Preventative Measures	Associated Barrier(s)
1-1a	High turbidity levels during spring freshet	High turbidity indicates the presence of suspended particulate matter, such as sediment, organic material and microorganisms. Unless filtered, particulate matter can reduce the effectiveness of disinfection, potentially causing illness if pathogens are present.	Feedback/ compound loop control system uses water flow metering and chlorine residual analyzer to signal chlorinator dose rate. Turbidity levels and chlorine residuals are measured and recorded continuously.	Source protection, treatment
1-2a	Slope failure in watershed	Landslides have occurred in the past. Slope failure could result in increased sediment load. See possible effects for 1-1a.	See 1-1a.	Source protection, treatment
1-3a	Wildlife in watershed	Wildlife serves as hosts for pathogenic organisms such as *giardia, crypto-sporidium*, and others.	Membrane filtration, chlorine disinfection with adequate contact time	Source protection, treatment
1-4b	Well at risk of flooding and not floodproofed		None identified	Source protection
1-5b	Aquifer classified as IA (heavily developed and highly vulnerable) under the British Columbia Aquifer Classification system	IA aquifers are most vulnerable to contamination from the surface because there is no layer of clay or till stopping contaminants from infiltrating the groundwater. High demand for water is another threat for IA aquifers.	None identified	Source protection

APPENDIX 1A: MODULE 1 ASSESSMENT AT A GLANCE

For Streams, Rivers, Lakes and Reservoirs

Component	Recommended Methods	Scope	Documentation and Reporting
1. Delineate the watershed area.	• Topographic delineation	• Streams, rivers, lakes, reservoirs, surface water-fed infiltration galleries	• Map with watershed delineated • Area of watershed
2. Define the assessment area.	• Intake protection zone (min 100 m radius) + watershed area. *OR:* • Intake protection zone (min 100 m radius) + o Corridors (fixed length, time of travel). o Arbitrary fixed radius from intake. o Custom delineation based on risk associated with certain biogeophysical or human features.	• All watersheds • Watersheds >500 km^2	• Map with assessment area demarcated • Supporting information and rationale for defining assessment area
3. Characterize the water source area.	• Assess bio-geophysical features of the source water body and watershed using: o Field investigation o Maps o Reference documents, existing	• See Appendix 1C. • Water quality constituents and microorganisms with potential impacts on human health or treatment processes including potential for	• Biogeophysical description of water source area • Map with key biogeophysical features or hazards shown • Discussion of water quality and quantity data analysis • Identify natural hazards/

Component	Recommended Methods	Scope	Documentation and Reporting
	watershed studies • Assess recent and historic source water quality and quantity data for status and trends focusing on implications for human health, treatment processes, and water sustainability.	formation of disinfection byproducts • Source water flow/volume trends with a view to determining the sustainability of the water source into the future and potential for flooding	vulnerabilities in the watershed (Hazard ID Table)
4. Evaluate the integrity and location of intake.	• Physical inspection of intake(s)	• Quality of design and configuration • Construction • Sanitary aspects • State of repair • Location of intake(s)	• Description of integrity and location of intake • Hazards/vulnerabilities associated with the intake (Hazard ID Table)

For Wells and Springs

Tasks	Recommended Methods	Scope	Assessment Report Requirements
1. Characterize the water source area.	• Assess hydrogeologic features of the water source area using: o Field investigation o Maps o Reference documents, existing hydrogeology studies • Assess recent and historic source water quality and quantity data for status and trends focusing on implications for human health, treatment processes, and water sustainability.	• See Appendix 1E. • Topographic and geologic settings • Aquifer characteristics • Water table elevations • Precipitation- spring discharge relationships • Water chemistry • Water quality constituents and microorganisms with potential impacts on human health or treatment processes including potential for formation of disinfection byproducts • Source water flow/volume trends with a view to determining the sustainability of the water source into the future and potential for flooding	• Hydrogeologic description of water source area and its influence on water quality and availability • Discussion of water quality and quantity data analysis • Identification of hazards/ vulnerabilities associated with the spring/well (Hazard ID Table)
2. Delineate the spring source area/well capture zone and spring/well protection zone.	• Use an acceptable delineation method (see Table 1.4 and Section 3.2) to define the spring source area/well capture zone. • Apply a spring/well protection zone (100 metre radius minimum).	• Springs and wells	• Map with spring source area/capture zone and spring/well protection zone and vulnerable areas demarcated • Supporting physical information and rationale for defining capture zone

Tasks	Recommended Methods	Scope	Assessment Report Requirements
3. Evaluate the integrity and location of the spring/well.	• Physical inspection of spring/well	• Quality of design and configuration • Construction • Sanitary aspects • State of repair • Security • Siting of spring/well (potential for flooding)	• Description of spring/well and location • Identification of hazards/ vulnerabilities associated with the spring/well (Hazard ID Table)

APPENDIX 1B: RECOMMENDED RESOURCES

Drinking Water in British Columbia

Province of British Columbia, Provincial Health Officer. 2001. *Provincial Health Officer's Annual Report 2000. Drinking Water Quality in British Columbia: The Public Health Perspective*. Victoria, B.C.: Ministry of Health Planning. http://www.hls.gov.bc.ca/pho/pdf/phoannual2000.pdf.

Living Water Smart: B.C.'s Water Action Plan - http://www.livingwatersmart.ca/

Waterbucket, Sustainable Approaches to Water Resources - http://www.waterbucket.ca/

Ministry of Environment, Water Stewardship Division - http://www.env.gov...ca/wsd/

Ministry of Healthy Living and Sport - Drinking Water Protection program http://www.hls.gov.bc.ca/protect/dw_index.html

Source Assessment Guidelines and Information

Canadian Council of Ministers of the Environment (CCME). 2004. *From source to tap: Guidance on the multi-barrier approach to safe drinking water*. Produced jointly by the Federal-Provincial-Territorial Committee on Drinking Water and the CCME Water Quality Task Group. http://www.ccme.ca/sourcetotap/mba.html.

FORREX. Water Management Links. http://www.forrex.org/programs/wmlinks.asp.

US Environmental Protection Agency. Source Water Assessments. http://cfpub.epa.gov/safewater/sourcewater/sourcewater.cfm?action=Assessments

Groundwater

Province of British Columbia. 2000. *Well Protection Toolkit*. Victoria: Province of British Columbia. http://www.env.gov.bc.ca/wsd/plan_protect_sustain/groundwater/wells/well_protection/acrobat.html..

Groundwater Foundation. *Using Technology to Conduct a Contaminant Source Inventory: A Primer for Small Communities*. http://www.groundwater.org/gi/actt_primer.html

Groundwater under the Influence of Surface Water

US Environmental Protection Agency. 1998. *Biological Indicators of Groundwater – Surface Water Interaction*. http://www.epa.gov/safewater/sourcewater/pubs/guide_bioind_1998.pdf

Winter, T.C., J.W. Harvey, O.L. Franke, and W.M. Alley. 1998. *Groundwater and Surface Water: A Single Resource*. US Geological Survey Circular 1139. http://water.usgs.gov/pubs/circ/circ1139/

Spring Delineation

Kreye, R., Wei, M., and D. Reksten, 1996. *Defining the Source Area of Water Supply Springs*. Victoria: Hydrology Branch, Ministry of Environment, Lands and Parks. http://www.env.gov.bc.ca/wat/wq/reference/springwater.pdf .

Surface Water Assessment

Watershed Professionals Network. 1999. *Oregon Watershed Assessment Manual*. Prepared for the Governor's Watershed Enhancement Board, Salem, Oregon. http://www.oweb.state.or.us/OWEB/docs/pubs/OR_wsassess_manuals.shtml

B.C. Source Water Data and Monitoring

Groundwater

Water Well Data Query https://a100.gov.bc.ca/pub/wells/public/indexreports.jsp

Observation Well Network
http://www.env.gov.bc.ca/wsd/data_searches/obswell/index.html

Aquifer Classification Database
https://a100.gov.bc.ca/pub/wells/public/common/aquifer_report.jsp

Surface Water

Community Watershed Data Query
http://www.env.gov.bc.ca/wsd/data_searches/comm_watersheds/index.html

Water License Query http://a100.gov.bc.ca/pub/wtrwhse/water_licences.input

River Forecast and Snow Survey http://www.env.gov.bc.ca/rfc/

Floodplain Mapping http://www.env.gov.bc.ca/wsd/data_searches/fpm/

Other

EcoCat http://www.env.gov.bc.ca/ecocat/

Water Quality Objective Reports
http://www.env.gov.bc.ca/wat/wq/wq_objectives.html

Working Water Quality Guidelines for B.C.
http://www.env.gov.bc.ca/wat/wq/BCguidelines/working.html

Approved Water Quality Guidelines
http://www.env.gov.bc.ca/wat/wq/wq_guidelines.html#approved

Water and Sediment Quality Monitoring Reports
http://www.env.gov.bc.ca/wat/wq/wq_sediment.html

iMapBC http://webmaps.gov.bc.ca/imfx/imf.jsp?site=imapbc

BC Water Resource Atlas
http://www.env.gov.bc.ca/wsd/data_searches/wrbc/index.html

