3 Wellhead Protection Area Delineations

3.1 Introduction

The State of Washington's Wellhead Protection Program requires the delineation of the capture zones that contribute groundwater to pumping wells over periods of one year, five years, and ten years. In addition, the state program allows water purveyors to delineate Special Wellhead Protection Areas (SWHPAs), which may be delineated from capture zones for shorter or longer periods of time. The initial task for the SAJB Wellhead Protection program consisted of:

- Delineating capture zones that correspond to Special Wellhead Protection Areas (SWHPAs) for each of the SAJB well/well-fields. Each SWHPA was delineated for a one-year time of travel (TOT), adjusted upwards or downwards for each well according to the importance of the well.
- Delineating aquifer-wide wellhead protection areas consisting of the combined capture zones for all SAJB well/well-fields. For each well, the delineations were performed for a sufficiently long period of time to allow the capture zones to extend up-gradient to the Washington-Idaho state line.

Numerical modeling methods were used to perform the delineations for well/well-fields located within the Spokane Valley Aquifer. For well/well-fields located outside the aquifer, analytical calculations were used together with information on hydrogeologic boundaries to derive the capture zones.

Groundwater capture zone analysis is the process of delineating the area of an aquifer that contributes groundwater to a well (or wells) within a specified time interval based on groundwater travel time. The area encompassed by a capture zone is delineated based on groundwater flow velocities and flow directions. The procedure for delineating capture zones with a numerical model consists of placing particles around a well and tracing the particle locations backward in time. The traces of each particle represent a flow-line to the well, and the ensemble of particle traces leading to a given well represent the capture zone for the well. Traces of particle movement can also be made forward in time; this is often a useful complement to conducting traces backwards in time.

When considering the movements of contaminants within a capture zone, it should be kept in mind that chemical reactions are not simulated by the capture zone delineation models. Chemical reactions that may occur in the aquifer include chemical adsorption onto soil; precipitation of dissolved constituents; biotransformation; hydrolysis; and volatilization. These processes can cause concentrations of dissolved contaminants to decrease with increased distance from the source area, and thus can slow the rate of contaminant movement relative to the ambient groundwater flow rate. Therefore, contaminants *typically* do not move as fast as groundwater, providing additional response time for the SAJB to implement necessary actions.

3.2 Delineation Approach

The SWHPAs for each well-field and the aquifer-wide wellhead protection area for all SAJB utilities were delineated using an "annual water rights" pumping scenario. Under this scenario, pumping rates for each well equaled the annual pumping volume allowed under the assigned water right for the well. The volume pumped (in acre-feet per year) was converted to an equivalent average constant pumping rate in gallons per minute.

The SWHPAs were delineated for a simulation travel time equal to a base travel time (1 year) multiplied by an importance factor. Separate importance factors were selected for each well. The importance factors were based on each water utility's judgment of the manner and timing of their likely response to a contamination event within the zone of contribution to each well. The goal of delineating SWHPAs using this approach was to delineate "optimally sized" management areas, which would have the two following characteristics:

- They would be large enough to give the water utility time to replace the water source if replacement is needed.
- They would not be so large that it would become unfeasible to implement management or contingency plans.

The derivation of the importance factors for each well is discussed in further detail in Appendix I.

In addition to the annual water rights pumping scenario, capture zones were also delineated for pumping rates equal to the total volumes of water pumped during calendar year 1994. For this scenario (called the 1994 annual pumping scenario), the volume pumped (given in acre feet per year) was converted to an equivalent average constant pumping rate in gallons per minute. As with the annual water rights pumping scenario, the capture zones were delineated for a simulation travel time equal to the base travel time of one year, multiplied by an importance factor. Because the SAJB has decided to base the SWHPAs on the annual water rights scenario, the capture zones for the 1994 annual pumping scenario are not presented in this report.

3.3 Delineation Procedures

Separate procedures were used to delineate capture zones for well/well-fields located within the Spokane Valley Aquifer (i.e., between the Washington-Idaho state-line and the Little Spokane River) and well/well-fields located outside of the aquifer (within the Little Spokane River basin). Each procedure is described below.

