4 DETERMINATION OF WELLHEAD PROTECTION AREAS

A wellhead protection area is defined as the surface and subsurface area surrounding a well, wellfield or spring that supplies a public water supply through which contaminants are likely to pass and eventually reach the water well(s). In simpler terms, it is the area managed by a community to protect groundwater based public drinking water supplies. As the distance from the pumping well is increased, the hypothetical travel time of a particle of water traveling in the aquifer to the well is lengthened.

Establishing the boundaries for each well, wellfield's, or spring's wellhead protection area is an essential element of a local wellhead protection program. Defining (delineating) the wellhead protection area boundaries is the responsibility of the public water system. Technical assistance on wellhead protection area delineation using a Calculated Fixed Radius method is provided in this document, in the Vulnerability Assessment Form (Appendix H), and from the NNEPA PWSSP technical staff (for example: hydrologist ,engineer and/or environmental specialist). For the more sophisticated delineation methods, the assistance of a hydrologist is often required.

Criteria for setting wellhead protection area boundaries must be selected before delineation can occur. A typical wellhead protection area for Navajo Nation water systems will consist of five zones:

- The sanitary control area,
- Three primary zones, based on 1, 5 and 10 year time of travel rates, and
- A buffer zone (or 20 year time of travel), if necessary.

The three primary zones are determined by estimating the travel paths (based on 1, 5, and 10 year travel times) of a hypothetical particle of water traveling through the aquifer to the pumping well. These zones define aquifer management areas around the pumping well that can be used to identify potential sources of contamination that may (if not controlled or better managed) impact the water supply. These travel-time based aquifer management areas can create an "early warning system," providing the public water system with time to respond to a contaminant moving in an aquifer before it arrives at the water supply well. It is important to recognize that contaminants released at the surface will take additional time to move from the surface down to the water bearing zone. However, the vertical travel time of a contaminant is not considered when calculating the time of travel estimates.

Two considerations are important to note. First, the time of travel calculations are for the rate that water moves through the aquifer. Contaminants may move at significantly different rates than water – either faster or slower depending on the specific contaminant.

Second, because the wellhead protection area delineation calculations ignore the vertical time of travel component (the time a particle of water, or contaminant, takes to move from the surface down to the aquifer) this factor should be considered when developing site specific wellhead protection area management plans. Similar contaminant sources may need to be managed differently in different hydrogeologic settings. For example, an activity located over a shallow water table aquifer where water moves from the land surface to the aquifer in a matter of hours or days may need to be managed differently than the same activity located in an area where a particle of water may take months or years to travel from the surface, through a series of confined layers (shales and clays) before reaching the aquifer.

Wellhead Protection Area Zones

Each management zone in the wellhead protection area is an area that corresponds to a certain established time-of-travel in the aquifer. Thus each of the zones represent a certain time interval between a particle of water at the zone boundary and its eventual arrival at the well.

Again it should be noted that these aquifer travel time zones do not consider vertical movement of a water particle or contaminant from the land surface down to the aquifer. The rate of vertical movement or infiltration rate for an aquifer can be highly variable. Within any given aquifer setting, the infiltration rate will depend on topography, soils, geology, and the nature of the land surface activities (relative percent impervious surfaces vs. open space). It may vary significantly over a region and even within an individual wellhead protection zone. Because it may be difficult to estimate and predict infiltration rates for all settings the wellhead protection area delineation methods recommended for the NNEPA PWSSP do not include vertical movement as a part of the base models. This creates a conservative (protective) estimate of travel time. Where infiltration characteristics are known, wellhead protection area zone management plans can and should consider the implication of vertical movement to the aquifer.

The Sanitary Control Area

The first component of a wellhead protection area is the protective area required by the NNEPA PWSSP (sanitary control area) This area should already be tightly controlled by the public water supply to minimize any direct contamination to the wellhead. It should be managed to reduce the possibility of surface flows reaching the wellhead and traveling down the casing. All public water systems are encouraged to have a wellhouse and/or fenced area around each wellhead. This helps protect individual wells from any direct introduction of contaminants.

Zone 1 - the one year horizontal time of travel boundary

Proper management of Zone 1 can protect the drinking water supply from viral, microbial and direct chemical contamination. This zone is defined by the surface area overlying the portion of the aquifer which contributes water to the well within a one year period. Within Zone 1, potential sources of microbial contamination should be strictly managed to eliminate or reduce the possibility that microbial contamination of the water supply will occur.