APPENDIX 1C: SURFACE WATER SOURCE CHARACTERIZATION DATA ELEMENTS, DATA SOURCES AND RATIONALE FOR COLLECTING DATA

KEY
* - in map form
** - in graphical form

Data Element	Source Type • **A**: all • **S**: stream, river • **L**: lake, reservoir	Suggested Sources of Data	Rationale for Data Element
1. Administrative Information			
Common name of intake	A	• Known/provided by water supplier	• Basic info about the source • Assists with communication between water supplier, regional health, etc. • May not apply to all systems, but sometimes water suppliers will use a name other than the water body name to refer to an intake (especially when there is more than one intake in a particular water body)

Data Element	Source Type • **A**: all • **S**: stream, river • **L**: lake, reservoir	Suggested Sources of Data	Rationale for Data Element
Watershed Code/Water Body Identifier Number	A	• BC Water Resources Atlas http://www.env.gov.bc.ca/wsd/data_searches/wrbc/ • Watershed code query http://a100.gov.bc.ca/pub/fidq/watershedGroupsSelect.do;jsessionid=8e248a8d30da36b828378b4346b581cb9d204a85f7f6.e3uMah8KbhmLe34Tbh8TchyLe6fznA5Pp7ftolbGmkTy	• Basic information about the source • Unique code for the water body • Relates the intake to the source
Health Region Name	A	• Health region	• Administrative: Health regions regulate the water systems.
WSACS Code HealthSpace Code Hedgehog Code WaterTrax (whichever are relevant)	A	• Health region	• Administrative: These codes are health-region-database unique identifiers for water systems and source(s) and are helpful in cross-referencing drinking water information.
EMS Number	A	• The Ministry of Environment assigns EMS numbers to water sources and sampling locations	• It is the unique georeferenced identifier for the database that stores water quality data. It is intended to provide cross-referencing to other databases.

Data Element	Source Type • **A**: all • **S**: stream, river • **L**: lake, reservoir	Suggested Sources of Data	Rationale for Data Element
Water licence number	A	• BC Water Resources Atlas http://www.env.gov.bc.ca/wsd/data_searches/wrbc/ • Water licences query http://www.elp.gov.bc.ca:8000/pls/wtrwhse/water_licences.input • Water supplier	• Unique identifier for surface water licences in B.C. • Basic info about allocation/domestic use • Provides info on type of use, POD, quantity allocated, water rights, etc. • Applicable to licensed sources only
Point of diversion (POD) number	A	• Water licences query http://www.elp.gov.bc.ca:8000/pls/wtrwhse/water_licences.input • BC Water Resources Atlas http://www.env.gov.bc.ca/wsd/data_searches/wrbc/	• Unique georeferenced identifier for intakes • Applicable to licensed sources only
Community Watershed Code	A	• BC Water Resources Atlas http://www.env.gov.bc.ca/wsd/data_searches/wrbc/ • Community watershed query http://www.env.gov.bc.ca/wsd/data_searches/comm_watersheds/index.html	• Provides information on the regulatory context for the source • Identifies possible source of additional watershed information (WAPs) • Cross-referencing for the sources

Data Element	**Source Type** • **A**: all • **S**: stream, river • **L**: lake, reservoir	Suggested Sources of Data	Rationale for Data Element
2. Information for Delineation of Source Area			
Source water body name	A	• Water supplier • Regional Health Authority (RHA) • Gazetteer • Water licence query http://www.elp.gov.bc.ca:8000/pls/wtrwhse/water_licences.input	• Basic information about the source
Latitude and Longitude or UTM coordinates of intake	A	• Global Positioning System (GPS) measurement • Water supplier • Large scale map • Geographic Information System (GIS)	• Provides location information for the intake • Georeferencing for use in mapping • Critical in delineating the watershed • Cross-reference/link to other spatial data, linking intake to source and system information
Mapped location of intake*	A	• Water supplier	• Basic information about the source • Useful for confirmation of intake location • Required to delineate the watershed boundary
Intake elevation	A	• GPS measurement • Altimeter • Estimate from topographic map	• Basic information about the source

Data Element	**Source Type** • **A**: all • **S**: stream, river • **L**: lake, reservoir	Suggested Sources of Data	Rationale for Data Element
Stream discharge; stream cross-sectional area and velocity	S	• For large rivers, from Water Survey of Canada (at a nominal cost) • Provincial hydrologic records • Field measurement	• For calculating TOT to establish a protection area • Discharge hydrographs are also used to assess peak flows (and that has implications on turbidity and treatment effectiveness). • Together with information about watershed area, surficial geology, gradient and discharge, may indicate potential water quality issues and implications for treatment. • Data availability may be limited. • Assessment of additional hydrologic information such as peak flows for given return period, and mean monthly flows to better gauge seasonal distribution (high/low flow periods), flashiness, and first-flush events
3. Intake Location and Integrity			
Description of intake location • Location description • depth/elevation of intake • intake type	A	• Water supplier • Obtained at source	• On the ground information that helps confirm the location of the intake • Can assist in identifying potential hydrological/limnological issues that could impact water quality • May provide anecdotal description of sanitary issues, hence appropriateness of intake or sampling location
Describe intake integrity and sanitary features	A	• Site visit to the intake	• Surface water intakes should have coarse screens free of excessive debris and be well maintained.
Lake/reservoir bathymetry	L	• Fisheries inventory data queries http://a100.gov.bc.ca/pub/fidq/main.do	• Lake/reservoir morphology

Data Element	Source Type • **A**: all • **S**: stream, river • **L**: lake, reservoir	Suggested Sources of Data	Rationale for Data Element
4. Intrinsic Vulnerability of Source Area			
Watershed area	A	• Calculated from map • GIS • Community watershed query http://www.env.gov.bc.ca/wsd/data_searches/comm_watersheds/index.html	• Basic information about the source • Size determines if watershed falls above or below the 500 km^2 watershed area threshold where different methods of delineating assessment areas apply • Also, together with relief, provides an indication of the steepness of the watershed (likelihood of landslides and other physical processes that may be happening that affect water quality)
General geology of watershed/source area*	A	• Maps from BC Geological Survey, GSC maps and reports • From air photo interpretation	• Can assist in explaining the chemical quality of the water • Geology has a strong influence on hydrogeology, physical processes in the watershed.
Soil types or surficial geology*	A	• Maps from BC Geological Survey	• To evaluate potential areas where erosion may occur (and affect the turbidity and sediment load) • To evaluate the spatial distribution of the various runoff producing processes that may be operative in a watershed to predict stream flashiness • To determine location of potential sediment sources that may impact water quality
Terrain stability*	A	• On the ground assessment • Air photo interpretation, and assessment of TRIM maps • Terrain stability mapping • B.C. stream/lake survey records • DFO stream surveys	• To identify potential areas of sediment (and turbidity) sources • Terrain stability is an issue that needs to be addressed, not only for streams but also lakes. Unstable terrain in a watershed has the potential to affect water quality—this extends beyond the stream channel stability and is related to the bedrock and surficial geology of the watershed.

Data Element	Source Type • **A**: all • **S**: stream, river • **L**: lake, reservoir	Suggested Sources of Data	Rationale for Data Element
Map showing areas of different runoff generating processes (areas of Horton overland flow, subsurface storm flow, saturated overland flow and areas of generating baseflow)*	A	• Field inspection during periods of runoff • Interpretation of soils and surficial geology maps • Assessment of runoff hydrograph	• To evaluate the spatial distribution of the various runoff producing processes that may be operative in a watershed to predict stream flashiness • Important to link geology to flow mechanisms
Relative relief	A	• Can be calculated from water supply maps once elevation difference and watershed area are determined	• Indicates the steepness of the watershed (likelihood of landslides and other physical processes that may be happening that affect water quality) • Calculated by finding the difference between the intake elevation and maximum elevation and dividing that by the square root of the watershed area
Extent and condition of riparian area	A	• Field inspection • Watershed study	• The condition of a stream's riparian area reflects the sediment erosion and deposition processes affecting turbidity in the water. • One solution to turbidity problems is to repair the upstream riparian area.
Type (and extent (%)) of vegetation cover in watershed	A	• Air photos • Forest inventory maps • Field survey	• Basic info about potential risks to source • Indication of amount of land disturbance in watershed or supply area • Indication of erosion/flashiness potential
Wildlife populations	A	• Ministry of Environment	• Wildlife are hosts to human pathogens that can enter the stream through feces
Percent crown/private land	A	• Land and Water BC (LWBC) • Crown Lands Registry	• Indication of level of control of land in watershed

Data Element	**Source Type** • **A**: all • **S**: stream, river • **L**: lake, reservoir	Suggested Sources of Data	Rationale for Data Element
Total impervious cover	A	• Air photos • GIS	• Influences runoff processes, stream responses to storm events, and corresponding stream bank erosion and sedimentation
Stream order at intake	S	• From map of given scale • BC Watershed Atlas	• Basic information about the source • Also gives an indication of the size of the stream and physical processes that may be happening that affect water quality • Dependent on map scale, map scale must be specified
5. Source Water Quality and Volume			
Water quality (source) - microbiological, physical, and chemical analyses.	A	• Water supplier/EHO • Field measurements	• Data are used to characterise water quality of the source, identify source water quality issues, and the nature/effectiveness of treatment. • Microbiologic results should be analysed for last two years. • The two most recent physical and chemical water quality analyses should be examined. • Additional water quality information may be available from monitoring and reporting activities not directly associated with drinking water (waste permits, ambient monitoring, trend monitoring, water quality objectives, impact assessments, etc.). • Water quality is a performance measure for risk management.
Licence quantity and type of use	A	• Water supplier • Water licences query http://www.elp.gov.bc.ca:8000/pls/wtrwhse/water_licences.input	• Information on the licensed water use • Provides information to assist in understanding water quantity issues • Applicable to licensed sources only

