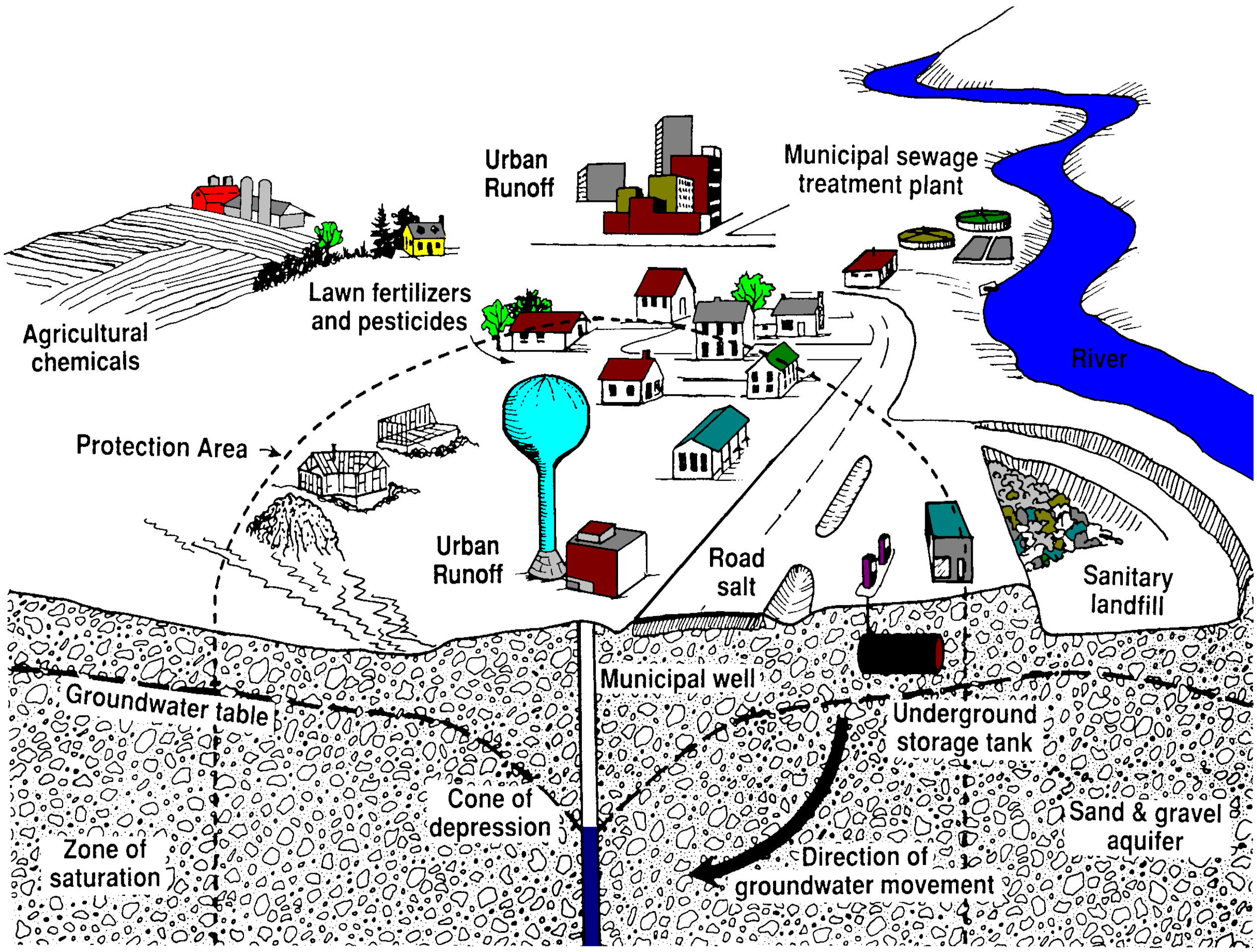
Determining Wellhead Protection Area Boundaries – An Introduction



GROUNDWATER

Wisconsin's Buried Treasure

Wisconsin Department of Natural Resources
January, 1993

Written by:

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and

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Special thanks is given to the individuals who provided technical advice, support, and review of this document.

Front cover: This graphic represents a typical wellhead protection area delineation and possible activities which may be occurring within the delineated area. These activities (i.e. underground storage tanks, lawn fertilizers and pesticides, and road salt usage) are the elements that are addressed in the remaining steps of a successful wellhead protection program.

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January 11, 1993

To: Wisconsin Residents Concerned About Groundwater Quality

The most important elements of an effective groundwater protection program are those that aim to prevent potential sources of contamination from releasing toxic substances where they may degrade the groundwater quality. Once groundwater quality is diminished, it is extremely costly and exceedingly difficult to return it to its pristine, usable condition. This is why it is imperative to prevent any contamination from occurring in the first place. Source controls are an important first step in any effective groundwater protection program.

The 1986 amendments to the federal Safe Drinking Water Act (SDW A) established a nationwide program to protect groundwater used for public water supplies. It provides protection from a wide range of potential sources of contamination through the establishment of state wellhead protection programs.

The goal of the federal wellhead protection program is to protect public water supply wellhead areas from contaminants which may have any adverse effects on the health of people. Wisconsin has a goal enumerated in state statutes (s.160.001, Wis. Stats.) of minimizing the concentration of polluting substances in groundwater and providing adequate safeguards for the public health and welfare. The specific goal of Wisconsin's Wellhead Protection Program is to achieve additional groundwater pollution prevention measures within public water supply wellhead areas.

The purpose of this document is to provide city and county planners with a basic understanding of how a wellhead protection area can be determined. With this knowledge, these planners may then proceed to initiate a wellhead protection program designed to protect the unique and valuable aquifer from which a community draws its drinking water.

Sincerely,

Lyman F. Wible, Administrator
Division for Environmental Quality
Department of Natural Resources

Table of Contents

I. Introduction

Wisconsin is rich in groundwater resources. This buried treasure supplies drinking water for approximately two-thirds of the state's residents, or approximately 3 million people. Almost 94% of the communities in the state rely on groundwater as their sole source of water. Wisconsin residents use almost 570 million gallons of groundwater every day. It might appear that our water resources are dependable and endless.

The supply may be dependable, but that doesn't mean that it isn't vulnerable. Groundwater can be contaminated by many different sources. The usefulness of Wisconsin's groundwater resource is directly related to its quality.

Once groundwater is degraded by contamination from human activities, its usefulness is greatly reduced. Leachate (the foul, sewage-like substance that forms when water percolates through solid waste) from old or poorly constructed landfills can travel toward groundwater. Pesticides can travel through the soil and into the groundwater in low but sometimes toxic concentrations. The over-use of fertilizers on lawns, gardens and farm fields can contaminate the water supply. Septic systems can increase pollutant levels in groundwater. Road salt can contaminate groundwater and gasoline or oil stored in damaged or rusting underground storage tanks can pollute groundwater. The sources of pollution are many, and the problem of contaminated groundwater extreme.

With proper management, groundwater is a renewable resource that provides a continuous source of fresh water for consumption. Even when no immediate water related concern appears to exist, communities need to be knowledgeable about their drinking water resources for a number of reasons:

- to minimize the potential risks to the health and vitality of the community;
- to avoid the potential costs associated with cleaning up contaminated groundwater and providing alternate supplies of water; and
- to avoid the negative economic impacts on a community that groundwater contamination could cause.

