Environmental and Natural Areas Management

Environment and Labour

Developing a Municipal Source Water Protection Plan: A Guide for Water Utilities and Municipalities

Step 2

Delineate a Source Water Protection Area Boundary

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Designing Plans For Source Water Protection In Nova Scotia

A Drinking Water Strategy For Nova Scotia describes a multiple-barrier approach to clean, safe drinking water for Nova Scotians. The first line of defence in this multiple-barrier approach is to keep clean water clean. This booklet series describes how water utilities and municipalities can do that. It guides you through the process of developing a source water protection plan for your municipal water supply.

To keep clean water clean, we must protect the drinking water supply area. This guide describes **Step Two** in the process recommended by Nova Scotia Environment and Labour (NSEL) for developing a source water protection plan: Delineate a Source Water Protection Area Boundary. This booklet will provide detailed technical information on recommended delineation procedures. During **Step Two**, the advisory committee may solicit public input in order to ensure that there are no gaps in the information that describes the source water protection area.

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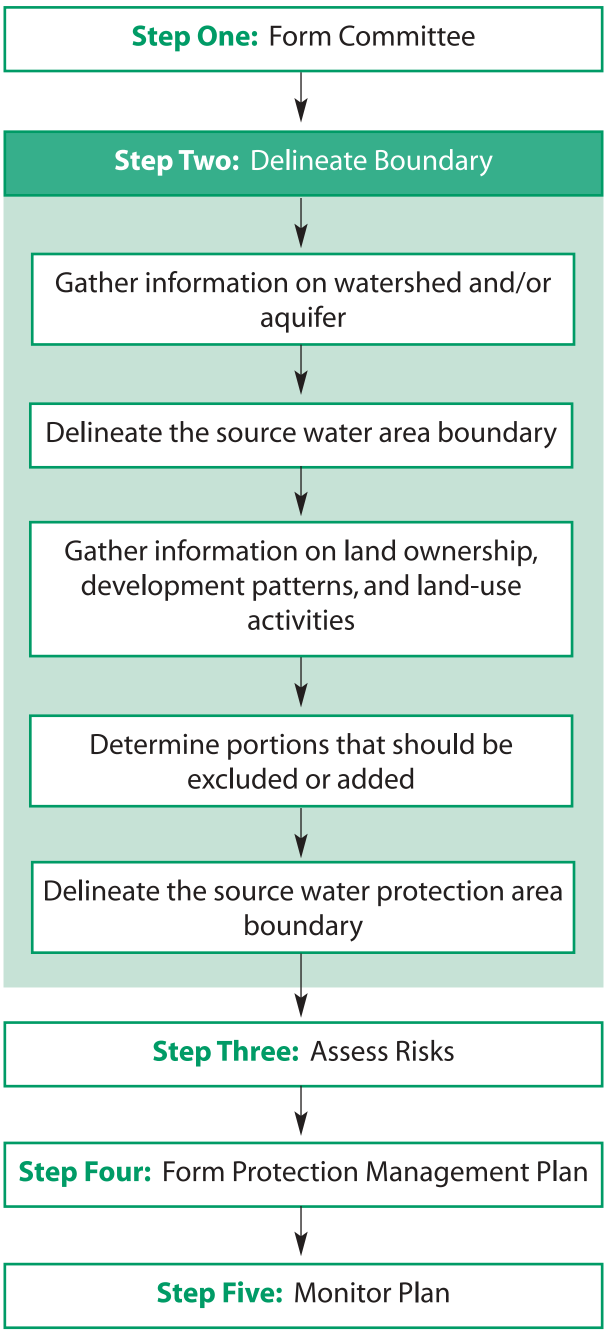
Step Two Flow Chart

The following identifies the five recommended steps for developing a municipal source water protection (SWP) plan, and lists the actions that should be used to delineate a SWP Area, whether it is surface water, groundwater, or Groundwater Under the Direct Influence of surface water (GUDI).