Data Element	**Source Type** • **A**: all • **S**: stream, river • **L**: lake, reservoir	Suggested Sources of Data	Rationale for Data Element
Actual measured quantity of use	A	• Water supplier • If actual measurements not available, can be estimated based on population or number of connections	• Information on the actual water use that may be different from the licensed amount
Climate data • Precipitation types/proportions • Mean monthly, annual temperature • Temperature range • Annual, monthly humidity • Average date of spring freshet • Likelihood, susceptibility of extreme weather such as storms, drought, severe heat and cold	A	• Environment Canada	• Climate information can help determine the volume of recharge via precipitation, evapotranspiration, and the timing of low and high stream flows. • For estimating gross water budgets • Together with info about watershed area, surficial geology, gradient and discharge, may indicate potential water quality issues • Would prefer to see mean monthly precipitation to better gauge seasonal distribution (high/low flow periods), flashiness and first flush events • Identify nearest relevant precipitation and stream station

APPENDIX 1D: CORRIDOR ZONE DELINEATION OPTIONS FOR LARGE WATERSHED AREAS

Corridor zones can serve dual purposes. In drinking water risk assessment, they function to define the area closest to the water body as an assessment area for hazard identification, and during the risk management phase they can serve as a protective buffer zone in which hazardous activities and uses are excluded.

For streams, rivers, lakes and reservoirs with watershed areas exceeding 500 km^2, corridor zones can be applied along a water body and its tributaries to create a smaller, more manageable assessment area within the contributing watershed. Using corridor zones to define assessment areas in large watersheds focuses the contaminant source inventory and source characterization on the area closest to the water source where, theoretically, the risk associated with potential hazards is highest.

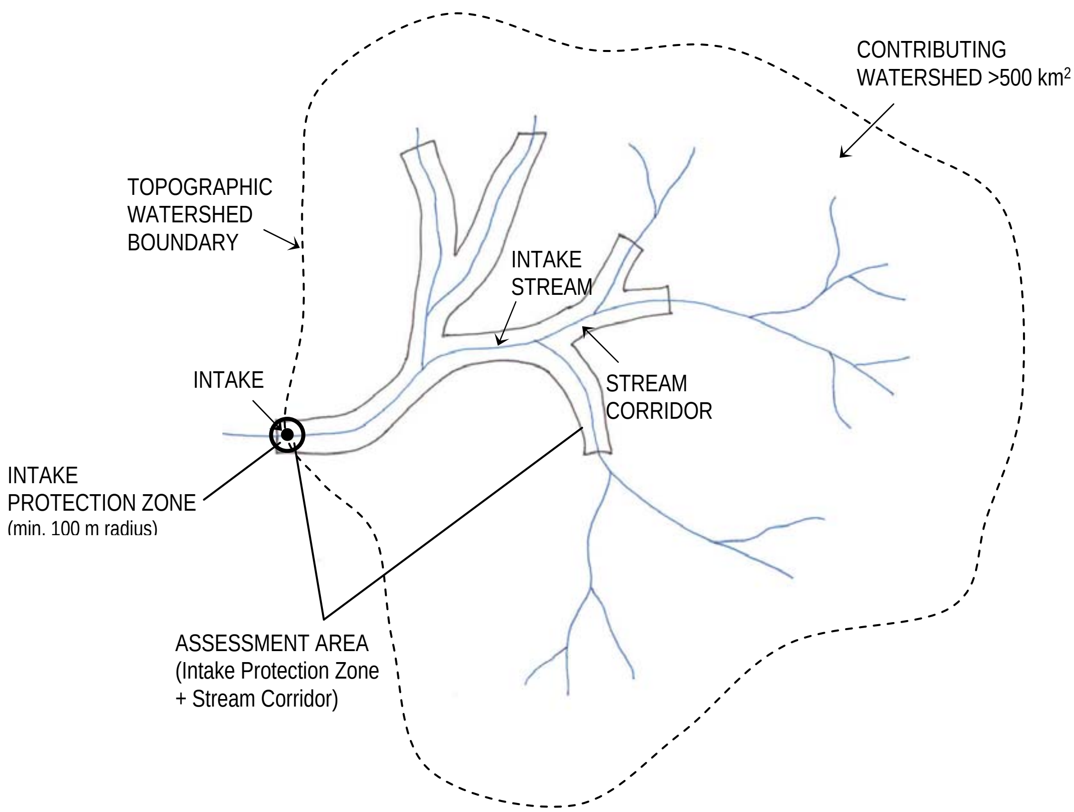


Figure 1-7. Example of Corridor Zone Assessment Area Delineation for Stream Sources with Watersheds Greater than 500 km^2 in Area

Two common methods are used in determining lengths of corridors: specified time of travel or fixed distance. Corridor widths are delineated using fixed distances for both methods. As a minimum standard, corridor widths should be at least 500 metres on each end of the stream. Also, site-specific characteristics, such as slope stability, gradient and amount of human development, should be considered in determining corridor widths.

Corridor zones can also be applied to tributaries of the intake stream—the watercourse in which the intake is situated. The assessor's professional judgement must be used in determining the tributaries on which to apply corridor zones. One approach would be to apply corridor zones to the tributaries of the next lower stream order than the intake stream. For example, if the intake stream is a 5th order stream, then corridor zones are applied to the tributaries that are 4th order streams within the assessment area. Generalized approaches like this need to be used with consideration for the site-specific issues and characteristics of the watershed.

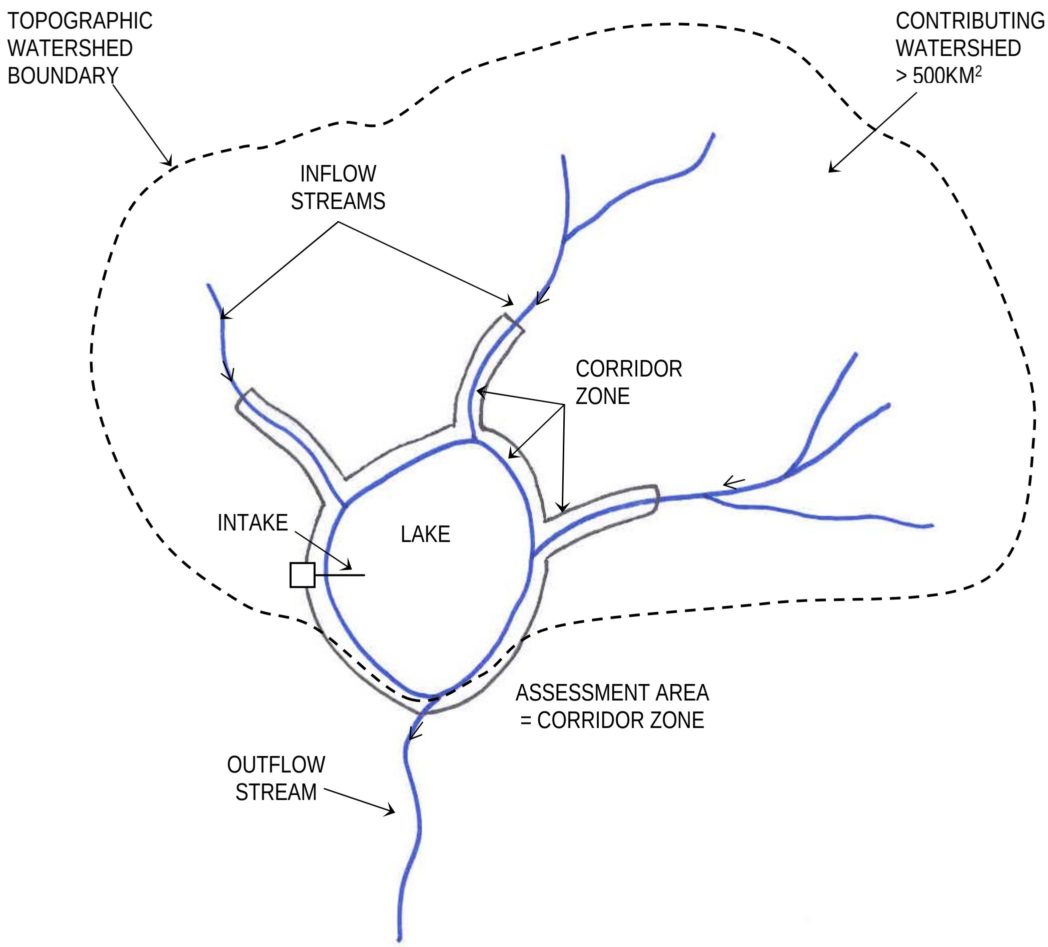


Figure 1-8. Example of Assessment Area Delineation for Lake Sources with Watersheds greater than 500 km^2 in Area

Lake corridor zones can be applied around the perimeter of the lake, as well as along inflow streams. Corridor widths should be determined based on lake and watershed characteristics.

As demonstrated in Figure 1-8, the length of corridors along streams can be limited by using a fixed distance or time of travel, described further below.

Fixed Distance Corridors

In the fixed distance method of delineating corridor zones, arbitrary distances are used to determine the length and width of the corridors. For the length, a predetermined distance upstream from the intake is used, and a set distance from the stream edge provides the width of the corridor on either side of the stream. Fixed width distances should take into account side slope gradient, slope stability, presence of potentially contaminating activities or land uses, as well as any other factors that may influence water quality or volumes.