One method to minimize the potential of groundwater contamination is to protect a portion of the land area supplying water to the well as a wellhead protection area (WHPA). After determining the area to be protected, a community will be able to focus pollution prevention efforts. A community can then create a management plan to control land use within the protection area to minimize the potential for groundwater contamination. Wellhead protection (WHP) is a progressive pollution prevention tool that has the potential to save each community many thousands of dollars and provide a quality drinking-water supply for the future.

A good discussion of wellhead protection activities can be found in *Protecting Local Groundwater Supplies Through Wellhead Protection (U.S. Environmental Protection Agency, Office of Water, EPA 570/9-91-007)* which outlines the five basic steps of an effective wellhead protection program: form a group of interested individuals; determine the area to be protected; identify and locate potential sources of contamination within the wellhead protection area; assess the adequacy of existing programs to protect groundwater; and plan for the future. The various approaches that can be used to define the area that is to be protected (step 2 in the wellhead protection process) are described, in detail, on the following pages.

II. What Is a Wellhead Protection Area?

The U.S. Environmental Protection Agency (U.S. EPA) defines a wellhead protection area as the "surface or subsurface area surrounding a water well or wellfield supplying a public water system, through which contaminants are reasonably likely to move toward and reach such well or wellfield" (U.S. EPA, 1987). Delineation of the wellhead protection area is the process of determining what geographic area should be included in a wellhead protection program. This area of land is then managed to minimize the potential of groundwater contamination by human activities that occur on the land surface or in the subsurface.

III. The Water Cycle and Groundwater Flow

A. The Water Cycle

Before deciding what area around a well should be protected, it is best to understand where groundwater comes from and how it flows through the subsurface. Gravity and the sun's energy play active roles in a continuous water recycling process called the *water cycle* (Figure 1). Precipitation is the beginning of the cycle. Some of the precipitation that reaches the ground surface can flow downhill as runoff into a lake, stream, or ocean; some evaporates; and some is used by plants and then released to the atmosphere as water vapor. The rest infiltrates into the ground, traveling through pore spaces and open cracks or fractures in the subsurface materials. When these pores and cracks are completely filled with water, the material is said to be *saturated.*

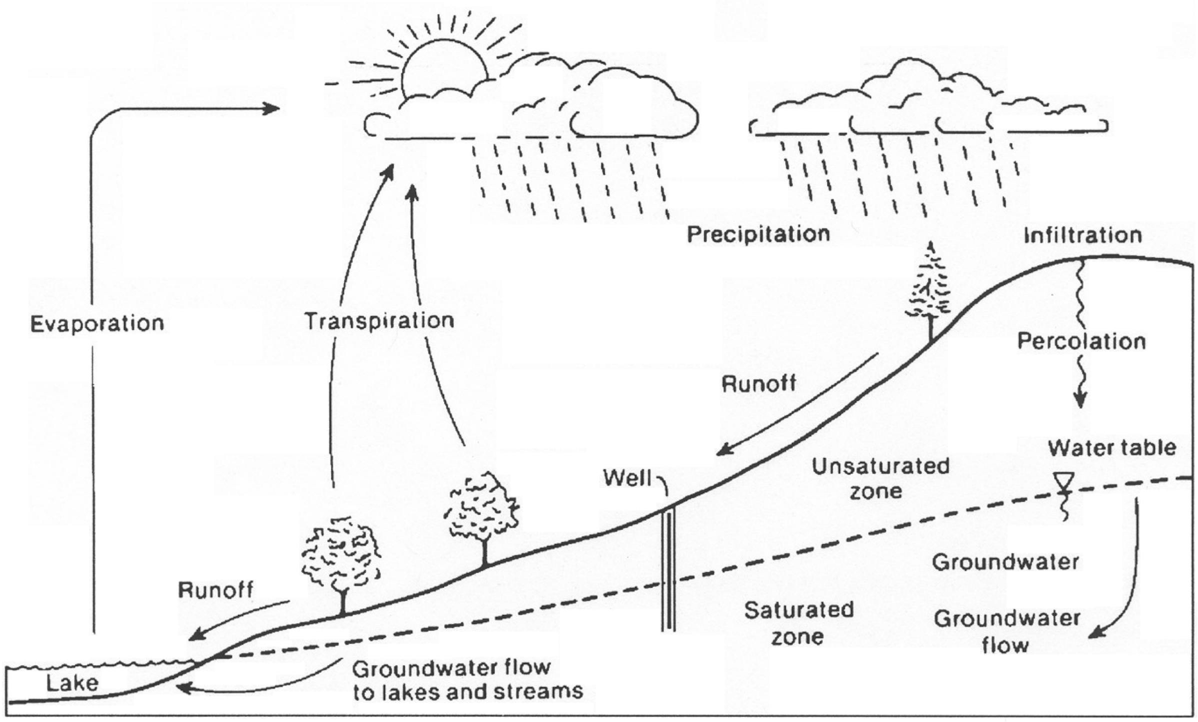
The *water table* marks the top of this saturated zone. *Groundwater* is the water contained in the saturated zone below the water table. Above the water table, pores and cracks are partly or completely filled with air and partly filled with water, and the material is said to be *unsaturated.* Gravity moves groundwater through pore spaces as it seeps from upland to lowland areas; eventually, the groundwater discharges to lakes, streams, or wetlands -- low places where the water table meets the land surface. The sun's energy evaporates some of it into the atmosphere. When water vapor accumulates in the atmosphere and clouds begin to form, the hydrologic cycle begins anew.

B. Types of Aquifers

An *aquifer* is saturated subsurface material that yields sufficient water to a well. In Wisconsin, we rely on several different aquifers for our water supply; the four principal aquifers include the sand and gravel aquifer, the eastern dolomite aquifer, the sandstone and dolomite aquifer, and the crystalline bedrock aquifer. Groundwater flows differently in different aquifers; flow rates can vary from hundreds of feet per day in the open fractures of the dolomite aquifer to several feet per day in porous sands and sandstones. Groundwater can move as slowly as less than 1 inch per year in clay or in unfractured crystalline rock. *Hydraulic conductivity* is the term used to describe the relative ease with which water can flow through an aquifer; it is dependent on the nature of the materials through which the water is flowing. In general, fine-grained units, like clays and shales, have low hydraulic conductivity and are not good aquifers because they yield water so slowly; however, they can provide more protection from contaminants than coarse-grained or fractured aquifers. Understanding the geologic setting of a well is the first step in wellhead protection since some settings are more vulnerable to contamination than others.

Aquifers can be divided into two broad categories. A *confined aquifer* is overlain by a geologic unit of lower hydraulic conductivity, while an *unconfined aquifer* has the water table as its upper boundary. The wellhead protection area delineation techniques discussed below