Importance of Delineating the Source Water Protection (SWP) Area Boundary

It is important to define or delineate your SWP Area boundary for the following reasons:

- You will know exactly what land area you will be dealing with, and, therefore the hydrogeological, ecological and hydrological factors that interact with the source water.
- It will help you determine what land owners will be affected by your protection plan, and what activities and land-uses you must concentrate on in your protection plan.

By clearly identifying what area supplies water to your source, you will be better able to provide adequate protection for it. However, if you do not clearly identify the boundary, there is a risk that a source or potential source of contamination may be over-looked in the protection planning process. Therefore, the utility or municipality should properly delineate the boundary to improve its confidence in the plan.

Before you begin the delineation process, it is important to understand the different types of source water. To begin with, **source water** is untreated water from streams, rivers, lakes, or underground aquifers, which is used to supply private wells and public drinking water. It can be divided into two types: 1) Surface water; and 2) Groundwater.

Surface water sources include lakes, rivers, streams, and ponds.

Groundwater is obtained from an aquifer through a drilled or dug well.

Although there are two types of source water, the two are often interlinked. Most rivers and lakes are fed by groundwater. Groundwater wells located near surface water bodies, or that are poorly constructed or "leaky," may be affected by surface water.

This document is divided into two parts: A) How to delineate a *surface* source water protection area; and B) How to delineate a *groundwater* source water protection area.

Several terms will be used throughout the remainder of the document that you should familiarize yourself with, and their definitions are located in the glossary at the end of this document.

Detailed Information on Each of the Actions
Once you have determined the type of source water you have, go to the appropriate section below (A: Surface Water or B: Groundwater). After you have completed the delineation of the boundary of the Source Water Protection Area, it may be submitted to NSEL for review and comments.

Source Water Protection Area Delineation

A) Surface Water

To protect a surface water supply, you must delineate the area that contributes water to the surface water body so that potential sources of contamination can be identified and managed. The following steps explain how to do this:

Gather information on physical aspects of source water area
The physical aspects that are important to define or delineate the surface water source water area boundary include the topography and location of surface water bodies (streams, rivers, lakes and wetlands). Maps of the local bedrock and soil geology or hydrogeological studies, if available, may also aid in this work.

Delineate the boundary of source water area
The most commonly used method to delineate a surface source water area is with topographical maps and aerial photographs (viewed through stereoscopes). A line is used to connect high elevation points around the water body. This is usually done by a knowledgeable technician.

To delineate the boundary from a topographic map or air photo, start at the outlet of the lake (usually a stream), or at the location of the chosen stream cross-section (most likely the water withdrawal point). Then draw the line away from the left or right stream bank, being sure to maintain the line at right angles to the contour lines (i.e. going up-slope). The line should stop at the watershed divide. Continue the line until its trend is generally opposite to the direction in which it began and is generally above the head/source waters of the lake or stream. Then return to the starting point and draw the boundary from the other bank, eventually connecting with the first line.

Frequent visual inspection of the contour pattern is required as the boundary is traced out to ensure an imaginary drop of water on the stream side of the divide (or inside the bowl) would flow downhill and eventually reach the lake or outlet. A boundary can never cross a stream. The lowest point in a watershed is always the outlet—that is, the starting point for the delineation.

It is also possible to use computers to do this more quickly, and the results are in a more useful format. Using a computer and a Geographic Information System (GIS) a knowledgeable technician can easily produce a map of the source water area boundary and can also show other relevant information on the same map, such as surface water bodies, existing water monitoring stations, and land-use patterns.

Whether you are using hard copy or a computer-based copy of a topographical map, it is recommended that you use information at a scale of at least 1:50,000, with a preferred scale of 1:10,000. Some mapping is available at Service Nova Scotia and Municipal Relations' Land Information Offices.

Gather information on land ownership, development patterns, and land-use activities

Once your source water area boundary is drawn on a map you should form a separate map that also shows land ownership, land-use activities, and, if available, municipal zoning information. This will help you determine if you should alter your source water area boundary in a way that will make management of the area more successful.