Corridors are delineated along the watercourse upon which the intake is situated (the "intake stream") as well as on either side of the major tributaries that flow into the intake stream within the specified distance for corridor length. The length of corridors delineated for tributaries is determined by subtracting the distance between the intake and the location where the tributary enters the intake stream from the total corridor length.

Box 1-2. Delineating a Corridor: An Example

Suppose that a 500-metre corridor width and a 15-kilometre corridor length are selected based on site-specific conditions for a particular drinking water source.

Corridors 500 metres in width on either side of the intake stream are delineated for the first 15 kilometres upstream of the intake. If a tributary enters the intake stream five kilometres upstream of the intake, then a corridor of 500 metres on either side of the stream is delineated for 10 kilometres (15 km total corridor length—5 km between intake and tributary confluence) upstream on the tributary as well as for 10 kilometres more up the intake stream.

Time of Travel Corridors

Time of travel (TOT) is an approach to determining corridor length that considers watercourse-specific hydrologic characteristics to estimate the time it would take a contaminant plume released to the stream to reach the drinking water intake downstream.

This method is typically used as an early warning system (CCME, 2004) to develop response times for major potential contaminant sources in the watershed. In this application, a predetermined time of travel can be used to define the length of corridors. This method is used for the EPA Source Water Assessment Program in California, Idaho, Kentucky and Montana.

With this approach, a desired travel time is selected, usually based on reasonable spill notification and response times, and is used along with stream velocity to calculate the corresponding distance upstream. Times-of-travel commonly used are eight to twelve hours.

One calculation used to find the upstream distance corresponding to a given travel time (assuming constant velocity) is:

$$\mathbf{L} = \tau \times \mathbf{V},$$

where L is the distance upstream of the intake and the corridor length based on the selected travel time (τ) and velocity (V) of the stream. It is important when using this calculation to specify the conditions for which velocity is derived because according to the mathematical relationships in this equation, the greater the selected travel time and velocity, the longer the corridor. Therefore, peak velocity would provide a longer corridor zone for a given time of travel, whereas average velocity would give a shorter corridor.

An integral of this equation can be used where velocity is not uniform and its variations are known along the reaches of the stream and where greater accuracy in time of travel calculations are desired. See Hemond and Fechner-Levy, 2000, for more detailed information.

Box 1-3. The Time of Travel Approach

To illustrate the time of travel approach, suppose a 12-hour travel time was selected to determine the corridor length for a given stream, and its average velocity was known to be 220 metres per hour. An assumption is made that the stream velocity is constant for all reaches of the stream above the intake, and therefore the calculation would be:

L = 12 hours (τ) × 220 metres per hour = 2640 metres or 2.64 kilometres

When the TOT method is used to determine the corridor length, arbitrary fixed distances or site-specific characteristics can be used to establish a corridor width.

When selecting an assessment area delineation approach for surface water sources, it is recommended that the method chosen provides the most conservative delineation and covers the areas of the watershed that are most susceptible to hazards. Even where a smaller assessment area needs to be delineated to make the source assessment manageable, the contributing watershed should also be delineated so managers and users know the full extent of the land area contributing water to the source.

APPENDIX 1E: GROUNDWATER SOURCE CHARACTERIZATION DATA ELEMENTS, DATA SOURCES AND RATIONALE FOR COLLECTING DATA

KEY

◎ Indicates that the data element is usually available in the driller's well log.
* - in map form
** - in graphical form

Data Element	Source Type • **A**: all • **W**: wells only • **Sp**: springs only	Suggested Sources of Data	Rationale for Data Element
1. Administrative Information			
Common name of well/spring	A	• Known/provided by water supplier	• Basic info about the source • Assists with communication between water supplier, regional health, etc. • May not apply to all systems, but sometimes water suppliers will use a name other than the water body name to refer to an intake (especially when there is more than one intake in a particular water body)

Data Element	**Source Type** • **A**: all • **W**: wells only • **Sp**: springs only	Suggested Sources of Data	Rationale for Data Element
Aquifer Number	A	• B.C. Aquifer Web Page http://www.env.gov.bc.ca/wsd/plan_protect_sustain/groundwater/aquifers/ • BC Water Resources Atlas http://www.env.gov.bc.ca/wsd/data_searches/wrbc/index.html	• Basic information about the source. • Unique code for the aquifer. • Links the water well/spring to its source aquifer.
Health Region Name	A	• Health region	• Administrative—health regions regulate the water systems.
WSACS Code HealthSpace Code Hedgehog Code WaterTrax (whichever are relevant)	A	• Health region	• Administrative – these codes are health region database unique identifiers for water systems and source(s) and are helpful in cross-referencing drinking water information.
EMS Number	A	• The Ministry of Environment assigns EMS numbers to water sources and sampling locations	• It is the unique georeferenced identifier for the database that stores water quality data. It is intended to provide cross-referencing to other databases.

Data Element	Source Type • **A**: all • **W**: wells only • **Sp**: springs only	Suggested Sources of Data	Rationale for Data Element
Well Tag Number (WTN)	W	• B.C. Aquifer website http://www.env.gov.bc.ca/wsd/plan_protect_sustain/groundwater/aquifers/ • WELL database https://a100.gov.bc.ca/pub/wells/public/indexreports.jsp • BC Water Resources Atlas http://www.env.gov.bc.ca/wsd/data_searches/wrbc/index.html	• Unique identifier for wells in B.C. (WTN is like a SIN for wells). • Well record is tied to that number. • If the well is not part of the WELL database, information to create a well log and WTN will need to be provided.
BCGS Number◎	W	• Well log • B.C. Aquifer Web Page http://www.env.gov.bc.ca/wsd/plan_protect_sustain/groundwater/aquifers/ • WELL database https://a100.gov.bc.ca/pub/wells/public/indexreports.jsp • BC Water Resources Atlas http://www.env.gov.bc.ca/wsd/data_searches/wrbc/index.html	• It is a georeferenced number providing spatial information for the well.
Well Identifier Plate Number	W	• Attached at well	• It is a visible number at the well to help positively identify the source in the field.

Data Element	**Source Type** • **A**: all • **W**: wells only • **Sp**: springs only	Suggested Sources of Data	Rationale for Data Element
Water licence number	Sp	• BC Water Resources Atlas http://www.env.gov.bc.ca/wsd/data_searches/wrbc/index.html • Water licences query http://www.elp.gov.bc.ca:8000/pls/wtrwhse/water_licences.input • Water supplier	• Unique identifier for water licences in B.C. • Basic info about allocation/domestic use. • Provides info on type of use, POD, quantity allocated, water rights, etc. • Applicable to licensed sources only.
Point of diversion (POD) number	Sp	• Water licences query http://www.elp.gov.bc.ca:8000/pls/wtrwhse/water_licences.input • BC Water Resources Atlas http://www.env.gov.bc.ca/wsd/data_searches/wrbc/index.html	• Unique georeferenced identifier for intakes. • Applicable to licensed sources only.
Community Watershed Code	Sp	• BC Water Resources Atlas http://www.env.gov.bc.ca/wsd/data_searches/wrbc/index.html • Community Watershed Quer http://www.env.gov.bc.ca/wsd/data_searches/comm_watersheds/index.html	• Provides information on the regulatory context for the source. • Identifies possible source of additional watershed information (WAPs). • Cross-referencing for the source.

Data Element	**Source Type** • **A**: all • **W**: wells only • **Sp**: springs only	Suggested Sources of Data	Rationale for Data Element
2. Information for Delineation of Source Area			
Source aquifer name	A	• B.C. Aquifer website http://www.env.gov.bc.ca/wsd/plan_protect_sustain/groundwater/aquifers/ • BC Water Resources Atlas http://www.env.gov.bc.ca/wsd/data_searches/wrbc/index.html	• Basic information about the source.
Latitude and Longitude or UTM coordinates of well/spring	A	• Global Positioning System (GPS) measurement • Water supplier • Large scale map • Geographic Information System (GIS)	• Provides location information for the well/spring • Georeferencing for use in mapping • Critical in delineating the land area contributing water to the well or spring • Cross-reference/link to other spatial data, linking intake/well to source and system information

Data Element	Source Type • **A**: all • **W**: wells only • **Sp**: springs only	Suggested Sources of Data	Rationale for Data Element
Legal description of the well/spring location	A (where applicable)	• Water supplier • Water licence query http://www.elp.gov.bc.ca:8000/pls/wtrwhse/water_licences.input • WELL database https://a100.gov.bc.ca/pub/wells/public/indexreports.jsp • Well log • Cadastral map • BC Online www.bconline.gov.bc.ca	• Property information is critical to confirm location and ownership of well/spring as there are responsibilities assigned to the owner of the well under legislation. • Although the latitude and longitude give the location of the source, the coordinates can be off by such an amount that it places the source off the property.
Mapped location of well/spring*	A	• Water supplier • B.C. Aquifer website http://www.env.gov.bc.ca/wsd/plan_protect_sustain/groundwater/aquifers/	• Basic information about the source • Useful for confirmation of well/spring location • Required to delineate the watershed boundary
Well/spring elevation	A	• GPS measurement • Altimeter • Estimate from topographic map	• Basic information about the source