The criterion threshold of a one year time of travel is considered appropriate to protect the wellfield from microbial contamination. Existing literature suggests that bacteria and viruses survive less than one year in groundwater, therefore travel times of greater than one year are not necessary. A threshold of less than one year may not provide adequate protection against possible microbial or viral contamination.

The one year time-of travel also defines the area for intensive management to protect the wellhead from direct chemical contamination. Within Zone 1, chemicals capable of contaminating groundwater should not be stored or used, or should be stored and used with sufficient precautions to protect the groundwater resource. A serious chemical release within Zone 1 may provide only a very limited time for a purveyor / community to respond aggressively, identify the spill, implement emergency remedial actions and prevent the contamination from reaching the distribution system.

Laboratory confirmation of the contamination, characterization of the contaminant plume, plus development and implementation of an on-the-ground remediation response traditionally takes a minimum of six months. Twelve to twenty four months is a more typical period for an initial (preliminary) remedial response. Because of these concerns, most management plans for Zone 1 include strong elements for the identification of potential contaminant sources and risk management. For this reason the one year time-of-travel functions as a buffer area and provides response time.

Zone 2 - the 5 year horizontal time of travel boundary

The entire area within the 5 year time of travel boundary defines Zone 2. This zone should be actively managed for control of potential chemical contaminants. While any significant chemical release within Zone 1 has the potential to contaminate the drinking water supply and render it unusable, the area lying between the 1 and 5 year zones should be used as a prioritizing tool for directing technical assistance, outreach programs, and for targeting inspections and enforcement actions.

Zone 3 - the 10 year horizontal time of travel boundary

The outer border of Zone 3, the area within the 10 year time of travel boundary, determines the boundary of the wellhead protection area. Within Zone 3, an inventory for potential contaminant sources should be conducted. High risk operations and facilities should be identified, and steps taken to reduce contaminant loading. A primary purpose of Zone 3 is to encourage decision makers and planners to recognize the long term source of the drinking water supplying community water systems. This allows the community to plan and site future high risk and medium risk sources of groundwater contamination outside wellhead protection areas. Zone 3 also serves as an educational tool for industry, the general public, and others to understand the source of their drinking water and the significance of their actions upgradient of drinking water wells.

Buffer Zone

The buffer zone is an area upgradient of Zone 3 or designated as the 20 year time of travel. It can extend to include the entire zone of contribution or may focus on selected areas of concern such as recharge areas or locations where the aquifer may be exposed at the surface. The buffer zone can be used to provide an area of added protection for the wellhead protection area. This zone helps compensate for errors when calculating the wellhead protection area boundaries, and provides information useful for long term planning.

A primary goal of the buffer zone is to provide information to planners on potential contaminant sources outside Zone 3 which have the potential for releasing contaminants into the wellhead protection area. Analysis may show the need for contingency plans to respond to uncontrolled surface discharges that may travel overland to enter a stream located in or adjacent to the wellhead protection area. It may also identify other non-contiguous critical aquifer recharge areas requiring protection.

A Review of Selected Wellhead Protection Area Delineation Methods

Four general delineation methods were selected from those evaluated by the NNEPA PWSSP:

- Calculated Fixed Radius
- Analytical Models
- Hydrogeologic Mapping
- Numerical Flow / Transport Models]

In general, there is an increase in complexity and cost from the top to the bottom of the above list. Along with increasing cost and complexity there is generally an increase in reliability of an adequate wellhead protection boundary that is not under- or over-protective. Once the boundaries of the WHPA are calculated, they are required to be displayed on a map of suitable scale.

It is critical to conduct a vulnerability assessment of the site prior to selecting a delineation method so an appropriate delineation method can be selected. Not all methods are suitable for all settings. A brief description of each of these methods is presented below.

Calculated Fixed Radius

The Calculated Fixed Radius method draws a circular protection area for a specified time-of-travel threshold. A simple volumetric flow equation is used to calculate the radius **(Figure 2)**. Data required are 1) well pumping rate, 2) porosity of aquifer and 3) open or screened interval of the well. If a site specific estimate of aquifer porosity is lacking, a generalized value of 0.22 may be substituted. If the actual screened interval is unknown, or if the well is constructed with an open interval at its base, a value of 10 feet should be used.

