State of Nevada
Wellhead Protection Program
Guidance Document

Wellhead Protection Area Delineation Recommendations

Nevada Division of Environmental Protection
Bureau of Water Quality Planning
Ground Water Protection Section

333 W. Nye Lane
Carson City, Nevada 89710

(702) 687-4670 x.3088

August 9, 1995

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DISCLAIMER

Mention of trade names, firm names or commercial products, does not constitute endorsement or recommendation for use by the State of Nevada. The Nevada Division of Environmental Protection (NDEP) believes that the models mentioned in this document may be very useful for wellhead protection program implementation, and NDEP utilizes several of these models in-house. However, NDEP does not select, endorse, or approve their use over any other approach. Since various ground water modeling software packages are continually updated, improved, and rereleased, there may be many models capable of facilitating wellhead protection area delineations.

ABSTRACT

Delineating wellhead protection areas is a crucial element of a wellhead protection program. To help ensure that wellhead protection areas in Nevada are delineated using sound technical methodology, this document containing wellhead protection area delineation recommendations was developed. This technical assistance document is intended to serve several purposes and may be useful to anyone delineating wellhead protection areas, including public water system operators and hydrogeological consultants. It may help wellhead protection program team members to understand the process of delineating wellhead protection areas. It outlines general recommendations regarding the criteria, thresholds and methods to be used in delineating wellhead protection areas in Nevada. It provides step-by-step instructions for two of the more simplified methods for individuals with limited, or no, technical background. However, these individuals may need to consult additional sources of information to fully comprehend the process. It also provides general recommendations for several methods directed at individuals with more technical expertise. However, the more sophisticated methods of delineating wellhead protection areas are not discussed in detail.

A general procedure is described for delineating wellhead protection areas, including: collection and compilation of information and data; determination of the degree of aquifer confinement and the aquifer type; and selection of appropriate criteria, thresholds, and methods.

The recommendations for wells withdrawing water from confined aquifers differ slightly from those withdrawing water from unconfined aquifers. Therefore, it is important to determine the degree of confinement of the aquifer. For unconfined and semi-confined aquifers, a minimum wellhead protection area corresponding to a 3000 foot radius or a ~~5-year~~ 10-year travel time capture zone should be used. For confined aquifers, a minimum wellhead protection area corresponding to a 2500 foot radius or a five year capture zone around the well is recommended. For many basin-fill aquifers in Nevada, the recharge areas for unconfined, semi-confined and confined aquifers tend to be located at the basin margins, which may be located some distance from the well. Therefore, the recharge area should be defined for basin-fill aquifers so that the portion of the recharge area contributing water to the wells may be included in the wellhead protection program.

It is recommended that the method that most realistically represents the hydrogeologic conditions of the site be used. For many cases, this will be the most sophisticated method practicable that utilizes all available appropriate data. In this way, the most realistic and protective wellhead protection area will be delineated. Methods using a time of travel and/or flow boundary criteria are recommended, including the calculated fixed radius method, analytical and semi-analytical methods, and numerical models. It is also recommended that hydrogeologic mapping be used by itself or to complement the methods listed above.

If there are not sufficient data or technical expertise to use the method deemed appropriate, a more simplistic method may be used to delineate a preliminary wellhead protection area. A preliminary wellhead protection area can be used to initiate wellhead protection efforts while the appropriate data and/or technical expertise are being acquired. The use of the arbitrary fixed radius method is not recommended, although it may be necessary in some cases. The State

advocates using the arbitrary fixed radius method **only** as a preliminary wellhead protection area delineation when insufficient data are available for the use of any other method.

Any individual delineating wellhead protection areas should be aware that the results of all delineation methods are only approximations of the actual capture zones -- even the results of numerical models. Additionally, with the exception of numerical contaminant transport models, all methods discussed in this document account for advective transport only. In other words, for all methods it is assumed that any contaminant would flow along with the ground water. The effects of mechanisms such as adsorption, attenuation, hydrodynamic dispersion, and diffusion are not considered. It should also be noted that if any change is made to the local hydrologic system, the wellhead protection area around the effected well should be re-delineated. Two examples are when a new well is added to a wellfield or when pumping rates are increased significantly.

I. INTRODUCTION

A wellhead protection program (WHPP) is a mechanism by which municipalities can protect their current and future drinking water supplies from known or potential causes of contamination. It is preferable technologically and economically, to use preventive measures to protect drinking water supplies rather than clean up contaminated water to drinking water standards.

A WHPP is composed of the seven elements listed below:

- formation of a WHPP team to identify the roles and responsibilities of involved entities and to take the lead in the development and implementation of the WHPP;
- delineation of the wellhead protection areas;
- inventory of potential and existing contamination sources;
- implementation of potential and existing contaminant management strategies;
- development of plans for siting new community wells;
- contingency plan development; and
- public participation and education.

Although public participation is listed as a separate component, it should be integrated into all of the other components.

I.A. Purpose

Delineating a wellhead protection area is a critical component of a wellhead protection program. It is also the component that demands the greatest amount of technical expertise. It is likely that many public water systems serving small communities will not have adequate in-house technical expertise and data to use complex wellhead protection area delineation methods. Such public water systems and communities may retain external technical expertise, although this option may be prohibitively expensive for small public water systems and communities. In part, the purpose of this technical assistance document is to recommend simplified approaches to delineating wellhead protection areas for small communities with limited resources. This document provides the necessary guidance for persons with limited technical expertise to delineate wellhead protection areas that will provide additional protection for the public drinking water supply, given the available information about the wells and the hydrogeologic setting.

Additionally, this document is intended to outline general recommendations for technical personnel to follow when using more complex methods of delineating wellhead protection areas. The State's goal is to ensure that all wellhead protection areas are delineated in a technically sound manner. The appropriate and continuous management of potential contaminant sources within a properly delineated wellhead protection area will go a long way in protecting the community's underground drinking water supply.

This document is not intended to be an instructional text in the discipline of hydrogeology. The glossary in Section IX should be consulted for brief explanations of the technical terms used

Note: The first time a key word appears in a major section, it will be underlined to indicate that it is defined in the glossary of this document.

in this document. The sources listed in Section VIII should be consulted for more detailed explanations of hydrogeologic concepts.

I.B. Definition of a Wellhead Protection Area

The 1986 amendments to the federal Safe Drinking Water Act define a wellhead protection area as "the surface and subsurface area surrounding a well or wellfield, supplying a public water system, through which contaminants are reasonably likely to move toward and reach such water well or wellfield." In other words, a wellhead protection area is the area on the ground surface which must be managed in order to protect the ground water below. This area is delineated by defining the area around a well that contributes water to the well. Often, a time-related capture zone is delineated as the wellhead protection area. A time-related capture zone can be represented as the land surface area overlying the portion of the aquifer from which the well draws water during a specific period of time (Figure 1).

A wellhead protection area surrounding a well should be conservative, or protective; it should include the surface and subsurface area contributing water to the well. To provide additional protection, the portion of the recharge area contributing water to the well should be identified and managed appropriately. **The goal of wellhead protection is to provide protection from contaminant releases, so that drinking water standards can be maintained at the well. It must be emphasized that it requires much less effort and money to protect an aquifer than to clean up a contaminated one.**

I.C. General Hydrogeology of Nevada

Most of Nevada lies within the Basin and Range physiographic province, which is characterized by isolated, long, narrow, roughly parallel mountain ranges and broad, intervening, nearly flat valleys and basins. Nevada has been divided into 14 major hydrographic regions that are made up of 256 hydrographic areas and subareas (Figure 2).

Hydrogeologic conditions in Nevada vary according to the statewide distribution of three basic aquifer types: basin-fill, carbonate rock, and volcanic rock (Figure 3). The basin-fill aquifers supply most of the ground water currently withdrawn in Nevada. These aquifers consist of alluvial and lacustrine deposits, and are generally contained within closed basins. Some of the basin-fill aquifers in closed basins may contain naturally occurring, poor quality, saline waters. Basin-fill aquifers may or may not be hydraulically connected to aquifers in adjacent basins via inter-basin flow. An extensive carbonate rock terrain covers much of the southern and eastern two-thirds of Nevada, and carbonates comprise much of the stratigraphy of the mountain ranges. A hydraulic connection between adjacent basins has been documented in this terrain; flow is believed to be through the carbonate rock aquifers that separate the basins. Volcanic rock aquifers are located in several isolated sections of the State, but only a relatively small amount of ground water is withdrawn from them. There are also areas in Figure 3 that are indicated "not a principal aquifer". However, portions of the area mapped as such may provide some water for small water systems, commonly through springs or wells in highly fractured bedrock. Each of these aquifer types is considered separately when outlining wellhead protection area delineation method guidelines.

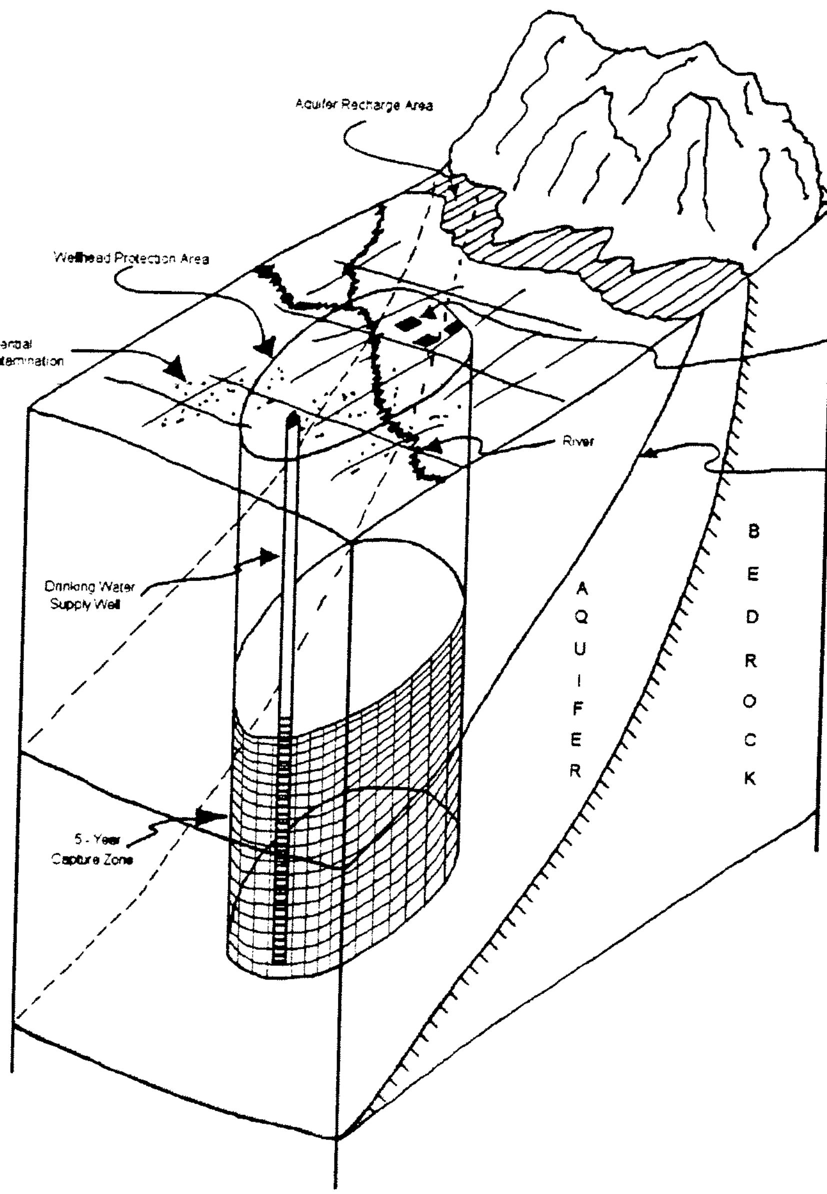


Figure 1. Schematic 3-dimensional drawing of a wellhead protection area for an unconfined, basin-fill aquifer. Drawing is not to scale. Figure was modified from a drawing by Matt Small, U.S. EPA, Region IX.