3.3.1 Well/well-fields Within Spokane Valley Aquifer

Capture zones for well/well-fields located within the Spokane Valley Aquifer were delineated using the groundwater flow model developed for the City of Spokane's wellhead protection program (CH2M HILL, 1997). The City's model was adapted to (1) incorporate additional pumping wells that were not represented in the model, (2) relocate selected SAJB wells that were not correctly located in the City's model, and (3) incorporate additional geologic information. The City's model was developed using the numerical finite-element modeling software Micro-Fem (Hemker and van Elburg, 1987). The City's model was developed using Version 2.50 of the model (April 1995). Version 3.0 (Hemker and Nijsten, 1996) was used to conduct the modeling work for the SAJB wellhead protection program.

3.3.1.1 Description of City Model

Detailed discussions of the construction, calibration, and simulation capabilities of the model developed for the City's wellhead protection planning program are presented in a report titled *City of Spokane Wellhead Protection Program: Phase I – Technical Assessment Report* (CH2M HILL, 1997). The City's model has the following principal characteristics:

- Simulates groundwater flow within the portion of the Spokane Valley Aquifer extending from the Washington-Idaho state-line west and north to Nine Mile Dam and the Little Spokane River valley. This includes areas east and west of Five Mile Prairie.
- Simulates groundwater flow in three individual layers. The upper two layers are each 100 feet thick, and the third (deepest) layer contains the remaining saturated thickness of the aquifer. The third layer is inactive in locations where the aquifer is less than 200 feet thick, and the second layer is inactive in locations where the aquifer is less than 100 feet thick. Based on well construction information and the definitions of the layers, groundwater pumping occurs exclusively from layers one and two. No pumping occurs from layer three.
- Simulates pumping at the following 77 wells:
  - Seven of the City's eight production wells.
  - Twenty-two privately owned wells.
  - Forty-eight wells owned by members of the SAJB.
- Simulates the exchange of water between the aquifer and the Spokane River. In areas east of Sullivan Road, groundwater is recharged by the river. In areas west of Sullivan Road, the direction of water exchange varies with location.
- Simulates area recharge of groundwater from precipitation, land-applied water (agricultural and nonagricultural), and septic systems. The model also simulates recharge from tributary valleys to the aquifer. For some tributary valleys, the magnitude of this recharge is seasonally variable because the source of water is surface water drainage from the valley and subsequent infiltration at the edge of the aquifer (which consists of coarse deposits).
- Incorporates geologic information gathered since the time of the most recent prior published modeling work that was conducted for the Spokane Valley (Bolke and Vaccaro, 1980). The additional geologic information provides improved understandings of the base elevation of the aquifer, the nature of groundwater / surface water exchange, the magnitude of groundwater flow across the state line, and the magnitudes of aquifer hydraulic parameters such as transmissivity.
- Is calibrated to hydrologic conditions measured during a four-day period in mid-September 1994. Hydrologic data were collected as part of a comprehensive data collection program that was conducted as part of the City's wellhead protection

planning program. The data that were collected included river stages, groundwater elevations, and pumping rates. The data collection period was a period of seasonally low groundwater elevations and river stages, and groundwater pumping rates were at or near their annual peak approximately one week beforehand. The model simulates this time period by running in steady-state mode (as opposed to transient mode).

- The calibrated model is also capable of simulating conditions during the period of seasonally high groundwater elevations, high river stages, and low pumping rates. Simulations of these hydrologic conditions were based on data collected in April 1995 as part of the City's wellhead protection planning program.

3.3.1.2 Adaptation Of City Model To SAJB Delineation Process

The City's model was modified prior to delineating the capture zones. The modifications consisted of adding in SAJB well/well-fields that had not been simulated in the City's model, refining the locations of SAJB wells that were included in the City's model, making minor revisions to the aquifer boundary conditions, and revising the model's representation of the aquifer in the vicinity of the Kaiser Aluminum Company's Trentwood Rolling Mill facility. These changes are summarized below.

