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Final - Memorandum

Date:	December 30, 2022
To:	Priscilla Tomlinson, Jing Song, Li Ma, Washington State Department of Ecology
Copies to:	Matt Ellis and Julie Wartes, City of Issaquah
From:	Julie Chambon, Bob Anderson, and Cindy Bartlett, Geosyntec Consultants Geosyntec Consultant
Subject:	Preliminary Groundwater Flow Model Calibration Lower Issaquah Valley Geosyntec Project Number: PNG0989

1. INTRODUCTION

This memorandum (memo) transmits the third deliverable for the interagency agreement (IAA[1]) between the Washington State Department of Ecology (Ecology) and the City of Issaquah (City) and has been prepared by Geosyntec Consultants, Inc. (Geosyntec) on behalf of the City. The purpose of this memo is to document preliminary development and calibration of a three-dimensional (3D) groundwater flow model for the Lower Issaquah Valley (LIV).

1.1 Background

Previous studies conducted by the Issaquah Valley Per- and Poly-Fluoroalkyl Substances (PFAS) Partnership (Partnership), which includes the City, Eastside Fire and Rescue (EFR), and Ecology, have focused along the central portion of the LIV and former fire training source areas where aqueous film forming foams (AFFF) have been used. The City is located in the LIV, extending from the Issaquah-Hobart Gap to Lake Sammamish and from the eastern portion of the City to Tibbets Creek.

A 3D numerical groundwater model was developed in 2017 (CDM Smith, 2017) by Sammamish Plateau Water District (SPWD) using a proprietary finite element code (DYNFLOW) to evaluate PFAS transport in the LIV. The City converted the DYNFLOW model to a public domain numerical model (MODFLOW, the CARA MODFLOW model) as part of the City's CARA update (Geosyntec, 2022a). In addition, the City conducted two-dimensional (2D) numerical modeling along the main groundwater flow paths from the EFR and the Elementary School

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[1] IAA No. C2200183

source areas towards City production wells COI-4 to improve our understanding of migration pathways and vertical transport within the LIV aquifer system (Geosyntec, 2021).

This work associated with the IAA is intended to result in a 3D groundwater flow and PFAS fate and transport model that will integrate aquifer data and hydrogeological information collected since the City's CARA groundwater modeling was completed and data from PFAS investigations completed since 2017. The CARA MODFLOW model forms the basis for the development of the numerical groundwater and fate and transport model for this work.

As part of this IAA, the City developed a Regional Conceptual Hydrogeological Model (HG Model) for the LIV, including identification of data gaps (Geosyntec, 2022b). Geosyntec prepared a draft Data Gaps Investigation Work Plan Addendum for additional investigations, including installation of a deep monitoring well along the dominant groundwater flow path (Geosyntec, 2022c).

This memo documents the preliminary development and calibration of the updated 3D groundwater flow model based on the HG Model for the LIV. Following additional investigations including installation of a deep monitoring well anticipated in November/December 2022, the 3D groundwater flow model will be refined based on the results of fieldwork conducted by the City and EFR, including refinement of model setup and flow model calibration. A fate and transport model will be set up and calibrated using MT3DMS to simulate PFAS migration in the LIV aquifer system.

1.2 Objectives

The objectives of this preliminary modeling work were to:

- Refine the CARA MODFLOW model, including layering, boundary conditions, and hydraulic properties based on the HG Model.
- Develop an initial flow model calibration database containing calibration locations, historical water levels, historical pumping rates at water supply wells, and precipitation.
- Perform preliminary steady-state and transient calibration of the flow model.

2. PRELIMINARY MODEL DEVELOPMENT

The 3D model for groundwater flow was developed using MODFLOW-NWT, an Industry-standard finite-difference code for groundwater flow simulations.