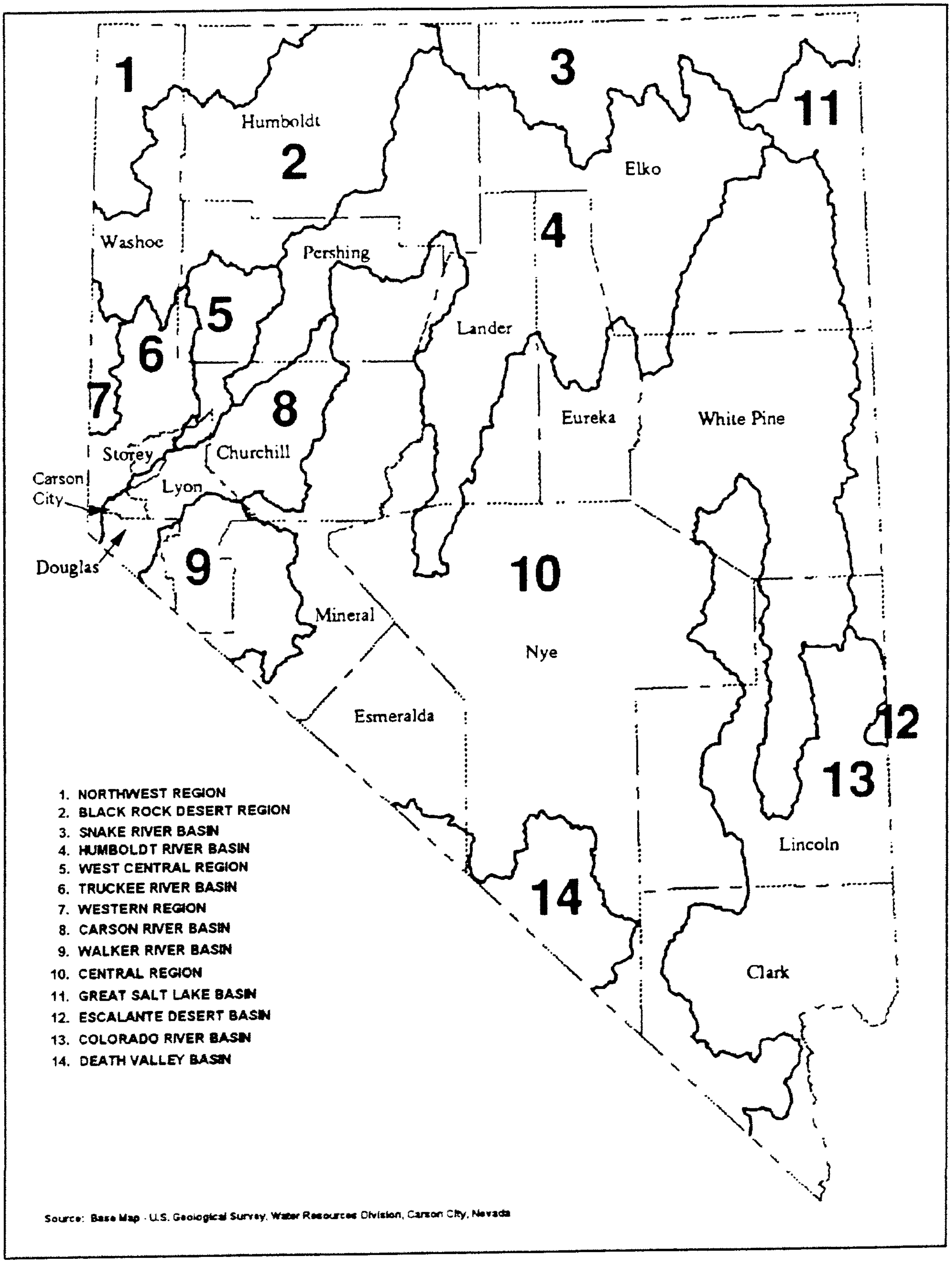


Figure 2. Hydrographic regions of Nevada. From Nevada Division of Water Planning, 1992, Water Facts.

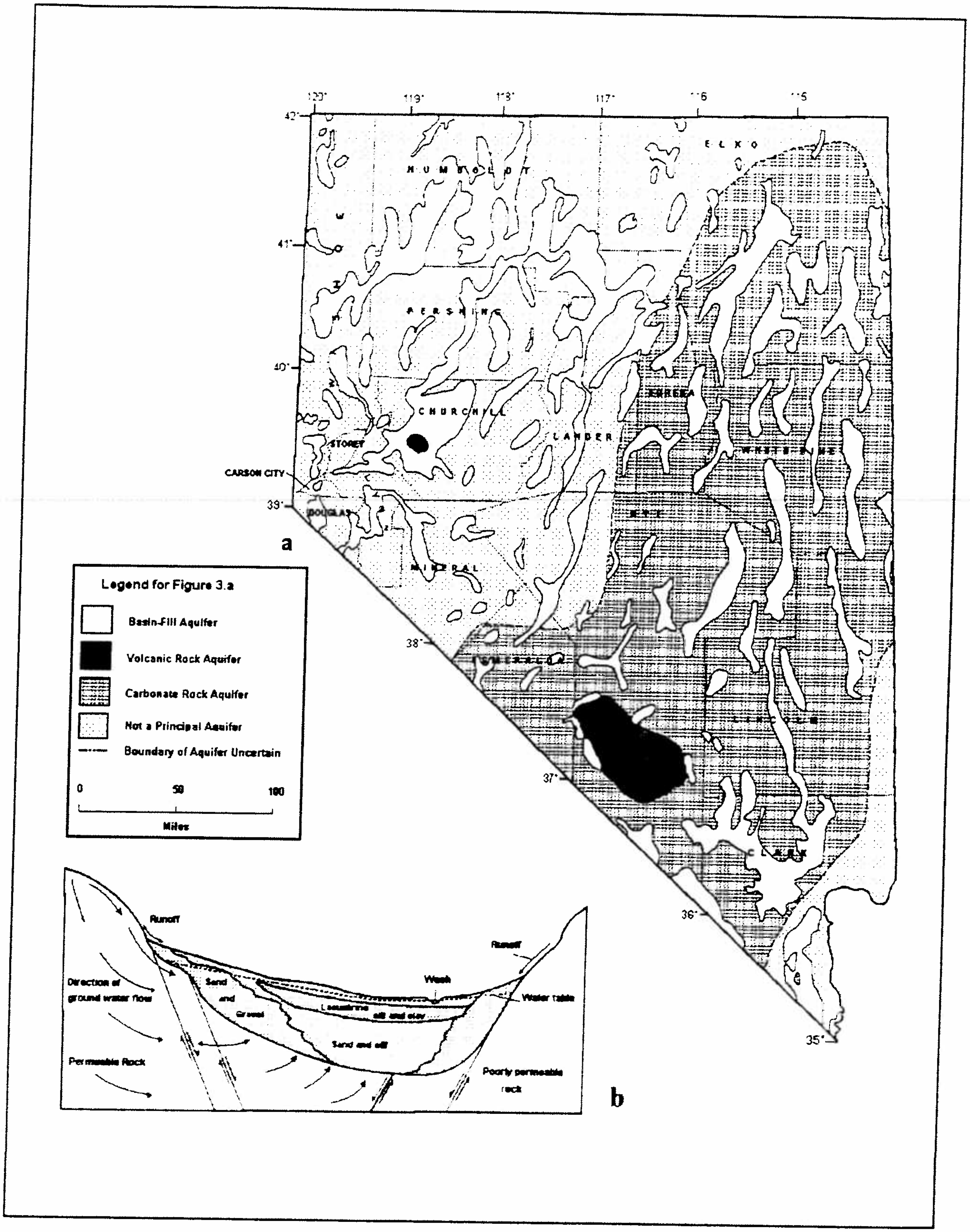


Figure 3. Principal aquifers in Nevada. A) Geographic distribution. B) Generalized cross section showing typical distribution of sand and gravel deposits in a basin-fill aquifer. From U.S. Geological Survey, 1984.

Since basin-fill, or alluvial, aquifers supply a majority of the public water system wells in Nevada, this guidance document focuses on the delineation of wellhead protection areas for wells drawing water from this type of aquifer. The degree of confinement of alluvial aquifers in Nevada can range from unconfined to semi-confined or highly confined. Most commonly, the alluvial aquifers used for drinking water supply are either unconfined or semi-confined. In addition, since a number of public water system wells draw water from the eastern Nevada carbonate aquifer or fractured rock aquifers in various parts of the State, recommended wellhead protection area delineation methods are discussed briefly for these hydrogeologic settings.

I.D. General Procedure for Delineating Wellhead Protection Areas

A general procedure for delineating wellhead protection areas is outlined in the flow chart in Figure 4. The first step is to collect and compile information regarding the water supply system itself, in addition to information and data about the local and regional hydrogeologic system. The information to be compiled should include, but not be limited to:

- locations of public water system (PWS) wells indicated on a map of the community or a U.S. Geological Survey topographic map;
- current peak demand and maximum possible pumping rates for all wells;
- locations and peak volume pumped of any large volume wells (other than PWS wells) within 3000 feet of any of the PWS wells;
- driller's reports;
- well logs;
- recent static water levels;
- recent water levels taken while pumping;
- pumping test data; and
- local or regional hydrogeologic assessments or reports.

The resources listed in Section VIII of this document may be consulted for some of this information.

Using this information and data, determine the type of aquifer from which the wells are drawing water. The degree of aquifer confinement should also be determined as described in Section III. Then the appropriate section of this document, as dictated by aquifer type and confinement, should be consulted to help in the selection of recommended criteria, thresholds and methods. After selecting an appropriate method, the recommendations specific to that method should be followed to delineate the wellhead protection areas.

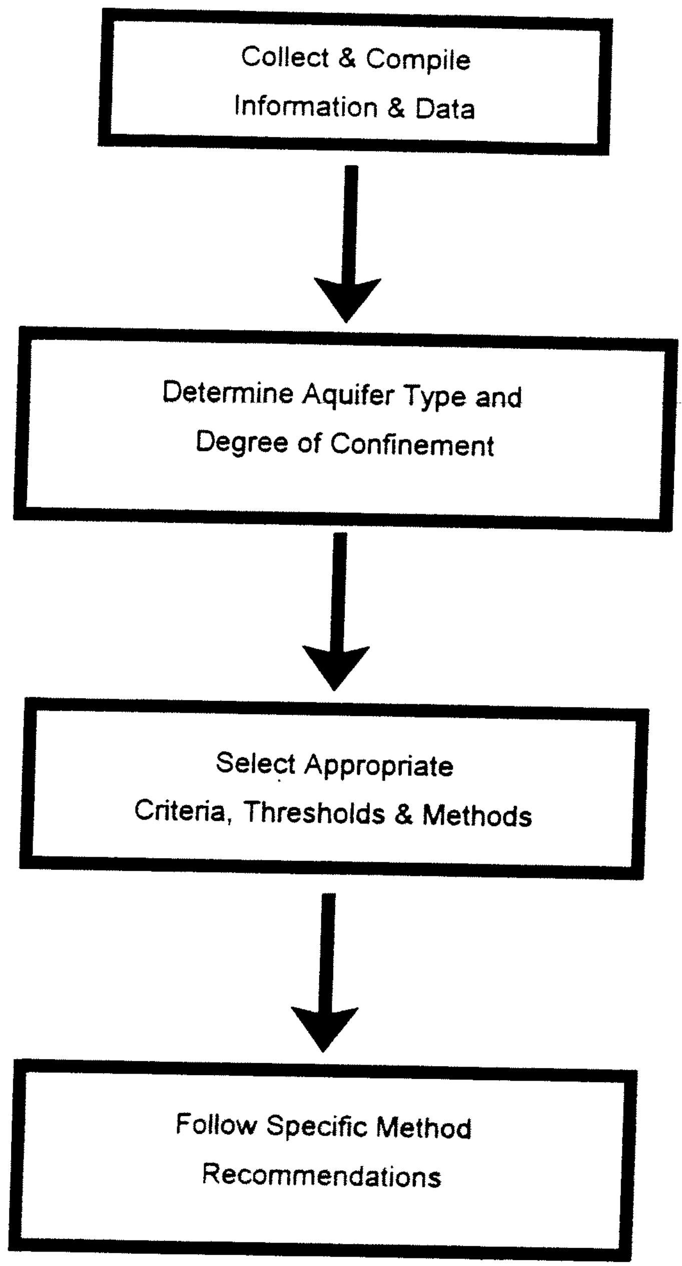


Figure 4. Procedure for delineating a wellhead protection area.

II. CRITERIA, THRESHOLDS AND METHODS RECOMMENDED BY U.S. EPA

There are several criteria that may be used in the delineation of a wellhead protection area. These criteria are physical features or parameters that may be mapped, measured or calculated. Examples of criteria include time of travel, distance, and flow boundaries. The values selected for these criteria are the thresholds. The selected criteria and thresholds will dictate the extent of the wellhead protection area. For example, 3000 feet is a threshold that may be used with the distance criterion and ~~5 years~~ 10 years is a threshold that may be used with the time of travel criterion. One or more of these criteria may be used in a particular wellhead protection area delineation method. Appropriate thresholds for a particular criterion must be set according to the desired level of protection, contingency plans and management goals. For example, if a community has contingency plans that require a minimum of five years for implementation, it should select a threshold of five years for time of travel and delineate a five year capture zone.

There are six wellhead protection area delineation methods recommended by the U.S. EPA (U.S. EPA, 1987). These methods are briefly described below in order of increasing sophistication. Not all of these methods are appropriate for use in typical hydrogeologic settings in Nevada. A summary of the advantages and disadvantages of the methods appropriate for use in Nevada is shown in Table 1. Some of these methods may not be practicable for use with a particular water system due to insufficient data, as well as technical and financial constraints. However, it is recommended that the method that most realistically represents the hydrogeologic conditions of the site be used so that an accurate and protective wellhead protection area is delineated.

II.A. Arbitrary Fixed Radius

The arbitrary fixed radius method uses the criterion of distance to define a circle of a specified radius around a well. The radius should be selected based on typical aquifer and pumping conditions which would result in a distance corresponding to a reasonable time of travel. This fixed radius is then arbitrarily applied to all wells. The arbitrary fixed radius method does not account for any variability in hydrologic conditions between locations of application, and the use of this method risks either under or over predicting the area around the well that should be managed. It is not recommended except to delineate a preliminary wellhead protection area and in cases where it is used, the State recommends a minimum radius of 3000 feet around a well in an unconfined aquifer and 2500 feet around a well in a confined aquifer. These arbitrary radii are conservative under most hydrogeologic conditions in Nevada, as compared to the radial distance corresponding to a ~~5-year~~ 10 year capture zone.

