Appendix P

Wellhead Protection Area Delineation Update

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2007 WELLHEAD PROTECTION AREA STUDY – PLATEAU WELLS

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Introduction

The SPWSD 3-Dimensional numerical regional groundwater flow model was used to estimate well head protection areas (WHPA) or hydraulic capture zones for district wells, using the following methodology:

- A transient groundwater flow simulation was performed for a 10-year simulation period. Pumping assignments for the simulation are shown in Table 1. ASR operations at SPWSD wells 1R and 15 are represented in the simulation. Wells 5 and 6 were not pumping in the simulation.

- The transient groundwater flow simulation was used to develop capture zones for the plateau wells (wells 1R, 2, 2.2, 4, 4R, 10, 11.1, 11.2 and 15). To compute a capture zone, a grid of computational "particles" was released to the water table over the model area. The particles were then tracked forward in time governed by the simulated 10-year flow field. The starting locations of the particles that were extracted by SPWSD wells were recorded and mapped for each well. The areal extent of these capture zones represents the contributing recharge area to the well over a 10 year period.

- The capture zones developed using the regional SPWSD groundwater flow model were compared to older WHPA delineations that were developed using analytical methods.

Zone II Wells

Figure 1 shows the simulated 1-year, 5-year and 10-year capture zones for Zone II wells 1R, 2, 2.2, 10 and 15. These wells are located in the southern portion of the plateau and near the southern edge of the groundwater flow model. The shape and extent of the simulated captures zones differs from the earlier WHPA delineation. Some reasons for the difference include:

- The groundwater flow model incorporates vertical flow through overlying units to Zone II. The analytical WHPA delineations do not account for any vertical flow from overlying aquifers, and assume that groundwater only flows horizontally/laterally towards a pumping well.

- The groundwater flow model incorporates monthly changes in groundwater pumping and recharge, and as such represents seasonal and monthly changes in head gradients and groundwater flow directions that are not considered in analytical WHPA calculation methods. The analytical WHPA calculation assumes a uniform groundwater flow direction and gradient.

- Earlier WHPA delineations most likely did not include ASR operations at wells 1R and 15; these operations are simulated in the groundwater flow model.

- Estimated transmissivities used in the earlier delineation differ from aquifer transmissivities in the groundwater flow model; although the differences are not great.

Zone III/IV Wells

Capture zone simulations for Zone IV wells 4, 4R and 11.2 and for Zone III wells 6 and 11.1 indicate that the ten-year capture zone for none of these wells extends up to the water table. Vertical groundwater flow from shallow zones to Zone III and IV is limited by the presence of Qaf and Qbf confining layers.

Reverse particle tracking simulations for a longer period (100 years) suggest that the Zone IV wells are supplied primarily by the "ramp" at the southern edge of the plateau. The Zone III wells are supplied by downward vertical flow from shallower layers (which occurs over a longer period than 10 years), and also from the "ramp".

Figures 2 and 3 show simulated reverse particle tracks from the Zone IV wells in plan view and cross-section, respectively.

Figures 4 and 5 show simulated reverse particle tracks from the Zone III wells in plan view and cross-section, respectively.

Summary

The existing SPWSD regional groundwater flow model was used to estimate WHPAs for plateau wells. The areal extent of the WHPA represents the contributing recharge area to the well over a given period. The simulated capture zones, or WHPAs, are different from WHPA delineations developed earlier using analytical methods. Since the groundwater flow model has been calibrated to transient conditions and incorporates vertical groundwater flow and monthly pumping and groundwater recharge variations, the model-simulated WHPAs may be more representative of well contributing areas than WHPAs estimated using analytical methods. However, for conservative protection of the groundwater resources it is recommended that the larger contributing recharge areas, delineated by the analytical WHPA delineation method, be used.

Table 1. Pumping Assignments For Transient Simulation

Month	Pumping (GPM)											
	1R	**2**	**2.2**	**4**	**4R**	**10**	**11.1**	**11.2**	**12**	**13**	**14**	**15**
Jan	-500	0	0	550	0	0	0	430	6	80	0	-500
Feb	-500	0	0	400	0	0	0	480	0	80	0	-500
Mar	-500	0	0	340	0	0	0	450	0	90	0	-500
Apr	-500	0	0	610	0	0	0	550	12	100	0	-500
May	400	0	0	460	0	0	0	990	50	140	0	1600
June	400	430	350	310	0	0	0	1470	80	130	0	1600
July	400	270	580	410	140	140	200	1380	90	110	90	1600
Aug	400	300	460	480	450	450	190	780	50	110	50	1600
Sep	400	120	370	240	450	450	60	450	4	100	0	1600
Oct	0	0	50	280	420	420	0	400	5	90	0	0
Nov	-500	0	1	320	0	0	350	940	40	30	0	-500
Dec	-500	0	0	540	0	0	0	930	80	0	0	-500

Notes:

Negative pumpage indicates injection

Pumping not assigned to #5 and #6

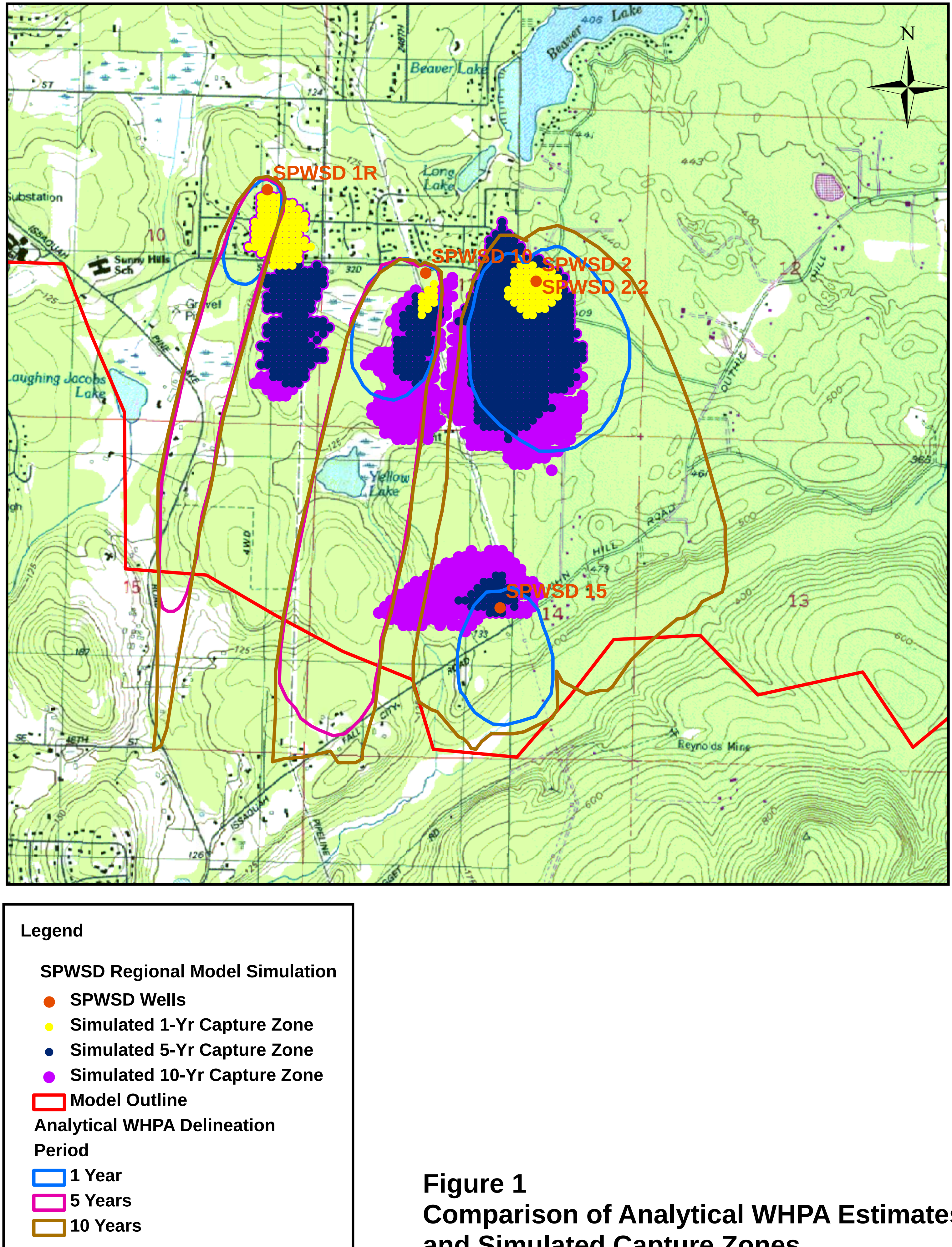
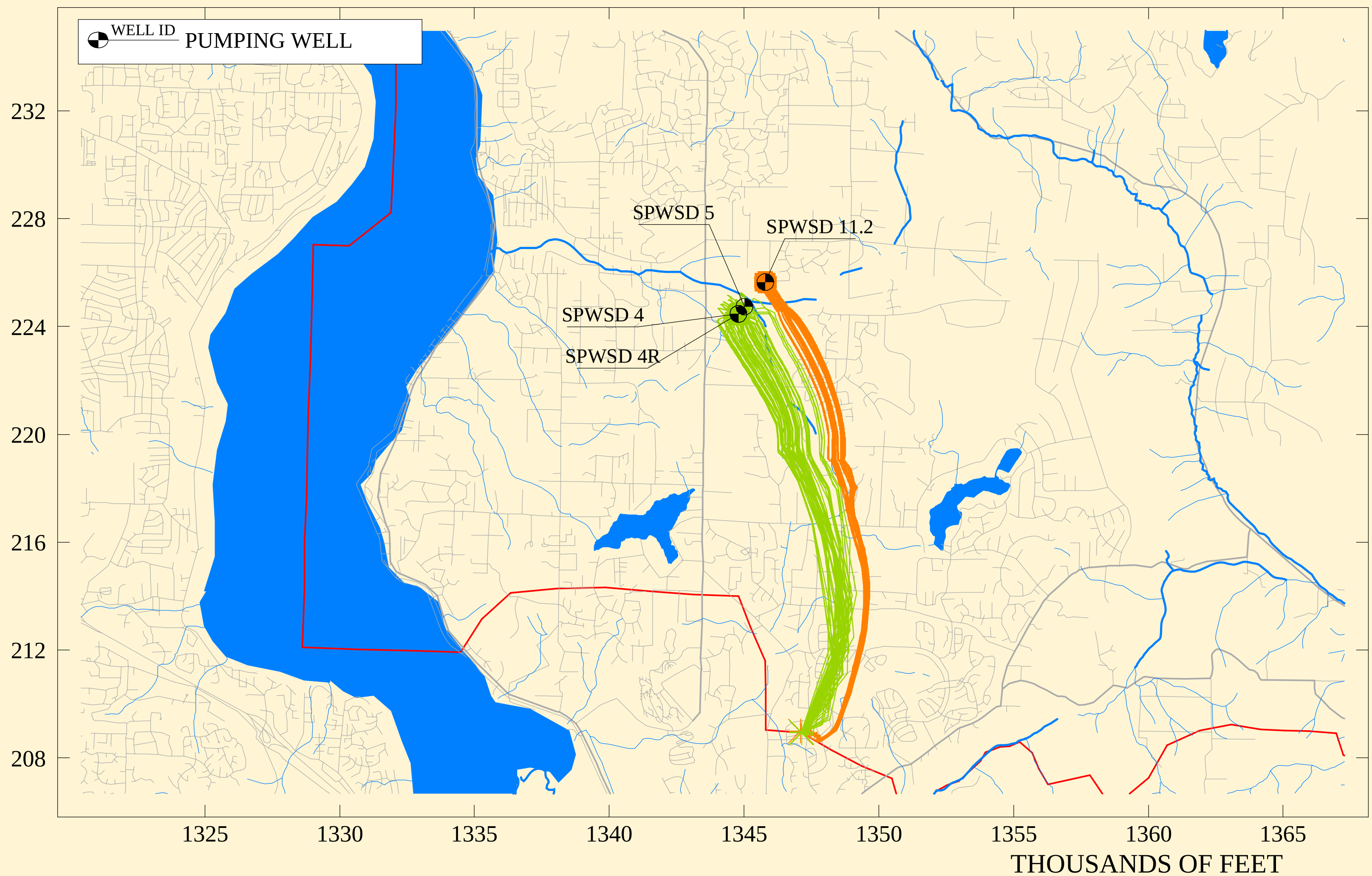