The Source Water Protection Advisory Committee may, in consultation with the utility or municipality, solicit public input at this point to gather further information on land ownership and land-use activities in the source water area.

The purpose of delineating the SWP Area is to determine the land area where potential contaminant sources should be identified and management options should be considered to reduce risks to the source water. Further information about identifying potential contaminant sources and possible management options is provided in booklets **Three** and **Four** of our series on **Developing a Municipal Source Water Protection Plan.**

Determine any portions of the source water area that should be excluded from or added to the source water protection area

Although your source water protection plan should cover the entire source area, you may decide to remove some portions of it or extend the boundary to cover some areas outside it. This will need to be determined by the utility or municipality in consultation with the SWP Advisory Committee and affected land owners on a case by case basis.

An example of a situation where this may occur is a land owner who has 80% of their land within the source water area. After consultation with the land owner, it may be decided to include the entire property in the SWP Area for the sake of easier management. However, if the land owner is uncooperative it may not be worth the effort required to include the land outside the source water area. You may also want to add a property to your SWP Area if it is a potential source of contamination, such as an industrial factory just outside of your source water area.

An example of a situation where it may be necessary to remove a portion of the source water area from the source water protection area would be a land owner who lives along the uppermost boundary of the watershed (the watershed divide). The source water area in this example is very large, and the portion of the land owner's property that is within it is only 1/2 hectare. In this case, it may be preferable to remove the property from the source water protection area.

Delineate the boundary of the source water protection area

From the information gathered in the previous sections it is now possible to form a map showing the area that will be covered by the source water protection plan (i.e. the source water protection area).

B) Groundwater

To protect a groundwater supply, you must delineate the area that contributes water to the well so that potential sources of contamination can be identified and managed. The source water protection area surrounding the well or well field where groundwater is to be protected is called the wellhead protection area (WHPA). The protection area includes all or part of the of the area that contributes groundwater to the well field and is typically divided into several smaller zones that are used to manage different types of contaminants. Delineating the protection area is usually done using mathematical or computer models that use site-specific hydrogeological data. This is the most technical step in the wellhead protection planning process. The advisory committee will probably need professional assistance from a hydrogeologist to complete this work.

Identify Wellhead Protection Zones[1]

The WHPA is divided into zones based on the time it takes groundwater to travel to the well. The different zones reflect the fact that different types of contaminants in groundwater will persist for different lengths of time, migrate at different rates and pose different health risks. Zones that are closer to the well require a higher level of protection because there is a shorter distance to travel before groundwater reaches the well and, therefore, less time to respond to contamination events and less opportunity for contaminants to be diluted or removed by the aquifer. Usually the WHPA is divided into two-year, five-year and twenty-five-year time of travel (TOT) areas. The two-year TOT area is closest to the well; the five and twenty-five-year is furthest away.

In Nova Scotia, a minimum of three WHPA zones are recommended. These zones are defined based on the groundwater travel time, as follows:

- **Zone 1** – 0 to 2 year travel time. This zone is used to protect against microbial contaminants (e.g., bacteria and viruses) and chemical contaminants.
- **Zone 2** – 2 to 5 year travel time. This zone is used to protect against all chemical contaminants (e.g., petroleum contaminants and persistent, mobile contaminants).
- **Zone 3** – 5 to 25 year travel time. This zone is used to protect against persistent, mobile chemical contaminants (e.g., chlorinated solvents, nitrates, etc.).

In addition to the zones defined above, identify a “well site control zone” to protect the area immediately surrounding the well. This area, which is considered to be the wellhead itself, is used to protect against the day-to-day activities of the water utility and any other potential sources of contamination, including vandalism. The well site control zone can be determined based on a simple fixed radius, which should be a minimum of 30m.