Data Element	**Source Type** • **A**: all • **W**: wells only • **Sp**: springs only	Suggested Sources of Data	Rationale for Data Element
Well logs and pumping rates of wells in the area	A	• WELL database https://a100.gov.bc.ca/pub/wells/public/indexreports.jsp • B.C. Aquifer website http://www.env.gov.bc.ca/wsd/plan_protect_sustain/groundwater/aquifers/	• Information from other wells is useful in identifying and characterising the type, location, and extent of the aquifer which are important in determining the capture zone for the well or source area for the spring. • Other pumping wells can have an influence on groundwater supply and flow direction in aquifer.
Aquifer geology	A	• WELL database https://a100.gov.bc.ca/pub/wells/public/indexreports.jsp • Surficial geology maps	• Assists in the characterization of the aquifer and its influence on water quality and availability
Static water level/depth to water table (and date measured) ◎	W	• Well log • WELL database https://a100.gov.bc.ca/pub/wells/public/indexreports.jsp • Measured directly	• Important because it is a governing factor in determining the vulnerability of the aquifer and in the well's pumping capacity. The static water level measured over time, can provide a lot of information about how the aquifer is behaving in response to climate variations or from pumping.
Street address of well location◎	W	• Water supplier or possibly WELL database or well log	• Helps confirm well location, especially on the ground

Data Element	Source Type • **A**: all • **W**: wells only • **Sp**: springs only	Suggested Sources of Data	Rationale for Data Element
Well log of the community well	W	• Water supplier • Well driller • WELL database https://a100.gov.bc.ca/pub/wells/public/indexreports.jsp	• Provides detailed information about well construction such as well diameter, water level, well capacity, well construction, lithology, etc. • Many of the data elements required are contained in the well log and are represented by the symbol "◎" in the data element column.
Well Type (drilled, dug, driven) ◎	W	• Determined at the well • Well owner • Well log • WELL database https://a100.gov.bc.ca/pub/wells/public/indexreports.jsp	• Well type has implications for intrinsic vulnerability for the well
Well diameter◎	W	• Well owner • Well log • WELL database https://a100.gov.bc.ca/pub/wells/public/indexreports.jsp • Measured directly	• A basic characteristic of the well • Determines the size of pump that can be installed in a well
Well depth◎	W	• Well log • WELL database https://a100.gov.bc.ca/pub/wells/public/indexreports.jsp • Well owner	• Provides indication on the depth of the aquifer, and together with the static water level, gives the available drawdown in a well, which is a governing factor in the well's pumping capacity • Also indicates the vulnerability of the well for protection

Data Element	**Source Type** • **A**: all • **W**: wells only • **Sp**: springs only	Suggested Sources of Data	Rationale for Data Element
Well lithology◎	W	• Well log • WELL database https://a100.gov.bc.ca/pub/wells/public/indexreports.jsp	• Critical in determining the type of source aquifer tapped by the well (e.g., sand and gravel, bedrock, aquifer depth and thickness) and the vulnerability of the geology at the well site. • The lithology of the well, when analysed together with other lithologic information from other wells, can allow the extent, depth, thickness of the aquifer to be determined. This information is also used to calculate the well's capture zone.
Depth to top of aquifer/depth to top of screen◎	W	• Interpreted from well log • WELL database https://a100.gov.bc.ca/pub/wells/public/indexreports.jsp	• Required to assess the vulnerability of the aquifer at the well
Aquifer thickness◎	W	• Interpreted from well log • WELL database https://a100.gov.bc.ca/pub/wells/public/indexreports.jsp	• Required to calculate the well capture zone
Screen length and location◎	W	• Well log • WELL database https://a100.gov.bc.ca/pub/wells/public/indexreports.jsp • Well owner	• Gives the zone in the (sand and gravel) aquifer that the well is actually drawing water from. • Required to help calculate the well's capture zone

Data Element	**Source Type** • **A**: all • **W**: wells only • **Sp**: springs only	Suggested Sources of Data	Rationale for Data Element
Screen Slot Size◎	W	• Well log • WELL database https://a100.gov.bc.ca/pub/wells/public/indexreports.jsp	• Provides an indication of the sediment size in the aquifer
Location and flow of water-bearing fractures at the well - if available (bedrock wells only) ◎	W	• Well log • WELL database https://a100.gov.bc.ca/pub/wells/public/indexreports.jsp	• Typically in fractured bedrock aquifers, groundwater occurs in the fractures of the rock. Knowing the depth and flow rate of water-bearing fractures in a bedrock well allows you to determine with much greater confidence the long-term pumping capacity of the well and the level below which the pumping water level should not be drawn down.
Casing length (bedrock wells only)◎	W	• Well log	• A sanitary consideration for bedrock wells
Maximum well pumping rate (indicate time of year and duration)	W	• Water supplier records • Smaller systems may use an estimate based on population served	• This information is used to calculate the well's capture zone and to determine water demand. Population served by a system may be estimated based on an assumed consumption rate of 760 litres (200 US gallons) per person per day.
Actual average annual volume pumped over last 3 years	W	• Water supplier records • Smaller systems may use an estimate based on population served	• This information could be used to calculate the well's capture zone. Smaller systems using a population estimate may assume that consumption is 50-200 gallons per person per day.

Data Element	**Source Type** • **A**: all • **W**: wells only • **Sp**: springs only	Suggested Sources of Data	Rationale for Data Element
Pump test rate and duration	W	• Consultant's report • Well log • WELL database https://a100.gov.bc.ca/pub/wells/public/indexreports.jsp • Pump installer	• This information is also used to calculate the actual permeability of the source aquifer at the well. The aquifer's permeability, in turn, is used to calculate the well's capture zone and to determine a firm estimate of the long-term pumping capacity of the well.
Permeability of the aquifer at the well	W	• Consultant report • Well log • WELL database https://a100.gov.bc.ca/pub/wells/public/indexreports.jsp	• This information is used to calculate the well's capture zone and the well's long-term pumping capacity.
Specific capacity	W	• Calculated from pump test	• Measures efficiency and performance of the well
Estimated well capacity◎	W	• Well log • WELL database https://a100.gov.bc.ca/pub/wells/public/indexreports.jsp Consultant report • Pump installer or need to determine by conducting pumping test	• This is often only roughly estimated, yet it governs the supply of the water system. A firm estimate of the well's capacity would help in water supply planning of the water system; it would also help in proper operation of the well (so it is not over-pumped). • Also used to calculate the well's capture zone • Indicate estimation method (driller's measurement, from pumping test, capacity of pump)
Aquifer transmissivity	W	• Calculated from pump test	• Required to calculate the well capture zone using analytical equations, hydrogeologic mapping, and numerical modeling

Data Element	Source Type • **A**: all • **W**: wells only • **Sp**: springs only	Suggested Sources of Data	Rationale for Data Element
Groundwater flow direction	A	• Hydrogeologic study report • Can be estimated from water levels in wells in the area	• Identifies the direction from which groundwater is flowing • Assists in creating more accurate capture zones • Assists in prioritizing sources of contamination
Type of spring (depression spring in sand and gravel, karst spring in limestone, contact spring—refer to Kreye et al, 1995)	Sp	• On-the-ground assessment by a qualified professional such as a hydrogeologist • WLIS file may also have information	• Knowing the type of spring allows you to know where the flow is derived from and assists in estimating the spring source area.
Spring discharge	Sp	• Spring discharge records • Field measurement	• For calculating TOT to establish a protection area • Discharge hydrographs are also used to assess peak flows (and that has implications for turbidity and treatment effectiveness). • Together with information about watershed area, surficial geology, gradient and discharge, may indicate potential water quality issues and implications for treatment. • Data availability may be limited.

Data Element	Source Type • **A**: all • **W**: wells only • **Sp**: springs only	Suggested Sources of Data	Rationale for Data Element
3. Intake/Well Location and Integrity			
Description of well/spring siting with respect to topography and its surroundings	A	• Site visit to the well	• Well siting is crucial in evaluating the well's vulnerability to flooding and contamination. • Understanding the immediate surroundings of a well identifies potential contaminant sources or activities.
Describe well/spring integrity and sanitary features	A	• Site visit to the well/intake	• A high integrity well/spring and sanitary features (such as well cover, sanitary seal) help to prevent surface water from flowing from into the well/spring.
Description of spring location • Location description • depth/elevation of intake • intake type	Sp	• Water supplier • Obtained at source	• On the ground information that helps confirm the location of the spring • Can assist in identifying potential hydrological/limnological issues that could impact water quality • May provide anecdotal description of sanitary issues, hence appropriateness of intake or sampling location

Data Element	Source Type • **A**: all • **W**: wells only • **Sp**: springs only	Suggested Sources of Data	Rationale for Data Element
4. Intrinsic Vulnerability of Source Area			
Well/spring construction date◎	A	• Well log • WELL database https://a100.gov.bc.ca/pub/wells/public/indexreports.jsp • Well owner	• A standard piece of information on the well record • Gives insight into interpreting the other information on the well record
Construction method◎	A	• Well log • WELL database https://a100.gov.bc.ca/pub/wells/public/indexreports.jsp • Well owner	• Critical information required to assess the sanitary nature of the well and for diagnosing some types of water quality problems (e.g., sand pumping)
Aquifer type (unconfined unconsolidated, confined unconsolidated, bedrock)	A	• Well log • WELL database https://a100.gov.bc.ca/pub/wells/public/indexreports.jsp • Consultant's report • B.C. Aquifer website http://www.env.gov.bc.ca/wsd/plan_protect_sustain/groundwater/aquifers/	• Gives an indication of the level of protection from surface contamination • Small water systems may use information for well itself • Larger water systems may need to look at a larger portion of the aquifer surrounding the well to define aquifer type.