3.3.2 Mesh Modification (Well Locations)

The finite-element mesh on which the City's model is based was modified in order to incorporate pumping from each of the SAJB wells. In addition to adding wells, adjustments were necessary in the locations of several wells that were simulated in the City model. Adjustments were necessary because the locations had been assigned in the City model by using digitizing processes that were based on field drawings and USGS topographic map coordinates. The correct locations were identified using the following procedures:

- A hand-held global positioning system (GPS) unit was taken to each well to record a set of location coordinates that could be converted into eastings and northings (on the NAD27 horizontal datum). The accuracy of the GPS units is about + 40 feet in all directions. Although GPS units do not provide survey-quality coordinate data, the measurements were taken in order to provide an initial check of the accuracy of the coordinates obtained during the City's wellhead protection program.

- The locations were then refined from the GPS locations by plotting the NAD27 coordinate data onto a road base map obtained from Spokane County's Geographic Information System (GIS). The displayed well locations were compared to their known locations, and the final coordinates were obtained once refinements of the well locations were complete.

At some locations, multiple wells were represented as a single pumping location in the final revised mesh. Table 3-2 presents an inventory of the wells for which delineations were conducted and indicates which wells were delineated individually or as a well-field.

Table 3-1: Inventory and Delineation Design Summary for SAJB Wells

3 3.3.3 Other Model Modifications

The following additional modifications were made to the model prior to performing the delineations:

- Specified-head nodes at the northern end of Hillyard Trough (south of the Little Spokane River) were converted to variable-head nodes so that delineations could be performed for three SAJB wells in this area (Water District #3 Helena well, and Whitworth Water District wells #3 and #3B).

- Recharge from tributary valleys was not simulated because of concerns that capture zones near the edges of the aquifer could be distorted if this recharge were to be simulated. This decision was also based on the observation that recharge is seasonal from several of the tributary valleys and may be near zero during the summer and early fall (the time period simulated in the model).

- The locations of the following three geologic boundaries were refined in the model.
  - The western boundary of a bedrock knoll in the vicinity of Pines Road (at the location of the former Walk-In-The-Wild Zoo).
  - The southern boundary of the aquifer in the vicinity of East Spokane Water District wells #5 and #6.
  - The southern boundary of the aquifer at Shelley Lake.

- Modifications were made at and west of the Kaiser Aluminum Company Trentwood Rolling Mill site to incorporate hydrogeologic data available at and adjacent to the site. Modifications were made to the aquifer base elevation, the hydraulic conductivity distribution, the stage of the Spokane River, and the vertical conductance of the bed of the river. The model was then re-calibrated to the same conditions (Fall 1994 hydrologic conditions) to which the City model had been calibrated. Detailed discussions of the modified parameter values and the re-calibration process are presented in Appendix J.

3.3.4 Delineation Results

The delineation procedure consisted of the following modeling steps:

- Calculation of groundwater elevations. This was performed using the annual water rights pumping scenario and Fall 1994 background hydrologic conditions in the Spokane River and the Spokane Valley Aquifer.

- Three-dimensional reverse particle-tracking. For each well, this was conducted by placing multiple particles around the well and at multiple depths throughout the open depth interval of the well. This procedure was conducted one well at a time. Separate travel times were specified for each well according to the value of the importance factor that was assigned to each well. The delineations were conducted using an aquifer effective porosity of 0.20, which is the same value as was used for delineation work conducted for the City of Spokane wellhead protection program.

3.4 Calculations of Groundwater Elevations

The calculation of groundwater elevations was performed using the Fall 1994 Spokane River stages and the following pumping rates:

- For each SAJB well, pumping was assigned to the appropriate model layer(s) based on the depth interval of the well screen (or casing perforation) and the regional water table elevation. The pumping rates were equal to the annual water rights volume, divided by 365 days per year. The pumping rates are listed in Table 3-1, which also lists the well penetration depths below the water table.
- Wells owned by the City of Spokane and by private parties were assumed to pump at rates equal to those in the Fall 1994 simulations. Table 3-2 provides an inventory of these wells (including well penetration depths).
- All SAJB and non-SAJB wells were pumped simultaneously in the model, which was run in steady-state mode.

Based on this representation of pumping, the total simulated annual basin-wide pumping volume for the annual water rights scenario was 296,150 acre-feet (Aft). This annual basin-wide pumping volume is equivalent to an average long-term pumping rate of 410 cubic feet per second (cfs), which is equivalent to 184,000 gallons per minute (gpm). These pumping rates are approximately 1.75 times higher than the pumping rates that occurred during Fall 1994 (234 cfs; 105,000 gpm). For the delineation scenario, the relative percentage contributions of the SAJB, the City, and the other wells to the total pumping are 64 percent, 27 percent, and 9 percent, respectively. For the Fall 1994 conditions, these percentages were 37 percent, 48 percent, and 15 percent, respectively.