Figure 1
The Hydrologic Cycle



From WGNHS Water-Table Maps

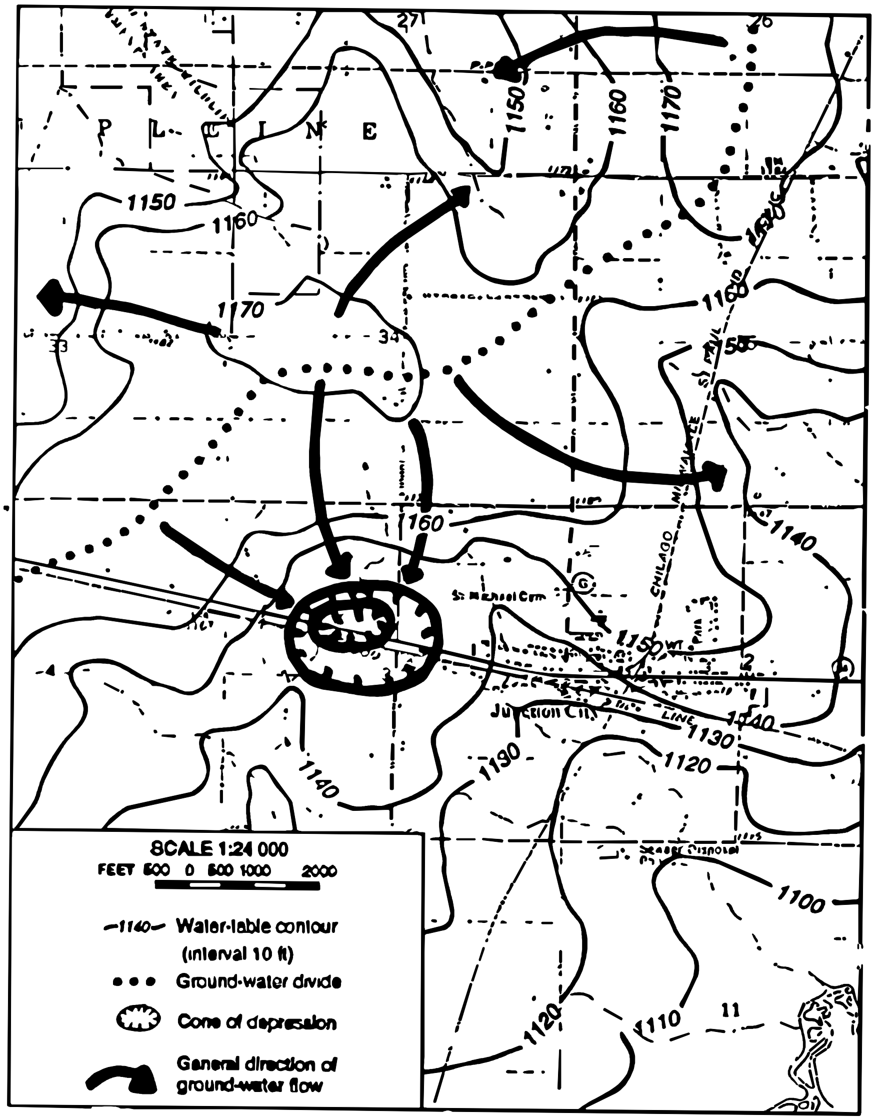
are appropriate for unconfined aquifers. If your public water supply is drawn from a confined aquifer, you should consult EPA's document *Wellhead Protection Strategies for Confined-Aquifer Settings* (U.S.EPA, Office of Water, EPA 570/9-91-008). Fractured-rock aquifers can also present problems for wellhead protection; if your public water supply is drawn from fractured granite, dolomite, or limestone you should consult EPA's document *Delineation of Wellhead Protection Areas in Fractured Rocks* (U.S.EPA, Office of Water, EPA 570/9-91-009).

C. Groundwater Flow Direction

Some of the WHPA delineation methods require knowledge of groundwater flow directions. A *water-table map,* which is a contour map of the elevation of the water table, is frequently used to predict groundwater flow directions in unconfined aquifers. Water flows from higher to lower water-table elevations; flow is generally at right-angles to the contour lines. A water-table map also lets us locate *groundwater divides;* these are ridges (high points) on the water-table surface. Figure 2 shows a water table map from Junction City, WI (EPA 570/9-91-009) showing water-table contour lines, flow directions, and the groundwater divide. In order to use a water-table map to predict flow directions, we must assume 1) that groundwater flow is more horizontal than vertical and 2) that hydraulic conductivity is uniform throughout the aquifer.

In confined aquifers, a *potentiometric-surface map,* which is a contour map of the elevation of water-levels in tightly cased wells that penetrate the confined aquifer, is used to predict flow directions. In order to use a potentiometric-surface map to predict groundwater flow directions, we must make the same assumptions as above.

Figure 2
Water Table Map with
Cone of Depression and
Groundwater Flow Direction Arrows
(from EPA 1991)

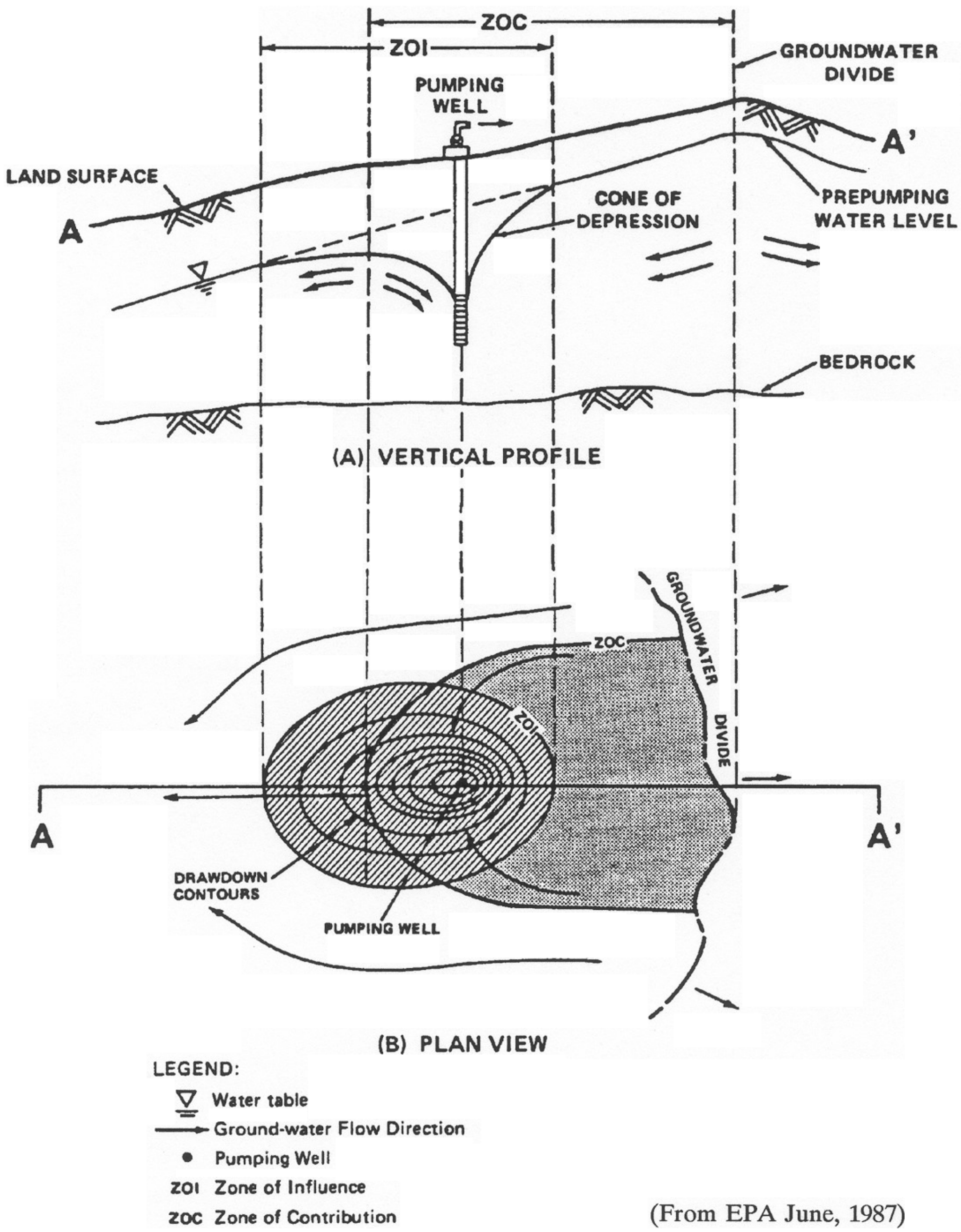


IV. How Wells Affect Groundwater Levels and Flow Direction

A pumping well in an unconfined aquifer tends to create a depression in the water table if water is withdrawn at a rate faster than the aquifer can supply water to the well. This drawdown of the water table is generally called a *cone of depression.* For the purposes of wellhead protection, the land area above the cone of depression is called the *zone of influence (ZOI)* for the well (see Figure 3).