The purpose of delineating the WHPA zones described above is to determine the land area where potential contaminant sources should be identified and management options should be considered to reduce risks to the well field. The Source Water Protection Advisory Committee may solicit public input at this point to gather further information on land ownership and land-use activities in the WHPA. Further information about identifying potential contaminant sources and possible management options is provided in booklets **Three** and **Four** of this series.

The use of WHPA zones is an industry standard and is commonly used in other provinces, including New Brunswick, Ontario, and British Columbia. Although these are the recommended WHPA zones for Nova Scotia, the advisory committee may choose to use larger zones to provide added protection. For example, the WHPA may be expanded to include the entire watershed, entire zone of contribution, indirect recharge areas, or areas where the aquifer is expected to be particularly vulnerable to contamination, such as

[1] Information has been adapted from the Government of British Columbia’s document “Step Two - Define the Well Protection Area”.

where fractured bedrock is exposed at ground surface. The most important area to protect is Zone 1. If the protection of Zone 2 and/or 3 is not practical and prevents the protection of Zone 1, then it may be necessary to focus your efforts on Zone 1 before proceeding to Zones 2 and 3. NSEL should be consulted before this decision is made.

Wells that have been classified as Groundwater Under the Direct Influence of surface water (GUDI) are considered surface water sources for the purposes of both source water protection and water treatment requirements. This means the Surface Water Treatment Standard applies to GUDI wells. For GUDI wells, there is potential for contaminants within the watershed to be rapidly carried to the well field by surface water, even if the contaminant sources are outside the 2-, 5-, or 25-year groundwater travel times. Therefore, the land area within the watershed boundaries also should be included within the WHPA. This approach ensures that the potential risk of contaminants migrating in surface water adjacent to a well field will be considered in the source water protection plan. Because groundwater outside the watershed may also contribute water to the well field, the WHPA Zones 1, 2, and 3 should still be delineated for GUDI wells.

Methods to Delineate the Wellhead Protection Area

It is important to define the WHPA accurately. Contaminants in the WHPA could pollute the source water. There are several methods to determine the WHPA, of which some are complex and technical. The five methods most commonly used to delineate WHPA's are

- Arbitrary Fixed Radius (AFR)
- Calculated Fixed Radius (CFR)
- Analytical equations
- Hydrogeologic Mapping
- Numerical Modeling (recommended)

Each of the methods listed above is described in Appendix A.

The preferred method for delineating wellhead protection areas in Nova Scotia is numerical modeling, which uses a computer model. When properly set up and calibrated with adequate field data, computed models provide the best method to accurately delineate the source water protection area.

Calculate the WHPA Zones

How do you decide which of the five methods to use? Some of the advantages and disadvantages are listed on the table on the next page. Although it is tempting to use simple and less expensive models (such as AFR), they are based on very simplistic assumptions. These assumptions may not apply in your situation, and could result in the planning team wasting resources on protection measures in an area that contributes little or no water to the groundwater supply. Experience in the United States shows that people may challenge your defined WHPA, because of the cost of implementing protection measures, and you must be able to justify your decisions.

However, AFR and CFR may be useful as interim methods to allow well protection planning to get underway. Once the community sees the value of groundwater protection and supports it, you may find additional funding to refine the WHPA using more accurate methods. You should attempt to delineate the WHPA as accurately as possible, based on the information and funding available, local conditions and size of the water system. For example, if your community is tapping a well in a sand and gravel aquifer where the geology is relatively simple and the water system has over 100 connections, then it may be appropriate to use analytical equations. However, you may choose to use methods that are more accurate, such as hydrogeologic mapping or numerical modeling, especially in populated areas where the WHPA boundary may need to be pinpointed more accurately. Technical advice on which method to use is available from the NSEL or groundwater consultants.

Gather Information and Conduct Analysis
In order to define the WHPA, it is necessary to collect available information on each community well and on the groundwater resources in the local region. Much of this information may already exist.

Seek Technical Expertise
Do you need to hire a groundwater consultant to help delineate the WHPA? As a rule, where the delineation involves methods other than AFR and CFR, it is recommended that a groundwater consultant is hired to assist in this work.