This delineation method is easy to apply and relatively inexpensive, it requires a minimum level of technical expertise. Because of its simplicity it can be used as a delineation method for moderate and smaller systems. It should be used by many systems as a first cut method for identifying immediate threats to the water quality. The calculated fixed radius method is a part of the basic NNEPA PWSSP Vulnerability Assessment Form. A major drawback of this method is that rarely does groundwater behave as simply as this method predicts. Please reference *Appendix E* to the Vulnerability Assessment Form (Primary Appendix H) for calculated fixed radius solutions for selected well settings.

Analytical Methods

Analytical methods include simple mathematical calculations and graphical methods to delineate wellhead zones of contribution or simple analytical solution based on computerized groundwater flow models **(Figure 3)**. While they require more skill and data (including hydraulic gradient, hydraulic conductivity, saturated thickness, and hydrogeologic divides) than the calculated fixed radius method, analytical models use equations that are generally easily understood by hydrogeologists and civil engineers.

In many cases a simple analytical model (such as EPA's WHPA Code), may provide a good approximation of the time-of-travel boundaries. However, in settings with significant aquifer boundaries and non-uniform hydrogeologic characteristics, more sophisticated methods such as detailed hydrogeologic mapping or numerical modeling may be warranted.

Hydrogeologic Mapping Methods

Hydrogeologic mapping methods are loosely defined by EPA as geologic, geophysical, and dye tracing methods that can be used to define zones of contribution. On the Navajo Nation, where hydrogeologic and geologic information is often either regional in scope or non-existent, hydrogeologic mapping is often required to characterize aquifer properties, groundwater flow directions, and aquifer boundaries as a prelude to analytical or numerical modeling.

Hydrogeologic mapping methods can be useful where hydrogeologic conditions preclude application of simple analytical models. Examples of settings where geologic features exert strong control over groundwater flow on Navajo include, fractured rock settings, small valley fill deposits, and irregular river / stream or barrier boundaries. Data required include geologic maps, aquifer water level mapping, pump test data, hydrogeologic reports, and well reports.

These methods require specialized expertise geologic and geomorphic mapping, plus significant judgement on what constitutes likely flow boundaries.

Numerical Flow / Transport Models

Wellhead protection areas can be delineated using computer models that approximate groundwater flow and / or solute transport equations numerically. These models are generally recognized as technically superior means to delineate wellhead zones of contribution, if sufficient data can be assembled. Models are generally grouped as two and three dimensional. Data requirements are similar to hydrogeologic mapping and analytical models. However, numerical models are able to incorporate much more of this information. A comparison of wellhead protection area boundaries delineated using the calculated fixed radius method, an analytical model, and a numerical model was presented by EPA **(Figure 4)**. Because there is wide variety in hydrogeologic settings, no set of examples should be considered typical.

Numerical models provide a very high potential degree of accuracy and can be applied to nearly all types of hydrogeologic settings. They may be very desirable in areas where there are other ongoing groundwater management programs in place. Costs for this method are relatively higher than others, and considerable technical expertise in hydrogeology and modeling is required to use this method. However, the cost may be warranted in areas where a high degree of reliability is necessary.

Criteria Influencing Selection of Delineation Method

Site specific delineation efforts are required for each public water supply well, wellfield or spring. Due to resource and information constraints, the initial minimum delineation method requirements are relatively unsophisticated (for most systems, the calculated fixed radius method).

Analytical methods can provide more reliable predictions of groundwater flow than a calculated fixed radius method because they incorporate a greater number of site specific parameters. When resources, site specific information, and technical expertise are available, water owners should delineate their wellhead protection area boundaries using analytical or other sophisticated approaches as soon as is practical.

When translating analytical predictions to boundaries on the ground, it is important to determine whether the results correspond well with the local hydrogeologic setting. Integrating a hydrogeologic mapping component (e.g. knowledge of hydrogeologic boundaries)into a model reduces the possibility of making improper assumptions about the groundwater system. Incorporating knowledge of groundwater flow divides and aquifer boundaries into the groundwater model allows more accurate understanding of groundwater flow patterns.

Sophisticated analytical methods, hydrogeologic mapping, and numerical groundwater flow models allow a very site specific approach to boundary area simulation, but require large amounts of site specific data and technical expertise to run and interpret the model results. As a result of these types of applications are generally considerably more expensive than many of the simpler models. Detailed models are valuable tools for ongoing resource management and contingency planning and may be a wise investment for communities with resources available.