The land area supplying water to a well is generally larger than the well's zone of influence. As discussed above, groundwater flows in response to gravity, from upland recharge areas to lowland discharge areas and groundwater divides separate different groundwater basins. The top portion of Figure 3 shows a cross-section of a water-table aquifer. The direction of groundwater flow is from the groundwater divide (on the right side of the diagram) to a discharge area (off the left

Figure 3
Terminology for WHPA Delineation
(Hypothetical Well in a Water-Table Aquifer)



(From EPA June, 1987)

side of the diagram). The area to the right of the well is considered to be *upgradient* of the well, while the area to the left of the well is *downgradient* in terms of groundwater flow. The entire land surface area over which water can infiltrate and move toward the well is called the *zone of contribution of the well (ZOC).* As Figure 3 shows, the ZOC is elongated in the upgradient direction from the well and the far boundary of the ZOC is the groundwater divide.

V. Factors Affecting Choice of WHPA Delineation Techniques

There are many options to consider when deciding how to delineate a wellhead protection area. Some methods incorporate a great deal of hydrogeologic data. These methods produce maps which represent the area and direction from which the groundwater is flowing. Some other methods produce less detailed maps, but will provide the community with the basic information needed to initiate an effective wellhead protection program. The choice of delineation method depends upon factors such as the perceived level of threat to the groundwater, the size of the population that may be potentially affected, and the economic resources that a community is willing or able to spend. The accuracy of the resulting map is directly related to the money and time invested. This document explains some of the different delineation methods available to a community that is interested in wellhead protection. It includes a detailed description of each method, the data required, and the advantages and disadvantages associated with each method. Also included is an estimation of the work requirements, time, and skill level required and costs.

There is an appropriate wellhead protection area delineation method for each and every community. The goal of a wellhead protection program is to further protect the water supply, and delineating an area as a protection area is a positive and progressive way to obtain that goal. The important step is to initiate a wellhead protection program, however simple it might be.

When delineating a wellhead protection area, there are several criteria that can be considered. These criteria include: 1) distance from the well, 2) drawdown of the water table around the well, 3) time of travel to the well, and 4) physical boundaries to the ground-water system. These criteria are described in greater detail below.

A) Distance: Distance from the wellhead is the simplest way to delineate a WHPA. However, distance criteria are generally arbitrary and disregard factors that control groundwater flow.

B) Drawdown: The WHPA may be defined on the basis of drawdown caused by the pumping of the well. The WHPA may be defined as the entire area throughout which drawdown results from pumping, or the "zone of influence" of the pumping well.

C) Time of Travel (TOT): This criterion is based on groundwater flow rates. A critical period of time (such as 5 or 10 years) is specified and designated as the time of travel. The *hydraulic conductivity* and the *hydraulic gradient* in the aquifer control the groundwater velocity. Once a time of travel has been specified, it can be multiplied by the velocity to obtain a distance. The resulting distance is then used to determine the size of the WHPA.

D) Flow-System Boundaries: Natural boundaries to groundwater flow can be used to define the protection area. Examples of hydrologic boundaries include groundwater divides, geologic contacts, geologic structures, and surface-water bodies. Identifying flow boundaries requires compilation and interpretation of existing data, possible collection of supportive field data, and professional judgment.

VI. Summary of Methods for Wellhead Protection Area Delineation

The majority of this section is summarized from: *Delineation of Wellhead Protection Areas in Fractured Rocks (U.S. EPA 5570/9-91-009).*

A. Fixed Radius Methods.

1. Arbitrary fixed radius

Description: The wellhead protection area (WHPA) is an arbitrary circle drawn with the well at its center.

Requirements: Research as to what would be a reasonable radius for the circle.

Advantages:
a) Easy to implement; requires no site-specific information.
b) Requires very little time.
c) Requires little technical expertise and a minimum of data.
d) Costs are low.

Disadvantages:
a) Least accurate method.
b) Based on very generalize considerations and professional judgement.
c) Criteria used to define the radius may be open to challenges.
d) Protection would only be incidental and the level of protection could not be easily evaluated.

2. Calculated fixed radius

Description: The radius is calculated by a simple equation that incorporates well pumping rates. The delineated circle defines a "zone of influence" (ZOI) for the well (Figure 3). One example of such an equation is given in Figure 4.

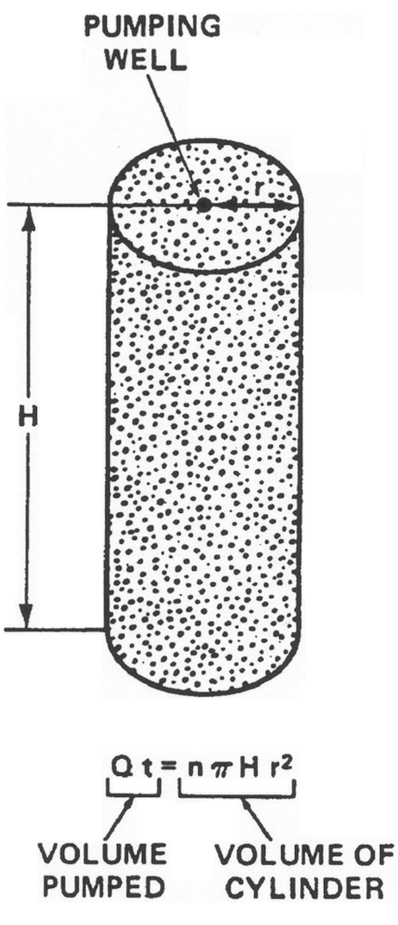
Requirements:
a) Data required include well pumping rate and some hydrogeologic parameters (porosity of aquifer, open interval of well, travel time to well).
b) May require some field investigation.

Advantages:
a) Represents an improvement in accuracy over the arbitrary method.
b) Still easy to determine - does not require much time.
c) Requires a limited amount of technical expertise.
d) Costs are still relatively low.

Disadvantages:
a) Relatively inaccurate for unconfined (water-table) aquifers because it does not account for the natural groundwater flow system. May be reasonably accurate for confined aquifers.

b) The calculated ZOI may include some areas that do not supply water to the well.

Figure 4
WHPA Delineation Using Volumetric Flow Equation
(Calculated Fixed Radius)



$$r = \sqrt{\frac{Q\,t}{\pi\,n\,H}} = 1138 \text{ ft}$$

WHERE

Q = Pumping Rate of Well = 694.4 gpm = 48,793,668 ft^3/yr

n = Aquifer Porosity = 0.2

H = Open Interval or Length of Well Screen = 300 ft

t = Travel Time to Well (5 Years)

(Any consistent system of units may be used.)

(From EPA June, 1987)

c) Some of these methods require an estimate of hydraulic conductivity which may not be easy to determine; the size of the calculated area can vary greatly depending on the hydraulic conductivity.