The following series of questions may provide some guidance:

- Is your community well in a fractured bedrock aquifer?
- Is there more than one well in the system, and are they located close to each other (e.g. less than 100 metres)?
- Is your community well supplying a significant number of customers (greater than 25 connections)?
- Are the local hydrogeologic conditions complex?

If your answer to any of these is yes, hiring a groundwater consultant to assist in delineating the WHPA is a good idea.

You will almost certainly need professional assistance if your aquifer is in fractured bedrock. Groundwater flow in many bedrock aquifers occurs through discrete fractures or through discrete zones, and flow in these aquifers is usually hard to predict. Therefore, capture zones for wells drilled in fractured bedrock aquifers require more data and greater hydrogeologic expertise to analyze. It is likely that hydrogeologic mapping or numerical modeling methods will be needed to delineate the WHPA.

Final Product

The information provided in this document is intended to provide a utility or municipality with sufficient information so that they are able to produce the following final product: Delineation of the Source Water Protection Area Boundary based on scientifically established data and criteria.

For More Information

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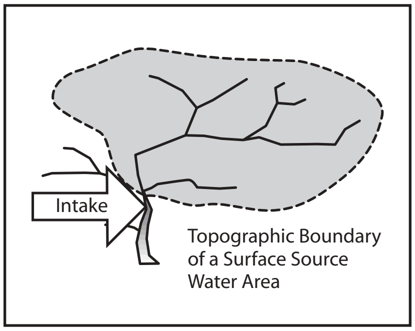
Glossary

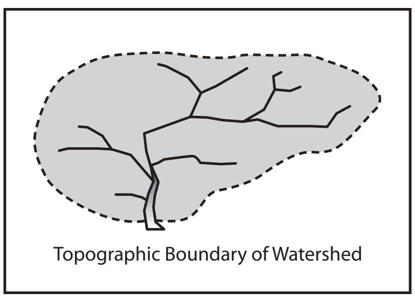
Source Water Protection (SWP) Area
The portion of the source water area that will be covered by the source water protection plan.

Source Water Area
The area of the watershed or wellhead that contributes all the water that is used to supply drinking water from the source.



Surface Water

Watershed



The area drained by, or contributing to a stream, lake or other body of water. It is the area that topographically appears to contribute all the water that passes through a given cross-section of a stream. Topography is the change in height of land relative to sea level.

Another way to think about what a watershed boundary represents is to consider a soup bowl. If you placed a small amount of water in the bowl it would settle at the bottom of the bowl. The water at the bottom of the bowl represents a lake, and the bowl represents the lake's watershed. If you pour water onto any part of the bowl it will eventually land at the bottom of the bowl, or in the lake. However, if you pour water outside of the bowl (i.e. on the other side of the bowl's lip) it will flow somewhere else. Therefore the bowl's lip can also be thought of as the watershed boundary.

Groundwater

Groundwater Source Water Protection (SWP) area or Wellhead Protection Area (WHPA)
The land area on which groundwater protection measures are taken.

Well field
The land area around a pumping well or group of pumping wells.

Time of Travel (TOT)
The wellhead protection area can be divided into sub-areas based on "time of travel": the time it takes water to flow from a given point to the well.

Zone of Contribution
The area of the aquifer that recharges the well.

GUDI
GUDI stands for Groundwater Under the Direct Influence of surface water. It is defined as any water beneath the surface of the ground with:

- significant occurrence of insects or other macro-organisms, algae, organic debris, or large-diameter pathogens such as *Giardia lamblia* or *Crytosporidium*; or
- significant and relatively rapid shifts in water characteristics such as turbidity, temperature, conductivity, or pH which closely correlate to climatological or surface water conditions.

Aquitard
An underground geological formation that is only slightly permeable and yields inappreciable amounts of water when compared to an aquifer. Aquitards essentially block the flow of water.

Isopach
A line on a map connecting points below which a particular rock stratum has the same thickness.

