

TECHNICAL MEMORANDUM

Update of Groundwater Capture Zones for Wellhead Protection Program: Spokane Aquifer Joint Board (Spokane County, Washington)

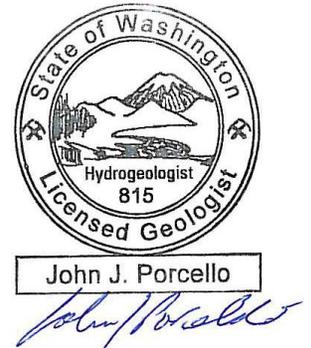
To: Jeremy Jenkins, President/Spokane Aquifer Joint Board

From: John Porcello, LHG (Washington)/GSI Water Solutions, Inc.
Andy Lapostol, PG (California)/GSI Water Solutions, Inc.

CC: Meagan Hayes, Program Manager/Spokane Aquifer Joint Board

Attachments: Tables 1 through 4
Figures 1 through 5
Attachment A: Process for Developing Time Durations for Special Wellhead Protection Areas
Attachment B: Capture Zone Maps for Each SAJB Member

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Introduction

On behalf of the Spokane Aquifer Joint Board (SAJB), GSI Water Solutions, Inc. (GSI), has used SAJB's updated groundwater flow model of the Spokane Valley-Rathdrum Prairie (SVRP) Aquifer to delineate updated groundwater capture zones for SAJB's Wellhead Protection (WHP) program. The SVRP Aquifer encompasses an area of approximately 370 square miles (Kahle et al., 2005) in Spokane County, Washington, and Kootenai and Bonner Counties, Idaho. The 21 SAJB members own and operate a total of 152 wells located in 103 wellfields that withdraw groundwater from the SVRP Aquifer in Spokane County.¹ Figure 1 shows the locations of the SAJB member wells and the geographic extent of the SVRP Aquifer. Together, the SAJB wells/wellfields provide the sole source of water supply to residential, commercial, and industrial water customers in the portions of Spokane County overlying and adjacent to the SVRP Aquifer. The SVRP Aquifer was designated as a Sole Source Aquifer by the U.S. Environmental Protection Agency (EPA) in 1978 because of the region's reliance on this aquifer for its sole source of drinking water supply.

GSI has delineated groundwater capture zones for each SAJB-member well for time periods of 1, 5, and 10 years, which are the three time periods required for capture zone delineation under the State of Washington's WHP program rules. The state program, which is administered by the Washington Department of Health (DOH), also allows municipal water purveyors (the owners of drinking water supply wells) to delineate Special Wellhead Protection Areas (SWPAs). Under the WHP program rules, SWPAs provide municipal water purveyors with enhanced flexibility to create management strategies for pollution prevention and risk reduction in an optimally-sized management area that best facilitates the type of response (and the response time) to a contamination event inside the SWPA.

¹ One SAJB member (Whitworth Water District #2) also owns five wells in the Little Spokane River watershed. These five wells provide water to a portion of Spokane County located just north of the northern boundary of the SVRP Aquifer.

This technical memorandum documents the delineation work and is organized into the following sections:

- **Section 1:** The definition and meaning of groundwater capture zones
- **Section 2:** The design of the delineation approach
- **Section 3:** The simulation technique used in the groundwater model
- **Section 4:** Discussion of delineation results
- **Section 5:** A list of references cited in this technical memorandum

1. Definition and Meaning of Groundwater Capture Zones

As described in SAJB's original WHP plan (CH2M HILL, 2000), groundwater capture zones delineate the land area overlying the portion of the aquifer that contributes groundwater to a well (or wells) during a specified time period, based on groundwater travel times and flow directions. The area encompassed by a capture zone is delineated based on groundwater flow velocities and flow directions. The groundwater flow velocities, flow directions, and capture zone delineations have been developed using the newest version of SAJB's three-dimensional numerical groundwater flow model of the SVRP Aquifer, which was developed in 2025 and is documented in GSI (2025a). This newest SAJB model has been developed by combining information from prior groundwater modeling efforts in the SVRP Aquifer (CH2M HILL, 1998; Hsieh et al., 2007; GSI, 2012) with new software tools (MODFLOW-USG, mod-PATH3DU, and Groundwater Vistas). As discussed in GSI (2025a), the MODFLOW-USG (Panday et al., 2013; Panday, 2025) and mod-PATH3DU (Muffels et al., 2021) software tools (1) have particularly robust groundwater simulation capabilities, including detailed and flexible solvers; (2) are well-supported by graphical user interfaces (GUIs) such as Groundwater Vistas (ESI, 2024) that help the modeler visualize and manage the modeling process; (3) have the ability to communicate with other software packages such as Geographic Information System (GIS) software; and (4) have broad familiarity by—and support and acceptance within—the groundwater modeling community.