B. Mapping Methods

1. Vulnerability Mapping

Description. Vulnerability mapping uses geologic maps, soils maps, water-table maps, aerial photographs, and mapping of surficial features to identify areas of the landscape particularly vulnerable to groundwater contamination. Vulnerability mapping does not produce a ZOC for a given well; however, it does identify areas near the well that may contribute to groundwater contamination. A boundary drawn around these susceptible areas can be delineated as a WHPA.

Requirements: Data requirements include soils maps; geologic maps; depth *to* water table maps; and location of major fracture zones, sinkholes, and structural features. Technical ability to determine which areas are particularly vulnerable to contamination.

Advantages:

a) Does not require detailed measurements of aquifer properties.
b) The method uses a variety of data, ranging from office-available maps to field-measured surface features.

Disadvantages:

a) Does not delineate a ZOC for the well.
b) The results are somewhat subjective.

2. Flow-System Mapping

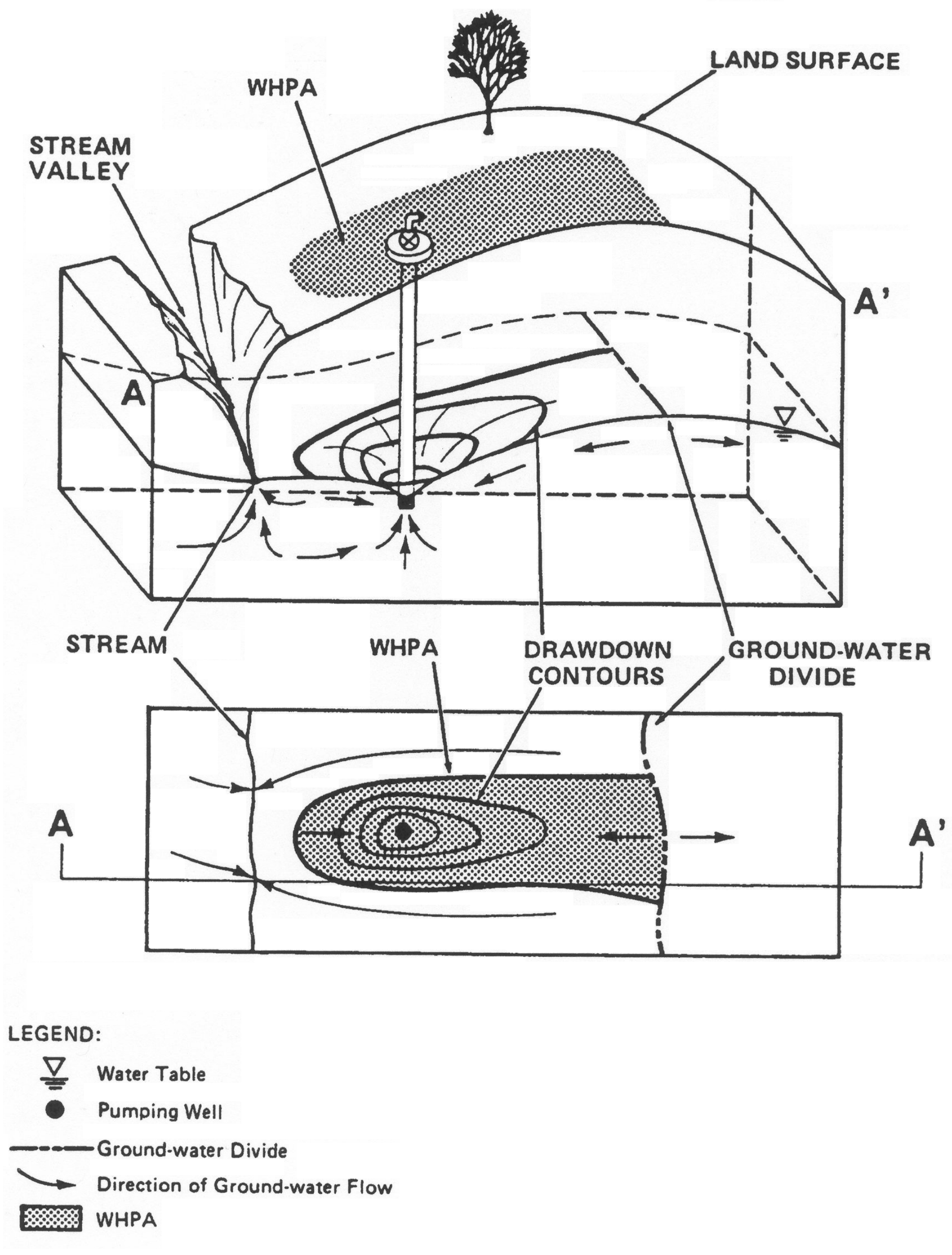
Description: Flow-system mapping uses ground-water divides and flow-system boundaries derived from a water-table map to delineate the ZOC for a given well (see Figure 5).

Requirements: A water-table map. If a published map exists (at an appropriate scale) it can be used. If no published map exists, then a water-table map must be created using either office data (i.e., data from well construction reports) or field-measured data. Some hydrogeologic training is needed in order to construct a water-table map and to define a ZOC based on the water-table map.

Advantages:

a) The method is more accurate because it takes into account the geometry of the groundwater flow system.

Figure 5
WHPA Delineation Using Hydrogeologic Mapping
(Use of Groundwater Divides)



(From EPA June, 1987)

b) The method is relatively simple, requiring only limited training in hydrogeology
c) Can be done without field investigations if sufficient well data are available.
d) The method uses mappable hydrogeologic boundaries.

Disadvantages:

a) The method assumes a uniform aquifer (hydraulic conductivity is the same throughout) and 2-dimensional groundwater flow.
b) The method can produce unacceptably large ZOC estimates if the protected well is located far from a ground-water divide.
c) Errors in the water-table map can cause large errors in ZOC delineation.
d) Costs may be high if little hydrogeologic information is available and wells are necessary to confirm mapping.

<u>3. Flow-System Mapping with Time of Travel (TOT) Calculations</u>

Description: Uses water-table map to estimate groundwater velocity. The velocity, in combination with a specified time of travel, can be used to limit the WHPA to that portion of the ZOC that will contribute water to the well within a specified amount of time.

Requirements: A water-table map and estimates of hydraulic conductivity and porosity.

Advantages:

a) The TOT criterion provides a way to limit the WHPA in areas where the ZOC delineated from flow-system boundaries is unacceptably large.
b) Adding the TOT criterion requires little additional work once the flow-system method has been completed.
c) The method requires only elementary mathematics.

Disadvantages:

a) Errors in estimates of porosity or hydraulic conductivity can cause large errors in the TOT calculation and thus in WHPA delineation.
b) Assumes a uniform aquifer (hydraulic conductivity is the same throughout) and 2-dimensional groundwater flow.
c) The presence of a highly conductive zone could cause very large errors in the TOT calculation and in the resulting WHPA.

<u>4. Flow-System Mapping with Uniform Flow Equation</u>

Description. --The construction of a water-table map allows the application of the uniform flow equation to define the ZOC to a pumping well in a sloping water table. The equation determines the pre-pumping downgradient stagnation point and the transverse boundary limits (see Figure 6).

Requirements: A water-table map and estimates of hydraulic conductivity, porosity, and aquifer thickness.

Advantages:

a) Accounts for some of the effects of pumping on the ZOC without detailed mapping of a cone of depression, which reduces the amount of required field work.
b) The method is simple and requires only limited training in hydrogeology.
c) Uses data derived from a water-table map.