Figure 1
Comparison of Analytical WHPA Estimates and Simulated Capture Zones



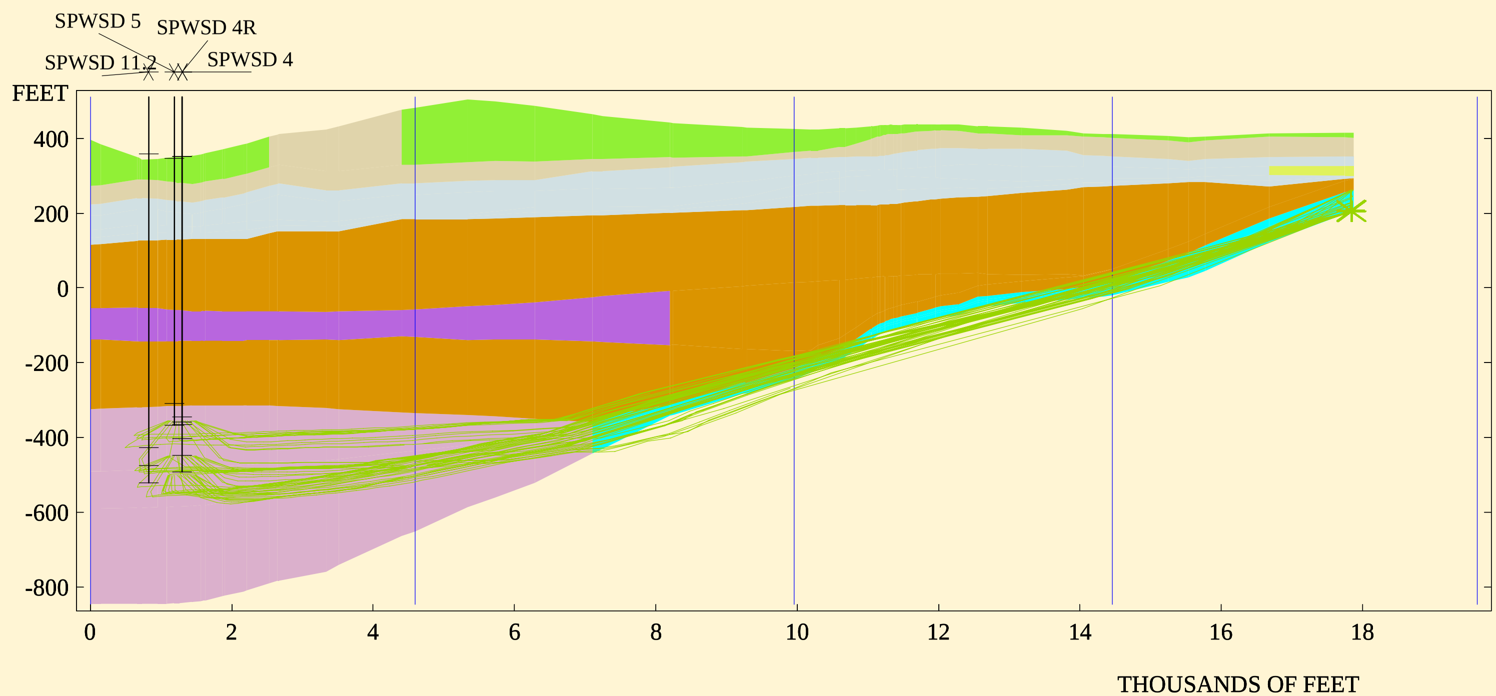
Oct19 07 model2004/sav/spwsd15_1c3_2007oct.sav

CDM

Simulated Reverse Particle Tracks From Zone IV Wells
(100 Year Travel Time)

SPWSD Groundwater Model

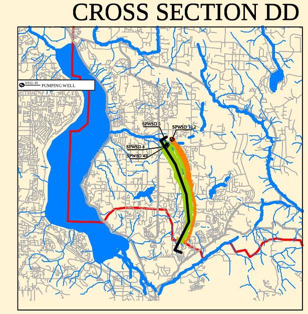
FIGURE
2



MATERIALS CROSS-SECTION DD

- Zone II Aquitard
- "Ramp"
- Zone I
- Till
- Zone II
- Zone III
- Aquitard
- Zone IV

CROSS SECTION DD



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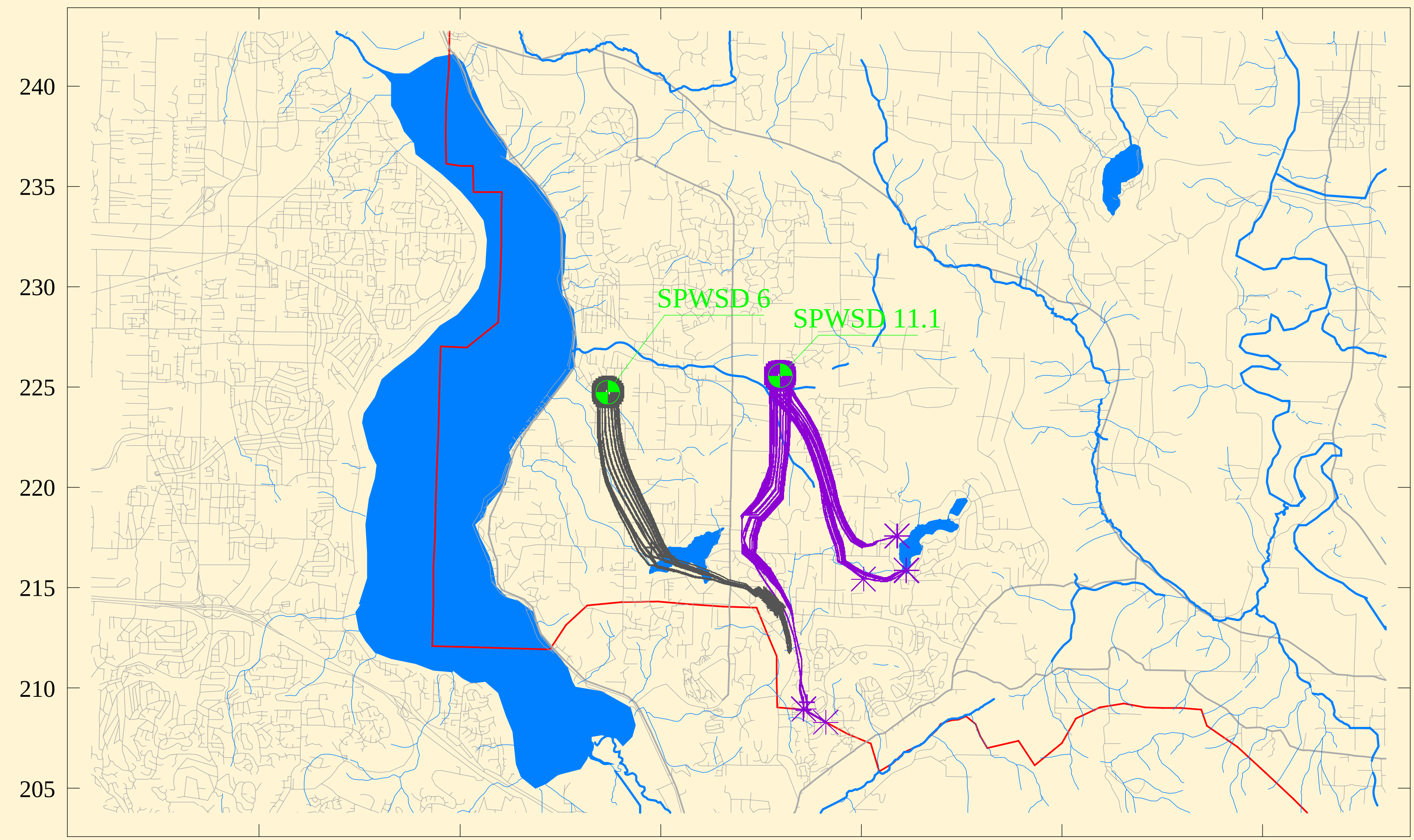
CDM