In the numerical model, the groundwater capture zones are delineated by placing multiple imaginary particles around a drinking water supply well and tracing the particle locations in reverse (i.e., backward in time) to trace the origin of the groundwater that is pumped by the well. The traces of each particle represent groundwater flowpaths to the well, and the ensemble of particle traces leading to the well represent the capture zone for the well. Traces of particle movement can also be conducted forward in time in the model, which provides a useful complement and important cross-check on the delineations calculated using the reverse-tracing technique.

2. Delineation Approach

The delineation update work for SAJB's WHP program consisted of two delineation steps:

- **Delineating SWPAs for groundwater travel times reflecting the importance of each well for providing drinking water supply.** For a given well, the travel time was selected by the SAJB member based on their judgment of the manner and timing of their likely response to a contamination event within the geographic area delineated for the SWPA. The process for this selection of the SWPA travel time is described in Attachment A, which also tabulates the selected travel time for the SWPA at each well. Table 1 summarizes the range of travel times selected by each SAJB member for their SWPAs.
- **Delineating aquifer-wide wellhead protection areas for uniform travel times for each well.** This part of the delineation process consisted of delineating the combined capture zones for all SAJB wells/wellfields for three specific time periods for groundwater to travel to each well: 1 year, 5 years, and 10 years.

Compared with prior delineation efforts conducted for SAJB, the technical approach for delineating the new capture zones differs in six respects:

- All wells were pumped simultaneously at their target rates for delineation in the updated capture zone analysis. In contrast, prior delineations relied on separate simulations for each SAJB member, in which all wells in the SVRP Aquifer were pumped at historical usage rates except for the wells owned by the member whose wells were being delineated (which were pumped at the target rates for delineation). Put another way, the updated delineations used a single pumping simulation model that was used to delineate the capture zones for all wells owned by all 21 SAJB members, whereas the prior delineations relied on 21 separate pumping simulation models. Table 2 identifies the instantaneous pumping rates and annual production volumes that were used in the delineation process for each SAJB member well.
- For the SWPAs, the pumping rate for each SAJB member well was set equal to the instantaneous pumping rate allowed under the SAJB member's water rights, rather than the annual production volume allowed at the well under those same water rights. For a given SAJB member, this resulted in the use of the highest allowed pumping rate during SWPA delineation to provide a sufficient area for protection of each well, which is especially important if one or more of the SAJB member's wells needs to operate at higher-than-historical rates and production volumes under a future emergency condition (particularly if one of that SAJB member's wells is offline because of contamination or other impacts).
- For the 1-, 5-, and 10-year capture zones, the pumping rate for each SAJB member well is based on the annual production volume allowed under the water right. The annual volume is distributed monthly according to the proportion of annual water use occurring each month, as derived from historical usage by the cities of Millwood and Spokane and projections by the City of Spokane of potential changes in future seasonal use patterns (see Table 3 for the values used in the delineation modeling runs).² The only exceptions to the use of annual pumping are in cases where the SWPA is for a 1-year or longer period of time, because the SWPA is delineated using the instantaneous pumping rate allowed under the water right.
- The new delineations were developed using an effective porosity value of 0.35 for the SVRP Aquifer sediments. Prior delineations have used values of 0.20. The use of a higher value in the updated delineations reflects new knowledge of the aquifer system that has resulted in the use of higher values of hydraulic conductivity in the SAJB model than in models used for prior delineations (as discussed in Section 4 of GSI, 2025a).³ The higher hydraulic conductivity values are particularly descriptive of an aquifer framework containing a significant percentage of gravels, cobbles, and boulders, which reside in the aquifer in a manner that creates large pore spaces through which groundwater moves. For this reason, and also because groundwater travel times are based on the ratio of hydraulic conductivity to effective porosity, the GSI team concluded that the use of increased hydraulic conductivity values derived from recent studies should be accompanied by an increase in the effective porosity for capture-zone delineation purposes.
- The new delineations were developed using transient (time-varying) groundwater model simulations, which varied pumping and background (natural) hydrologic conditions in the aquifer on a monthly basis.