Disadvantages:

a) Assumes a uniform aquifer (hydraulic conductivity is the same throughout) and 2-dimensional groundwater flow.
b) Ignores the effects of hydrologic boundaries (except groundwater divides), aquifer heterogeneities, and non-uniform recharge.
c) Can produce unacceptably large ZOC estimates if the protected well is located far from the groundwater divide.
d) Errors in the water-table map or in estimates of porosity or hydraulic conductivity can cause large errors in ZOC delineation.

C. Residence Time Approach

Description. Isotopes (i.e., tritium) can be used to estimate groundwater age and provide a check on the time of travel and ZOC determination by other methods. Groundwater chemistry may help identify specific rock types or areas supplying water to the well and help identify flow paths. Comparison of groundwater and surface-water chemistry can be used to assess whether the systems are directly connected.

Requirements: Collection of accurate groundwater samples. Relatively advanced knowledge of groundwater chemistry in order to interpret the results.

Advantages:

a) The method can give information about relative ground-water age, which can be useful in determining the appropriateness of WHPA delineation.
b) The method helps confirm TOT estimates made by other techniques.
c) Does not require detailed measurements of aquifer parameters, although knowledge of such parameters increases the method's usefulness.

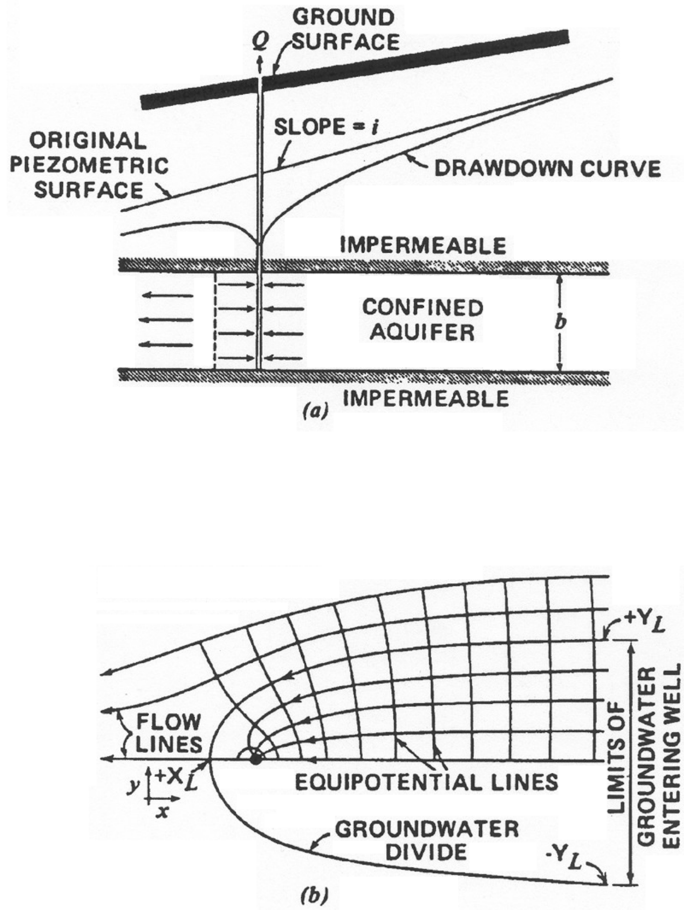
Disadvantages:

a) Requires skill and experience in geochemical and isotopic interpretation;
b) Is not applicable to all settings, and results are sometimes ambiguous.
c) Geochemical and isotopic analyses can be expensive;
d) May not produce a mappable ZOC, but it can help confirm a ZOC and TOTs delineated by some other method.

D. Semi-analytical Flow/Particle-Tracking Models

Description. Uses computer codes to solve the analytical equations for two- dimensional flow to a well under various combinations of parameters. A linked particle-tracking code delineates the zone of contribution for the well. (The most common such model is the EPA's WHPA code, distributed by the International Ground Water Modeling Center).

Figure 6
WHPA Delineation Using the Uniform Flow Equation



$$-\frac{Y}{X} = \tan\left(\frac{2\pi Kbi}{Q}\, Y\right)$$

UNIFORM-FLOW EQUATION

$$X_L = -\frac{Q}{2\pi Kbi}$$

DISTANCE TO DOWN-GRADIENT NULL POINT

$$Y_L = \pm\frac{Q}{2Kbi}$$

BOUNDARY LIMIT

LEGEND:

● Pumping Well

Where:
Q = Well Pumping Rate
K = Hydraulic Conductivity
b = Saturated Thickness
i = Hydraulic Gradient
π = 3.1416

SOURCE: Todd, 1980
(From EPA June, 1987)

NOT TO SCALE

Requirements: Knowledge of the hydrogeologic setting including: aquifer thickness, hydraulic conductivity, aquifer porosity, pumping rate of well, and some experience with computer modeling methods.

Advantages:

a) Allows rapid and accurate solution of the well flow equations for simple settings and geometries, combined with automatic delineation of capture zones.
b) Can rapidly calculate the effects of multiple pumping wells.
c) Can determine groundwater flow paths and travel times with much greater precision than the previous methods.
d) WHPA code is user-friendly and widely available.

Disadvantages:

a) Semi-analytical models are limited to two-dimensional problems in relatively simple settings.
b) There is a danger of hidden errors because the programs are so simple to operate.
c) Most solutions assume a uniform aquifer (hydraulic conductivity is the same throughout).

E. Numerical Flow/Transport Models

Description. Uses computer models to approximate three-dimensional groundwater flow systems and to simulate contaminant flow paths.

Requirements: Detailed knowledge of the hydrogeologic setting including: aquifer geometries, hydrogeologic boundaries, vertical and spatial variations in hydraulic conductivity, porosities, pumping rates, aquifer storativity, areal distribution of recharge, and training in numerical modeling methods.

Advantages:

a) Most accurate method of determining the ZOC; commonly available numerical models can simulate aquifers in three dimensions and can include most of the aquifer variation and changing water levels observed in the field.
b) Because numerical models give an integrated solution over the model domain, ground-water flow paths and travel times can be determined with much greater precision than with other methods;
c) Adequate numerical codes are widely available.

Disadvantages:

a) Models require significant amounts of data for proper calibration, verification, and prediction.
b) Modeling is often very expensive and time-consuming because it requires substantial amounts of data and expertise.

VII. Comparison of WHP Delineation Methods

A. Cost Analysis (Taken from *Delineation of Wellhead Protection Area in Fractured Rocks.* U. S. EPA Technical Guidance Document, Office of Water. EPA 570/9-91-009.)

Exact prediction of the costs inherent in each of the methods is difficult because the amount of field work required for each method depends on how much information is already available, the complexity of the problem area, and the degree of accuracy desired by the wellhead protection program. For example, the work required for aquifer parameter estimation can range from the least costly and least accurate method of simply citing the average values of parameters (such as hydraulic conductivity or porosity) found in literature to the most costly and most accurate method of performing a pumping test. The latter requires extensive field work and many hours of technical data analysis. The parameters necessary for each ZOC delineation method are included in Table 1. Table 2 summarizes some of the work, time, skill, and approximate cost requirements of performing the individual tasks for each of the methods.

The cost estimates are primarily based on an hourly rate that represents the actual salary to an individual at a particular skill level. It does not include general overhead, benefits, taxes, profit, or the amortization of equipment. If a consultant were employed to perform the same tasks, s/he would usually charge three times the hourly costs that are listed in Table 2. Six groundwater consultants or consulting firms in Wisconsin were contacted regarding typical costs for this type of work. They would charge $40 to $100/hr for tasks with skill levels IV, V, and VI. The cost of the flow-system mapping method with calculations (but without drilling or monitoring-well installation) probably would be between $10,000 and $20,000.