Reverse Particle Tracks From Zone IV Wells in Cross Section
(100 Year Travel Time)

SPWSD Groundwater Model

FIGURE
3



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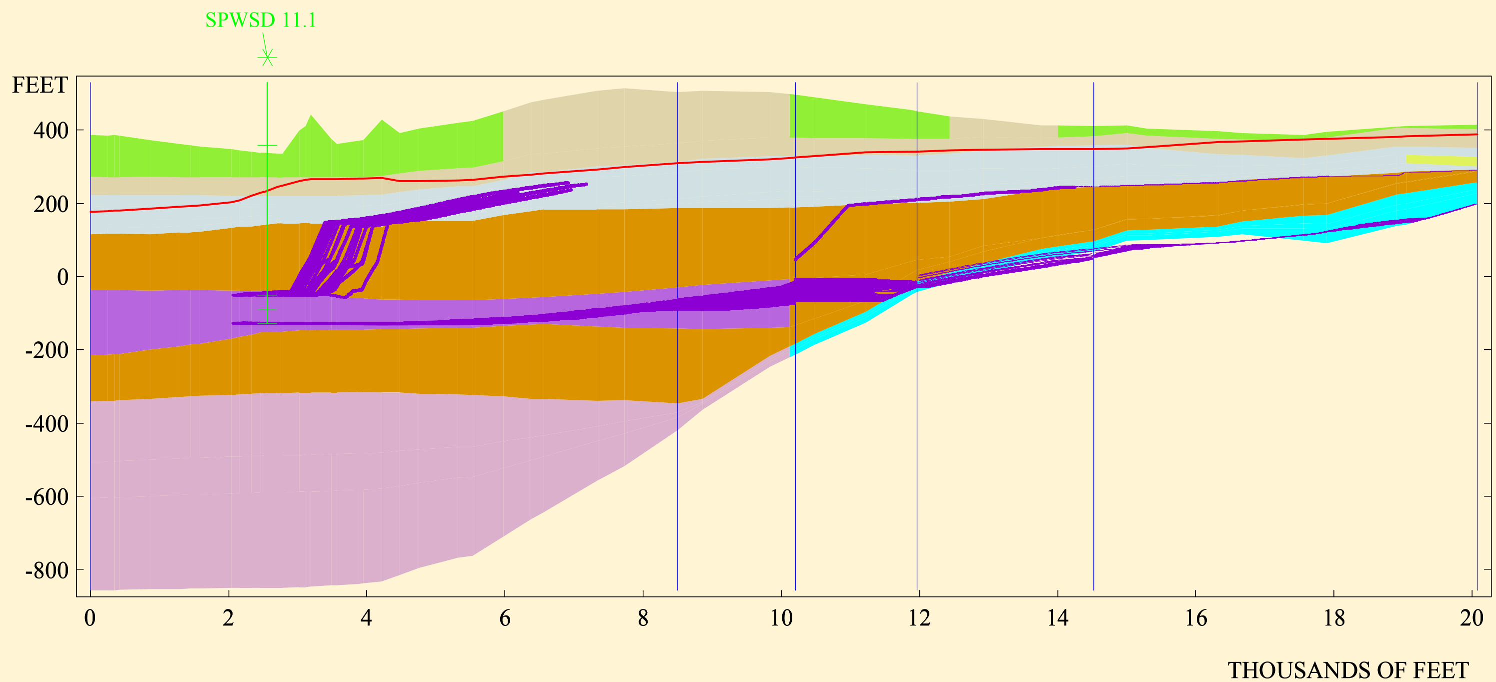
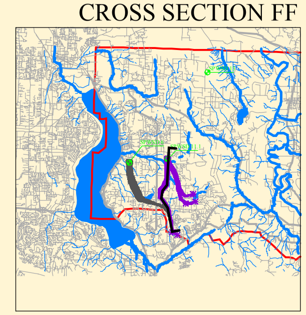
Simulated Reverse Particle Tracks From Zone III Wells

SPWSD Groundwater Model

FIGURE 4



CROSS SECTION FF



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CDM

Reverse Particle Tracks From Zone III Wells in Cross Section
(100 Year Travel Time)

SPWSD Groundwater Model

FIGURE
5

HYDROGEOLOGIC ASSESSMENT AND UPDATE TO LOWER ISSAQUAH VALLEY AQUIFER PRODUCTION WELLS 7, 8 AND 9 PROTECTION AREAS (2017)

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Sammamish Plateau Water District: Hydrogeologic Assessment and Update to Lower Issaquah Valley Aquifer Production Wells 7, 8 and 9 Wellhead Protection Areas

October 3, 2017

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Figure 8 Well 8 - Wellhead Protection Zone
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Section 1

Introduction

Under a current groundwater investigation project related to Perfluorinated Chemicals (PFCs) in the Lower Issaquah Valley Aquifer, the Sammamish Plateau Water District (the District) has performed a hydrogeologic assessment that incorporates a comprehensive set of PFC, hydrologic and hydrogeologic data within the Valley Aquifer System. At the direction of the District, these data were evaluated and used by CDM Smith to construct and calibrate a transient 3D numerical groundwater model of the valley aquifer system. The constructed model was subsequently used to develop simulations of varied production well operation by the District, City of Issaquah (the City) and known industrial wells to evaluate risk to the District's water supply wells located in the Issaquah Valley Aquifer and determine the optimum management scheme for well operation in the valley to minimize PFC entrainment (CDM Smith, 2017). In addition to using the newly constructed and calibrated model for understanding the fate and transport of the identified PFC contaminant plume, the District used the more refined model[1] to create updated wellhead protection areas (WHPAs) for their valley aquifer wells 7, 8 and 9.

The information below represents the information required by the City and other land use regulatory agencies to adopt the updated WHPA capture zones for the District's Lower Issaquah Valley Aquifer Production Wells 7, 8 and 9.

1.1 Hydrogeologic Assessment and Groundwater Model Construction

Table 1 below presents the data collection and subsequent evaluation effort that SPWD performed for the hydrogeologic assessment and transient 3D numerical groundwater model development and calibration.

Table 1-1 LFT SPWSD Project Data Collection Effort

Data Request List			
Item	Parameter	Data Period	Data Comment
Well Lithology Logs and Construction Drawings and Well Site Drawings	Well lithology descriptions, total and screen completion depths.		Includes both production and monitoring wells
	Well site drawings and layouts showing storage tanks, treatment facilities, etc.		
Well Capacities, Production History, and Utilization	All Production Wells	2006-2016	Monthly data

[1] The previous modeled WHPA capture zones are based on a 1993 analytical model that does not incorporate groundwater flow through multiple aquifer and aquitard layers in 3-dimensions

Aquifer Testing Data	Water Level and Hydraulic Test Results from Aquifer Testing at Production and Monitoring wells, or any geophysical testing data		Aquifer Testing Data from recent aquifer tests
Long-Term Water Level Data	Water Level Records from Production and Monitoring Wells collected manually and from automated datalogging systems at hourly to daily intervals	2006-2016	
Water Quality Data	All Production and Monitoring Wells	2006-2016	All water quality parameters available electronically

The groundwater model simulates transient groundwater flow patterns using available data for the period of 1/1/2015 through 12/31/2016 and the hydrogeologic framework documented in the following:

- Report on Impacts of Increased Pumping from Wells 7 and 8 (Carr Associates, 1990)
- Evaluation and Interpretation of Well 9 Pumping Test (Carr Associates, 1993)
- Lower Issaquah Valley Wellhead Protection Plan (Golder Associates, 1993)
- Issaquah Creek Valley Ground Water Management Plan (Issaquah Creek Valley Ground Water Advisory Committee, 1994)
- Geophysical Investigation of the Lower Issaquah Valley (Golder Associates, 1996)
- Hydrogeological Characterization Report (Geosyntec, 2016)
- Summary of Perfluorinated Compounds (PFCs) Results for Water Samples Collected January 5, 2017 (Corona, 2017)

The numerical groundwater flow model simulates the movement of groundwater, and the discharge of groundwater baseflow to surface streams, based on model assignments of water balance inputs (recharge) and outputs (pumping) over the simulation period.

The period between 1/1/2015 and 12/31/2016 is considered the hydraulic (groundwater flow field) calibration period, during which the model utilizes available data, including the more recent COI monitoring wells drilled and constructed in 2016, and relies on estimates where data gaps exist. The model is calibrated to piezometric heads.

DYNSYSTEM groundwater modeling software was utilized for groundwater model construction, including DYNFLOW (groundwater flow), and DYNTRACK (solute transport). DYNFLOW is a fully three- dimensional, finite element groundwater flow model code. This code has been developed over the past 40 years by CDM Smith engineering staff, and is in general use for large scale basin modeling projects and site specific remedial design investigations. It has been applied to over 200 groundwater modeling studies in the United States. The DYNFLOW code has been reviewed and tested by the International Groundwater Modeling Center (IGWMC) (van der Heijde 1985, 2000) and has been extensively tested and documented by CDM Smith.

DYNTRACK is the companion solute transport code to DYNFLOW. DYNTRACK uses the random-walk technique to solve the advection-dispersion equation. DYNTRACK has been developed over the past 35 years by CDM Smith engineering staff and has also been reviewed and tested by the IGWMC (van der Heijde 1985).