Because of the difference in pumping rates between Fall 1994 conditions and the SAJB delineation scenario, simulated groundwater elevations in areas east of the city limits were between three and seven feet lower for the annual water rights model (the delineation scenario) than for recalibrated model of Fall 1994 conditions. (See Figure 3-1 for a map showing the two sets of simulated groundwater elevations.) In addition, the annual water rights simulation indicated that the Spokane River could potentially become a losing stream from the state line downstream to Upriver Dam. (See Table 3-3.) Over this reach, the model predicted the net loss of water from the river to the aquifer to be 171 cubic feet per second (cfs), compared with 61 cfs for the re-calibrated City model (Fall 1994 conditions). A similar contrast between these simulations is indicated in Table 3-3 for the reach from the state line to river mile 75 (just downstream of the SIRTI campus near downtown Spokane [5 miles downstream of Upriver Dam]) would have a net loss of surface water of 101 cfs under the SAJB pumping scenario, as opposed to an estimated 68 cfs net gain under Fall 1994 conditions (re-calibrated City model).

Table 3-2: Inventory of Non-SAJB Wells Simulated During SAJB Delineation Process

3.4.1 Particle-Tracking Procedure

3.4.1.1 Particle Initiation Procedure

At any given well, particles were initiated at multiple depths throughout the uppermost model layer. In addition, if the well screen penetrated all or a portion of model layer two, then particles were placed as deep as the bottom of the open interval.

3.4.1.2 Travel Time Criteria

For the SWHPAs, each capture zone represents a one-year time of travel (TOT). The input travel time criterion for the model equals the 1-year TOT multiplied by the importance factor discussed in Chapter/Section 3.2. For importance factors greater than 1.0, the well is of relatively high importance, and the travel time specified in the model is greater than one year. For importance factors less than 1.0, the well is of less importance (e.g., its supply could be quickly replaced by production from another well), and the travel time specified in the model is less than 1 year. Appendix I presents the rationale for selecting the importance factors, which was based on consideration of 15 separate importance factor scenarios describing the use of each well, the availability of production capacity from other system wells, the availability of interties with other water utilities, and the capabilities of the overall water distribution system. Table 3-1 lists the importance factor scenarios and importance factors selected by each water utility for their wells.

For the aquifer-wide delineations, the modeling procedure did not require specification of a pre-determined TOT. Instead, the model was run for a sufficiently long period of time to cause the capture zones to extend up-gradient to the Washington-Idaho state-line. Figures 3-1 through 3-20 show examples of particle tracking figures for each SAJB purveyor.

3.4.2 Wells Outside Spokane Valley Aquifer

Five wells owned by SAJB utilities are situated in the Little Spokane River valley and are not within the Spokane Valley aquifer system. The Whitworth Water District #2 owns four wells, and Spokane County Water District #3 well owns one.

3.5 Delineations of SWHPAs

SWHPAs for wells located outside the Spokane Valley Aquifer were delineated using (1) information on geologic boundaries and (2) analytical calculations of potential zones of contribution to each well. The analytical calculations used the calculated-fixed-radius (CFR) method and analytical equations for uniform groundwater flow. The delineation approach consisted of the following components:

- Use of the CFR method to estimate the size of a circular area that would be expected to contribute groundwater to a well. This method assumes that no ambient groundwater flow is occurring within the aquifer (other than flow induced exclusively by pumping). The CFR method requires specification of the well's pumping rate, its open interval (the depth interval between the top and bottom of the well screen or casing perforations), the importance factor for the well, and the effective porosity of the aquifer. This method is described in Chapter 4 of the state guidance document for wellhead protection planning (Washington State Department of Health, December 1993). The CFR calculations are presented in Table 3-4.