Vulnerability Assessment

An important initial step in selecting the appropriate delineation method is to evaluate the vulnerability of the wells. The NNEPA PWSSP has prepared a ***Vulnerability Assessment Form*** which must be completed by the WATER OWNER for each well (Appendix H). **This is the same form NNEPA PWSSP requires from WATER OWNERS applying for a monitoring waiver.** Assessment responses help determine which delineation methods are most appropriate.

Drinking water supplies vary in their vulnerability to contaminants discharged at the surface. A well's vulnerability increases when it is poorly constructed or improperly cased, or located in a geologic setting where no confining layer (shale or clay layers) exists between the aquifer and the surface. Conversely, properly constructed and sealed wells, drawing water from deep below the surface, with several different impermeable layers overlying the aquifer are less vulnerable to contaminants entering the surface at or near the wellhead. NNEPA PWSSPs wellhead protection program groups wells into three classes of vulnerability: 1) high vulnerability, 2) moderate vulnerability, and 3) low vulnerability.

Assessment of Hydrogeologic Setting

The initial wellhead delineation method required of most public water systems is the calculated fixed radius method. This is an inexpensive method to use as it only requires knowledge of a well's pumping rate, the length of the open (screened) interval and an estimate of the porosity of the aquifer. The model predicts concentric circles (circular zones of contribution) around the wellhead corresponding to the 1, 5, 10, and 20 year time-of-travel of groundwater flowing to the well. A major drawback of this model is that rarely does groundwater behave as simply as this model predicts. For this reason, public water systems using the calculated fixed radius method should evaluate the extent in which their hydrogeologic setting varies from a circular zone of contribution through the use of the Vulnerability Assessment Form (Appendix H). Assessment responses help determine if delineating methods other than the calculated fixed radius method are more appropriate. This assessment process is the same one that NNEPA PWSSP is using to evaluate water system's vulnerability for chemical monitoring requirements.

Selection of Delineation Method

Public Water Systems with Less Than 1,000 Connections

The Calculated Fixed Radius method is the minimum acceptable interim method of delineation for public water systems with less than 1,000 connections. Currently, the NNEPA PWSSP database indicates there are approximately 225 water systems with less than 1,000 connections. There are twelve (12) community water systems with greater than 1,000 connections. A calculated fixed radius delineation should by conducted by October, 2003. There are three scenarios under which the water system should give serious consideration to upgrading their initial delineation. They are: 1) if the vulnerability assessment form indicates that the system is highly susceptible to contamination, 2) if their hydrogeologic setting is strongly non-circular, or 3) if the results of the inventory reveal the presence of high risk potential contaminant sources. If the initial delineation to an analytical or other more sophisticated ground water flow model within five (5) years **(Figure 5)**. If the system's contingency plan can not readily identify an alternate water supply in the event of source water contamination, NNEPA PWSSP urges the system to upgrade the delineation using a more reliable method as soon as is feasible.

Public Water Systems with 1,000 or more Connections

The minimum acceptable method of delineation for public water systems with 1,000 or more connections is determined based on the vulnerability assessment and hydrogeologic setting. If the system is highly vulnerable to contamination, the initial delineation should be calculated using an analytical or other more sophisticated ground water flow method by October 2004.

For those water systems found to be of low or moderate vulnerability, the minimum acceptable method of delineation is the calculated fixed radius method. The NNEPA PWSSP recommends that these water systems upgrade their initial delineation to a more sophisticated ground water flow model **(Figure 6)** within 5 years, particularly if the hydrogeologic setting is strongly non-circular or if the results of the inventory reveal the presence of high risk potential contaminant sources.

Other Considerations

Delineation of Springs

Community water systems using springs as a source of supply are also required to develop a wellhead protection program. For technical assistance on delineating wellhead protection areas for springs, please contact the NNEPA PWSSPs hydrologist.

Delineation of Multiple Wells

If the wellhead protection areas of wells overlap, and the Calculated Fixed Radius method was used, the wellhead protection areas of the wellfield should be defined either by combining the wellhead protection areas of those wells **(Figure 7)** or by treating all the wells (combining pumping rates) as a single well located in the center of the wellfield. If other, more sophisticated modeling approaches were used, interference of the wells on one another should be incorporated into the modeling.