Conceptual Model

The conceptual model of groundwater flow within the study area is summarized below:

- The approximate boundaries of the watershed are depicted in **Figure 1**. The watershed spans approximately 42,000 acres and includes both valley and upland components.
- Groundwater flow in the uplands is generally towards the valley, following the steep slope of bedrock. Once in the valley, ambient (non-pumping condition) groundwater flow is towards the regional groundwater discharge point, Lake Sammamish. The in-valley groundwater flow direction is towards the northwest.
- Groundwater recharge occurs both in upland and valley areas, though the percentage of rainfall that becomes recharge is higher in the valley than in the uplands, as described in the Issaquah Creek Valley Ground Water Management Plan (Issaquah Creek Valley Ground Water Advisory Committee, 1994).
- The groundwater flow field is influenced locally by water supply and industrial well pumping. The locations of these wells, characterized as COI wells, District wells, and industrial wells are shown in **Figure 2**. Monitoring wells referenced in this study are also included on this figure.
- Groundwater provides baseflow to several streams that ultimately discharge to Lake Sammamish. The flow of groundwater towards these streams is evident near the ground surface, but not in deeper formations. The major streams in the study area are highlighted in **Figure 2**.
- Hydrogeologic cross-sections constructed from soil borings and well logs from the references noted above depict a system of alternating aquifers and leaky aquitards present from ground surface to the contact with underlying bedrock, which is assumed to be the bottom of the aquifer system. The locations of cross-sections developed during earlier studies are shown in plan view and color coded by source reference in **Figure 3**.
- The cross-sections show that in addition to surficial water bearing units that are in direct hydraulic connection with surface streams, there are 2 distinct and relatively continuous semi-confined aquifers, characterized herein as the A Sand and B Sand aquifers. In the Well 9 Aquifer Performance Test Report (Carr, 1993), an additional C Sand aquifer is delineated,

though the hydraulic connection between this C Sand aquifer and the B Sand aquifer is either spatially variable or not consistently defined in the above references. A selection of three cross sections, C-C' from Golder Associates (1996), A-A' from Carr (1993), and B-B' from Golder Associates (1996), are included as **Figures 4, 5,** and **6**, respectively, to illustrate the presence of these hydrostratigraphic layers.

1.2 Wellhead Protection Area Simulation Process

To estimate the WHPAs, baseline future conditions, as described in detail in CDM Smith, 2017, were used to generate the hydraulic conditions from which water movement was assessed. These baseline conditions include monthly-varying inputs of pumping and recharge rates, indicative of the large seasonal variations observed within the aquifer system. Model inputs (including monthly pumping for each public supply and industrial well) and output in the form of simulated piezometric head contours for each month simulated are included in CDM Smith, 2017. These simulations indicate that month-to-month operational variation in well usage causes differences in groundwater flow directions and well capture throughout a typical operating year. The model simulations used to estimate the WHPAs incorporate these seasonal variations in operation. As a result, the capture simulations for each District Lower Issaquah Valley production well are simulated under a transient seasonal operational pattern rather than under a combined simultaneous steady-state pumping scenario[2]. This better represents how the District Valley production wells are operated.

Numerical particle tracking was then used to estimate the 3-dimensional extent of hydraulic capture that represents the Wellhead Protection Areas for each of wells 7, 8, and 9 over a 1, 5 and 10-year duration, assuming baseline future conditions.

1.3 Updated Wellhead Project Areas and Request for Adoption

Figures 7, 8 and 9 present the updated WHPAs determined from the district numerical groundwater flow model. Based on the updated hydrogeologic information, the District request all land use review agencies adopt these updated WHPAs for District Wells 7, 8 and 9 into their critical aquifer recharge area maps and ordinances.

[2] The 1993 analytical WHPA capture zones were representative of simultaneous combined pumping.

Section 2

References

Carr Associates, 1990. Report on Impacts of Increased Pumping from Wells 7 and 8, December 7, 1990.

Carr Associates, 1993. Evaluation and Interpretation of Well 9 Pumping Test, October 25, 1993.

CDM Smith, 2017. Groundwater Model Development and Applications for PFC Risk Mitigation, April 17, 2017.

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International Ground Water Modeling Center, 1985. *Review of DYNFLOW and DYNTRACK Groundwater Simulation Computer Codes*. Report of Findings by Paul K.M. vab der Heijde for

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van der Heijde, Paul K.M., 1999. DYNFLOW Version 5.18: Testing and Evaluation of Code

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Figures

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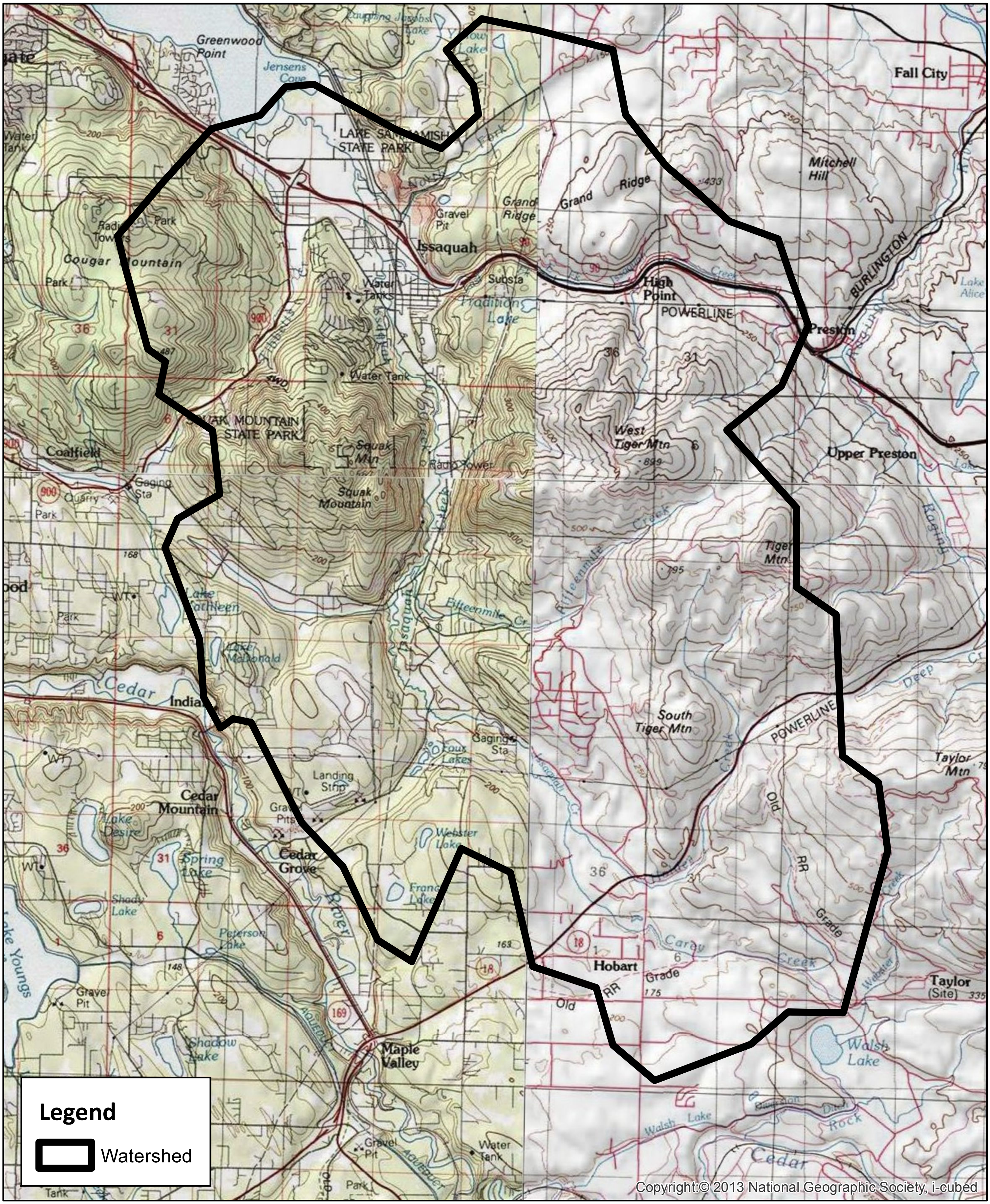