- Calculation of the capture zone area and alignment under the influence of a naturally-occurring hydraulic gradient in the aquifer. The resulting capture zones are elongated in plan view and extend up-gradient from each well. This calculation was performed because a natural gradient likely exists, and the resulting capture zones would include areas not included in the CFR calculations. However, the magnitude of the hydraulic gradient is not well characterized in the Little Spokane Valley. For these calculations, it was assumed that the gradient is similar to the hydraulic gradient of the Little Spokane River and that ambient groundwater flow on a regional scale is generally the same as the flow direction in the river.

- Superposition of the two sets of capture zones to obtain the SWHPA. To obtain the SWHPA required the translation of both sets of capture zones onto a base map, and selection of a SWHPA that encompasses both capture zones. The capture zones are laterally truncated at geologic boundaries and encompass only alluvial deposits that lie within the Little Spokane River valley or tributaries. This is based on geologic mapping, which indicates that granite, basalt, and low-permeability sedimentary deposits form the lateral boundaries of the aquifer. This same information indicates that Whitworth Water District's Rivilla well lies in a separate aquifer system within the Little Spokane River valley than the other four wells.

3.5.1 SWHPAs

Figures 3-22 through 3-42 represent the SWHPAs for each SAJB water utility. In general, the SWHPAs extend smoothly in an up-gradient direction from each well. Some capture zones also broaden as they extend further up-gradient, and some appear to branch. Generally, capture zone irregularities and branching occur for wells with:

- Long travel times (particularly 5-year travel times).
- High pumping rates.
- Locations close to other pumping wells.
- In the case of the North Spokane Irrigation District, wells with capture zones that extend close to high-volume production wells operated by the City of Spokane.

For each water utility, the figures show the combined SWHPA for all wells. In some cases, the capture zones for individual wells owned by a given utility partially overlap. In addition, the combined SWHPA for a given utility overlaps partially with the SWHPA for one or more other utilities. Combined SWHPAs that overlap between utilities are tabulated in Table 3-5, which includes information on the area duplicated by each SWHPA. The general observations regarding overlap between water utilities are as follows:

3.5.2 Aquifer-Wide Delineation

The SWHPAs encompass the entire width of the Little Spokane River valley alluvial aquifer system. Consequently, the aquifer-wide delineation consists of the combined SWHPAs for the five wells.

Table 3-4: CFR Calculations For SAJB Wells Located Outside The Spokane Valley Aquifer System

Well	Delineation Scenario	Annual Q (Aft/yr)	Annual Q (ft^3/yr)	Importance Factor	H (feet)	Notes	Radius (feet)	Area (ft^2)	Area (sq. miles)
WD #3 Pineriver Park	Water Rights	374	16,291,440	5	32	(a)	1,919	11,570,625	0.42
	Hottest Day	178	7,753,680				1,324	5,506,875	0.20
WWD #2 8A1	Water Rights	168	7,318,080	0.5	25	(b)	460	665,280	0.02
	Hottest Day	168	7,318,080				460	665,280	0.02
WWD #2 8A2	Water Rights	985.6	42,932,736	1.5	44	(c)	1,455	6,652,800	0.24
	Hottest Day	791	34,455,960				1,304	5,339,250	0.19
WWD #2 8B	Water Rights	8000	348,480,000	1.5	81	(d)	3,056	29,333,333	1.05
	Hottest Day	1133	49,353,480				1,150	4,154,333	0.15
WWD #2 RIV	Water Rights	78	3,397,680	0.1	10	(e)	222	154,440	0.01
	Hottest Day	78	3,397,680				222	154,440	0.01

Area = Q * t / (n * H) where Q = annual pumping rate (ft^3/yr)
t = importance factor (time of travel)
n = effective porosity = 0.22
H = open interval (length of well screen)

Radius = (Q * t / [3.1415 * n * H]) $^{1/2}$

Notes:

(a) Based on well log attached to Susceptibility Assessment Survey for source number S01. Shows 12-inch diameter well screen for depth interval 172-204 ft bgs.

(b) Length of open interval equals value used for calculated fixed radius calculation performed for Susceptibility Assessment Survey (source number S02).

(c) Length of open interval is value reported on page 5 of Susceptibility Assessment Survey. Calculated fixed radius presented in Susceptibility Assessment Survey used 50 feet.

(d) Length of open interval is value reported on page 5 of Susceptibility Assessment Survey. Calculated fixed radius presented in Susceptibility Assessment Survey used 75 feet.