Note: The first time a key word appears in a major section, it will be underlined to indicate that it is defined in the glossary of this document.

Table 1. Summary of wellhead protection area delineation methods.

Delineation Method	Advantages	Disadvantages
Arbitrary Fixed Radius	▸ easy to use ▸ may serve as a preliminary wellhead protection area	▸ is not accurate for any particular site, since it does not account for local hydrogeologic conditions ▸ is not recommended, but may be used in the absence of data necessary for the use of any other method
Calculated Fixed Radius	▸ minimal data required ▸ uses data specific to the well ▸ simple calculation ▸ minimal technical expertise required	▸ is not suitable for use at sites with a high hydraulic gradient ▸ some of the necessary data may not be readily available
Analytical Methods	▸ uses data specific to both the well and the hydrogeologic setting ▸ is suitable for use at many sites	▸ some of the necessary data may not be readily available ▸ some technical expertise is necessary
Hydrogeologic Mapping	▸ uses data specific to the hydrogeologic setting ▸ is suitable for use at most sites ▸ may be used in combination with another method to improve the accuracy of a delineation	▸ some of the necessary data may not be readily available ▸ considerable technical expertise is necessary
Numerical Flow/Transport Models	▸ uses data specific to both the well and the hydrogeologic setting ▸ is suitable for use at most sites ▸ models can be calibrated and verified to ensure that the site is being modeled accurately	▸ much of the necessary data may not be readily available ▸ considerable technical expertise is necessary

II.B. Calculated Fixed Radius

The calculated fixed radius method uses a specified threshold for the time of travel criterion to define a radius around a well. An analytical equation is used to calculate the radius of the circle on the ground surface that represents the water flowing to the well during the specified period of time. This method uses data specific to the well and the aquifer, and is applicable when only limited data or expertise are available.

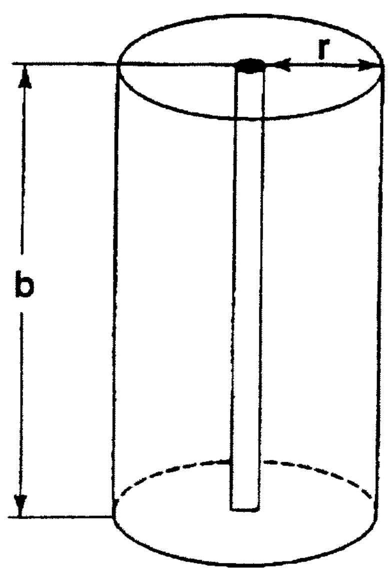
The volumetric flow equation is the most commonly used calculated fixed radius method using the time of travel criterion. It is relatively simple to use if the required data are available. The equation calculates the radius of the cylinder representing the volume of water flowing to the well within the specified period of time (Figure 5). The ground surface representation of this cylindrical volume, a circle with the well at its center, is essentially a fixed radius, time-related capture zone. This simple mass-balance equation is shown below along with the required data. The assumptions that are used in the development of this equation, listed in Section V.A., should be consulted before applying this equation. Consistent units must be used in the equation, for example feet and days or meters and days. An example of a consistent set of units is give in parentheses below.

$$r = \sqrt{\frac{Qt}{\pi n b}}$$

Where:
- r = radius of capture zone around well corresponding to specified travel time (ft)
- Q = pumping rate of well (ft^3/day)
- t = travel time to well -- a minimum of 5 years recommended (1825 days)
- π = 3.1416
- n = porosity (dimensionless -- no units)
- b = open interval or length of well screen (ft)

Parameter value recommendations and an example calculation using the volumetric flow equation are contained in Section V.A.

VOLUMETRIC FLOW EQUATION



$$r = \sqrt{\frac{Q\,t}{\pi\, n\, b}}$$

Where:
- **Q = Pumping Rate of Well**
- **n = Aquifer Porosity**
- **b = Open Interval or Length of Well Screen**
- **t = Travel Time to Well**

Figure 5. The volumetric flow equation. From U.S. EPA, 1992.

II.C. Simplified Variable Shapes

The simplified variable shapes method uses analytic equations, such as those described in the calculated fixed radius and analytical methods sections, to define shapes representative of a particular aquifer using time of travel and flow boundary criteria. These shapes are then oriented with respect to the ambient ground water flow direction; size is determined by the quantity of water pumped from the well. The simplified variable shapes method is appropriate for geographically extensive aquifers in which hydrologic conditions do not vary significantly. However, the basin and range hydrogeologic setting of Nevada does not produce this type of aquifer. The alluvial basin-fill aquifers of Nevada are restricted to basins and the hydrologic conditions will vary somewhat within a basin-fill aquifer as well as between basin-fill aquifers. Considering this information, it is not recommended that the simplified variable shapes method be used for alluvial basin-fill aquifers in Nevada. This method also is not appropriate for fractured rock aquifers because of potential geologic non-uniformities produced by variation in the size and orientation of fractures.

II.D. Analytical Methods

Analytical methods use a set of equations to define a steady-state capture zone of an infinite time period in an area having a sloping water table or sizable hydraulic gradient. These equations also consider data specific to both the well and the aquifer. However, these data are generally more difficult to measure or estimate than data used in the previously described methods.

The most commonly used set of equations are based upon the uniform flow equation. The uniform flow equation describes the outer boundary of a steady-state capture zone for an infinite time period:

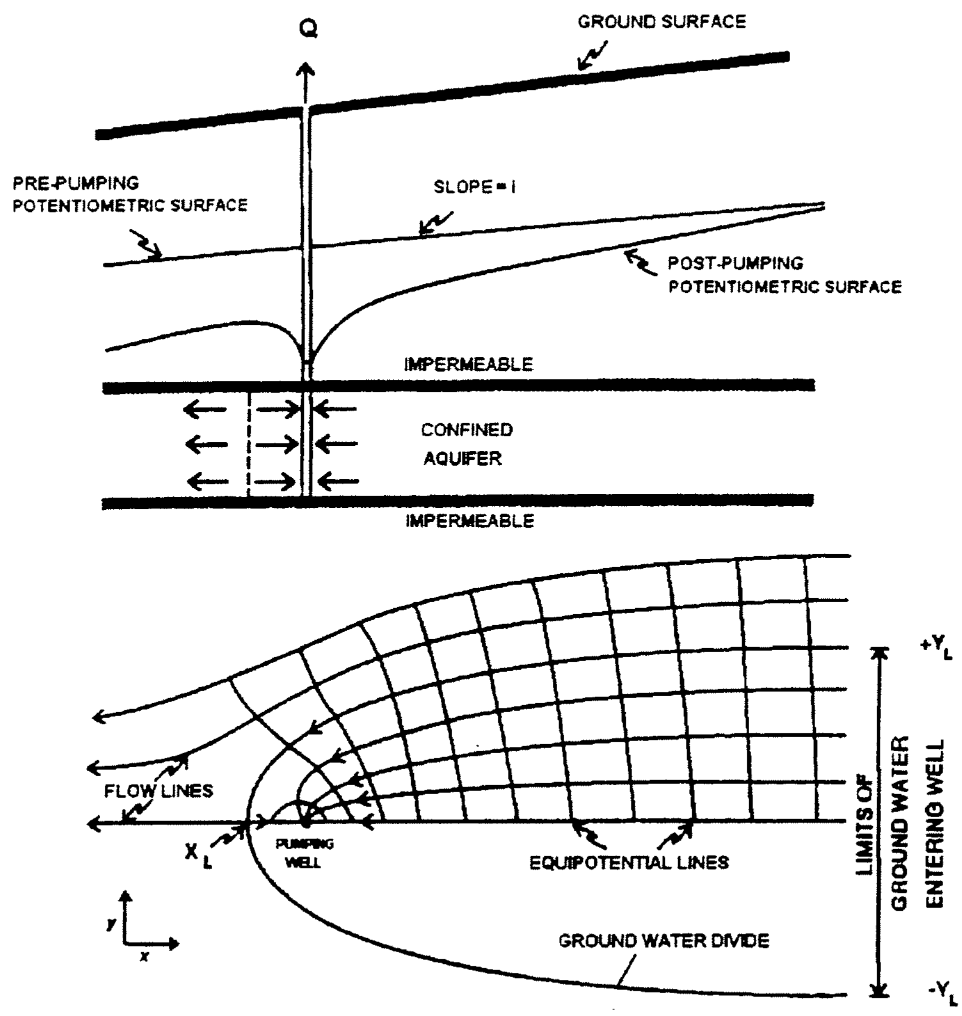
$$\frac{y}{x} = \pm \tan\left(\frac{2\pi K b i}{Q} y\right)$$

+ for y>0   - for y<0

Where:

y = y-coordinate in a two dimensional coordinate system
x = x-coordinate in a two dimensional coordinate system
π = 3.1416
K = hydraulic conductivity
b = open or screened interval
i = hydraulic gradient magnitude
Q = well pumping rate

As shown in Figure 6, the coordinate system is oriented so that the x-direction is parallel to the hydraulic gradient and the y-direction is perpendicular to the hydraulic gradient. This equation may be solved for x (X_L) to determine the down-gradient extent of the capture zone. Solving for y (Y_L) yields the extent of the capture zone perpendicular to the gradient. These equations are shown in Figure 6, along with corresponding features of the capture zone. The assumptions that are used in the development of these equations, discussed in Section V.B., should be consulted before applying this equation. The resulting capture zone is generally a parabolic shape oriented so that it is elongated and open in the up-gradient direction with a stagnation point down-gradient of the well. The capture zone extends up-gradient until a ground water divide or impermeable barrier is reached. All water within this capture zone will eventually reach and be pumped from the well. Parameter value recommendations and an example calculation using the uniform flow equation are contained in Section V.B.



$$\pm \frac{Y}{X} = \tan\left(\frac{2\pi K b i}{Q} Y\right)$$

+ for y>0 − for y<0

Uniform Flow Equation

$$X_L = -\frac{Q}{2\pi K b i}$$

Distance to Stagnation Point

$$Y_L = \pm \frac{Q}{2 K b i}$$

Boundary Limit

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

Figure 6. Equations derived from the uniform flow equation and corresponding points of a steady-state (infinite time) capture zone. Not to scale. Modified from U.S. EPA, 1987.

Another method of delineating wellhead protection areas based on analytical equations is through the use of the computer program called WHPA (U.S. EPA, 1991c) which is a modular semi-analytical model. The RESSQC module of the WHPA program uses the uniform flow equation described above and incorporates reverse particle tracking to define a finite time-related capture zone. Reverse particle tracking is a method by which the path of water particles are traced backwards from the well. Because particle tracking is used, RESSQC has been termed a semi-analytical model. The RESSQC module requires the same basic data as the uniform flow equation above, and produces a capture zone that is generally circular to elliptical in shape, elongated in the up-gradient direction. The RESSQC module may be used for both relatively flat and sloping hydraulic gradients. The advantages to using RESSQC over the uniform flow equation are: 1) that RESSQC allows for the calculation of a capture zone of finite time period (e.g. 5, 10, 20 years) and 2) that RESSQC is able to account for the effects of pumping interference between two or more wells.

II.E. Hydrogeologic Mapping

Hydrogeologic mapping uses flow boundary and time of travel criteria to define the area contributing water to the well. Geologic, geophysical, and dye tracing techniques may be utilized to determine ground water flow patterns and flow boundaries such as ground water divides, impermeable structures and aquifer extent. Hydrogeologic mapping is well-suited for the most commonly used aquifers in Nevada: basin-fill and fractured rock aquifers. Hydrogeologic mapping generally requires a large amount of data and a great deal of technical expertise. For these reasons, it is unlikely that a small community with limited finances would use this method. However, hydrogeologic mapping is a recommended method if sufficient funds are available to obtain the necessary data and technical expertise. This method is particularly useful if used in combination with an analytical or numerical method. Since a clear, basic conceptual understanding of the hydrogeologic setting will contribute to a more accurate wellhead protection area delineation, some amount of hydrogeologic mapping should be done for all methods. Recommendations for hydrogeologic mapping to supplement other methods are contained in the sections describing the use of those methods.

II.F. Numerical Flow and Transport Models

Numerical flow and transport techniques are utilized by a number of computer programs that simulate ground water flow and solute transport. This type of method may be particularly useful in complex hydrologic situations, but requires a significant amount of detailed data and technical expertise. For these reasons, it is unlikely that a small community with limited finances would use this method. However, if sufficient funds can be raised to obtain the necessary data and technical expertise, the use of numerical models is a recommended method. Numerical models can provide a high degree of accuracy and can be applied to most hydrogeologic settings, both simple and complex. In addition, they can be used to predict potential changes due to anthropogenic and natural causes.

III. DETERMINATION OF DEGREE OF AQUIFER CONFINEMENT

The flow hydraulics of an aquifer will be dictated, in part, by the degree of confinement of the aquifer, which will affect the size and shape of the wellhead protection area. Additionally, taking into consideration differing hydraulics due to degree of confinement, recommendations for delineating wellhead protection areas vary somewhat according to the aquifer's degree of confinement.