N

0 2,500 5,000 10,000 Feet

CDM Smith

Figure 1
Approximate Watershed Boundary
Sammamish Plateau Water

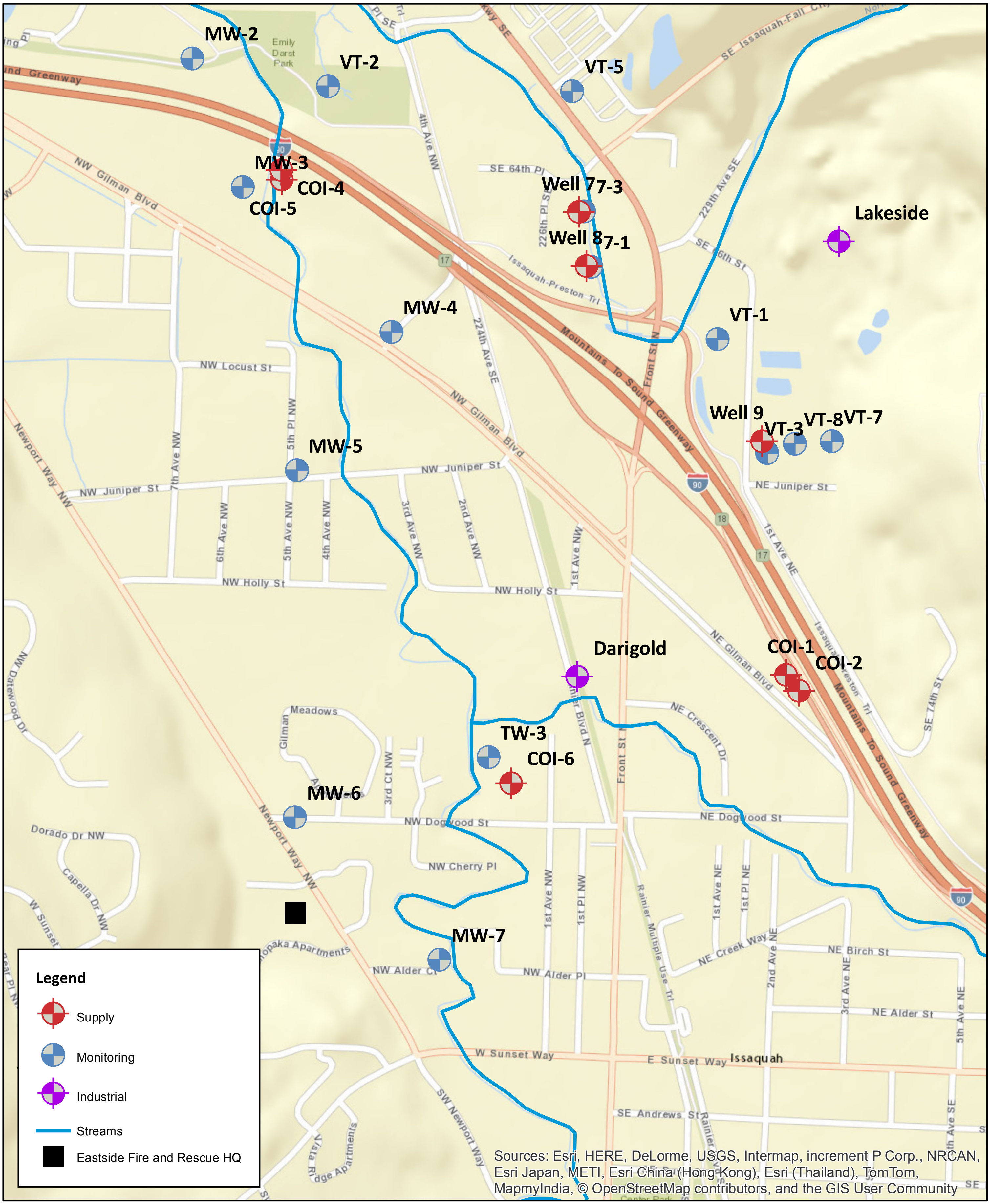

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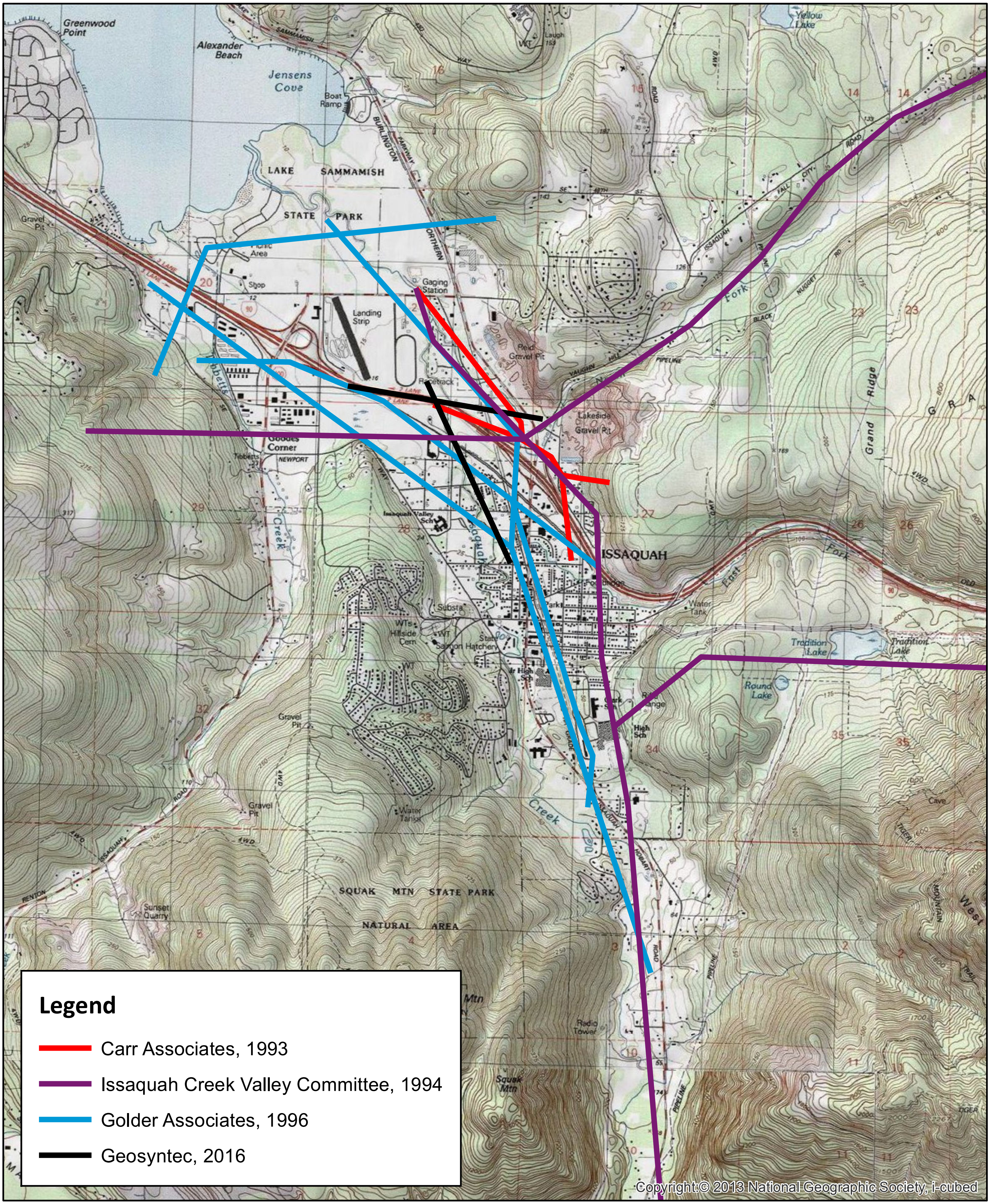
Figure 2
Well Locations
Sammamish Plateau Water



CDM Smith

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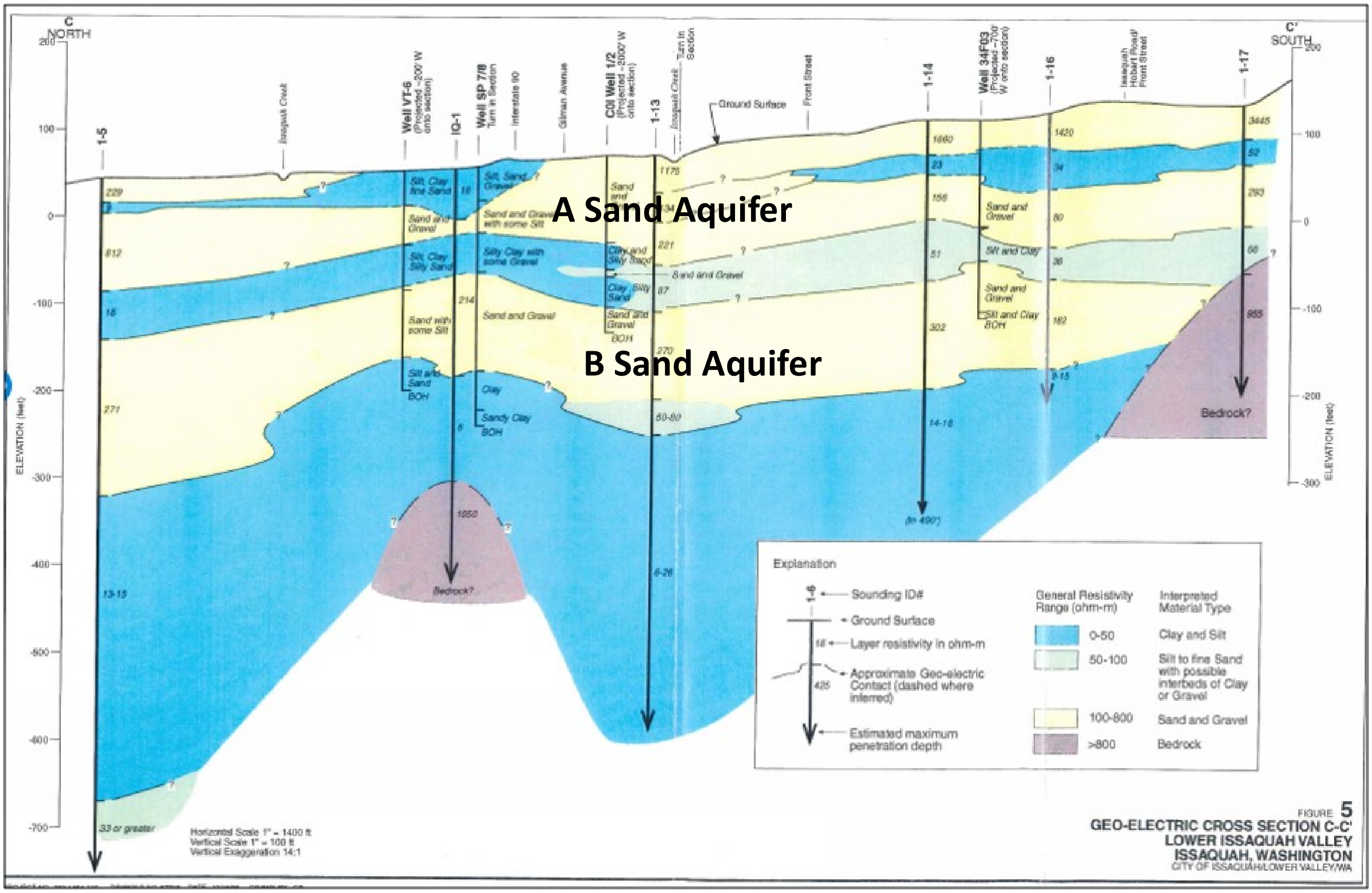
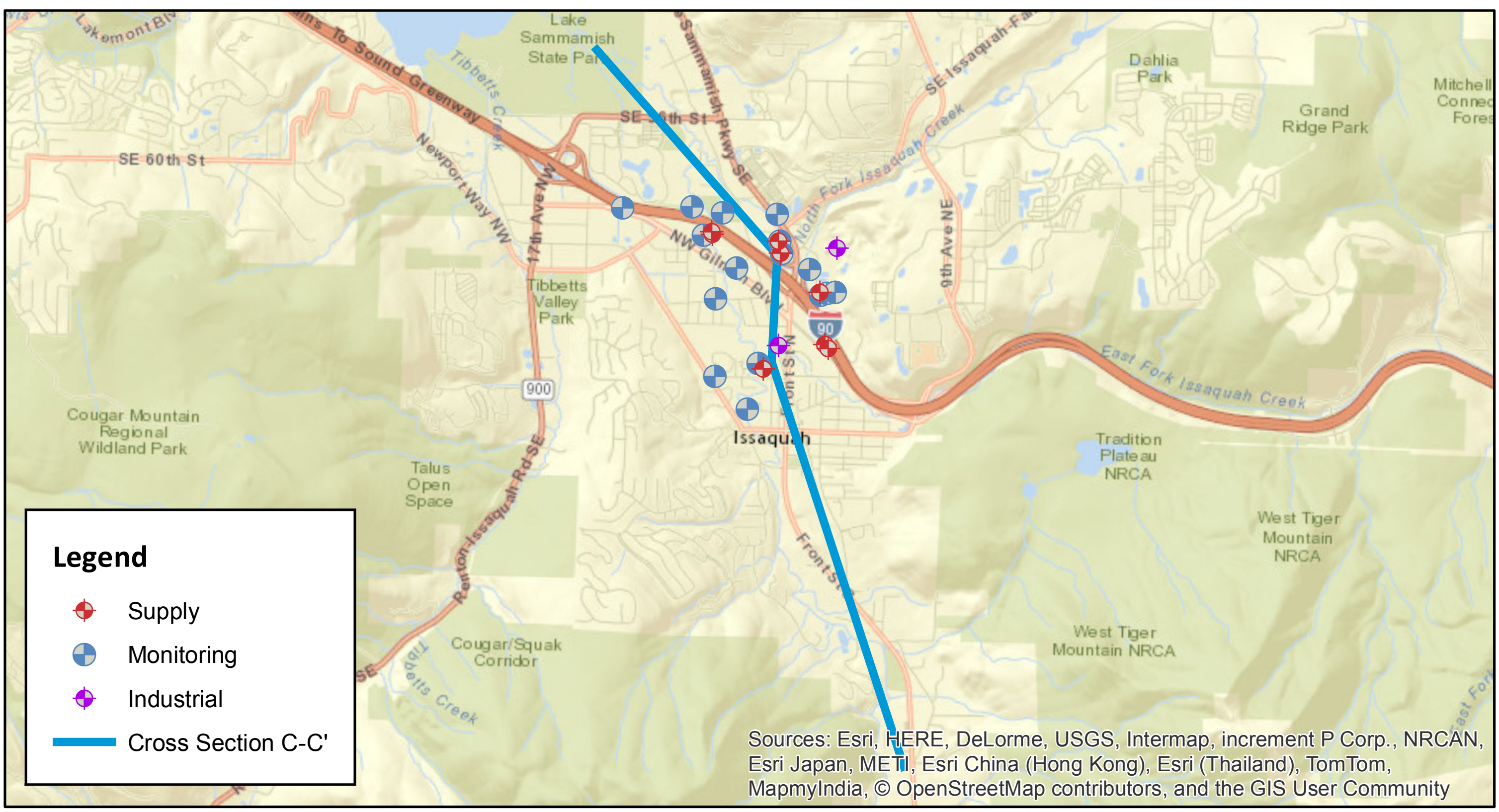
Figure 3
Locations of Cross-Sections Presented in Historical Reports
Sammamish Plateau Water