(e) Calculated fixed radius presented in Susceptibility Assessment Survey used 10 feet. Page 5 of Susceptibility Assessment Survey indicates actual length is 6 feet. A hand-written note on a photocopy states that the open interval is "21 to 29 feet according to well log".

Figure 3-43 represents all of the SAJB's proposed WHPs and the aquifer wide protection area. The figure shows that the combined capture zones for all SAJB wells and well-fields cover virtually the entire aquifer east of Fancher Avenue. West of Fancher Avenue, the capture zones separate into three groups of flow lines with the largest ones lying along both the northern boundary and the center of the aquifer; and extending northwards towards wells owned by Spokane County Water District #3, Kaiser Mead, North Spokane Irrigation District, and Whitworth Water District at the north end of Hillyard Trough. Where the capture zones for these four utilities extend to areas east of the city limits, the capture zones lie primarily south of the Spokane River and draw water from deeper portions of the aquifer than wells situated in this area.

The SWHPAs capture zones show considerable overlap between the various SAJB water utilities in this area. As with the SWHPAs, the capture zones lie at different depths within the aquifer wherever they overlap. In addition, because of the regional pumping and ambient groundwater flow patterns near and east of the city limits, the capture zones for each SAJB well draw water from progressively deeper portions of the aquifer as they extend up-gradient towards the state line. Consequently, when viewing the capture zone configurations at the state line, the wells closest to the state line draw water from the shallowest portions of the aquifer and the wells furthest from the state line draw water from the deepest portions of the aquifer. This influence is partially due to pumping influences east of the City of Spokane, but it also arises from the "funneling" of groundwater flow through the narrow portion of the aquifer in the eastern portion of the city. In this area, deep groundwater moves upwards under ambient conditions and eventually flows to the SAJB wells that lie north of the city. Table 3-5 summarizes the overlaps.

3.5 Overlap of SWHPAs

3.6.1 Causes of Overlaps

The overlapping nature of the delineated SWHPAs is due to differences in the depth intervals from which individual wells withdraw water, particularly in the remote ends of their capture zones. Even though a well may be screened in the uppermost portion of the aquifer, a certain amount of the pumped groundwater may be obtained from deeper portions of the aquifer because of the influences of vertical groundwater flow.

In the groundwater flow model, the aquifer is represented as a three-layer system. The two uppermost layers of the model are each 100 feet thick, with the top of the upper layer being the water table. By design, all groundwater pumping within the Spokane Valley Aquifer is contained within these two layers. The third model layer represents the remaining thickness of the aquifer, and it simulates the deepest portions of the aquifer where no pumping is occurring. Although pumping is simulated within the first two layers (the upper 200 feet of the aquifer), the influences of pumping on groundwater flow patterns are exerted throughout the full thickness of the aquifer, particularly close to pumping wells and in areas where there are many wells. Consequently, the SWHPAs for each well-field overlap because of the following factors, which have varying degrees of influence between each SWHPA:

- The proximity of wells to other pumping wells, and the relative difference in pumping rates between the wells. For wells that are close together and have relatively high pumping rates, vertical hydraulic gradients may be present for a substantial distance around each well. These gradients can cause groundwater to be obtained from several directions (horizontally and vertically) and from a greater thickness of the aquifer than in the case of wells that are spaced further apart and/or have lower pumping rates.

- The magnitudes of the importance factors. For wells with low importance factors (short travel times), the capture zones will be primarily contained within a depth interval similar to the open interval of the well. For wells with high importance factors (long travel times), the capture zones typically occupy a progressively greater proportion of the aquifer's thickness in the up-gradient direction as water is obtained from deeper in the aquifer. The increasingly three-dimensional nature of the capture zones with increasing travel times reflects the greater regional scale of the capture zones for long travel times as opposed to short travel times; specifically, greater mixing occurs within the aquifer over long distances (long travel times) as opposed to short distances (short travel times).