B. Data requirements for WHPA delineation methods (Table 1)

Method	Data Requirements									
	K	V	Q	n	i	b	S	R	Hydrologic Boundaries	Aquifer Geometries
Vulnerability Mapping	Geologic, soils, and water-table maps Field mapping of surficial features									
Flow-System Mapping								X	X	
Flow-System Mapping with TOT	X			X	X				X	X
with Uniform Flow Equation	X		X	X	X	X			X	X
Residence Time	Water sampling and analyses									
Semi-analytical Flow/ Particle-Tracking Tools	X		X	X	X	X				
Numerical Flow/ Transport Model	X	X	X	X		X	X	X	X	X

Explanation:

K = hydraulic conductivity
V = vertical leakance
Q = well pumping rate
n = porosity

i = hydraulic gradient
b = aquifer thickness
S = storativity
R = recharge rate

C. Estimated work, time, skill, and cost requirements for selected WHPA delineation methods (Table 2). (Costs do not include overhead, equipment, travel expenses, or other administrative charges).

Method	Work Requirements	Approx. Time Requirement[1]	Skill Level[2]	Approx. Costs ($)[3]
Vulnerability Mapping	Field			
	- Location of measurable wells	2 days	I	300
	- Depth to groundwater measurements	several days	IV	600
	- Location of bedrock outcrops	several days	III, IV	1,500
				2,400
	Office			
	- Interpretation of soil surveys	several days	soils expert	500
	- Constructing depth to groundwater maps	2 days	III	400
	- Constructing depth to bedrock map	2 days	III	400
	- Map compilation	2 days	III	400
				1,700
				4,100
Flow-System Mapping	Field			
	- Location of measurable wells	2 days	I	100
	- Surveying well elevations	3 days	IV	400
	- Piezometer installations	3 days	III, IV	2,000
	- Water level measurements	1 day	IV	120
				2,620
	Office			
	- Collection and plotting of well logs	2-3 days	III	240
	- Hand contouring of maps	2 days	III	160
	-Computer contouring	2 days	V	800
	- ZOC delineation	4 hours	IV	60
				1,260
				3,880
Flow-System Mapping with TOT calculations	All work listed under flow-system mapping method plus:			**3,880**
	Field			
	- Aquifer parameter estimation	2-3 days	III, IV	**1,000**
	Office			
	- Interpretation of hydraulic gradients	1 hr	II	20
	- Hydraulic conductivity estimates (from literature, specific capacity estimates, analysis of field data)	2-3 days	VI	1,500
	- Application of groundwater velocity equation to establish TOTs	5 hours	III, IV	50
				1,570
				6,450
Flow-System Mapping with Uniform Flow Equation	All work listed under flow-system mapping method plus:			**3,880**
	Field			
	- Aquifer parameter estimation	2-3 days	III, IV	**1,000**
	Office			
	- Interpretation of hydraulic gradients	1 hr	II	20
	- Hydraulic conductivity estimates	2-3 days	VI	1,500
	- Application of uniform flow equations	4 hr	II	60
				1,580
				6,460

Residence-Time Approach	<u>Field</u>			
	- Water sampling	2 days	IV	300
	<u>Laboratory</u>			
	- Sample analyses	-	chem lab	3,000
	<u>Office</u>			
	- Data interpretation	2 days	VI	<u>1,200</u>
				4,500
Semi-analytical Flow/Particle-Tracking Models	All work listed under flow-system mapping method plus:			**3,880**
	Office			
	- Interpretation of hydraulic gradients	1 hr	III	10
	- Determine well coordinates	2 hr	II	15
	- Determine pumping rates	2 hr	II	15
	-Modelling	4 hr	V	<u>200</u>
				<u>240</u>
				4,120
Numerical Modelling	<u>Field</u>			
	Might include:			
	- Location of measureable wells	2 days	I	100
	- Surveying well elevations	3 days	IV	400
	- Water level measurements	several days	IV	500
	- Piezometer installation	3 days	III, IV	2,000
	- Borehole drilling and logging	1 week	III, IV	15,000
	- Geophysical logging	several days	III, IV	5,000
	- Video logging	1 day	IV	1,000
	- Slug tests	1-2 weeks	IV	1,500
	- Aquifer pumping test	2 days	III, IV	2,000
	- Location of bedrock outcrops	2 days	III, IV	<u>500</u>
				28,000
	<u>Office</u>			
	- Water table mapping	1 week	III	500
	- Bedrock surface elevation mapping	2 days	III	200
	- Analysis of field data:	2-3 weeks		5,000
	- Slug tests		VI	
	- Geophysical logs		III	
	- Pumping test		VI	
	- Borehole drilling		III	
	- Initial model construction	3 weeks	VI	9,000
	- Parameter selection			
	- Boundaries			
	- Spatial discretization (horizontal and vertical)			
	- Data management			
	- Model calibration	2 weeks	VI	6,000
	- Transient simulations	1 week	VI	3,000
	- Application of particle tracking program to delineate ZOC	2 weeks	VI	6,000
	- Preparation of graphic output	1 week	V	<u>2,000</u>
				<u>31,700</u>
				59,700

[1]Time requirements depend on the scale and complexity of the problem.

[2] Skill Level:	Hourly Rate ($)
I - Little or no technical expertise required	5
II - Some knowledge of hydrogeology helpful	7.50
III - Training in hydrogeology and/or mapping required	10
IV - Training in hydrogeologic field methods required	15
V - Computer expertise required	50
VI - Requires combination of computer and hydrogeologic expertise	

[3] Costs do not include overhead, equipment, travel expense, and other administrative charges.

Decisions which can result in groundwater pollution or protection are made by individual people. They decide to install a septic system, fertilize their yard or garden, start a feedlot, open a gas station, improve an industrial process, reduce waste or recycle and many other activities. People can make better decisions if they understand the impact of their actions. Wellhead protection is a tool that is designed to minimize the potential for groundwater contamination to occur. Protection, management and education are the tools used by a successful wellhead protection program. Many groups and individuals need to cooperate. People getting involved - as citizens, agency staff, local leaders and industry representatives - will supply the energy to make wellhead protection work. Take positive and progressive steps to protect the quality of life that your community now enjoys.

VIII. For more information about wellhead protection contact:

1. **DNR New Well Wellhead Protection Coordinator** Lee Boushon
   Public Water Supply Section
   P. O. Box 7921
   Madison, WI 53707-7921
   (608) 266-0857
   email: Lee.Boushon@dnr.state.wi.us

2. **DNR Voluntary Wellhead Protection Coordinator** David Lindorff
   Groundwater Section
   P. O. Box 7921
   Madison, WI 53707-7921
   (608) 266-9265 or (877) 268-9355 toll free
   email: David.Lindorff@dnr.state.wi.us

3. **DNR Regional Water Supply Specialists**

Northeast Region
1125 N Military Avenue
Box 10448
Green Bay, WI 54307-0488
(920) 492-5800

South Central Region
3911 Fish Hatchery Road
Fitchburg, WI 53711
(608) 275-3266

Southeast Region
2300 N Dr. Martin Luther King Jr Dr
P O Box 12436
Milwaukee, WI 53212
(414) 263-8500

West Central Region
1300 W Clairemont Avenue
P O Box 4001
Eau Claire, WI 54702-4001
(715) 839-3700

Northern Region
810 W Maple Street
Spooner, WI 54801
(715) 635-2101

Northern Region
107 Sutliff Avenue
Rhinelander, WI 54501
(715) 365-8900

4. The **Wisconsin Geological and Natural History Survey** (WGNHS) can provide information on what type of geological and hydrogeological data are available for your area. For a list ofWGNHS publications, write or call:

Wisconsin Geological and Natural History Survey
3817 Mineral Point Road
Madison, WI 53705
(608) 262-1705

5. The **Central Wisconsin Groundwater Center** is a clearinghouse for information on groundwater issues in central Wisconsin.