CDM Smith

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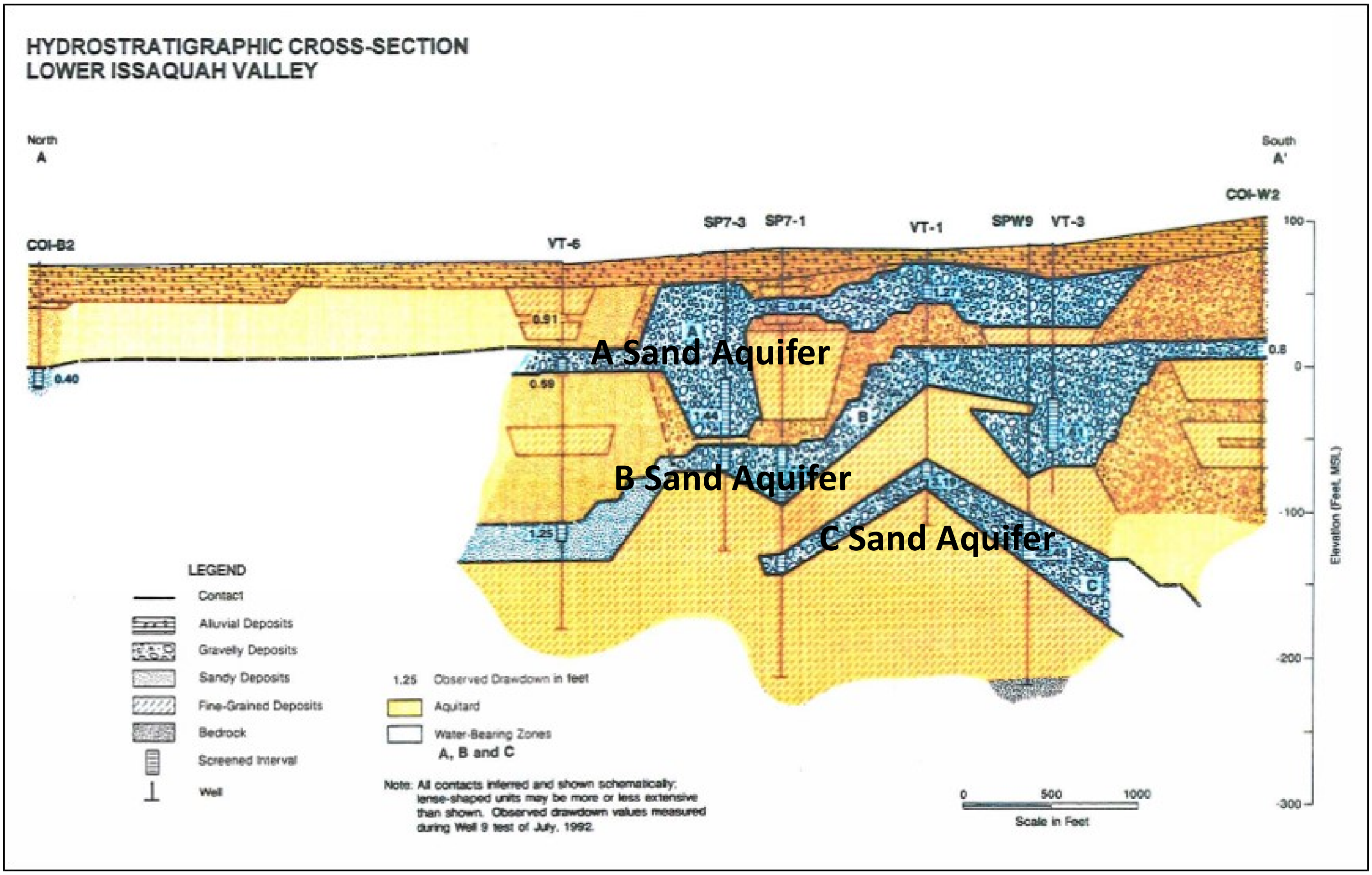
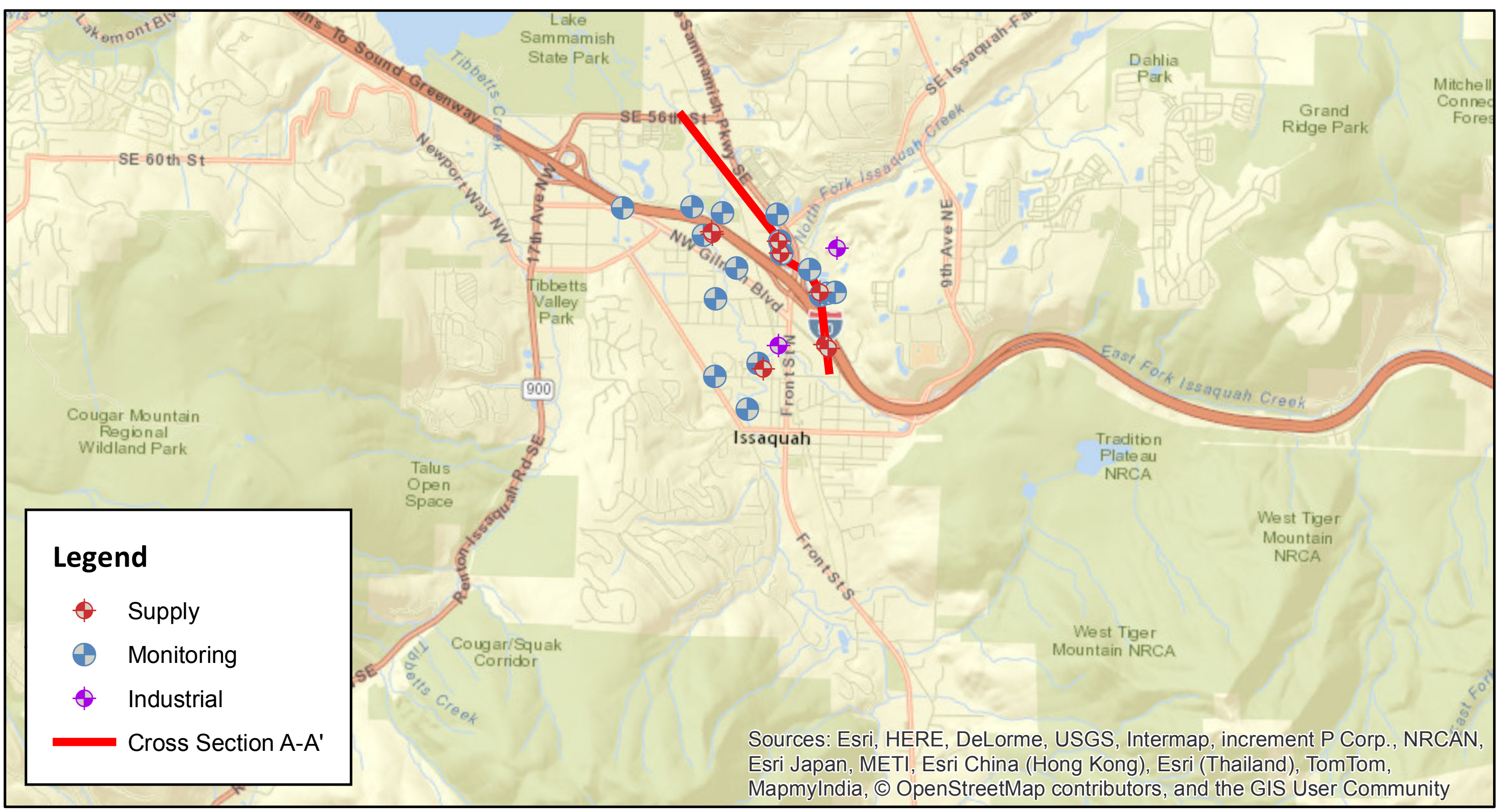
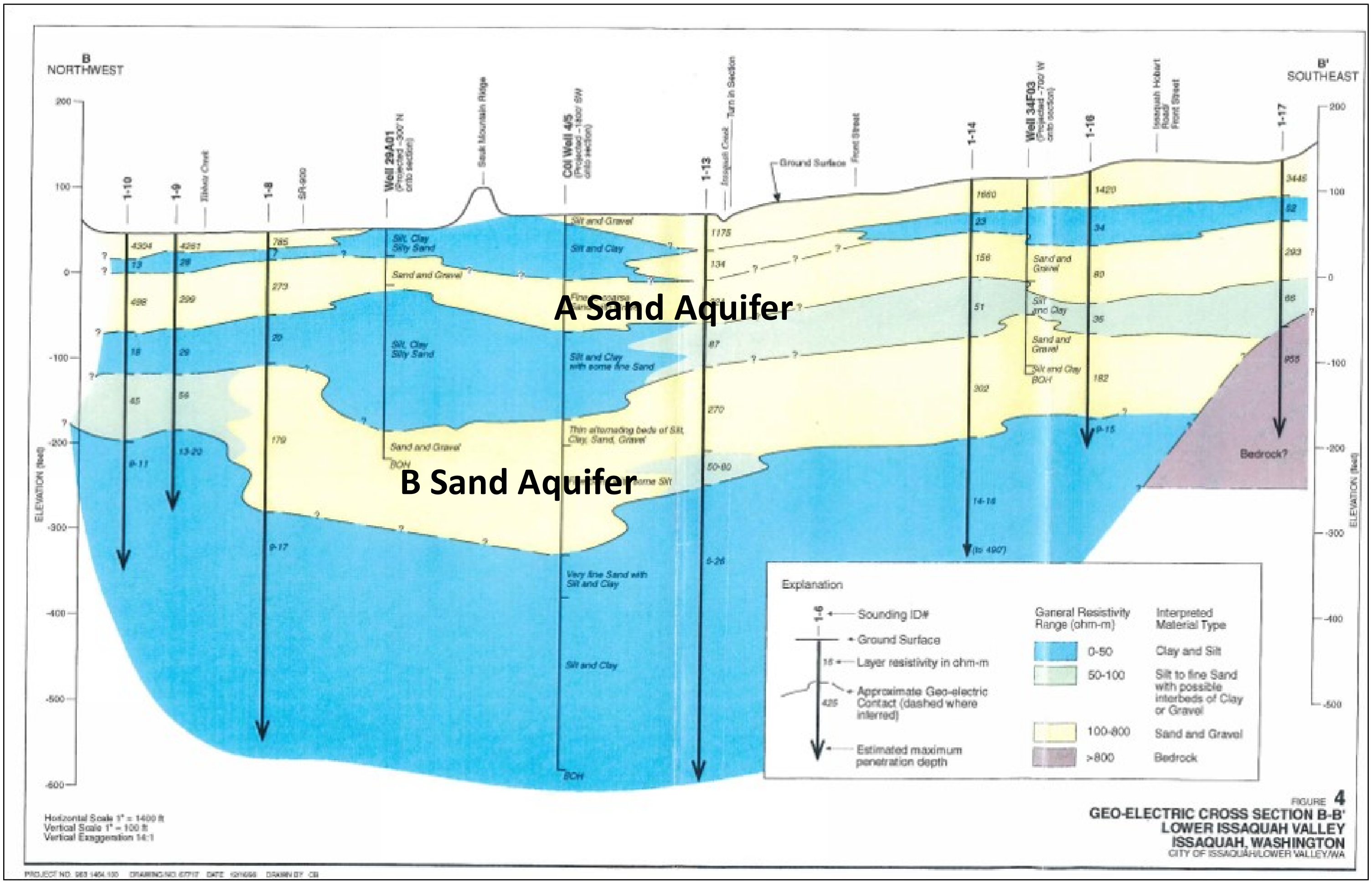
Figure 4
Cross Section C-C' (From Golder Associates, 1993)
Sammamish Plateau Water