The degree of confinement of an aquifer refers to the amount of pressure to which the water in the aquifer is subjected. An unconfined aquifer is a relatively shallow aquifer. However, in Nevada unconfined aquifers may be as deep as 300 to 500 feet below the ground surface. The upper surface of an unconfined aquifer is the water table (Figures 7a & 7b). The water table is under atmospheric pressure. Unconfined aquifers are often bounded on the bottom by less permeable material, composed of clay-rich sediments, volcanics or bedrock. This material may form an aquitard through which water moves vertically relatively slowly. The aquitard may act as a confining unit, below which lies a confined aquifer that is generally under pressure greater than atmospheric. As a result, the water level in a well that is open only to a confined aquifer will rise above the confining, or less permeable, layer. The confined aquifer will be bounded both above and below by material that is less permeable than the aquifer.

An aquifer may be semi-confined where the aquifer may exhibit confined characteristics, but has significant leakage through either the upper or lower aquitard. Alternatively, semi-confined conditions may exist due to the upper confined unit not being spatially extensive, resulting in unconfined conditions away from the well. The hydrogeologic setting depicted in Figure 7c showing discontinuous layers of low-permeability material interbedded with high-permeability material, is probably relatively common in the alluvial basin-fill aquifers of Nevada.

There are several methods that may be used to determine the degree of confinement of an aquifer. The U.S. EPA (1991b) technical guidance document, *Wellhead Protection Strategies for Confined-Aquifer Settings*, describes these methods in more detail. The methods described briefly in the following paragraphs are those that require minimal data and expense to utilize.

The first step is to make a schematic drawing of the well construction information displayed on the driller's report for the well (Figure 8). The drawing should include: the types and depths of material encountered during drilling; the depths of the intervals that are screened, perforated or open; and the static water level. If the well is screened above any significant low-permeability layers, most likely clay-rich, it is most likely drawing water from an unconfined aquifer. If the well is screened below a significant low-permeability layer and the static water level in the well rises above that low-permeability layer, the aquifer may be semi-confined or confined. The lateral extent of the potentially confining layer may be confirmed by inspecting and correlating well logs from nearby wells. If the well is screened both above and below a low permeability layer, it may be drawing water from both unconfined and confined aquifers. If that is the case, the recommendations for delineating a wellhead protection area directly around the well in an unconfined aquifer should be followed (See Section IV.A.). However, it is also recommended

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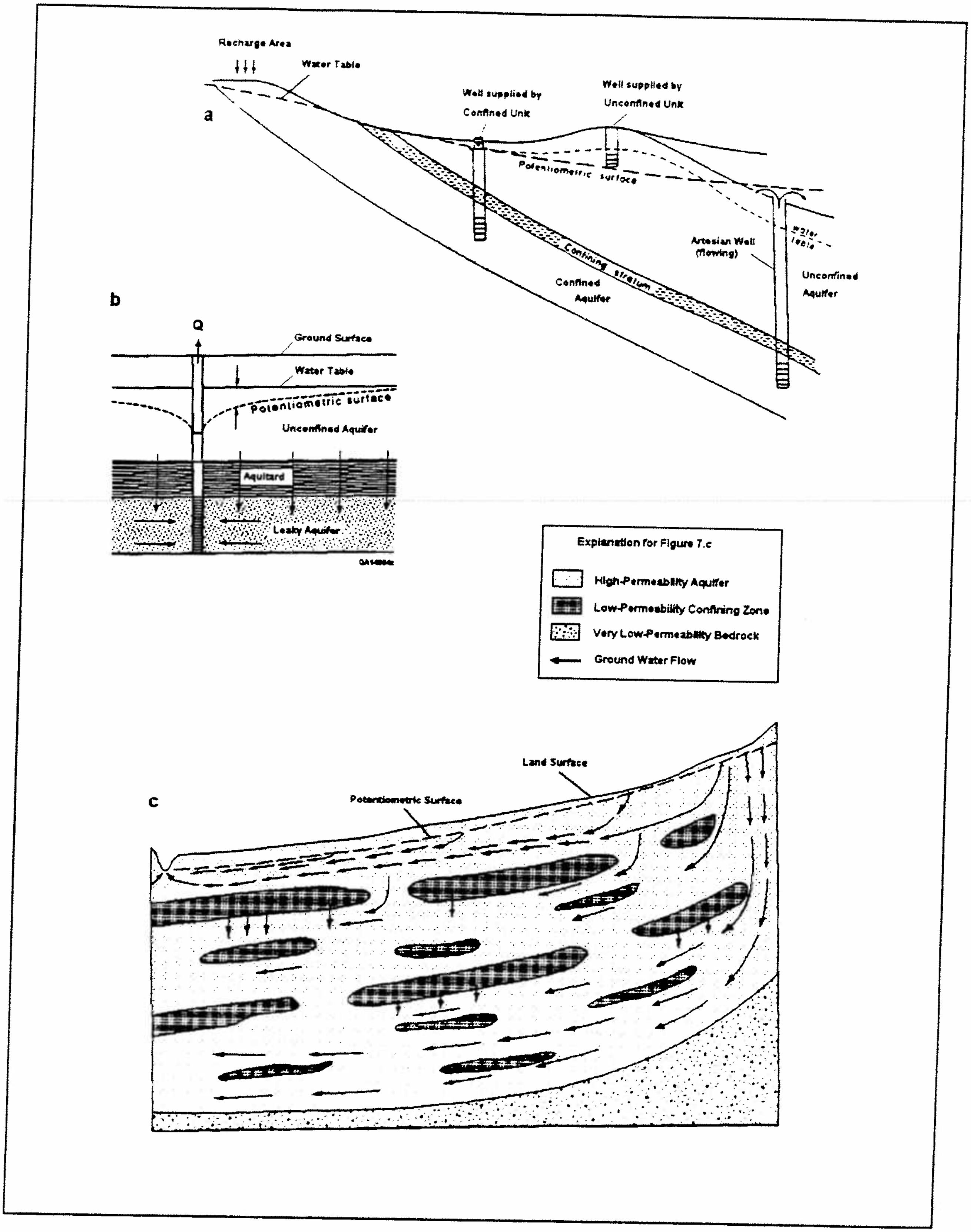

Figure 7. Schematic drawings of: a) a confined aquifer (unconfined in outcrop area); b) a semi-confined (leaky) aquifer; c) an aquifer containing low-permeability strata that are interbedded between permeable strata causing confining conditions locally. From U.S. EPA (1991b).

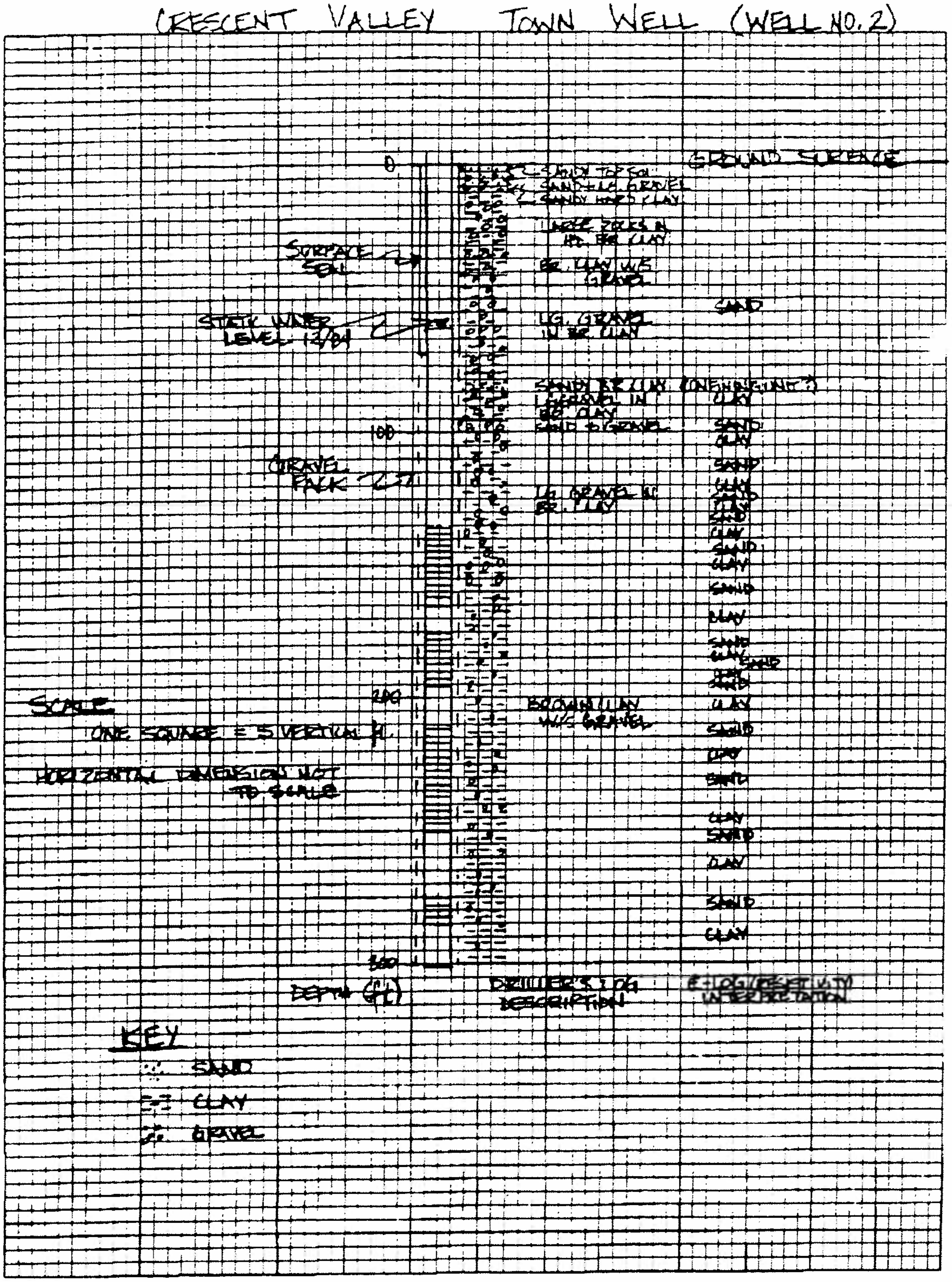

Figure 8. Schematic diagram of well construction and penetrated lithology.

that the portion of the recharge area contributing water to the well be defined and managed appropriately as recommended for a confined aquifer (See Section IV.B.).

Another method of determining the degree of confinement involves estimating the aquifer's storativity or storage coefficient, which is a measure of how much water an aquifer can hold in storage. The storativity value calculated from aquifer test data generally indicates whether the aquifer is confined or unconfined. Storativity in a confined aquifer commonly lies within the range of 0.00005 to 0.005 (Freeze and Cherry, 1979; Todd, 1980). For an unconfined aquifer, the comparable parameter is termed the specific yield, and is calculated in the same manner as the storativity. The specific yield for an unconfined aquifer commonly lies within the range of 0.01 to 0.30 (Freeze and Cherry, 1979).

While this method is very useful, it may require more data than are readily available. Also, it is recommended that individuals having some technical expertise perform these tests and calculations. If the data are not available, it is recommended that an attempt be made to collect the data, if practicable. The results of an aquifer test, or pumping test, lasting at least 6 hours and using at least one observation well are required for this calculation. This type of aquifer test will yield aquifer parameters that are representative of the aquifer, locally. The longer the test, the larger the portion of the aquifer that will be sampled. The method of calculating the storativity from an aquifer test is described in a number of references (Freeze and Cherry, 1979, Todd, 1980, Driscoll, 1986). A slug test may also be used to calculate the storativity, but is not recommended, since the values resulting from a slug test will be representative of only a small portion of the aquifer. Caution should be used when slug test data are utilized, because a storativity value calculated with a slug test may not be representative of the aquifer.

Other methods for determining degree of confinement include calculating the amount of leakage into a confined aquifer using the results of a long term pumping test and continuous monitoring of water level responses. Age-dating water pumped from a well may sometimes be used to determine the length of time the water has been in the aquifer and thus the degree of confinement or distance to the recharge area. This method is useful, but it can be expensive. All of the methods mentioned above are described in more detail in *Wellhead Protection Strategies for Confined-Aquifer Settings* (U.S. EPA, 1991b).

The results of the methods described above should indicate the degree of confinement of the aquifer from which the well is drawing water. The recommended procedures for delineating a wellhead protection area in an unconfined, semi-confined or a confined aquifer should be followed. If the results of the methods applied are inconclusive, the recommendations for delineating a wellhead protection area directly around the well in an unconfined aquifer should be followed, since the recommendations for an unconfined aquifer are slightly more protective than those for a confined aquifer.

IV. NEVADA RECOMMENDATIONS

This section contains recommendations for several hydrologic settings encountered in Nevada. After determining the degree of confinement of the aquifer from which the well is drawing water, the appropriate aquifer-specific recommendations in this section should be followed. More attention is given to unconfined, semi-confined and confined alluvial basin aquifers, since most public water systems draw drinking water from these aquifer types. Carbonate aquifers and fractured rock aquifers are discussed only briefly, as these aquifers are used for public water supply only to a limited extent.

IV.A. Recommended Criteria, Thresholds and Methods for Semi-confined or Unconfined Basin-fill Aquifer Settings

The recommended criterion for wellhead protection area delineation is the time of travel criterion. The time of travel criterion is preferred because it allows for hydrogeologic variation between sites, since the concept of time of travel is based on the physical processes driving ground water flow. The time of travel criterion also allows flexibility to define multiple areas around a well to be managed differentially.