Evapotranspiration
The return of water vapour to the atmosphere by evaporation from land and water surfaces and by the transpiration of vegetation.

Detailed methodologies for WHPA Delineation[1]

This information is meant to give a general understanding of the five different methods used to delineate a WHPA. This information should be used to decide which method is best for your situation. Although NSEL recommends method five, there may be other factors that a utility or municipality needs to consider (such as financial resources). Careful consideration should be given to the consequences of choosing a method other than method five.

1 & 2. Arbitrary Fixed Radius and Calculated Fixed Radius

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

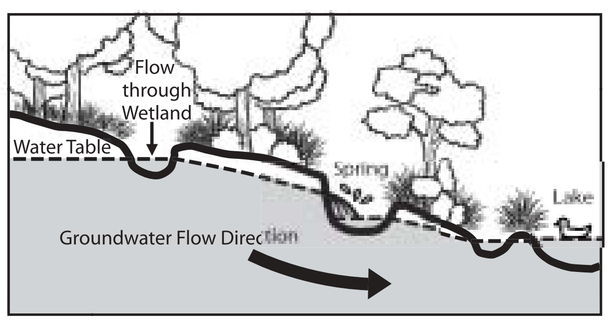
The AFR usually covers the area within 300 metres of the well. This WHPA covers land beyond the immediate area of the well, but is not so large that protection of the source area becomes too difficult. Major disadvantages of this method are that it is arbitrary, and the circular area cannot be subdivided into time of travel areas. The AFR should be used as a temporary measure and only where no information exists on the well, water use, or the aquifer.

The CFR calculates a circular area based on the volume of water pumped by the well over a specified period of time (e.g. two, five or twenty-five years). This reflects the time it takes a contaminant to travel from the CFR boundary to the well, based on the pumping rate. The CFR method is suitable for sand and gravel aquifers, where the water table is relatively level and wells supply no more than 100 connections.

3. Analytical Equations

If the water table slopes, the fixed radius methods do not work. The shape of the WHPA around the pumping well is not circular, as recharge to the well comes from "up-gradient" and has a long, finger-like shape.

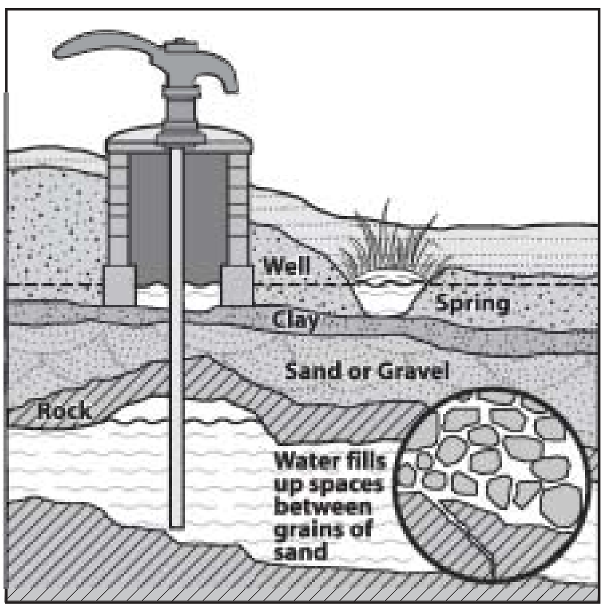
Simple equations have been developed for delineating WHPAs where the water table slopes. Analytical equations are suitable for sand and gravel aquifers where conditions are uniform and there is sufficient information on the pumping rate, aquifer transmissivity, and water table slope. This method may not work well for fractured bedrock aquifers.



[1] Adapted from the Government of British Columbia's document "Step Two - Define the Well Protection Area".

4. Hydrogeologic Mapping
Hydrogeologic mapping locates and maps the groundwater flow. The WHPA is defined by identifying the aquifers and aquitards, mapping the groundwater levels, and then determining flow directions from water level contours. This method requires considerable expertise and should be carried out with the assistance of a professional hydrogeologist.