CDM Smith

Figure 5
Cross Section A-A' (From Carr Associates, 1993)
Sammamish Plateau Water



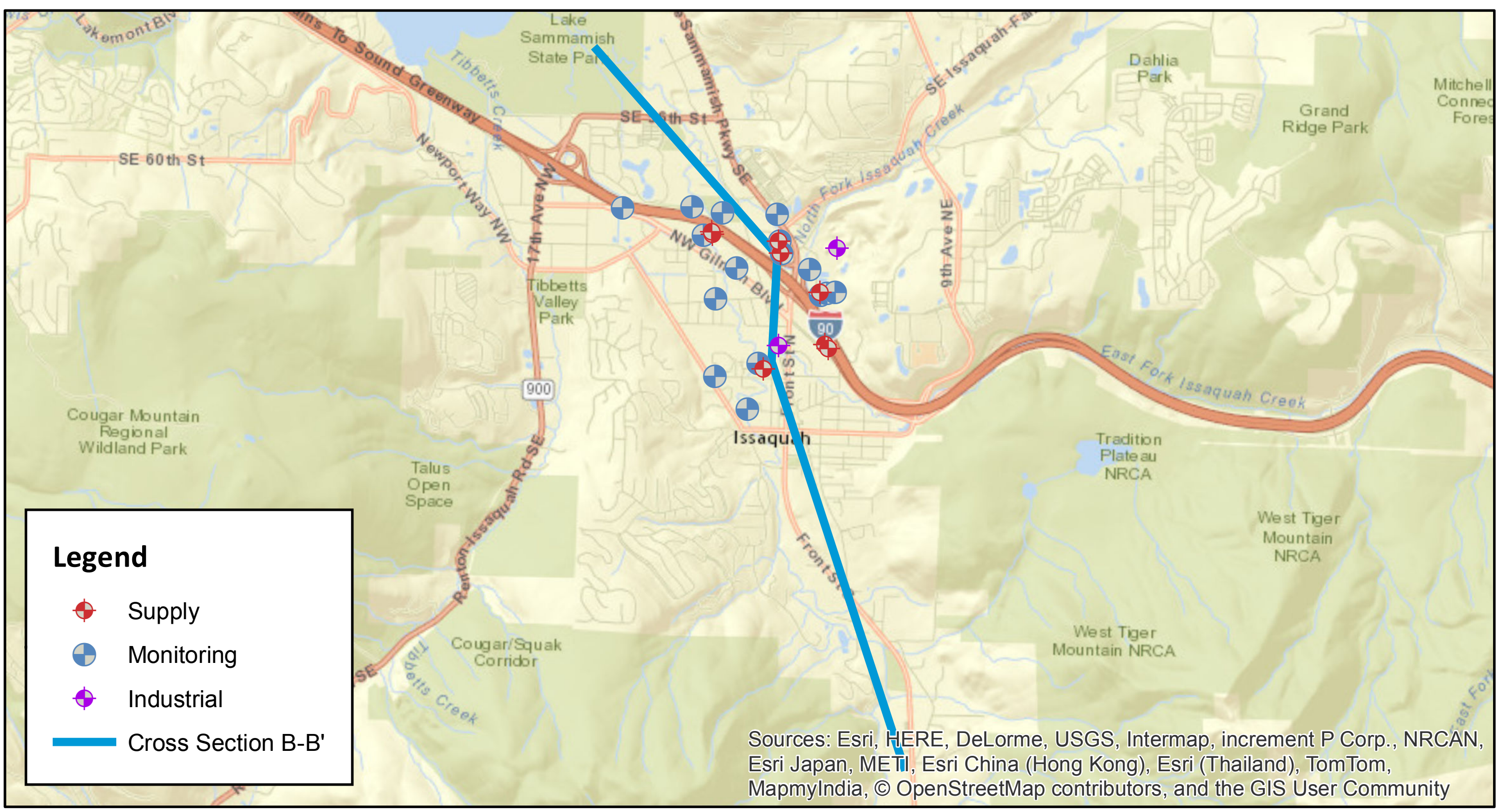
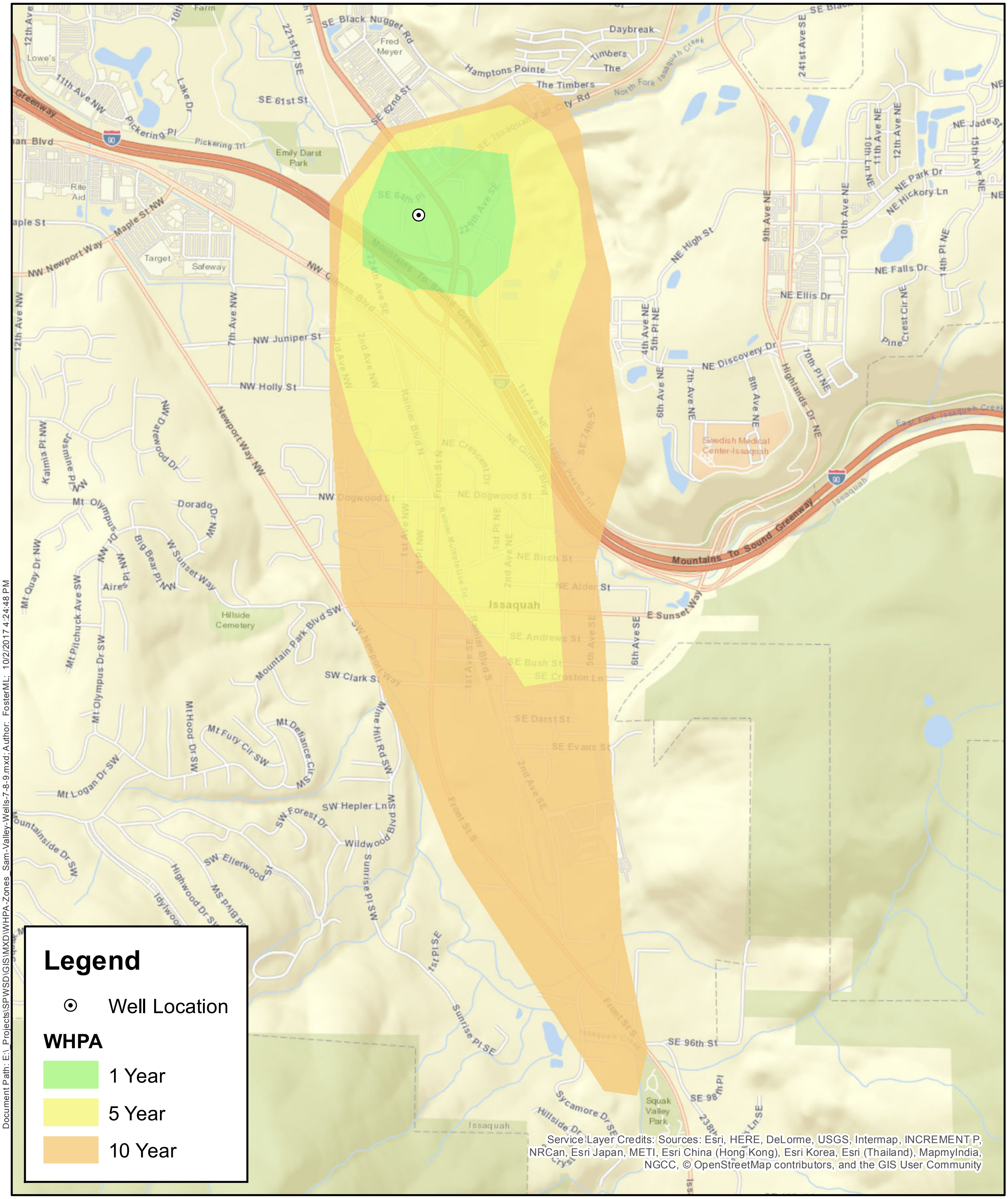