² The values shown in Table 3 were developed by first reviewing historical production data for the City of Spokane from 2015 to 2020 and historical production data for the City of Millwood from 2021 to 2023. Those data showed peak-month usage being 16 percent to 21 percent of year-round usage. Projections by the City of Spokane for 20-year and 50-year time periods that included consideration of climate-change impacts on future water demands identified lower peak-month percentages (between 13 and 14 percent) because of higher demands (percentages) during the shoulder season months of April, May, and September (see GSI, 2024). The future values shown in Table 3, that are used for capture zone delineations for all SAJB members, are the averages of the two historical percentages (Millwood and Spokane) and the future projection for Spokane.

³ This new knowledge has occurred from field investigation studies conducted by the City of Spokane at its new Havana Street Well Station (see GSI et al., 2017) and its Well Electric Well Station (GSI, 2025c).

Prior delineations were developed using steady-state simulation methods, which simulated long-term stable “average” conditions in the aquifer and non-varying pumping rates from each SAJB member well.

- Two different possible futures for climate and ambient (natural) hydrologic conditions in the aquifer were simulated, which affect the simulated timing and rates of recharge to the aquifer from rainfall, inflow from tributary watersheds, and leakage from the Spokane River in its losing reaches (reaches where the riverbed lies above the water table). Prior delineations assumed just one set of background conditions, which were based on historically observed conditions rather than on potential future climates and aquifer-recharge patterns. The updated delineations were developed using two scenarios described by GSI (2025b), which are low-impact and high-impact end-members of potential future climate impacts that scientific studies and global climate models indicate could occur under a future greenhouse gas emissions scenario in which emissions continue rising throughout the 21st century. These two scenarios are labeled 8.5-Low and 8.5-High for the purposes of discussion in this technical memorandum. (See GSI, 2025b, for further details regarding the meaning, attributes, and analyses of these two scenarios.) The use of two possible future climates accounts for uncertainties in future aquifer conditions.

3. Simulation Technique in the Groundwater Model

The simulation technique for conducting the delineation modeling work consisted of the following steps:

- **Running the Groundwater Flow Model.** This step used MODFLOW-USG to calculate time-varying groundwater elevations and groundwater budgets on a monthly basis for a 10-year (120-month) period of time. The model calculates this information at each grid cell and in each of the eight model layers, which at any given location range in thickness from a few feet to up to 75 feet in any given model layer to allow for simulation of vertical hydraulic gradients throughout the regional aquifer system (including around pumping wells and near surface water bodies such as the Spokane River, which recharges the aquifer in some locations and receives groundwater discharge from the aquifer in other locations). Key characteristics of the MODFLOW-USG simulation are:
 - Each year of the MODFLOW-USG model run used the same month-by-month values of groundwater recharge terms and aquifer boundary conditions (such as recharge from perimeter lakes and other tributary watersheds).
 - For the duration of the SWPA at a given well, the SWPA-based pumping rate (which is based on the instantaneous pumping capacity allowed under the water right) was assigned to the end of the 10-year simulation period, while lower rates (which are based on annual production limits in the water right and the seasonality of pumping) were assigned to the preceding time periods in the simulation. The need to use annual volume-based rates during the early portion of the 10-year run and higher capacity-based rates at the end of the run is based on how the particle-tracking procedure relies on reverse-tracking methods to delineate the largest reasonable protective area for SWPA purposes before delineating the remainder of the capture zone for longer periods of time. Examples of how the two sets of rates were coupled during the 10-year model runs are as follows:
 - For a well having a 1-year travel time for the SWPA, year 10 (months 109 through 120) uses the instantaneous allowed pumping rate, while years 1 through 9 (months 1 through 108) use lower monthly-varying pumping rates that were calculated by applying the monthly pumping percentages in Table 3 to the annual production volume (Table 2) that is allowed under the well’s water right.
 - A well with a 1.5-year travel time for the SWPA simulated the instantaneous pumping rate during the last 1.5 years of the simulation (months 103 through 120) and the lower pumping rates during the prior 8.5 years (months 1 through 102).

- **Running the Particle-Tracking Simulator.** In this step, the mod-PATH3DU software reads the output from MODFLOW-USG to conduct the particle-tracing calculations through the aquifer in three dimensions. This process relied on the following specific details regarding particle placement around each well:
 - In each model layer penetrated by the well, three rings of particles were placed in a circular pattern at a distance of 25 feet away from the well. Each ring contained 15 particles, and the rings were placed near the tops and bottoms of the layer and in the midpoint of the layer.
 - Most wells are completed in the uppermost model layer and hence have delineations that were developed using a total of 45 particles. A few deep wells penetrate both the first and second of the eight model layers and hence used 90 particles in the delineation process.
- **Conducting the Delineation Work Twice to Account for Uncertainties About Future Aquifer Conditions.** The MODFLOW-USG and mod-PATH3DU simulations were conducted twice: once for each of the two future climate scenarios discussed at the end of Section 2.