Data Element	**Source Type** • **A**: all • **W**: wells only • **Sp**: springs only	Suggested Sources of Data	Rationale for Data Element
Areal and depth extent of aquifer	A	• B.C. Aquifer website http://www.env.gov.bc.ca/wsd/plan_protect_sustain/groundwater/aquifers/ • Ministry of Environment (MoE)	• Basic aquifer information
B.C. Aquifer Classification	A	• B.C. Aquifer website http://www.env.gov.bc.ca/wsd/plan_protect_sustain/groundwater/aquifers/	• Available for all mapped aquifers in British Columbia • If well/spring is drawing from unclassified aquifer, please indicate such.
AVI rating	A	• Needs to be calculated from lithology in the well log	• Gives an indication of the intrinsic vulnerability to contamination from the surface of the well/spring based on geologic setting
DRASTIC rating	A	• Determined from lithological information in the well log	• Gives an indication of the intrinsic vulnerability to contamination from the surface of the well/spring based on geologic setting
Aquifer cross-section or schematic profile for wells	A	• Created based on geologic data for area around wells.	• Gives visual understanding of the source aquifer
Vulnerability of aquifer	A	• B.C. Aquifer website http://www.env.gov.bc.ca/wsd/plan_protect_sustain/groundwater/aquifers/ • Hydrogeologic reports	• Provides generalized understanding of the intrinsic vulnerability of the aquifer as a whole—in contrast to AVI and DRASTIC above, which indicate vulnerability for the aquifer at the well only

Data Element	**Source Type** • **A**: all • **W**: wells only • **Sp**: springs only	Suggested Sources of Data	Rationale for Data Element
Sources of recharge for the aquifer	A	• Hydrogeologic reports • Surficial geology maps	• Identifies sources of water input to the aquifer, including those that may be distant, but could have major influence on water quality
Well hydraulically connected or under influence of surface water?	W	• Determined through pump test and water quality analysis	• If surface water is entering the well, microbes not usually present in groundwater can be pumped into the well.
Well vulnerable to salt water intrusion?	W	• Water quality analysis • Hydrogeologic study	• Salt water intrusion may affect water potability.
Extent and condition of riparian area	Sp	• Field inspection • Watershed study	• The condition of a spring's riparian area indicates its ability to attenuate contaminants in surface water flowing to the spring.

Data Element	Source Type • **A**: all • **W**: wells only • **Sp**: springs only	Suggested Sources of Data	Rationale for Data Element
5. Source Water Quality and Volume			
Water quality (source) - microbiological, physical, and chemical analyses.	A	• Water supplier/EHO • Field measurements	• Data are used to characterise the water quality of the source, identify source water quality issues, and the nature/effectiveness of treatment. • Microbiologic results should be analysed for last two years. • The two most recent physical and chemical water quality analyses should be examined. • Additional water quality information may be available from monitoring and reporting activities not directly associated with drinking water (waste permits, ambient monitoring, trend monitoring, water quality objectives, impact assessments, etc.). • Water quality is a performance measure for risk management.
Actual measured quantity of use	A	• Water supplier • If actual measurements not available, can be estimated based on population or number of connections	• Information on the actual water use that may be different from the licensed amount

Data Element	**Source Type** • **A**: all • **W**: wells only • **Sp**: springs only	Suggested Sources of Data	Rationale for Data Element
Climate data • Precipitation types/proportions • Mean monthly, annual temperature • Temperature range • Annual, monthly humidity • Average date of spring freshet • Likelihood, susceptibility of extreme weather such as storms, drought, severe heat and cold	A	• Environment Canada	• Climate information can help determine the volume of recharge via precipitation, evapotranspiration, and the timing of low and high stream flows.
Mean monthly precipitation/ Mean annual precipitation	A	• Water Survey of Canada • Provincial hydrologic and climate databases	• For estimating gross water budgets • Together with information about watershed area, surficial geology, gradient and discharge, may indicate potential water quality issues. • Would prefer to see mean monthly precipitation to better gauge seasonal distribution (high/low flow periods), flashiness and first flush events. • Identify nearest relevant precipitation and stream station
Licence quantity and type of use	Sp	• Water supplier • Water licences query http://www.elp.gov.bc.ca:8000/pls/wtrwhse/water_licences.input	• Information on the licensed water use • Provides information to assist in understanding water quantity issues • Applicable to licensed sources only

Data Element	**Source Type** • **A**: all • **W**: wells only • **Sp**: springs only	Suggested Sources of Data	Rationale for Data Element
Spring discharge (and date of measurement)	Sp	• Measured by water supplier • Water license file in regional MSRM office	• Allows a water balance to be calculated, which in turn allows the size of the source area to be estimated • The area is used as a check on the delineated source area. • May require advance notice to water suppliers that may have this requirement, so that they can install equipment and begin measurements if necessary
Spring flow discharge hydrograph**	Sp	• Measured over time by water supplier	• Quantifies the variability and permanence of the spring flow

APPENDIX 1F: SUMMARY OF AVI AND DRASTIC METHODS FOR ESTIMATING AQUIFER VULNERABILITY[3]

Aquifer Vulnerability Index (AVI)

In the AVI method, an aquifer's vulnerability at any given location is quantified by the hydraulic resistance (c) to the vertical flow of water through the geologic sediments above the aquifer. The hydraulic resistance is calculated from two variables: the thickness (d) of each sedimentary layer above the uppermost aquifer and the hydraulic conductivity (K) of each of the layers (Equation 1).

$$\text{Hydraulic resistance, } c = \Sigma d_i / K_i \text{, for layers 1 to i} \qquad (1)$$

Hydraulic resistance (c) has the dimension of time (e.g., years) and represents the flux-time per unit head gradient for water travelling downward through the various sediment layers to the aquifer. The lower the hydraulic resistance (c), the greater the vulnerability. A vulnerability map can be constructed by calculating the logarithm of the hydraulic resistance (log c) for each well and delineating areas of similar log c (AVI) values. The resultant areas represent areas of varying resistance which are grouped into the vulnerability categories (Table 1-7). AVI defines an aquifer as any water-bearing zone of >0.6 metre thickness with at least one well tapping it. AVI considers all aquifers to be of equal value and ignores water quality and water use of aquifers.

Table 1-7. Aquifer Vulnerability Index (AVI) Categories

Hydraulic Resistance, c (years)	Log (c)	Vulnerability Category
< 10 years	<1	extremely high vulnerability
10 -100 years	1 to 2	high vulnerability
100 -1000 years	2 to 3	moderate vulnerability
1000 -10000 years	3 to 4	low vulnerability
>10,000 years	>4	extremely low vulnerability

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3 Extracted from:
Wei, M., 1998. *Evaluating AVI and DRASTIC for Assessing Groundwater Pollution Potential in the Fraser Valley*. In Proceedings to the Mountains to Sea: Humans Interacting with the Hydrologic Cycle Conference, Canadian Water Resources Association, Victoria, British Columbia, pp 446-453.

DRASTIC

DRASTIC identifies and maps vulnerability areas that are composite representations of the **D**epth to water, net **R**echarge, **A**quifer media, **S**oil media, **T**opography, **I**mpact of the vadose zone and the hydraulic **C**onductivity of the aquifer (Equation 2).

$$\text{DRASTIC Index} = D_R D_5 + R_R R_4 + A_R A_3 + S_R S_2 + T_R T_1 + I_R I_5 + C_R C_3 \qquad (2)$$

e.g., $D_R D_5$ where
D_R = the DRASTIC rating for Depth to water; and
D_5 = the weight assigned to the Depth to water
(each DRASTIC factor has an assigned weight)

DRASTIC incorporates a relative ranking scheme that uses a combination of weights and ratings to produce a numerical value called the DRASTIC index. Hydrogeologic settings combine with DRASTIC indexes to form polygon areas graphically on a map. Each polygon area represents similar hydrogeological conditions and consequently similar vulnerability.

The higher the DRASTIC index, the greater the vulnerability. Although DRASTIC is physically based, the final DRASTIC index, unlike AVI, has no physical meaning, but rather is a numerical index.

Assumptions of AVI and DRASTIC

AVI and DRASTIC have common assumptions including that the potential contaminant source is at or near the land surface, the contaminant has the same behaviour as water, recharge to the aquifer is from vertical infiltration of precipitation, and flow in the vadose (and saturated) zone above the aquifer is vertically downward.

For more detailed descriptions of AVI and DRASTIC, refer to:

Aller, L., Bennett, T., Lehr, J., Petty, R. and G. Hackett. (1987). *DRASTIC: A Standardized System for Evaluating Ground Water Pollution Potential Using Hydrogeologic Settings*. National Water Well Association, Dublin Ohio/EPA Ada, Oklahoma, USA. EPA-600/2-87-035.

Van Stempvoort, D., Ewert, L., and L. Wassenaar. (1992). *AVI: A Method for Groundwater Protection Mapping in the Prairie Provinces of Canada*. Prairie Provinces Water Board, Regina, Saskatchewan.

APPENDIX 1G: SUMMARY OF WELL CAPTURE ZONE DELINEATION METHODS[4]

Arbitrary Fixed Radius/Modified Arbitrary Fixed Radius

Both the Arbitrary Fixed Radius (AFR) and Calculated Fixed Radius (CFR) methods define the well protection area by drawing a circle around the wellhead. The difference between the two methods is that the circular AFR area is based solely on a fixed distance from the wellhead, while the area for the CFR is calculated using the volume of water pumped.