NDEP recommends using a 5-year threshold for the time of travel criterion. NDEP believes that 5 years represents a minimum time period for responding to and mitigating contamination events. Therefore, activities that may pose a threat to the ground water quality should be heavily supervised within this area or should be kept out of the area.

Using the recommended criterion and threshold results in the delineation of a capture zone representing a minimum of a 5-year time of travel around a well as the wellhead protection area. However, some communities may decide that a longer period of time better suits the protection goals of the community. As mentioned above, another approach is to delineate several time of travel capture zones of different time periods, both longer and shorter than 5 years, around the well and utilize different management strategies in each. This approach is described in Section VIII of the Nevada Wellhead Protection Program.

NDEP recommends using methods that employ the time of travel criterion, including the calculated fixed radius method, analytical methods, and numerical flow and transport models. Ideally, one of the above methods should be used in combination with some amount of hydrogeologic mapping.

In delineating wellhead protection areas for unconfined or semi-confined aquifers, it is recommended that an appropriate method be chosen based upon data availability, hydrogeologic system complexity, and financial and technical constraints. Table 1 may be consulted for a summary of the advantages and disadvantages of each method. If a more advanced method is deemed appropriate, but cannot be applied due to insufficient data, a more simplistic method could be used to delineate a preliminary wellhead protection area. Generally, there will be enough

Note: The first time a key word appears in a major section, it will be underlined to indicate that it is defined in the glossary of this document.

information to apply the calculated fixed radius method to delineate a preliminary wellhead protection area. However, if there are insufficient data for the use of the calculated fixed radius method, a minimum fixed radius of 3000 feet should be used while data are being collected or generated to enable use of a more advanced method. However, this arbitrary fixed radius should be used **only** as a preliminary wellhead protection area. An arbitrary fixed radius is **not** recommended for use as a permanent wellhead protection area, since it does not use any site-specific data.

If a more simplistic method is used initially with available data and expertise to delineate a preliminary wellhead protection area, Section V should be consulted for detailed descriptions, specific parameter recommendations and sample calculations for the calculated fixed radius and analytical methods. Once the appropriate data have been collected, a more advanced method could be used to refine the wellhead protection area. Section V also contains recommendations specific to the use of hydrogeologic mapping and numerical flow and transport models.

It is also recommended that some amount of hydrogeologic mapping be utilized for all wellhead protection area delineations. Appropriate hydrogeologic mapping activities for each of the recommended methods are discussed in the sections describing the use of those methods. There are several resources (e.g. U.S. Geological Survey, Nevada Division of Water Planning, University of Nevada Library System) that should be consulted to locate any reports of regional or local ground water studies. Gaining a conceptual understanding of the local and regional hydrologic settings will be useful in selecting the appropriate wellhead protection area delineation method. Additionally, general knowledge of the hydrologic system will indicate if it might be necessary to use one method to delineate a preliminary wellhead protection area while collecting sufficient data for a more appropriate method.

In Nevada, most recharge to a basin-fill aquifer occurs toward the basin edges, where precipitation tends to be higher. Generally, very little if any recharge occurs in the immediate vicinity of wells located on the valley floor. Therefore, it should be assumed that any recharge from precipitation and infiltration occurs in a recharge area some distance from the well, not at the ground surface above the aquifer and within the capture zone. It is important to identify the portion of the recharge area contributing water to the well. This is because in the recharge area, any water, along with any contaminants that might be on the ground surface or in the soil, entering the aquifer will eventually reach the well. Hydrogeologic mapping using the criterion of flow boundaries may be utilized alone, or in addition to an analytical or numerical method with a steady state capture zone, to determine the portion of the recharge area contributing water to the well.

For the purpose of delineating the capture zone around a well, the assumption that all recharge occurs in a recharge area distant from the well, in a manner similar to a confined aquifer, will result in larger, more protective, wellhead protection areas for unconfined and semi-confined aquifers. For many alluvial basins in Nevada, this assumption is valid, since most basins receive a small amount of precipitation and the depth to the water table may be great. The calculated fixed radius method and the analytical methods mentioned below do not consider this type of local recharge. For numerical methods, recharge will be a separate input parameter, and where appropriate, a minimum value should be used for recharge occurring directly around the well.

IV.B. Criteria, Thresholds and Methods for a Confined Basin-fill Aquifer Setting

For confined aquifer settings, NDEP also recommends the use of wellhead protection area delineation methods that use the time of travel criterion. The time of travel criterion is preferred because it allows for hydrogeologic variation between sites, since the concept of time of travel is based on the physical processes driving ground water flow. The time of travel criterion also allows flexibility to define multiple areas around a well to be managed differentially.

It is recommended that a capture zone of a minimum of five years or a minimum radius of 2500 feet around the well be used. A radial distance of 2500 feet is a conservative value for a ~~five~~ year capture zone under most hydrogeologic settings. However, recent experience has shown that a 3000 foot radius, like that to be used for unconfined basin-fill aquifers, will be even more likely to encompass the five year capture zone. In the area surrounding a well, management strategies should focus on potential contaminant sources located near the well, and should include both natural and artificial penetrations into and close to the depth of the top of the confined aquifer. These penetrations may be wells, particularly poorly constructed or improperly abandoned wells, or fractures and faults that might act as conduits for contaminants through the confining layer.

For a confined aquifer setting, any method that uses the time of travel criterion may be utilized to delineate the wellhead protection area around the well. It is recommended that an appropriate method be chosen based upon data availability, hydrogeologic system complexity, and financial and technical constraints. Table 1 may be consulted for a summary of the advantages and disadvantages of each method. If a more sophisticated method is deemed appropriate, but cannot be applied due to insufficient data, a more simplistic method could be used to delineate a preliminary wellhead protection area. Generally, there will be enough information to apply the calculated fixed radius method to delineate a preliminary wellhead protection area. Once the appropriate data have been collected, the more sophisticated method could then be used to refine the wellhead protection area. Recommendations for specific parameters utilized in the calculated fixed radius and analytical methods, as well as sample calculations, are contained in Section V. Recommendations for the use of hydrogeologic mapping and numerical models are also outlined in Section V.

For a confined aquifer, it is important to define the portion of the recharge area that contributes water to the well, in addition to delineating the wellhead protection area surrounding the well. To do this, hydrogeologic mapping using the criterion of flow boundaries may be utilized alone, or in addition to, an analytical or numerical method with a steady state capture zone. The community should be aware that land use and activities that occur or have occurred in the recharge area may eventually affect the quality of the water that is pumped from the well. The community may decide that it is necessary to manage land use and activities that occur in the recharge area to provide long-term protection for their drinking water supply.

IV.C. Criteria, Thresholds and Methods for a Fractured Rock Aquifer Setting

A fractured rock aquifer setting is often very difficult to model accurately. Therefore, it is recommended that appropriate technical expertise be retained to delineate wellhead protection areas in this type of setting. The hydrologic complexity of a fractured rock aquifer makes numerical modeling combined with hydrogeologic mapping the methods recommended for wellhead protection area delineation in this setting. To support these methods, it is likely that a large amount of data will have to be collected. The U.S. EPA technical assistance document entitled *Delineation of Wellhead Protection Areas in Fractured Rocks* (1991a) may be consulted for method comparisons and examples.

With the exception of hydrogeologic mapping, all of the wellhead protection area delineation methods described in this document assume that water flow is intergranular through a porous medium. When water is actually flowing through fractures, this may or may not be a valid assumption depending upon the relative scale and distribution of the fractures. In fractured rocks, the interconnected fractures are considered to be the primary flow paths, while the solid blocks between fractures are considered to be impermeable. If the fractures or fracture zones are fairly evenly distributed with respect to direction and they are small with respect to the scale of the entire wellhead protection area, flow may be similar to intergranular flow through a porous medium. The assumption of a porous medium may be tested by observing an aquifer test response, inspecting a graph of drawdown versus pumping time elapsed, and/or inspecting the spatial distribution of drawdown during an aquifer test. Water chemistry and temperature fluctuations over the period of a year may also be observed to help determine if flow is predominantly through discrete fractures, or if it approximates flow through a porous medium. If during testing, the aquifer follows the expected response of an aquifer composed of a porous medium, then the porous medium assumption is probably valid. For more information about these tests and a comparison of both porous media and non-porous media responses, see U.S. EPA's *Delineation of Wellhead Protection Areas in Fractured Rocks* (1991a).

If the porous medium assumption is valid, the criteria, thresholds and methods recommended for alluvial basin-fill aquifers are suitable for use: calculated fixed radius, analytical methods, hydrogeologic mapping, and numerical modeling. However, it is recommended that an analytical method or numerical model be used in combination with hydrogeologic mapping. Hydrogeologic mapping may be used to determine the orientation and extent of fractures and then appropriate discretization, model grid spacing, in a numerical flow model may be applied to approximate fracture flow.

If the porous medium assumption is **not** valid, hydrogeologic mapping should be used and may be combined with numerical modeling. Again, hydrogeologic mapping may be used to determine the orientation and extent of fractures and then appropriate discretization, spacing of model grids, in a numerical flow model may be applied to approximate fracture flow. It should be realized that this option will require a large amount of data and will be expensive. If, for these reasons, numerical modeling and hydrogeologic mapping cannot be utilized immediately, it is recommended that the existing data be used to determine preliminary wellhead protection areas using a more simplistic method (i.e. analytical methods or calculated fixed radius). In this way, the ground water will receive some protection while the data and resources are being gathered in order to utilize hydrogeologic mapping and/or numerical modeling to refine the wellhead protection area.

IV.D. Criteria, Thresholds and Methods for a Carbonate Rock Aquifer Setting

A carbonate rock aquifer setting is often very difficult to accurately model, because flow often occurs through fractures or solution cavities. It may take a large amount of data to determine the location and direction of ground water flow through these fractures or solution cavities. Therefore, it is recommended that appropriate technical expertise be retained to delineate wellhead protection areas in this type of setting. Because of the hydrogeologic complexity of a carbonate aquifer, numerical modeling combined with hydrogeologic mapping are the methods recommended for wellhead protection area delineation. However, if it is not practicable to use these methods initially, an analytical, semi-analytical or calculated fixed radius method may be used to define a preliminary wellhead protection area.

In carbonate rock aquifers, flow may occur through the pores of the carbonate but it is likely that most flow is through fractures or solution cavities. In Nevada's carbonate rock aquifers located in the eastern and southern parts of the State, most ground water flow occurs through fractures (J. Thomas, pers. comm., 1995). Therefore, the section addressing the delineation of wellhead protection areas in fractured rock should be consulted. Commonly in relatively wet climates, fractures in carbonate aquifers are enlarged through dissolution, ultimately producing karstic features. This has occurred only to a limited extent in Nevada, and is not widespread. For example Lehman Caves in Great Basin National Park was formed in this manner.

V. SPECIFIC METHOD AND PROCEDURAL RECOMMENDATIONS

This section contains specific recommendations for the parameters required when using the calculated fixed radius and analytical methods. Sample calculations have also been included to facilitate the use of these methods by individuals not having an extensive technical background. Additionally, general recommendations for the use of hydrogeologic mapping and numerical modeling in delineating wellhead protection areas are targeted toward individuals with more technical expertise.

Any individual delineating wellhead protection areas should be aware that the results of all delineation methods are only approximations of the actual capture zones -- even the results of numerical models. Additionally, with the exception of numerical contaminant transport models, all methods discussed in this document account for advective transport only. In other words, for all methods it is assumed that any contaminant would flow along with the ground water. The effects of mechanisms such as adsorption, attenuation, hydrodynamic dispersion, and diffusion are not considered. It should also be noted that if any change is made to the local hydrologic system, the wellhead protection area around the effected well should be re-delineated. Two examples are when a new well is added to a wellfield or when pumping rates are increased significantly.

V.A. Calculated Fixed Radius Method

The parameter requirements for the volumetric flow equation are relatively straight-forward. Guidance and recommendations for each parameter are outlined below. There are a number of assumptions made in developing the volumetric flow equation. Each assumption is stated and briefly discussed below.

- **Ground water flow is <u>intergranular</u> through <u>porous media</u>.** For alluvial aquifers this will be true. However, it is generally not true for <u>fractured rock</u> and <u>carbonate rock</u> aquifers.

- **The well is fully penetrating and is open to the full <u>saturated thickness</u> of the <u>aquifer</u>.** This assumption is generally not true. Partial penetration of an aquifer by a well may result in some vertical flow toward the well, which would likely result in a <u>capture zone</u> that is smaller than if there was no vertical flow. The length of the screened or open interval of the well is almost always less than the saturated thickness. To compensate for this fact, the length of screened or open interval should be used instead of the saturated thickness. This will result in a larger, but more protective capture zone.

- **The saturated thickness is spatially constant.** For <u>alluvial</u> aquifers in Nevada this may or may not be true. For the central portion of larger basins, it is likely that the thickness will be approximately constant over the scale of a 25-year capture zone or less. For smaller basins or basin margins, the assumption is less likely to be true. However, it may be an acceptable assumption on the scale of a 5 to 10 year capture zone.