Refinement of Wellhead Protection Areas

Wellhead protection area boundaries should be periodically reviewed for changes. These include revised hydrogeologic data, changes in pumping capacities or rates, and new wells coming on-line. Changes in pumping rates or number of wells will likely require a new delineation of the wellhead protection area. Another reason to review is to confirm or reevaluate the potential contaminant sources within each of the zones. These are expected to change over time based on changes in land use as well as result of management practices in place within each zone. The vulnerability assessment should be reevaluated on a periodic basis for the same reasons.

Redefining wellhead protection area boundaries (with the resulting need to update maps, re-inventory and notify owners / operators of potential contaminant sources and regulatory agencies) should only be undertaken when new information changes the boundaries significantly. It is suggested that revising wellhead protection area boundaries be considered during the vulnerability assessment updating.

When the Time of Travel Criteria is Inappropriate

There are areas on the Navajo Nation where the use of the 1, 5, and 10 year travel time based criteria may not be appropriate. This may be due to:

- a capture zone which is recharged in less than 10 years,
- complicated geologic factors (river valley settings, high aquifer transmissivity, or complex geologic conditions that are not conducive to simplified modeling approaches), or
- settings where a significant portion of the contribution to the well is from surface water or GWUDI (wells adjacent to river systems, Ranney interceptor wells, or water-bearing zones having significant hydrologic continuity with surface waters).

In these settings, wellhead protection zones established using alternative criteria instead of the basic time of travel criteria – or different time-of-travel criteria, may be more appropriate.

Prior to using alternate criteria, water system owners must contact the NNEPA PWSSP and present the rationale for their conclusions. The water owners must also propose alternative criteria or methods to be used for the delineation or wellhead protection zone boundary determinations. Deviations from the 1, 5, and 10 year time of travel criteria required NNEPA PWSSPs concurrence.

Groundwater Under the Direct Influence of surface water (GWUDI)

Groundwater and surface waters may be connected. This is referred to as hydraulic continuity. Wells located near rivers may draw a significant portion of their total withdrawal from the surface source. This is particularly true when the wells are lateral collector type wells such as Ranney wells. A connection between a well and surface source may be established by examining water temperature fluctuation, fluctuations in water chemistry of the well water which reflect changes in surface water, or conducting a microparticulate analysis (MPA). Another method of identifying hydrologic continuity is by the correlation of water levels and impacts of pumping on adjacent water levels both in surface waters and other wells.

If surface waters are discharging to the groundwater, or the well is drawing water from surface supplies into its capture zone, that groundwater supply may be considered by the NNEPA PWSSP as groundwater under the direct influence of surface water (GWUDI). A groundwater source classified by NNEPA PWSSP as a GWUDI may be subject to additional protection measures including surface watershed control plans, increased disinfection and possible filtration requirements reflecting risks traditionally associated with surface waters. Most groundwaters experience some degree of hydraulic continuity with surface waters; however, the majority of groundwater based public water systems will not be classified as GWUDIs by NNEPA PWSSP. Approximately six (6) public water systems have been officially designated GWUDI's and there are fourteen (14) unofficial GWUDI systems yet to be determined on the Navajo Nation.

Wells in direct hydraulic continuity with surface sources need to incorporate this fact into their delineation effort. Depending on the degree of connection, the surface source (river, lake) may serve as a hydrologic boundary and usually leads to a smaller wellhead protection area defined. Situations such as this will usually require professional assistance in delineation efforts.

Specific Delineation Reporting Requirements

The wellhead protection area boundaries should be plotted on a base map that shows major landmarks and topography, with a scale large enough to adequately display the delineated area(s). A map with a scale of three to four inches per mile may be highly desirable. If you are unable to locate a map of this scale, a 7 ½ minute U.S. Geological Survey topographic map can be used, if enlarged by photocopying. Prior to enlarging, draw a one (1) mile bar of the correct scale on the map. Please ensure that the wellhead protection area boundaries on the map are drawn to scale as well.

If the Calculated Fixed Radius method is used, the following should be included in your water system plan:

1. Map of wellhead protection area delineations at the appropriate scale,
2. Screened interval of the well (or statement that well is of open hole construction),
3. Pumping rate of the well,
4. An example of the notification letter used, and
5. A listing of those notified of the wellhead protection area boundaries.

If a more site specific method is used, the following should be included:

1. Map of wellhead protection area delineations at the appropriate scale,
2. Explanation of methodology used,
3. An example of the notification letter used, and
4. A listing of those notified of the wellhead protection area boundaries.