The SWHPAs have been delineated using a technique (numerical modeling) that both EPA and the State of Washington consider to be state-of-the-art for wellhead protection area delineation. The use of numerical modeling methods is considered state-of-the-art because these methods consider the spatial variability in geologic conditions, the presence of geologic boundaries, the influence of surface water bodies on groundwater flow patterns, the spatial variability of groundwater recharge (e.g., from land-applied water, septic systems, and inflow from tributary valleys), and other features specific to the aquifer. Nevertheless, the delineations possess a certain degree of uncertainty. The uncertainties arise from the following aspects of the delineation procedures:

- Steady-state modeling. The delineations are calculated from steady-state simulations of groundwater flow directions and elevations, river stages, and pumping rates. These aquifer conditions are simulated as being constant throughout the delineation period, even though they can actually vary on a seasonal basis (particularly at a localized scale).

- The importance factor. Uncertainties in the locations of the SWHPAs increase with increasing values of the importance factors. Delineations for high importance factors (long travel times) are more uncertain because they can be influenced by (1) the cumulative effects of uncertainties in the flow direction with up-gradient distance from the well; and (2) the cumulative effects of seasonal variations in aquifer conditions, which can affect groundwater flow directions and velocities to varying degrees throughout the aquifer.

3.6.2 Notable Overlaps for SAJB Wells/Well-fields

In general, the SWHPAs exhibit shapes that are consistent with the regional groundwater flow direction, and SWHPA overlaps arise primarily where wells for a given purveyor are directly up-gradient or down-gradient of another purveyor. The notable exception to this general trend are the shapes of the SWHPAs for both North Spokane Irrigation District #8 (NSID) and Kaiser's Mead facility. These SWHPAs exhibit a markedly "fanned" shape east of the Spokane River, and the SWHPAs partially overlap the wellhead protection areas of six other water utilities in the vicinity of the Upriver Pool. In this area, the NSID and Kaiser Mead capture zones lie within the second model layer (i.e., between 100 and 200 feet below the water table), while the capture zones for the six other well-fields lie primarily within the first model layer (the upper 100 feet of the aquifer). The unusual shapes of the NSID and Kaiser Mead capture zones result from three factors:

- The concentrated pumping in this area by other SAJB purveyors and by the City of Spokane's Parkwater pump station.
- The influence of the Spokane River, which lies substantially above the water table above the dam, but lies below the water table and therefore receives substantial groundwater inflows in the reach below Upriver Dam.
- The long travel times (high importance factors) used to delineate the capture zones for both the NSID and Kaiser Mead wells.

The causes for the shape of NSID's and Kaiser Mead's SWHPA are summarized below for three distinct portions of the SWHPA, proceeding in an up-gradient direction from the wells.

- Between the wells and the Spokane River. In this area, groundwater flow is relatively uniform and horizontal because of the relatively great distance between wells (compared to other portions of the Spokane Valley Aquifer). In addition, the pumping rates for both the NSID and Kaiser Mead wells are relatively low compared to many other wells in the valley. Consequently, the capture zone has its narrowest extent in this area, and its shape is governed by the relatively uniform nature of the flow field.
- In the immediate vicinity of the river. Here, groundwater is discharging to the Spokane River from the uppermost portion of the aquifer. Because the groundwater moving into the river is derived from the uppermost portion of the aquifer, groundwater in deeper portions of the aquifer can pass beneath the river. The SWHPA reflects this phenomenon, residing within the second model layer in this area (i.e., more than 100 feet below the water table and the river) and exhibiting a somewhat wider shape due to the contribution of water from deeper portions of the aquifer.
- Up-gradient (east) of the river. The shape of the capture zone is affected primarily by the large number of wells in this area and the relatively high pumping rates from many of the wells. Pumping rates are particularly high at the City's Parkwater pump station (15,960 gpm in Fall 1994; the water right is 51,240 Aft/year [equivalent to an annual average pumping rate of 31,765 gpm]), and the pump station operates at most times because of its use as a primary water supply. Consequently, the high pumping rate creates a wide-spread draw-down of the aquifer around the pump station, which causes the groundwater capture zones for NSID's and Kaiser Mead's wells to pass (1) underneath the northern portion of Parkwater's groundwater capture zone and (2) to the north of the Parkwater well. For similar reasons, the pumping action of other SAJB wells in this area also cause NSID's and Kaiser Mead's capture zone to lie beneath the capture zones for these wells. The model predicts that the capture zone is largely unaffected by the presence of the Spokane River, which

> lies several feet above the water table in this area (behind Upriver Dam). This is consistent with available data that indicate the pool behind Upriver Dam likely contributes negligible quantities of water to the underlying aquifer.