This method 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.



Recommended Method:

5. Numerical Modeling
Numerical modeling develops and uses computer models of the groundwater flow system.
The computer model most commonly used is MODFLOW. Information on the hydrogeology of the area is entered into a computer program, which calculates the water level, flow rates, and flow directions. This information is used to define the WHPA and time of travel of the contaminants.

The modeling exercise must be properly documented so that users and reviewers of the model results can understand the assumptions and limitations of the model. The model documentation should include a description of the purpose of the model, formulation of the conceptual model, boundary and initial conditions, aquifer parameters, the grid of the numerical model with locations of boundaries and internal source and sinks, calibration and sensitivity analyses, and results of predictive simulations.

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

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 models make them a valuable tool for on-going 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.

Data requirements for groundwater flow models.

A. Physical framework

1. Geologic map and cross sections showing the areal and vertical extent and boundaries of the system.
2. Topographic map showing surface water bodies and divides.
3. Contour maps showing the elevation of the base of the aquifers and confining beds.
4. Isopach maps showing the thickness of aquifers and confining beds.
5. Maps showing the extent and thickness of stream and lake sediments.

B. Hydrogeologic framework

1. Water table and potentiometric maps for all aquifers.
2. Hydrographs of groundwater head and surface water levels and discharge rates.
3. Maps and cross sections showing the hydraulic conductivity and/or transmissivity distribution.
4. Maps and cross-sections showing the storage properties of the aquifers and confining beds.
5. Hydraulic conductivity values and their distribution for stream and lake sediments.
6. Spatial and temporal distribution of rates of evapotranspiration; groundwater recharge; surface water-groundwater interaction, groundwater pumping, and natural groundwater discharge.

Adapted from Anderson and Woessner, 1992.

METHOD	EXPLANATION
Arbitrary Fixed Radius	Assign circular area of fixed radius (300 m) around well
Calculated Fixed Radius	Calculate cylindrical volume of aquifer supplying water to well for a given pumping rate and time period
Analytical Equations	Calculate source water protection area dimensions using analytical equations accounting for uniform ambient flow
Hydrogeologic Mapping	Map source water protection area from measured groundwater level contours and geomorphologic, topographic and hydrologic features
Numerical Modeling	Delineate source water protection area using numerical flow modeling incorporating actual hydrogeologic information

ASSUMPTIONS	TYPICAL DATA REQUIRED	ADVANTAGES/ DISADVANTAGES	WHEN APPLICABLE
• Uniform aquifer • Negligible ambient flow	None	• Easy and inexpensive to apply • Arbitrary • May be difficult to defend	Inadequate information on well construction, pumping rate and hydrogeology; typically used for drive points and dug wells
• Uniform aquifer • Negligible ambient flow	• Pumping rate and/or water use • Aquifer thickness • Aquifer porosity	• Easy and inexpensive to apply • Accounts for some site-specific information • Based on simple physical equations	Well construction and pumping rate are known, hydraulic gradient is low and aquifer thickness can be estimated; not appropriate for fractured bedrock aquifers
• 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	• Easy and inexpensive to apply • Accounts for some local information • 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
• Groundwater flow direction same as topographic slope • Horizontal flow	• Aquifer boundary • Water table contours (or topographic contours) • Geology • Water quality	• Accounts for local information • Physically based • Moderate-expensive to apply • Large data requirement	May be especially useful for shallow, unconfined aquifers, springs, as well as karstic and fractured bedrock aquifers
• Depends on the model	• Aquifer boundary • Geology • Water table elevations • Aquifer transmissivity • Hydraulic conductivity of aquitards • Knowledge of boundary conditions	• Accounts for local information • Physically based • Predictive capability • Moderate-expensive to apply • Large data requirement	Where hydrogeology and groundwater conditions can't be adequately represented by simple analytical models (e.g. bedrock aquifers, complex hydrogeology, vulnerable aquifers or multiple wells)

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