The AFR usually covers the area within 300 metres of the wellhead. This capture zone covers land beyond the immediate area of the well, but is not so large that management of the well protection area becomes too difficult. Major disadvantages of this method are that it is arbitrary, and the circular area cannot be subdivided into time of travel zones. The AFR should be used as a temporary measure and only where no information exists on the water use, well, or the aquifer. We recommend that only WS4 water systems with bedrock aquifer sources use the arbitrary fixed radius method.

A Modified Arbitrary Fixed Radius (Figure 1-9) can be used to increase the accuracy of the AFR method where there is considerable topographic relief and where it is suspected that ambient groundwater flow is significant. In this delineation method, the arbitrary radius is applied downslope as it would be for a simple AFR, but upslope of the well the area is extended to either the height of topographic divide or to the edge of the aquifer, whichever is encountered first.

[4] Delineation method descriptions are excerpted from:
Ministry of Environment, Lands and Parks and Ministry of Health. (2000). *Well Protection Toolkit*. Victoria: Province of British Columbia. http://www.env.gov.bc.ca/wsd/plan_protect_sustain/groundwater/wells/well_protection/wellprotect.html .

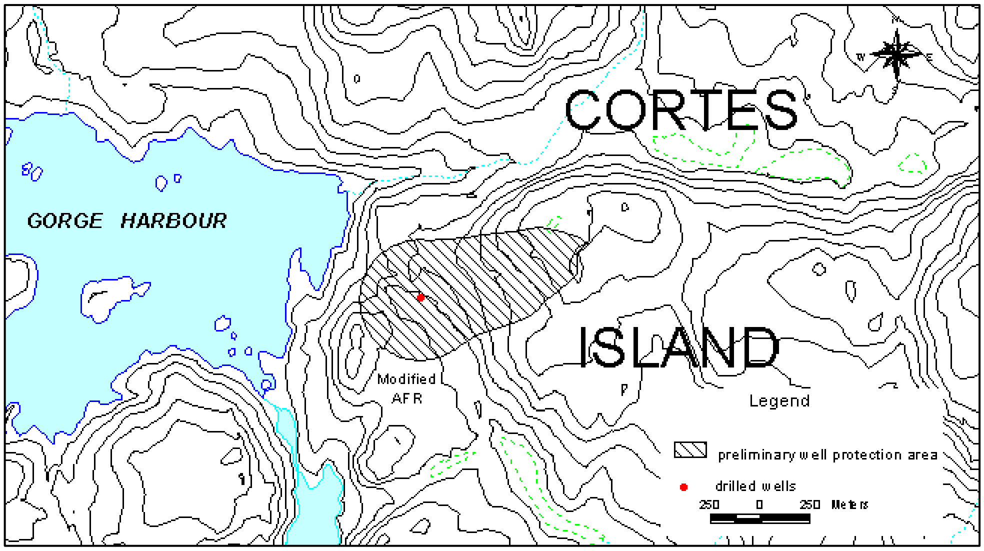


Figure 1-9. Example of a Modified Arbitrary Fixed Radius Capture Zone

The 300-metre radius is meant to be sufficiently large to offset uncertainties and unknowns related to smaller systems. AFR and modified AFR are still useful because they cover the immediate area of the well where impacts would potentially be greatest.

Calculated Fixed Radius

The CFR method (Figure 1-10) calculates a circular area, based on the volume of water pumped by the well over a specified period of time (e.g., 1, 5, or 10 years). This implies the time it takes a contaminant to travel from the CFR boundary to the well, based on the pumping rate, aquifer thickness and aquifer porosity. This method assumes negligible ambient groundwater flow and an aquifer of uniform thickness.

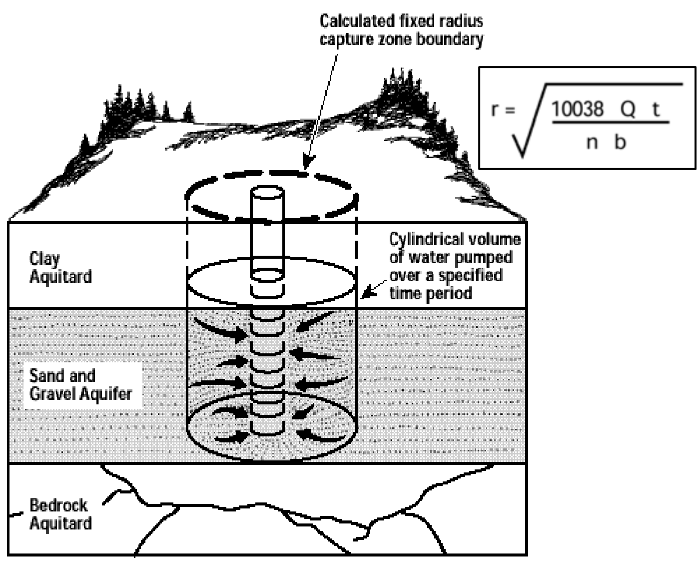


Figure 1-10: Calculated Fixed Radius Method of Capture Zone Delineation (Source: *Well Protection Toolkit*)

The CFR method is suitable for sand and gravel aquifers, where the water table is relatively flat and for wells supplying no more than 100 connections (WS2a, WS3 and WS4 water systems). The CFR method is not considered suitable for bedrock aquifers.

The formula for calculating the capture zone radius of the volume of water pumped from a pumping well is:

$$r = \sqrt{(10038 \times Q \times t) / (n \times b)}$$

where:

r = The calculated radius around the pumping well in metres

Q = Pumping rate in litres per second (L/s)

- Estimated by averaging the volume of water pumped annually
- Estimated by assuming the amount of water used is approximately 2271 L/d (500 Igal/d) per connection or per household
- Estimates can be checked against the reported well capacity and the pump rating; note: the well can not be pumped at a higher rate than its capacity nor the capacity of the pump

t = The allowed travel time to the well in years

- Usually specified for 1-year, 5-years, and 10-years period

n = Aquifer porosity

- for sand and gravel aquifers, n can be assumed to be about 0.25

b = Aquifer thickness or screen length (m)

- estimated from the well record(s) and hydrogeologic cross-sections of the local area
- Where the aquifer thickness is unknown, the screen length could be used (though aquifer thickness is preferable because it represents more accurately the actual physical conditions of pumping)
- The radius calculated using the screen length is larger than the radius calculated using the aquifer thickness and so is more conservative

Figure 1-11 presents an actual example of a CFR capture zone for a community well on Vancouver Island with 1-, 5-, and 10-year times of travel.

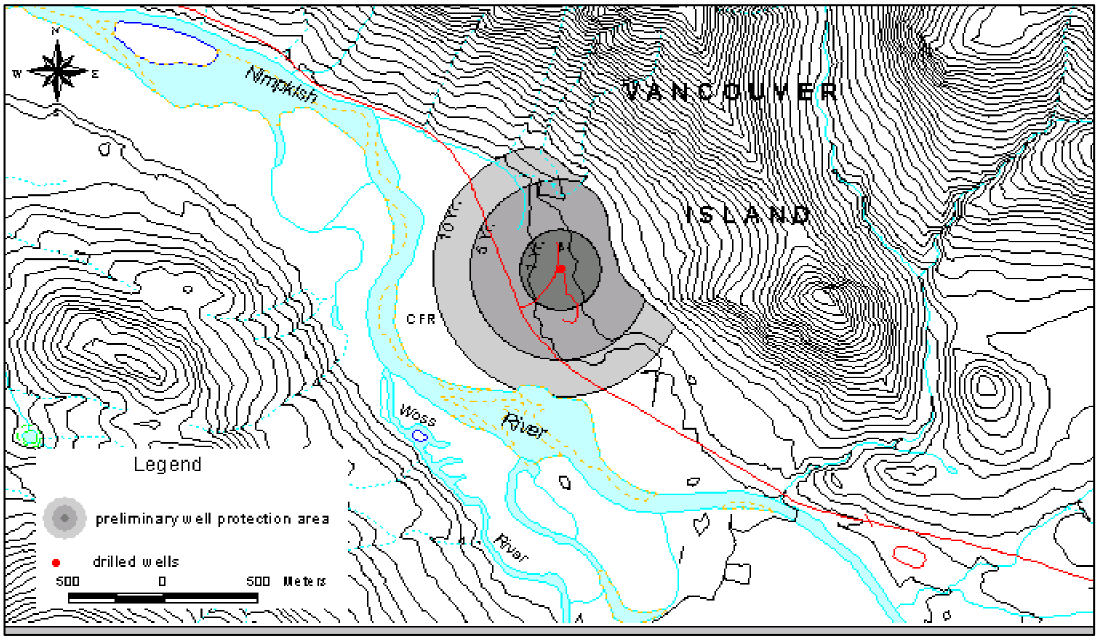
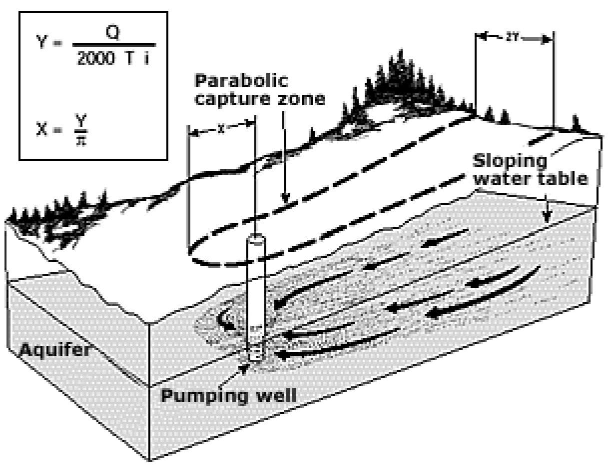


Figure 1-11. Example of a Calculated Fixed Radius Capture Zone

Analytical Equations

Where the water table has a significant slope, the fixed radius methods do not work. The shape of the drawdown cone around the pumping well is no longer circular, as recharge to the well comes from "up-hill" and has a long, parabola-like shape (Figure 1-12).