2.1 Numerical Model Domain, Grid, and Layers

The model domain is illustrated in Figure 1, where the scale is 1 inch = 5,250 feet. . The model domain is approximately five square miles. The model domain was developed based on the geology to represent the extent of the LIV. The model extends from the Tiger Mountain Gap in the south to Lake Sammamish in the north.

The hydrostratigraphy is represented with nine layers, consistent with the CARA MODFLOW model and the HG Model, and summarized in the table below. The layering is consistent with the CARA MODFLOW model; however, it may be adjusted to better represent the hydrostratigraphic units following additional field investigations.

MODFLOW Layers	Hydrostratigraphic Unit	Material
1	Shallow Aquifer	Fine Sand
2		Silt
3		Sand
4	Shallow Aquitard	Silt
5	A Zone Aquifer	Fine to medium, poorly graded sand with gravel
6	Deep Aquitard	Grey silt and clay
7	B Zone Aquifer	Coarse sand and gravel grading to a silty medium coarse sand
8	B/C Zone Aquifer	Glaciofluvial channels
9	Lower Deep Aquitard	Silt

2.2 Simulation Period

Preliminary flow model calibration was performed so that predicted groundwater elevations matched observed groundwater elevations for both steady-state and transient conditions. The steady-state conditions represent average annual groundwater elevations, recharge, and flow conditions between October 2017 and September 2022, which were selected based on data availability and because operation of production wells remained consistent throughout this period (i.e., SPWD production wells 7 and 8 are not operating, SPWD production well 9 is operating, and the four City production wells COI-1, COI-2, COI-4 and COI-5 are operating). Currently, wells COI-1 and COI-2 are in minimal operation with plans to utilize them during peak summer months, and well COI-5 is not operating. The transient calibration period is based on water level data between October 2017 and September 2022, and boundary conditions (i.e., recharge, pumping rates, specified head) were varied quarterly to match seasonal water level fluctuations.

The simulation period for the transient model calibration was divided into 20 stress periods of three months to represent the variations in boundary conditions. One time-step was defined for each stress period.

2.3 Model Boundaries and Stresses

The boundary conditions are provided in Figure 1.

2.3.1 Specified Head Boundary

Groundwater flow in the model domain is from south to north. Specified head boundaries are applied to the south of the model at Tiger Mountain Gap and the north of the model at Lake Sammamish. The head value assigned at Tiger Mountain Gap is currently set to a constant head value of 190 feet NAVD88 based on groundwater elevation. When transient groundwater elevations are available, they will be incorporated to this boundary condition. For the northern boundary, the head values vary quarterly for the transient simulations based on the lake stage recorded by the United State Geological Survey (USGS)[2] (Figure 2). The average value (30.28 feet NAVD88) is used for the steady-state simulation.

2.3.2 Specified Flux Boundary

The eastern and western margins of the model are specified flow boundaries (also known as specified flux boundaries) representing mountain-front recharge into the LIV along the foothills. The transient flux boundary conditions are shown on Figure 3. Total steady-state flux from this boundary is 100,000 and 125,000 cubic feet per day along the eastern and western margins, respectively. For the transient simulation, the flux varies consistent with precipitation fluctuations (Figure 3) and ranges from 0 to 335,000 cubic feet per day.

2.3.3 Areal Recharge

Areal recharge is defined throughout the model domain based on the recharge area potential described in the CARA report and used in the CARA MODFLOW model (Geosyntec, 2022a). The recharge potential was assigned high, medium, or low based on the geologic and soil properties (Figure 4). Throughout the model, recharge fluxes are assigned to the highest active cell. The monthly recharge rates for the three recharge potential zones are shown in Figure 5. Total steady-state recharge from precipitation is 5,200 AFY, corresponding to an average recharge rate of 20 inches per year over the entire model domain. The transient recharge rate ranges from 0 to 5 inches per month and is consistent with precipitation patterns (Figure 5).