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- **There is negligible flow in the vertical direction (flow to the well is horizontal only).** This assumption is likely to be violated somewhat as described above in the case of a partially penetrating well. Of more concern would be vertical flow caused by the close proximity of a flow barrier, a recharge area or a discharge area.

- **Pumping rate is constant over time.** This assumption is also not likely to be true, since many public water system wells pump only during a portion of a 24-hour period. If this is the case it is acceptable to average the actual volume pumped over a 24-hour period. However, if the well is used only seasonally, this is probably not a good assumption and the use of a transient model should be considered.

- **There is no pumping interference between wells.** The validity of this assumption will depend upon the pumped volumes of the wells in question and the hydrogeologic properties of the area. If there are no other large volume wells (other public water system, irrigation or industrial wells) within a 3000 foot radius of the well, this may be a valid assumption. If capture zones for different wells overlap, this assumption has probably been violated and a method that considers well interference should be used.

- **The aquifer is isotropic and homogeneous.** For most aquifers in Nevada this generally is not true. For the central portion of larger basins, it is more likely to be true than for smaller basins or basin margins. However, it is an assumption that must be made to some extent, even for more complex methods. Therefore, to minimize error due to the violation of this assumption, make sure that the porosity value chosen is representative of the entire screened or open interval of the well.

- **The aquifer is of infinite areal extent.** This is not generally true. However, over the scale for which a capture zone will be delineated, it is probably a good assumption except in the following cases: if the well is located near the edge of the aquifer or near a flow barrier.

- **The ambient hydraulic gradient is small; there is little or no slope to the water table.** This is more likely to be true for wells in aquifers located in the center portion of basins. If the well is located toward the margin of a basin, this may not be a good assumption.

- **Flow conditions are steady state.** This assumes that flow at any one point does not change with time, implying that recharge and discharge within the hydrogeologic system are in balance. This is generally not true, since recharge and discharge are likely to vary somewhat over time. It is likely to be a better assumption for shorter time periods, since it takes time for changes to be felt throughout the flow system. If recharge and discharge tend to fluctuate greatly, it is a poor assumption. However, the alternative of applying a transient method, generally a numerical model, requires additional data.

- **For an unconfined aquifer, drawdown is small (negligible) relative to the saturated thickness.** If the drawdown in the well due to pumping at the specified rate is less than ten per cent of the open or screened interval, this assumption is probably good. Wells in relatively porous material and/or screened over a large interval will be more likely to meet this assumption. If the drawdown is ten per cent or more, this method will probably define a capture zone that is not representative of the hydrogeologic conditions and a method that specifically accounts for unconfined conditions should be used.

- **For a confined aquifer there is no leakage, and for an unconfined aquifer there is no recharge in the capture zone.** For confined aquifers in Nevada, this assumption may or may not be true. For unconfined aquifers, this is probably a valid assumption for any well drilled in the center portion of a basin with a static water level of more than 10 feet below ground surface. Even in the case that the assumption may not be true, making the assumption will result in the delineation of a larger, more protective capture zone.

If any of the assumptions are significantly violated, this method will not produce an accurate capture zone, but may be used to delineate a preliminary wellhead protection area. However, a more complex method, one that does not require the assumption suspected of being violated should be used. This preliminary wellhead protection area may be used while more data are being collected and/or funds are being obtained to enable a more complex wellhead protection area delineation.

Additionally, the volumetric flow equation does not account for any boundary conditions such as flow barriers or streams (constant head boundaries). The volumetric flow equation is repeated here for convenience. Please refer to Figure 5 as necessary.

$$r = \sqrt{\frac{Qt}{\pi n b}}$$

A sensitivity analysis was conducted on the volumetric flow equation using input parameter values representative of an alluvial basin-fill aquifer and small community wells (Helsel, 1994). The sensitivity analysis indicated that for input values within 10% of the assumed actual value, all input parameters have approximately the same relatively small influence on the size of the resulting area. In other words, if the estimates of the input parameters are close to the "true" values, the radius will be close to the "true" size as long as none of the above assumptions are significantly violated. Since the time period (t) is an arbitrary value, and the pumping rate (Q) and the screened interval (b) are measured values, the estimated porosity (n) is the only parameter that will have some associated uncertainty. Since porosity values for alluvial aquifers generally range from 0.10 to 0.35, estimates of porosity are likely to be relatively close to the actual value. Therefore, the volumetric flow equation is relatively insensitive to small errors in the estimation of input parameters. However large errors will yield a radius that does not reflect the actual hydrogeologic conditions and will be either under- or overprotective.

Parameter Recommendations

The pumping rate (Q) can be estimated from the system operator's production records. The pumping rate must be converted to ft^3/day (or m^3/day). Conversion factors are listed in Section X. The pumping rate during peak demand periods or the maximum pumping rate of the pump currently in the well should be used. Using the maximum pumping rate of the pump over the period of a day would result in the most conservative capture zone. Keep in mind that in the event that the pumping rate is increased significantly due to increased consumer demand, the capture zone should be redefined using the increased volume.

The time period (t) is the travel time to the well and should be selected as appropriate for management and contingency plans. For this equation, time must be expressed in days. For convenience, commonly used time periods are converted to days in Table 2 below. It is recommended that several time periods be selected and capture zones calculated for each period, before selecting the most appropriate zone. Additionally, multiple capture zones may be managed in a tiered or progressive manner.

Table 2. Common Capture Zone Time Periods.

Years	Days
2	730
5	1825
10	3650
15	5475
20	7300
25	9125

The porosity (n) is dimensionless and can be estimated by inspecting the driller's log and/or any other available logs. Based upon the predominant material from which water is being drawn, Table 3 may be consulted for average porosity values for various aquifer materials. The lowest value listed for the material type will yield the most conservative, and therefore largest, capture zone radius.

Table 3. Porosity Value Ranges for Aquifer Materials (modified from Bedinger *et al.*, 1986 and Freeze and Cherry, 1979).

Material type	n (dimensionless)
Basin-fill	
Coarse-grained (sand and gravel)	0.12 - 0.23
Fine-grained (clay and silt)	0.29 - 0.36
Carbonate	
Fractured, karstic	0.09 - 0.16
Dense, unfractured	0.00 - 0.02
Crystalline Rock (metamorphic, intrusive igneous)	
Fractured	0.00 - 0.10
Dense	0.00 - 0.05
Volcanic Rock	
Lava flows, fractured	0.11 - 0.19
Tuff, nonwelded tuff	0.33 - 0.37

The open or screened interval (b) can be determined from the driller's log or well construction diagrams. This open interval must be expressed in feet (meters). Generally, wells are screened in sections of the aquifer. The lengths of these sections of screened or perforated casing should be added together to result in the total open interval.

Sample Calculation

The volumetric flow equation will be used in a sample calculation using the types of data that are likely to be available. This may be used as an example when applying this method to another well. Figure 9 is a sample of a driller's log for a well located in an alluvial basin. Figure 8 shows a well construction and lithologic diagram for this well.

The time period (t), representing the time of travel to the well, is an arbitrary value based upon desired potential management of contaminant sources and contingency plans. A 10-year capture zone will be delineated in this example. This term must be expressed in days, so in this case t = 3650 days.

The total screened interval (b) can be determined from the information supplied on the driller's log. On the bottom part of the Well Construction portion, the depths through which the casing is perforated or screened should be listed. In this example, the driller used the whole section to describe the depths of casing and perforated casing. The following calculation can be made from the sample log:

$$b = (166 \text{ ft} - 136 \text{ ft}) + (196 \text{ ft} - 176 \text{ ft}) + (251 \text{ ft} - 211 \text{ ft}) + (286 \text{ ft} - 276 \text{ ft})$$

$$= 30 \text{ ft} + 20 \text{ ft} + 40 \text{ ft} + 10 \text{ ft}$$

$$b = 100 \text{ ft}$$

The porosity (n) can be estimated from the driller's log lithologic description. This well seems to be drawing water from material that is predominantly a mix of clay and gravel in an alluvial basin, so a porosity between the fine and coarse ranges can be assigned (see Table 3): n = 0.25.

The pumping rate (Q) can be determined from the meter on the well. During a high use period, May, the meter on this well indicated that 4,678,800 gallons of water were pumped during the month. This must be converted to a constant pumping rate expressed in terms of cubic feet per day (ft^3/day) as follows:

$$Q = \frac{4{,}678{,}800 \ gallons}{31 \ days} = 150{,}929 \ gal/day$$

$$Q = 150{,}929 \ gal/day \times 0.1337 = 20{,}179 \ ft^3/day$$

WHITE—DIVISION OF WATER RESOURCES
CANARY—CLIENT'S COPY
PINK—WELL DRILLER'S COPY

STATE OF NEVADA
DIVISION OF WATER RESOURCES

OFFICE USE ONLY
Log No. ____
Permit No. ____
Basin ____

WELL DRILLERS REPORT
Please complete this form in its entirety

PRINT OR TYPE ONLY

NOTICE OF INTENT NO. 3363

WELL OWNER TOWN OF CRESCENT VALLEY
ADDRESS AT WELL LOCATION ____
MAILING ADDRESS CRESCENT VALLEY, NEV

2. LOCATION SW ¼ SW ¼ Sec. 33 T 30 N/S R 48 E EUREKA County
PERMIT NO. 47663
Issued by Water Resources | Parcel No. | Subdivision Name

3. TYPE OF WORK
New Well ☒ Recondition ☐
Deepen ☐ Other ☐

4. PROPOSED USE
Domestic ☒ Irrigation ☐ Test ☐
Municipal ☐ Industrial ☐ Stock ☐

5. TYPE WELL
Cable ☐ Rotary ☒
Other ☐

6. LITHOLOGIC LOG

Material	Water Strata	From	To	Thickness
SANDY TOP SOIL		0	2	2
SAND & LG< GRAVEL		2	8	6
SANDY HARD CLAY		8	10	2
LG. ROCKS IN HD BRT CLAY		10	30	20
BR. CLAY w/s GRAVEL		30	42	12
LG GRAVEL in BR CLAY		42	80	38
SANDY BR< CLAY		80	85	5
LG GRAVEL IN BRRCLAY		85	96	11
SAND & GRAVEL		96	100	4
LG. GRAVEL IN BR CLAY		100	160	60
BR CLAY w/s GRAVEL		160	300	140

Date started ~~12-10-84~~ , 19__
Date completed ~~12-29-84~~ , 19__

7. WELL TEST DATA

Pump RPM	G.P.M.	Draw Down	After Hours Pump
	~~500~~	~~93~~	~~28~~

BAILER TEST
G.P.M. ____ Draw down ____ feet ____ hours
G.P.M. ____ Draw down ____ feet ____ hours
G.P.M. ____ Draw down ____ feet ____ hours

8. WELL CONSTRUCTION
Diameter hole 18 inches Total depth 300 feet
Casing record 8 5/8
Weight per foot ~~16.79~~ Thickness 3/16

Diameter	From	To
8 5/8 BLANK inches	0 feet	136 feet
8 5/8 PERF inches	136 feet	166 feet
8 5/8 BLANK inches	166 feet	176 feet
8 5/8 PERF inches	176 feet	196 feet
8 5/8 BLANK inches	196 feet	211 feet
8 5/8 PERF inches	211 feet	251 feet

CONTINUED BELOW

Surface seal: Yes ☒ No ☐ Type ~~CONCRETE~~
Depth of seal ~~70~~ feet
Gravel packed: Yes ☒ No ☐
Gravel packed from ~~70~~ feet to ~~300~~ feet

Perforations: BLANK STAINLESS STEEL
Type perforation PERF- ROSCOE MOSS
Size perforation 3/32
From ~~8 5/8 BLANK~~ feet to ~~251 - 276~~ feet
From ~~8 5/8 PERF~~ feet to ~~276 - 286~~ feet
From ~~8 5/8 BLANK~~ feet to ~~286 - 301~~ feet
From ____ feet to ____ feet
From ____ feet to ____ feet

9. WATER LEVEL
Static water level 61 feet below land surface
Flow ____ G.P.M. ____ P.S.I.
Water temperature ____ °F. Quality ____

10. DRILLERS CERTIFICATION
This well was drilled under my supervision and the report is true to the best of my knowledge.
Name HUMBOLDT DRILLING & PUMP CO
Contractor
Address BOX 592, WINNEMUCCA, NEV 89445
Contractor
Nevada contractor's license number 015234
Nevada contractor's drillers number C-23
Nevada driller's license number 295
Actual Driller
Signed [signature]
Contractor
Date [handwritten date]

USE ADDITIONAL SHEETS IF NECESSARY

Figure 9. Example of a Well Driller's Report.

The conversion factor (0.1337) used in this calculation is contained in the conversion table in Section X of this document. The conversion results in: Q = 20,179 ft^3/day.

The above numbers are then substituted into the volumetric flow equation and the radius is calculated as follows:

$$r = \sqrt{\frac{20{,}179\ ft^3/day \times 3650\ days}{3.1416 \times 0.25 \times 100\ ft}}$$

$$r = \sqrt{\frac{73{,}653{,}350\ ft^2}{78.54}}$$

$$r = \sqrt{937{,}781.385\ ft^2}$$

$$r = 968.4\ ft$$

Therefore, according to this calculation the 10-year capture zone is a circle around the well with a radius of 968.4 feet.