4. Discussion of Delineation Results

The capture zones are displayed in multiple ways as follows:

- Figures 2, 3, 4, and 5 show the SWPA, 1-year, 5-year, and 10-year composite capture zones, respectively, for the combined SAJB membership. For each map, the capture zones are derived from the simulations for both future climate scenarios.
- Attachment B contains separate capture zone maps for each of the 21 SAJB members. Two maps are provided for each SAJB member:
 - The first map shows the 1-, 5-, and 10-year capture zones. In this map, the 5-year capture zone is overlain on top of the 10-year capture zone, and the 1-year capture zone is overlain on top of the 5-year capture zone.
 - The second map shows the SWPAs, with two colors that distinguish the capture zones for the two different climate scenarios that were simulated.

In general, the capture zones follow the east-to-west groundwater flow direction known to exist in Spokane Valley and the south-to-north groundwater flow direction that is known to exist in the northern part of the SVRP Aquifer. Two noteworthy observations about the capture zones are as follows:

- For most wells, the 5-year capture zones cover a longer groundwater flowpath than the portion of the 10-year capture zone that lies outside the 5-year capture zone. This was observed early in the delineation process and was the subject of model testing to verify the accuracy of these differences. The testing work identified that the comparatively short upgradient extents of the 10-year capture zones (compared with the lengths of the 5-year capture zones) arise because the 10-year capture zones reach into an area (in Idaho) where the aquifer's width and thickness are greater than the areas in Washington where the 5-year capture zones lie. The collective pumping of the SAJB members requires that during the first 5 years, the capture zones must reach long distances upgradient to obtain groundwater, due to the relatively narrow width of the aquifer in Washington. In contrast, the capture zones for longer time periods then fan out across the Rathdrum Prairie portion of the SVRP Aquifer (just east of the state line) because of the increased aquifer width and thickness, which reduce hydraulic gradients more so than in Washington.
- The delineated capture zones overlap in some locations because of differences in the depth intervals from which individual wells withdraw groundwater, particularly in the distal ends of their capture zones. Table 4 provides a descriptive summary of the overlaps on a member-by-member basis. Even though each well is screened in shallow depths of the aquifer, a certain amount of the pumped groundwater is

obtained from deeper portions of the aquifer because of the influences of vertical groundwater flow arising from both the pumping action of the well and the three-dimensional (vertical) flowpaths that naturally exist through the full thickness of the aquifer. The wells owned by SAJB members generally penetrate no more than 150 feet into the water table,⁴ which means groundwater pumping occurs from the upper two model layers in the 8-layer model. As discussed in SAJB's original WHP report (CH2M HILL, 2000), although pumping is simulated in the upper two model layers, 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 containing many wells. The degree of capture zone overlap for different wells and between various SAJB members arises from:

- The proximity of wells to each other, and the relative differences in pumping rates between the overlapping wells.
- The time durations, in the case of the SWPAs. For wells with short travel times for the SWPAs, the capture zones are primarily contained within a depth interval similar to the open interval of the well. For some (though not all) wells with longer travel times for the SWPAs, the SWPA typically extends to progressively greater depths in the upgradient direction as water is obtained from deeper in the aquifer.

When considering the movement of contaminants within a capture zone, it should be kept in mind that chemical reactions and the mechanical dispersion of contaminants occurring from groundwater flow processes are not simulated by the numerical groundwater flow model during the delineation process. The influences of these processes is as follows:

- **Chemical Reactions.** As discussed by CH2M HILL (2000), 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 a source area and can also slow the rate of contaminant movement relative to the ambient groundwater flow velocity. Therefore, contaminants typically do not move as fast as groundwater, which can provide additional response time for an SAJB member to implement necessary actions in the event a water supply well is impacted by contamination.
- **Mechanical Dispersion.** Mechanical dispersion can cause the leading edge of a plume of a highly-conservative (i.e., non-degradable) contaminant to reach a drinking water supply well sooner than would be predicted by the capture zone delineations produced from a numerical groundwater flow model. Mechanical dispersion can also cause the plume to spread vertically and be wider than the groundwater flowpaths identified from the capture zone delineation process. For contaminants that are not conservative (and undergo one or more of the processes described in the prior paragraph), the effects of mechanical dispersion may be less significant than the effects of the chemical reactions that degrade and reduce the concentrations of the contaminant in the subsurface.

⁴ The only known exceptions at this time being two new wells that were drilled to a depth of 355 feet by Pasadena Park Irrigation District in 2024 (WNR Group, 2024).

5. References

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