Central Wisconsin Groundwater Center
College of Natural Resources, room 224
University of Wisconsin - Stevens Point
Stevens Point, WI 54481
(715) 346-4270

6. The **Wisconsin Rural Water Association** (WRWA) provides technical assistance to rural communities (with water supplies that serve 10,000 people or less) that are trying to establish WHP programs.

Wisconsin Rural Water Association
350 Water Way
Plover, WI 54467
(715) 344-7778

7. Your **county University of Wisconsin - Extension** office can provide general information on wellhead protection. Look for the address and phone number in the telephone book under the county listings.

8. The **National Technical Information** Service can provide you with the EPA publications. There may be a cost.

National Technical Information Service
U. S. Department of Commerce
Springfield, VA 22161
1-800-553-6847

REFERENCES

<u>Wisconsin Department of Natural Resources Publications:</u>

Groundwater: Protecting Wisconsin's Buried Treasure: Supplement to Wisconsin Natural Resources Magazine, 1999, 32 p.

<u>Wisconsin Geological and Natural History Survey Publications:</u>

A Guide to Groundwater Quality Planning and Management for Local Governments: Wis. Geological and Natural History Survey Spec. Rept. 9, 1987, 91 p.

Wellhead Protection Districts in Wisconsin: An Analysis and Test Applications. Special Report 10, 1988, 75 pages.

Groundwater Protection Through Local Land-Use Controls. Special Report 11, 1991, 48 p.

Water Table Maps. Miscellaneous Papers, 81-1.

<u>United States Environmental Protection Agency Publications:</u>

Guidelines for Delineation of Wellhead Protection Areas: U.S. EPA Office of Ground-Water Protection, Chapters paginated separately, June, 1987.

Wellhead Protection Programs: Tools for Local Governments: U.S. EPA, Office of Ground-Water Protection, 1989, 50 p.

Protecting Local Groundwater Supplies Through Wellhead Protection: U.S. EPA, Office of Water, 1991, EPA 570/9-90-007, 18 p.

Delineation of Wellhead Protection Areas in Fractured Rocks. U.S. EPA Technical Guidance Document, Written by K. R. Bradbury, M. A Muldoon and A. Zaporozec. USEPA Office of Water, (June 1991) EPA 570/9-91-009, 144 p.

Wellhead Protection Strategies for Confined Aquifer Settings. USEPA Office of Water, June 1991, (EPA 570/9-91-008) 168 pages.

ANNOTATED BIBLIOGRAPHY

WISCONSIN PUBLICATIONS

Designs for Wellhead Protection in Central Wisconsin - Case Studies in the Town of Weston and City of Wisconsin Rapids. Thomas J. Osborne, et al. (1989).

Wellhead protection basics. WHPA delineation, time of travel calculations, potential contamination sources, and designing groundwater protection strategies. Available from the Central Wisconsin Groundwater Center. 95 pages. (715) 346-4270 $4.50

A Guide to Groundwater Quality Planning and Management for Local Governments. Stephen M. Born et al. (1987).

Detailed discussion on the individual steps in the wellhead protection process. The discussion on regulatory and nonregulatory tools is particularly good. Available from the Wisconsin Geological and Natural History Survey (WGNHS), (608) 263-7389; (Ask for Spec. Rept. 9). 91 p., $5.00

Wellhead Protection Districts in Wisconsin: An Analysis and Test Applications. Stephen M. Born et al. (1988).

Reviews various methods for delineating wellhead protection districts and assesses the methods in a variety of settings representative of Wisconsin's hydrogeology. This publication may be the best single source of information concerning wellhead protection. Available from the WGNHS, $3.00.

Groundwater Protection Through Local Land-Use Controls. Douglas A. Yanggen and Bruce Webendorfer. (1991).

Focuses on how local governments can use zoning and subdivision control powers to regulate the land uses that may contaminate groundwater. It is designed as a guide for elected officials, planning and zoning officials, and their technical advisors. Available from the WGNHS, 48 pages. (608) 263-7398; (Ask for Spec. Rept. 11) $4.00

Groundwater Quality Regulation: Existing Governmental Authority and Recommended Roles. Douglas M. Yanggen and Leslie L. Amrhein. (1989).

Focuses on roles that local governments can play in joint local/state regulatory schemes to protect groundwater. Intended for persons preparing local regulations and their legal advisors. Available from the WGNHS, 109 pages. (608) 263-7398 $6.00

EPA GUIDANCE DOCUMENTS AND OTHER PUBLICATIONS

Guidelines for Delineation of Wellhead Protection Areas: U.S. EPA, Office of Groundwater Protection, Washington, DC, (1987).

Identifies and describes the various methods used to delineate a wellhead protection area. US EPA Office of Groundwater Protection, Washington, D.C. Separate chapters.

Protecting Loca1 Groundwater Supplies Through Wellhead Protection (May, 1991).

Intended to be used by city or town officials, water supply managers or interested citizens. It contains a five step procedure to help you delineate, inventory, and manage your local wellhead protection area. 18 pages. EPA Document 570/9-91-007.

Groundwater: Managing the Unseen Resource. Edwin H. Clark II and Philip J. Cherry. (1992).

This handbook attempts to point out the most innovative and effective programs in groundwater protection and temper expectations with cautionary notes on problems encountered in other areas or programs. Available from the World Wildlife Fund Publications, P.O. Box 4866, Hampden Post Office, Baltimore, MD. 21211. (419) 516- 6951. $8.50 34 Pages.

A Review of Sources of Groundwater Contamination from Light Industry (May 1990).

This Technical Assistance Document is intended to assist managers and officials in identifying and controlling potential light industrial sources of contamination that may pose a threat to public water supplies. 48 pages. EPA Document 440/6-90-005.

Local Financing for Wellhead Protection (June 1989).

Provides information to state and local managers of water supplies about financing available to support wellhead protection programs. 57 pages. EPA Document 440/6-89-002.

Wellhead Protection Programs: Tools for Local Governments (April 1989)

A Technical Assistance Document to be used as a reference source by planners and officials when they are looking for ways to manage their wellhead protection areas. 50 pages. EPA Document 440/6-89-002.

Developing A State Wellhead Protection Program: A User's Guide to Assist State Agencies Under the Safe Drinking Water Act (July 1988).

This Technical Document outlines the range of options available and examples of different approaches that can be used to develop each element of a wellhead protection plan. 44 pages. EPA Document 440/6-88-003.

Surface Geophysical Techniques for Aquifer and Wellhead Protection Area Delineation (December 1987).

This Technical Assistance Document details one scientific approach to delineation of wellhead protection areas. It may be appropriate for groundwater system managers. 49 pages. EPA Document 440/12-87-016.

An Annotated Bibliography on Wellhead Protection Programs (August 1987).

Contains references on 142 documents that contain one or more of the six statutorily required elements of a wellhead protection program. 75 pages. EPA Document 440/6-87-004.