For a more conservative, protective, capture zone, the maximum possible pumping rate with the currently installed pump should be used. The pump is capable of pumping 300 gallons per minute (gpm). This calculation results in a circular, 10-year capture zone having a radius of 1638 feet. In both cases, the calculated fixed radius would be used instead of the 3000 foot arbitrary fixed radius. However, it is recommended that several capture zones of different time periods be calculated for each well. Potential contaminant sources may be managed differently within different capture zones, as appropriate.

V.B. Analytical Methods

The two analytical methods that will be described here are based upon the uniform flow equation that is briefly described in section II.D. A steady-state capture zone of an infinite time period may be defined by using the uniform flow equation and manually orienting the capture zone with respect to the local hydraulic gradient. There are a number of assumptions that have been used in the derivation of the uniform flow equation. The assumptions are the same as for the derivation of the volumetric flow equation (See Section V.A. Calculated Fixed Radius Method), with one exception. For this method, it is assumed that there is a significant hydraulic gradient or slope to the water table.

The assumptions listed in the previous section should be reviewed within the context of applying an analytical method. If any of these assumptions are significantly violated, this method will not produce an acceptably accurate capture zone and should be used only to delineate a preliminary wellhead protection area. This preliminary wellhead protection area may be used while more data are being collected and/or funds are being obtained to enable use of a more complex wellhead protection area delineation method, one for which all assumptions are valid.

The analytical methods do not account for any boundary conditions such as flow barriers or streams (constant head boundaries). However, the capture zone area may be extended out to and terminated at a mapped hydrogeologic boundary, such as an impermeable barrier or a ground water divide.

The x and y coordinate solutions of the uniform flow equation are repeated here for convenience. Please refer to Figure 6 as necessary.

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

The coordinate system is oriented so that the x-direction is parallel to the hydraulic gradient and the y-direction is perpendicular to the hydraulic gradient.

It is recommended that at least some amount of hydrogeologic mapping be utilized when using an analytical method in order to gain a comprehensive conceptual understanding of the hydrogeology. For example, it is suggested that geologic and hydrologic reports and studies be consulted for hydrogeologic maps of the area. A potentiometric or water level map should be constructed for the aquifer(s) from which drinking water is drawn. These mapping efforts will be useful in defining the appropriate hydraulic gradient magnitude and direction to be used in analytical methods. Additionally, if a flow net is developed from a potentiometric surface map, the flow lines can be used to refine the capture zone boundaries.

The RESSQC module of the computer program WHPA is also based upon the uniform flow equation. An advantage of using the RESSQC module is that since it uses reverse particle tracking, it will define a time related capture zone. Another advantage of using RESSQC is that it considers pumping interference between wells. Therefore, RESSQC is appropriate for delineating wellhead protection areas for multiple wells within a wellfield. The computer program WHPA may be obtained directly from the U.S. EPA (See Section VIII.) or by contacting the NDEP.

The RESSQC module assumes an aquifer of infinite extent; it does not account for any boundary conditions, such as flow boundaries. However, the MWCAP and GPTRAC modules of the WHPA computer program may be used in the same manner, or may be used to account for the effects of barrier or stream boundaries on a capture zone.

A sensitivity analysis was conducted on the RESSQC module using input parameters representative of an alluvial basin aquifer and small community wells (Helsel, 1994). The results indicated that uncertainty in estimating porosity, screened interval, pumping rate or time period affected both the size and shape of the resulting capture zone. However, uncertainty in estimating the hydraulic gradient or the hydraulic conductivity affected only the shape of the resulting capture zone. RESSQC is most sensitive to uncertainty in estimating the hydraulic conductivity, the hydraulic gradient, the pumping rate, and the time period. The influence of the porosity is minimized, in part, because the range of values typically encountered in an alluvial aquifer is small. Of the input parameters to which RESSQC is sensitive, the hydraulic conductivity and hydraulic gradient are the most difficult to estimate accurately. Therefore, a long-term aquifer test should be performed, if at all possible, to minimize the estimation error for hydraulic conductivity. A discussion of uncertainty in the estimation of hydraulic gradient is contained in the parameter recommendations for the hydraulic gradient. Since the RESSQC module employs the uniform flow equation, it is likely that the uniform flow equation exhibits similar sensitivities.

Parameter recommendations

Several of the parameter recommendations made for the calculated fixed radius method are also applicable to analytical methods. For the following parameters, the parameter recommendations for the calculated fixed radius method should be consulted: pumping rate (Q), time period (t), porosity (n), and aquifer thickness or screened interval (b). However, analytical methods utilize additional parameters. These are described below.

The hydraulic gradient magnitude (i) and direction representative of pre-pumping or ambient flow conditions should be estimated from a static water level map constructed from measured levels in local wells. An effort should be made to use static water levels from wells completed in the same aquifer as the well for which a capture zone is being delineated. The water levels should be collected over a period of less than five years and preferably at the same time of year to minimize errors introduced by water table fluctuations. Hydrogeologic studies conducted either regionally or locally should also be consulted for estimates of hydraulic gradient magnitude and direction. This type of information may be used as supporting information in the estimation of the hydraulic gradient.

It is likely that there will be some amount of uncertainty associated with the hydraulic gradient direction, since it is a difficult parameter to measure accurately. Also, it is likely that the hydraulic gradient direction will vary somewhat spatially. The uniform flow equation is relatively sensitive to variation in the hydraulic gradient direction, particularly when the magnitude of the hydraulic gradient is significant. Therefore, if the uncertainty or spatial variation is estimated to be significant (greater than 20 degrees), it is recommended that two capture zones be defined using the two endmember directions. The two capture zones should then be combined to yield a conservative, or protective, wellhead protection area. If the uncertainty or the local variation in the hydraulic gradient direction is large (greater than 180 degrees), it is recommended that the calculated fixed radius method be used, because of its circular shape, to delineate a preliminary wellhead protection area. Additional data should be collected to refine the hydraulic gradient estimate and delineate a final wellhead protection area.

The hydraulic conductivity (K) should be estimated from a long-term aquifer (pumping) test of the well for which the capture zone is being defined or a well located close to it that is drawing water from the same aquifer. Because a long-term (greater than 6 hours) aquifer test will yield a hydraulic conductivity value that is representative of a larger portion of the aquifer, it is recommended over a short-term (less than 6 hours) aquifer test or a slug test. However, these other tests may be used if the results are interpreted with caution. Analytical methods are relatively sensitive to variation in the hydraulic conductivity. Therefore, if aquifer test data are not available, an aquifer test should be performed. However, if this is not practicable, local or regional hydrogeologic reports should be consulted for estimates of the local hydraulic conductivity.

Sample Calculation

The uniform flow equations will be used in an example of an analytical method here. The documentation for the WHPA computer program should be consulted for detailed information regarding its development, sample data sets and examples of how it may be used.

The same well that was used for the calculated fixed radius sample calculation will be used in this sample calculation. Please refer to the driller's log (Figure 9) and parameter value calculations above, as they will also be used here. Additionally, for the uniform flow equation calculations, the pre-pumping or ambient hydraulic gradient (i) must be estimated. For this well, the hydraulic gradient was estimated by constructing a potentiometric surface map from a map of static water levels contained in a report (WMC, 1992). The average estimated gradient was used: i = 0.00188.

The hydraulic conductivity (K) must also be estimated. There were no aquifer test data from which a hydraulic conductivity could be calculated, but a transmissivity estimate was available for a well nearby that was drawing water from the same interval (Zones, 1961). This transmissivity estimate was used to calculate a hydraulic conductivity to be used for this well. This resulted in K = 21.98 ft/day.

The distance down-gradient of the well to the edge of the capture zone, the stagnation point (X_L), is calculated as follows:

$$X_L = \frac{Q}{2\pi K b i}$$

$$X_L = \frac{20{,}179\,ft^3/day}{2 \times 3.1416 \times 21.98\,ft/day \times 100\,ft \times 0.00188}$$

$$X_L = \frac{20{,}179\,ft^3/day}{25.96\,ft^2/day}$$

$$X_L = 777.2\,ft$$

The extent of the capture zone perpendicular to the hydraulic gradient direction (or flow direction) is represented by Y_L which is calculated as follows:

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

$$Y_L = \pm \frac{20{,}179\,ft^3/day}{2 \times 21.98\,ft/day \times 100\,ft \times 0.00188}$$

$$Y_L = \pm \frac{20{,}179\,ft^3/day}{8.264\,ft^2/day}$$

$$Y_L = \pm 2442\,ft$$

The steady-state capture zone of infinite time, as opposed to an arbitrary number of years, should be oriented so that the wide, open end extends up-gradient until a flow boundary is reached. The flow boundary may be a ground water divide, a fault acting as an impermeable boundary, or the lateral extent of the aquifer. In applying this method to other wells, if a flow net has been constructed, the capture zone boundaries, in part, should be dictated by the flow lines of a constructed flow net. Therefore, if the flow lines have some curvature, the capture zone boundaries should follow the same curvature. For this well, it was determined that the direction of the hydraulic gradient could lie between 43° east of north to 72° east of north. Capture zones for these two endmembers were drawn on the map, and should be composited to produce a protective wellhead protection area (Figure 10). Both capture zones could be extended until some type of flow boundary is reached.

V.C. Hydrogeologic Mapping

Hydrogeologic mapping is a method that may be used by itself, but it is also very useful when used in conjunction with another method, such as an analytical method or a numerical model. There are many aspects to hydrogeologic mapping. Using geologic maps and cross-sections, the physical extent of the aquifer may be delineated, along with other potential flow boundaries such as faults. Detailed geologic mapping may also be used to locate geologic features acting as flow conduits, such as joints, fractures or faults. Using static water level measurements, a water table or potentiometric map may be constructed for the aquifer. This type of map may then be used to determine the locations of any ground water divides and construct a flow net to define the flow system. Knowing the orientation of flow lines in the vicinity of the well is crucial in delineating a wellhead protection area for that well. Hydrogeologic mapping is particularly useful in determining recharge areas for both confined and unconfined aquifers.

It is recommended that hydrogeologic mapping be utilized for all wellhead protection area delineations to the extent practicable. Only through the use of hydrogeologic mapping can a true conceptual picture of the aquifer system be gained. A good conceptual model is essential when applying analytical or numerical methods, since the outcome of these methods is only as reliable as the data that were used in applying the method.

Some of the information and maps necessary for hydrogeologic mapping may already exist in the reports of studies that have been conducted previously. These may be used to compliment new data collection or if new data collection is not currently practicable. It is recommended that the resources listed in Section VIII of this document be consulted for information about the area in which the wells are located.

V.D. Numerical Flow and Transport Models

There are a number of numerical models that may be used to delineate capture zones. The primary advantage of using numerical models is that the models may be calibrated using one set of hydrologic data and then verified using another set of data reflecting different recharge and/or pumping conditions for the same location. The results of the calibration and verification process yield an indication of how accurately the hydrologic system is being represented. It is essential that the calibration and verification process be followed when numerical models are being utilized to delineate wellhead protection areas.

Numerical models are not constrained by many of the assumptions that are required for analytical solutions. Therefore, numerical models may be appropriate for use when assumptions are suspected of being significantly violated. By not making many of the assumptions listed previously, numerical models have the flexibility to simulate many hydrogeologic situations, including: leaky aquifers, unconfined or semi-confined conditions, heterogeneity, anisotropy, partial penetration, vertical flow, aquifers of variable thickness, transient conditions, constant head boundaries, variable or constant flux boundaries and flow barrier boundaries. There are many flow and transport models available including 2-dimensional numerical models and 3-dimensional numerical models. It is recommended that the model selected, be a model that has been sufficiently and favorably peer-reviewed, and/or has been used extensively. Documentation for the selected model should be consulted for examples and sample data sets.

Numerical models require a large amount of hydrologic data and technical expertise in order to be utilized properly. Therefore, there is generally a significant expenditure of funds associated with this method. If sufficient and appropriate data are not available, they must be collected in order to use this method. Using numerical models with insufficient or inappropriate data will most likely result in wellhead protection area delineations that do not reflect the actual hydrologic conditions. In other words, the resulting wellhead protection areas will not provide adequate protection for the ground water supply. While supplementary data are being collected for use with a numerical model, an analytical method may be utilized with the available data to delineate a preliminary wellhead protection area.

General parameter recommendations for the methods described above should be consulted. There are several additional parameters commonly used by numerical models including recharge, leakage and spatially distributed hydraulic head measurements. For local aquifer recharge, either from infiltration or from surface water in the immediate vicinity of the well, the estimated values should be minimized. It is recommended that a long-term aquifer test be performed to estimate the amount of leakage into the confined aquifer. When making any parameter assumptions, it is recommended that assumptions be made such that any error introduced should result in a more, rather than a less, protective wellhead protection area.