Figure 6
Cross Section B-B' (From Golder Associates, 1996)
Sammamish Plateau Water



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CDM Smith

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Figure 7
Well 7 - Wellhead Protection Zone
Sammamish Plateau Water

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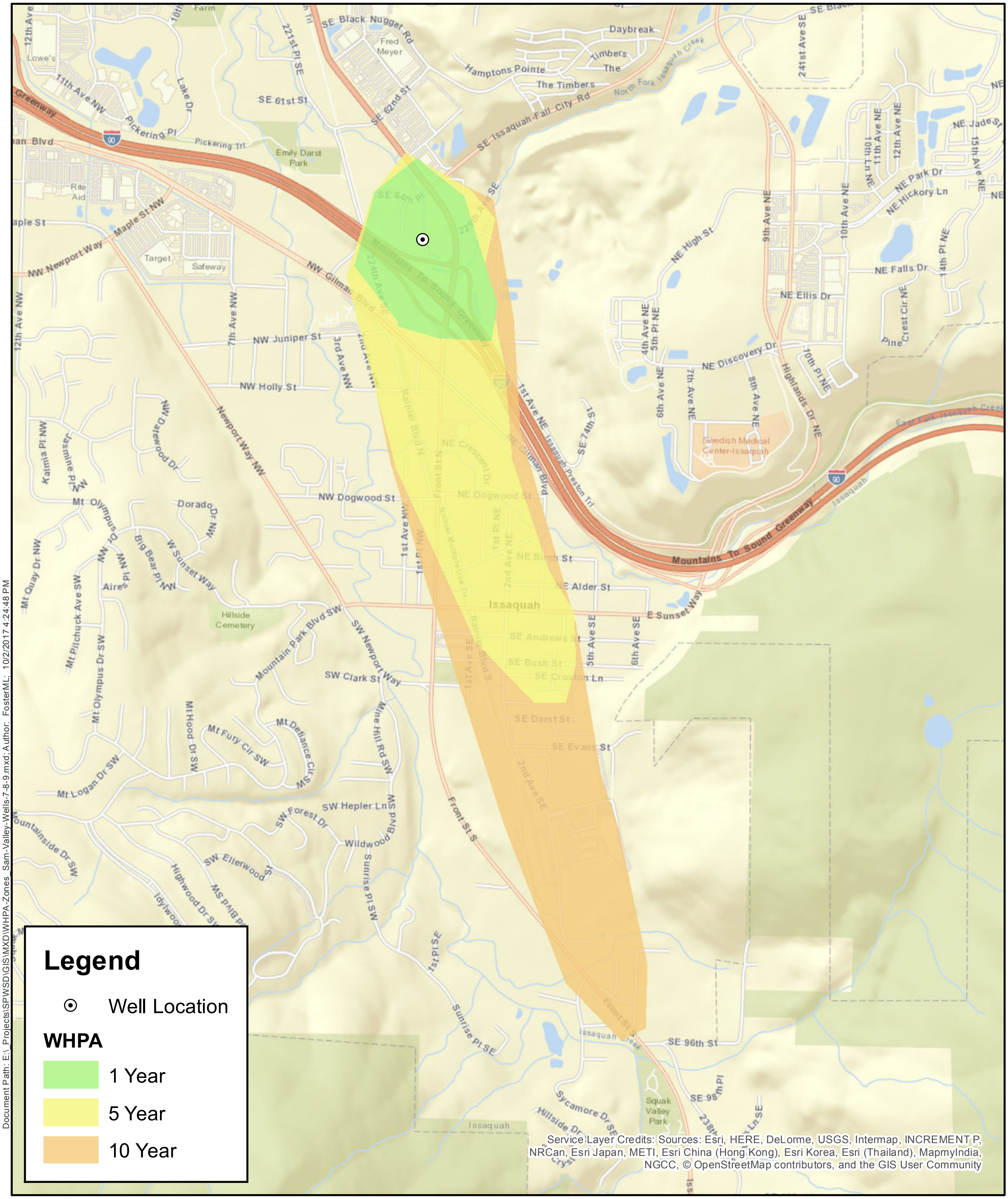

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Figure 8
Well 8 - Wellhead Protection Zone
Sammamish Plateau Water

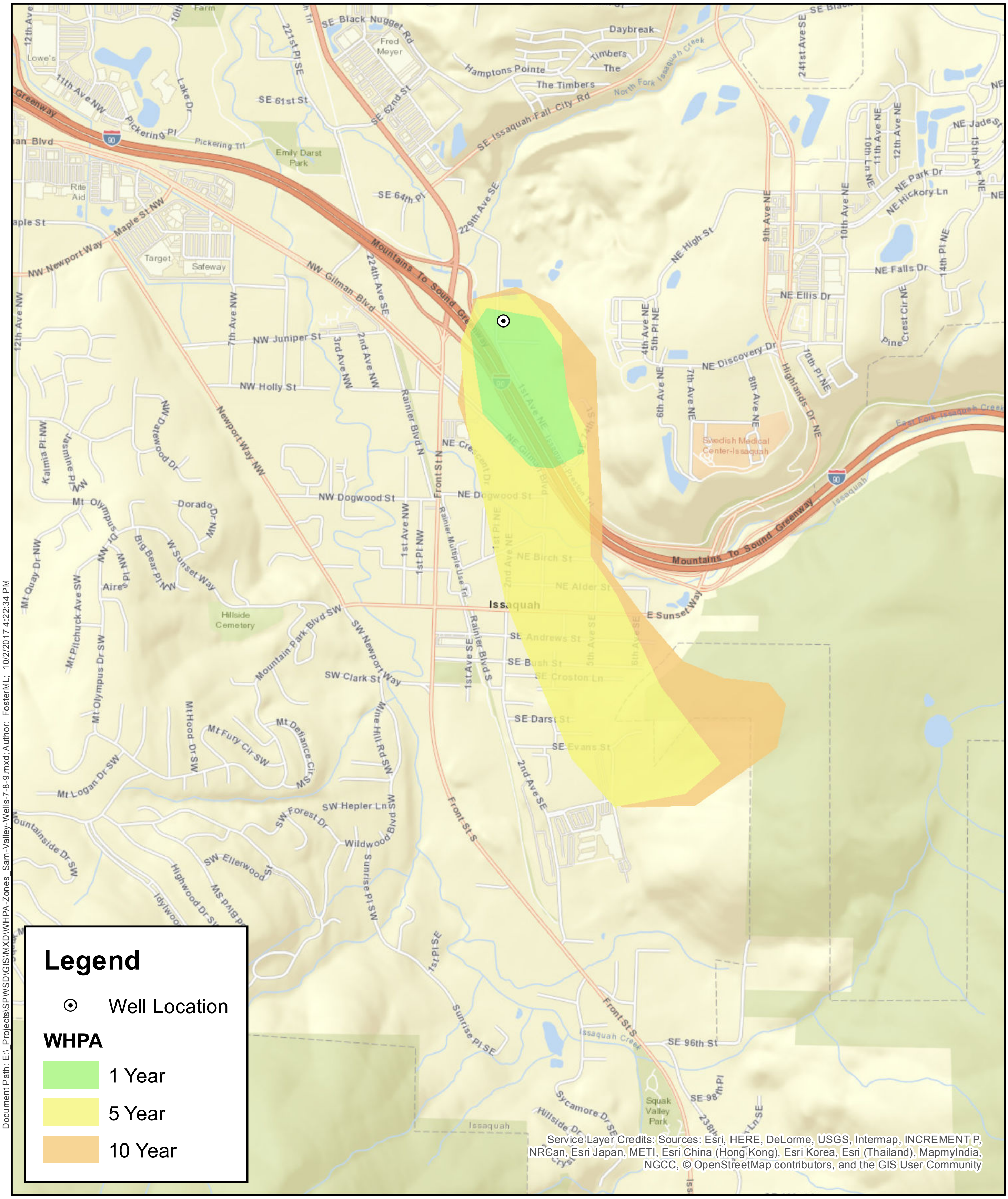

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Figure 9
Well 9 - Wellhead Protection Zone
Sammamish Plateau Water

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