Analytical equations are suitable for sand and gravel aquifers where conditions are uniform and there is sufficient information on the pumping rate, aquifer transmissivity, and water table slope. It may not work well for bedrock aquifers where groundwater flow occurs in discrete fractures.

Figure 1-12. Analytical Equation Method of Capture Zone Delineation
(Source: *Well Protection Toolkit*)

Simple equations have been developed for delineating capture zones where the water table is sloping. Formulas for calculating the dimensions of the capture zone and time of travel boundaries are presented below.

For aquifers that have a uniform ambient water table slope, the distance of the capture zone boundary (X) down-gradient of the pumping well and the width (2Y) of the capture zone up-gradient of the pumping well can be calculated as follows:

$$Y = Q / (2000 * T * i)$$

$$X = Y / \pi$$

where:

Y = The half width of the capture zone in metres

X = Distance to the capture one boundary down-gradient of the pumping well in metres

Q = Pumping rate in litres per second (L/s)
- Estimated by averaging the volume of water pumped annually
- Estimated by assuming the amount of water used is approximately 2271 L/d (500 Igal/d) per connection or per household
- Estimates can be checked against the reported well capacity and the pump rating; the well can not be pumped at a higher rate than its capacity nor the capacity of the pump

T = Transmissivity of the aquifer in m^2/s
- Measured by conducting a constant rate pumping test and measuring the drawdown in the water level in the aquifer
- Transmissivity values may be available from the original groundwater consultant's report
- Estimated from the well's specific capacity (see Driscoll, 1986)

i = Slope of the water table or hydraulic gradient (-)
- Measured from water table or groundwater level contour maps
- Often estimated from the local topographic slope

This method assumes the aquifer has uniform properties and characteristics (i.e., thickness, permeability, steady-state ambient flow) and constant pumping rate.

Time of Travel Zones

The distance to the 1-, 5-, and 10-year time of travel boundary in the capture zone calculated through analytical equations can be estimated from the following formula:

$$d_{TOT} = (t * K * i) / n$$

where:

d_{TOT} = The distance representing the 1-, 5-, or 10-year time of travel in metres

t = Specified time of travel (1, 5, 10 years)

K = The hydraulic conductivity of the aquifer (m/y),
- Hydraulic conductivity of the aquifer is the transmissivity divided by the aquifer thickness

i = Slope of the water table or hydraulic gradient
- Measured from water table or groundwater level contour maps
- Often estimated from the local topographic slope

n = Porosity of the aquifer
- For sand and gravel aquifers, n can be assumed to be about 0.25

See Kreitler and Senger (1991) for a description of methods used to calculate TOT distances that take into account the change in hydraulic gradient due to the pumping of the well.

Hydrogeologic Mapping

Hydrogeologic mapping (Figure 1-13) locates and maps the groundwater flow. The capture zone is defined by identifying the aquifers and aquitards, mapping the groundwater levels, and then determining flow directions from water level contours.[5]

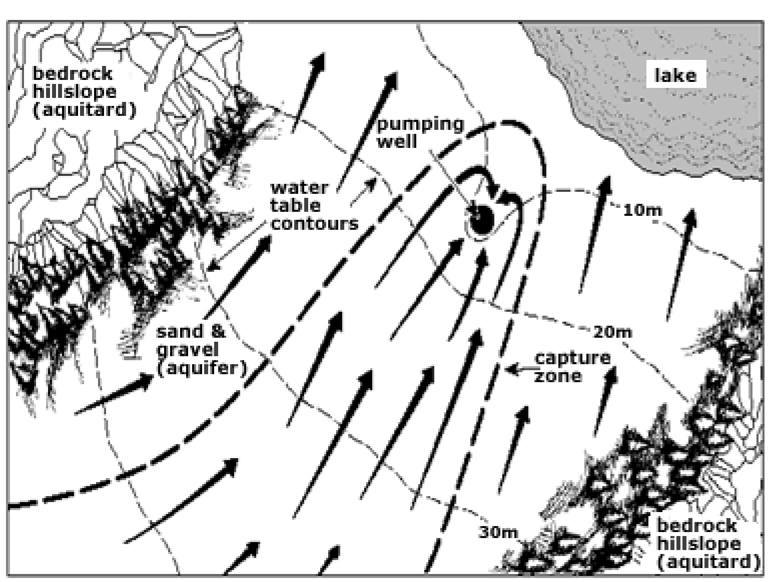


Figure 1-13. Hydrogeologic Mapping Method of Capture Zone Delineation
(Source: *Well Protection Toolkit*)

[5] In fractured bedrock aquifers and karst limestone bedrock aquifers, tracer dye tests can be used with field mapping of fractures or solution channels to delineate the capture zone area.

This method requires considerable expertise and should be carried out with the assistance of a professional hydrogeologist. It is particularly suitable for shallow sand and gravel aquifers where ambient groundwater flow directions can be directly implied from topography and where the surface geology can be used to identify aquifer boundaries.

Numerical Modeling

Numerical models are computer models of the groundwater flow system. Information on the hydrogeology of the area is entered into a computer program, which calculates the water level, flow rates and flow directions. It uses this information to define the capture zone for the well and time of travel of the contaminants.

The main advantage of numerical modeling is that it can combine variations in hydrogeology and pumping conditions, which analytical equations and other simpler methods can not. However, considerable amounts of data, technical expertise and interpretation are required to develop a numerical model, and it is a relatively costly technique to use.

Developing a numerical model requires large amounts of data, so it may not be practical to develop models for areas of the province where data are scarce. However, the capabilities of computer models make them a valuable tool for ongoing resource management and contingency planning. For (larger) communities with good data and the resources to develop and maintain a computer model, this type of model is an excellent long-term investment.

Grand Forks and Chilliwack are areas where numerical models have been used to delineate well capture zones. Numerical modeling was used because the community wells were not “isolated” (i.e., they may be affected by other wells) and there was sufficient information.

Table 1-8. Summary of Well Protection Area Delineation Methods (Source: *Well Protection Toolkit*)

Method	Explanation	Assumptions	Typical Data Required	Advantages/ Disadvantages	When Applicable
Arbitrary Fixed Radius	Assign circle area of a fixed radius (300 metres) around the well.	• Uniform aquifer • Negligible ambient flow	• None	*Advantages* • Easy and inexpensive to apply *Disadvantages* • Arbitrary • May be difficult to defend	Inadequate information on well construction, pumping rate, and hydrogeology; typically used for drive points and dug wells.
Calculated Fixed Radius	Calculate cylindrical volume of aquifer supplying water to a well for a given time period.	• Uniform aquifer • Negligible ambient flow	• Pumping rate and/or water use • Aquifer thickness • Aquifer porosity	*Advantages* • Easy and inexpensive to apply • Accounts for some site-specific information *Disadvantages* • Based on simple physical assumptions	Well construction and pumping rate are known, hydraulic gradient is low and aquifer thickness can be estimated; not appropriate for fractured bedrock aquifers.
Analytical Equations	Calculate capture zone dimensions using analytical equations accounting for uniform ambient flow. Produces a parabola-shaped recharge area.	• Uniform aquifer • Horizontal, steady-state flow • Uniform ambient flow • Capture zone does not extend beyond watershed divide	• Pumping rate and/or water use • Aquifer transmissivity • Ambient hydraulic gradient • Aquifer porosity • Aquifer boundary	*Advantages* • Easy and inexpensive to apply • Accounts for some local information *Disadvantages* • Based on simple physical assumptions	Aquifer transmissivity and pumping rate are known and a uniform hydraulic gradient can be estimated; may not be appropriate for fractured bedrock aquifers.

Method	Explanation	Assumptions	Typical Data Required	Advantages/ Disadvantages	When Applicable
Hydrogeologic Mapping	Map capture zone from measured groundwater level contours and geomorphologic, topographic, and hydrologic features.	• Groundwater flow direction same as topographic slope • Horizontal flow	• Aquifer boundary • Water table contours (or topographic contours) • Geology • Water quality	*Advantages* • Accounts for local information • Physically-based *Disadvantages* • Moderate to expensive to apply • Large data requirement	May be useful for shallow, unconfined aquifers, springs, as well as karstic and fractured bedrock aquifers.
Numerical Modeling	Delineate capture zone using numerical flow modeling incorporating actual hydrogeologic information.	• Depends on model	• Aquifer boundary • Geology • Water level elevations • Aquifer transmissivity • Hydraulic conductivity of aquitards • Knowledge of boundary conditions	*Advantages* • Accounts for local information • Physically-based • Predictive capability *Disadvantages* • Moderate to expensive to apply • Large data requirement	Where hydrogeology and groundwater conditions cannot be adequately represented by simple analytical models (e.g., bedrock aquifers or complex hydrogeology and vulnerable aquifers).