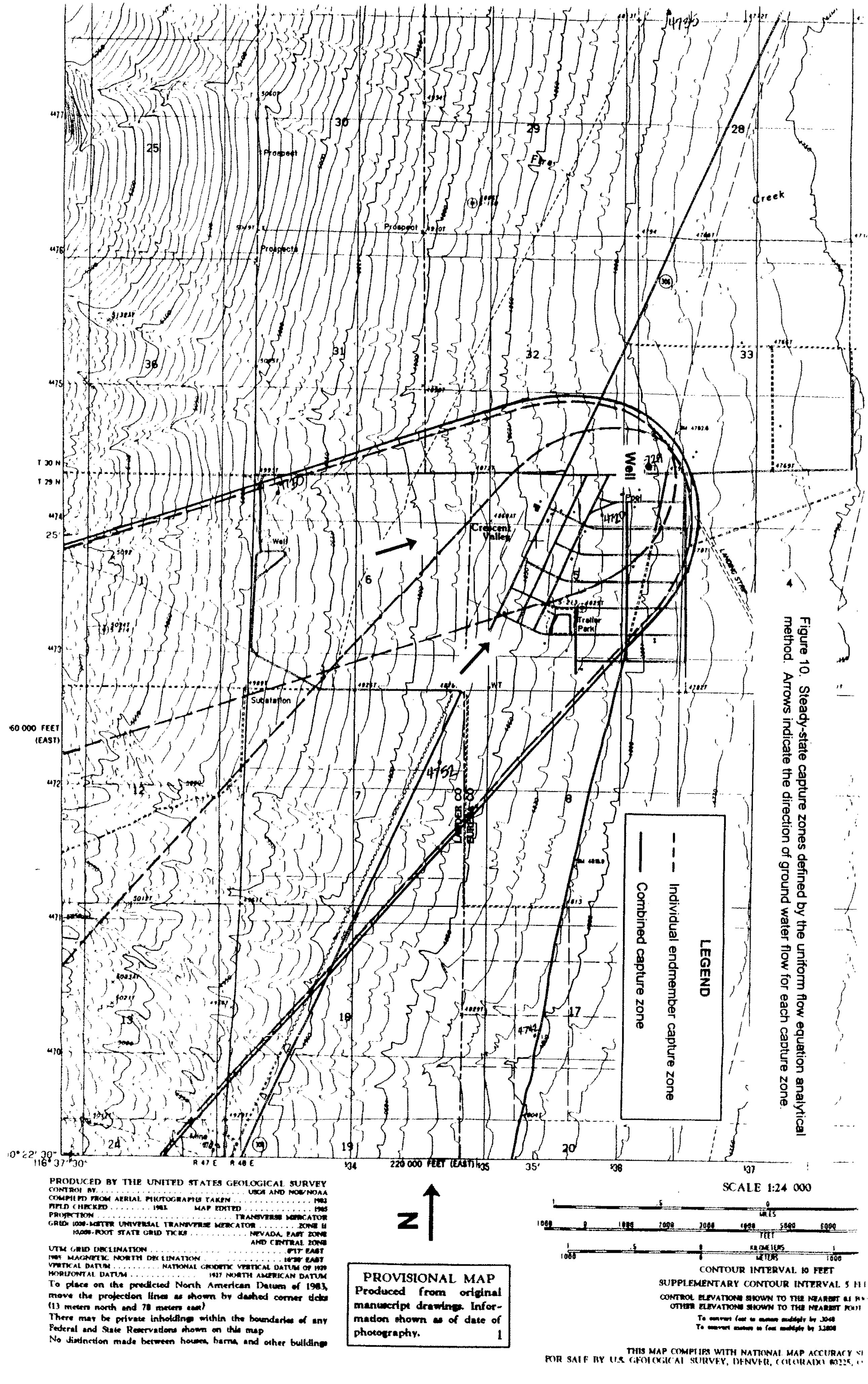

Figure 10. Steady-state capture zones defined by the uniform flow equation analytical method. Arrows indicate the direction of ground water flow for each capture zone.

VI. WELLHEAD PROTECTION AREA DELINEATION REQUIREMENTS FOR STATE ENDORSEMENT

The criteria for State endorsement of community wellhead protection programs are detailed in the State Wellhead Protection Program. The criteria for the wellhead protection area delineation component are repeated here for convenience.

- The method, criteria, and threshold selected for the wellhead protection areas must be outlined as well as the rationale for selection.
- A map, or maps, should be constructed that clearly and accurately depicts the wellhead protection areas at a scale that is consistent with the community's base maps.
- A summary report of the wellhead protection area delineation process should be generated.

The wellhead protection area delineation component, like the entire wellhead protection program, should be well documented. This will facilitate continuity in the program through time and through turn-over in the membership of the local wellhead protection program team.

Note: The first time a key word appears in a major section, it will be underlined to indicate that it is defined in the glossary of this document.

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VIII. RESOURCES

Agencies in Nevada that may be of assistance in obtaining hydrogeologic information and data:

U.S. Environmental Protection Agency - Safe Drinking Water Act Hotline: 1 (800) 426-4791

U.S. Geological Survey, Water Resources Division, Carson City: (702) 887-7600

Nevada Department of Conservation and Natural Resources, Division of Water Resources, Carson City: (702) 687-4380

Nevada Department of Conservation and Natural Resources, Division of Water Planning, Carson City: (702) 687-3600

University and Community College System of Nevada Libraries, Reno:
Desert Research Institute Library (702) 677-3155
Mackay School of Mines Library (702) 784-6596

Frequently referenced books:

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U.S. EPA, WHPA: A Modular Semi-Analytical Model for the Delineation of Wellhead Protection Areas (Version 2.2)

To obtain a copy of the WHPA software package and the user's manual, send two (2) pre-formatted, high density, 3.5 inch diskettes in a floppy disk mailer to the following address:

U.S. Environmental Protection Agency
Robert S. Kerr Environmental Research Laboratory
Center for Subsurface Modeling Support
P.O. Box 1198
Ada, OK 74820
(405) 436-8500

U.S. EPA Documents:

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IX. GLOSSARY OF HYDROGEOLOGIC TERMS

Note that terms that are defined in this glossary appear in bold print the first time they are used in each major section of the text.

Alluvial: Pertaining to or composed of granular, sorted or semi-sorted, unconsolidated material of all sizes deposited by a stream or other running water.

Anisotropy: The condition under which one or more of the hydraulic properties of an aquifer vary according to the direction of flow.

Aquifer: A geologic formation, or group of formations, that contains water, and is capable of conducting useable amounts of water to wells and springs.

Aquifer test: A test to determine hydrologic properties of an aquifer. Conducted by withdrawing measured quantities of water from, or adding to, a well and measuring the resulting changes in water levels in the aquifer both during and after the period of pumping or addition of water.

Aquitard: A geologic formation, or group of formations, through which water moves so slowly that very little water moves through it.

Attenuation: The decrease of contaminant concentration in ground water, through filtration, biodegradation, dilution, sorption, volatilization, and other processes.

Basin-fill aquifer: An aquifer located in a basin surrounded by mountains and composed of sediments and debris shed from those mountains (sediments are often predominantly sand and gravel with some clay).

Bedrock: A general term for solid rock that lies underneath soil and loose sediments.

Capture zone: The zone around a well contributing water to the well; the area on the ground surface from which a well captures water.

Carbonate rock: A rock consisting dominantly of calcium or magnesium carbonate minerals, such as limestone or dolomite.

Confined: Conditions in which an aquifer is bounded above and below by geologic units of much lower permeability than the aquifer material, and is under pressure significantly greater than atmospheric.

Contaminant: An undesirable substance not normally present, or an undesirably high concentration of a naturally occurring substance.

Criterion (criteria) - WHPA: Conceptual standard(s) that form the basis for WHPA delineation. WHPA criteria can include distance, time of travel, and flow boundaries.

Discharge area: The place at which ground water flows out of the ground and into a surface water body, or onto the ground surface, such as springs, some wetland areas, some streams and some lakes. In many basins in Nevada, ground water may be discharged through evaporation at a playa located near the center of the basin.

Drawdown: The vertical distance that ground water (potentiometric surface) elevation is lowered due to the removal of ground water from the aquifer.

Equipotential line: A contour line on the water table or potentiometric surface; a line, in two dimensions, along which the potential, hydraulic head, is constant.

Fault: A fracture or zone of fractures along which there has been movement of the sides relative to each other.

Flow boundaries: Anything which inhibits ground water flow, such as a ground water divide or an impermeable geologic unit.

Flow net: A graphical representation of flow lines and equipotential lines for two-dimensional, steady-state ground water flow. Fluid flow is perpendicular to the equipotential lines in the direction of decreasing fluid potential.

Fracture: A general term for any break in a rock, including cracks, joints and faults.

Fractured rock aquifer: An aquifer composed of solid rock, but where most water flows through cracks and fractures in the rock instead of through pores. Flow through fractured rock is typically relatively fast.

Ground water divide: A ridge in the water table from which ground water moves away.

Homogeneous: Uniform in structure or composition throughout.

Hydraulic conductivity: A coefficient of proportionality describing the rate at which water can move through a porous medium. The rate of flow through a cross section of a unit area under a unit hydraulic gradient, at the prevailing temperature.

Hydraulic gradient: For an unconfined aquifer, the direction and magnitude of the slope of the water table; for a confined aquifer, the direction and magnitude of the slope of the potentiometric surface.

Hydrogeologic: Relating to subsurface water, the geologic units through which subsurface water flows; also, relating to geologic aspects of surface water.

Hydrologic: Relating to the study of water in natural systems.

Hydrographic: A region or area defined by stream drainage boundaries.

Impermeable: Unable to transmit water.

Infiltration: The movement of water downward into soil and/or rock.

Intergranular: Occurring between grains or particles in an aquifer.

Intrusive igneous rock: Rock that solidified from molten or partly molten material injected beneath the Earth's surface. Often these rocks have relatively large crystals as a result of slow cooling.

Isotropic: A medium whose properties are the same in all directions.

Joint: A fracture in a rock along which there is no movement; usually occurring in sets with a regular orientation.

Karstic: Related to features formed in limestone by dissolution, and characterized by sinkholes, caves, and underground drainage.

Lacustrine: Pertaining to, derived from, or deposited by a lake or lakes.

Leakage: Flow of water from one hydrogeologic unit to another.

Leaky aquifer: An aquifer that loses or gains water through adjacent semipermeable confining units.

Lithologic: Relating to rock, unconsolidated material, or soil.

Metamorphic rock: Any rock derived from pre-existing rocks, through physical and chemical changes, as a result of significant changes in temperature and/or pressure.

Particle tracking: A process where the path of an individual particle of water is followed through an aquifer over time.

Permeability: The ability of a geologic formation to transmit fluids.

Porosity: The ratio (expressed either as a percentage or decimal) of the total volume of voids in a rock or soil to the total volume of the rock or soil.

Porous medium(media): A rock or sediments having spaces, or pores, between grains.

Potentiometric surface: A surface that represents the level to which water will rise in a cased well; usually referring to confined conditions.

Pumping test: A test conducted by pumping water from a well to determine aquifer or well characteristics.

Recharge area: The land surface area that allows water to percolate down through the soil and loose sediments to an aquifer.

Saline/poor quality aquifer: An aquifer containing water that is high in total dissolved solids (generally greater than 500 milligrams per liter), and is unacceptable for use as drinking water.

Saturated thickness: The thickness of the portion of the aquifer in which all pores, or voids, are filled with water. In a confined aquifer, generally the aquifer thickness. In an unconfined aquifer, the distance between the water table and the base of the aquifer.

Semi-confined: Conditions in which at least one of the bounding units of an aquifer conducts some measurable amount of water into or out of the aquifer.

Slug test: A test to determine hydraulic conductivity, in which a known volume of water is added to a well instantaneously and the response of the water level in the well is observed.

Solute transport: The movement of dissolved substances through hydrogeologic units.

Solution cavities: Channels and cave-like features formed in carbonate rock terrains through the action of water dissolving carbonate rock, often along joints or fractures.

Specific yield: The ratio of the volume of water that a given mass of saturated rock or soil will yield by gravity to the volume of that mass.

Stagnation point: A place in the ground-water flow field at which the ground water is not moving. At this point the hydraulic gradient magnitude is equal but in opposite directions.

Static water level: The level of water in a well that is not being affected by withdrawal of ground water from the well being measured or any other well.

Steady-state flow: A condition in which at any point in a flow field, the magnitude and direction of the flow velocity are constant with time.

Storativity (Storage coefficient): A dimensionless term representing the volume of water an aquifer releases from or takes into storage per unit surface area per unit change in head. In an unconfined aquifer, the storativity is equal to the specific yield.

Threshold, WHPA: The value assigned to a criterion which is to be used to define the extent of the WHPA. For example, a 5-year threshold for a time of travel criterion.

Time of travel: The time required for a particle of water to move through an aquifer from a specific point to a well.

Transient: A condition in which at any point in a flow field, the magnitude and direction of the flow velocity change with time. Non-steady flow.

Transmissivity: The rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient.

Tuff, nonwelded: Unconsolidated material resulting from the accumulation of ash expelled during a volcanic eruption.

Unconfined: Conditions in which the upper surface of the aquifer is at atmospheric pressure and is expressed as a water table.

Volcanic rock aquifer: An aquifer composed of rock that originated from a volcano, such as basalt. This type of rock may or may not be very permeable.

Water table: The top surface of an unconfined aquifer above which pores, or voids, are filled with air, and at which the pressure is atmospheric.

Wellhead protection area: The surface and subsurface area surrounding a well or wellfield, supplying a public water system, through which contaminants are reasonably likely to move toward and reach such water well or wellfield.

X. CONVERSION FACTORS

	Multiply by	
feet	0.3048	meters
gallons/day	0.1337	ft^3/day
gallons/day	0.003785	m^3/day
gallons/minute (gpm)	192.5	ft^3/day
gallons/minute (gpm)	5.45	m^3/day