One way to visualize this situation is to realize that pumping from the NSID and Kaiser Mead wells exerts a demand on the aquifer. Near the well, groundwater is available in the shallow zone at approximately the same elevation as the well intakes, so the capture zone is relatively narrow and located in the first model layer. Stated another way, the aquifer can easily meet both purveyors demands, so the capture zones remain small. Further up-gradient, the combined effect of groundwater discharge to the Spokane River and pumping from the City's Parkwater well captures a large proportion of shallow groundwater flow in this area. Water feeding NSID's and Kaiser Mead's wells must therefore be obtained from deeper zones and from zones located to the sides of the zone feeding the Parkwater pump station. It is this effect that causes the distinctive shape of a both NSID's and Kaiser Mead's SWHPA.

3.6.3 Implications for Management Planning

For SWHPAs delineated with multiple importance factors (i.e., not the same factor for every well in the well-field), the uncertainty in the area extent of the capture zones is not uniform within an individual SWHPA. For those SWHPAs delineated with a single importance factor for every well in the well-field (CID, HID, MEWCO, and NSID), the delineated SWHPA has a more uniform level of uncertainty throughout its area of coverage. An example of the type of uncertainty can be illustrated as follows:

> "Should a gas station located 4,000 feet from a well (within the edge of its 3 year SWHPA, but far enough out that uncertainties inherent in the delineation mean that there is some probability the gas station may not actually be capable of contaminating the well) be subject to the same level of control as a gas station located only 200 feet from another well owned by the same utility (within the 1 year SWHPA for that well)? They both are within the SWHPA designated by the utility."

The issue then becomes a basic question of management program complexity. A more simplified program will not take into account all of the potential variables and a more complicated system will add to regulatory and administrative problems that are prone to challenge because of their complexity. The SAJB developed its program with public and business input, working toward a resulting management plan that is simple, but also contain the regulations that the public and business is willing to live with.

Table 3-5 Summary of SWHPA Overlap Between SAJB Member Wells/Well-Fields

Spokane Aquifer Joint Board Wellhead Protection Program

Utility (Abbreviation)	Utilities With Overlapping SWHPAs
Carnhope (Carnhope)	ESWD, MEWCO, Model ID, VID, WD3E
Consolidated Irrigation District #19 (CID)	HID, IWD (Slight), NSID, VID, SIP, K-T
East Spokane Water District #1 (ESWD)	Carnhope, MEWCO, Model ID, VID, WD3E
Hutchinson Irrigation District #16 (HID)	CID, MEWCO (Slight), VID
Irvin Water District #6 (IWD)	PPID, TID, MOAB,
Kaiser – Mead (K-M)	NSID, OID, WD3E
Kaiser – Trentwood (K-T)	SIP, CID
Liberty Lake Service District (LLSD)	WD#3E
Modern Electric Water Company (MEWCO)	Carnhope, ESWD, HID (Slight), Model ID (Slight), VID, WD3E, NSID
City of Millwood (Millwood)	IWD, NSID
Moab Irrigation District (MOAB)	IWD
Model Irrigation District #18 (Model ID)	Carnhope, ESWD, MEWCO (Slight), VID, WD3E
North Spokane Irrigation District #8 (NSID)	Millwood, OID WD3E (Slight), K-M, MEWCO
Orchard Irrigation District #6 (OID)	NSID, WD3E, MEWCO (Slight), K-M
Pasadena Park Irrigation District #7 (PPID)	IWD, SIP, TID
Trentwood Irrigation District (TID)	IWD, PPID
Vera Water And Power (VID)	Carnhope, CID, ESWD, HID, MEWCO, Model ID, WD3E, K-T
Spokane Industrial Park (SIP)	CID, K-T
Spokane Co. Water District #3, East Well-field (WD3E)	Carnhope, ESWD, MEWCO, Model ID, NSID (Slight), VID, K-M
Spokane Co. Water District #3, North Well-field (WD3N)	WWD
Whitworth Water District (WWD)	WD3N