2.3.4 Production Wells

The production wells were defined in the model based on the screen intervals (shown in Table 1) and the pumping rates provided in Figure 6. For the period selected for the transient simulation SPWD production wells SP-PW 7 and SP-PW 8 were not operating. The pumping rates for SPWD and City wells were based on records provided by the City and SPWD. The pumping rates for Darigold and Lakeside wells were based on the CDM Smith Model Report (1997) and documentation in the Well 9 Aquifer Performance Test Report (Carr, 1993) and will be updated

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[2] https://waterdata.usgs.gov/monitoring-location/12122000/#parameterCode=62614&startDT=2017-01-01&endDT=2022-11-14

during model refinement if new data become available. . When additional information on pumping at these wells becomes available, including recent shutdown of COI-5 and less frequent pumping of COI-1 and COI-2, the pumping rates will be adjusted as part of model refinement. Steady-state pumping rates are provided in the table below.

Well	Pumping Rates (gallons per minute)
SP-PW7	0
SP-PW8	0
SP-PW9	945
COI-1	240
COI-2	440
COI-4	185
COI-5	225
Darigold	150
Lakeside	475

2.3.5 Rivers

River boundary conditions are defined along Issaquah and Tibbett Creeks (Figure 1). River stages are defined based on the digital elevation model (DEM) along each river and are assumed constant for this preliminary model, consistent with the CARA MODFLOW model. The riverbed conductance values were adjusted as part of model calibration, and vary between 0.5 and 8 square feet per day per foot of river length.

2.3.6 Initial Conditions

The simulated steady-state conditions (heads) were used as initial conditions (starting heads) for the transient simulation.

2.4 Material Properties

Material properties assigned to each cell of the model include horizontal conductivity, vertical anisotropy, specific storage, and specific yield. There are nine hydrostratigraphic units in the model representing the layered system of aquifers and intervening aquitards. Sand and gravel units (aquifers) have higher hydraulic conductivity, while siltier units (aquitards) have lower hydraulic conductivity. The hydraulic properties were based on the 3D CARA MODFLOW model, the 2D cross-section model and slightly adjusted as part of model calibration (Section 3). The designation of horizontal and vertical conductivity for each layer is provided in Figure 7. Current efforts are ongoing to adjust the hydraulic conductivities of the model so they better reflect the flow properties in the area. The efforts will reconcile existing geologic layers in the model to newly acquired knowledge about the lithology such as those obtained from recent well installations. Cross-sections reflecting the changes will be provided when the reconciliation is completed.

The specific yield and specific storage are defined uniformly over the entire model domain at 0.15 and $1*10^{-6}$ 1/feet, respectively, consistent with the CARA MODFLOW model.

3. PRELIMINARY MODEL CALIBRATION

3.1 Calibration Data

The primary output from a model consists of hydraulic head (water level) and groundwater flux at every active cell for every model time-step. The following data sets were used to perform preliminary calibration of the model:

1. Average water level data measured at 72 monitoring wells. The average water levels were calculated based on available measured water levels between October 2017 and September 2022. Water level data were also categorized by model layer. These steady-state observation data are summarized in Table 1, and locations are shown on Figure 8. As illustrated in Table 1 and Figure 8, there are limited data for the B and B/C aquifers.
2. Water level data between October 2017 and September 2022 were used for transient calibration. A total of 972 head observations from 72 monitoring wells were used in the transient calibration process.

Additional calibration data, including from transducers installed as part of the ongoing investigations, will be available to refine model calibration.

3.2 Calibration Results

Figure 9 presents a scatter diagram for the 72 steady-state calibration observations. Each point on the graph represents an observed water level (x-axis) plotted against its corresponding simulated water level (y-axis). The centerline represents perfect agreement (calibration) between observed and simulated, and the distance away from the centerline represents the magnitude of the error for each point. The scatter diagram provides a visual illustration of the goodness of fit achieved during this preliminary calibration process.

In addition to the visual illustration provided by the scatter diagram, a number of quantitative metrics were used to assess model error. The following statistics were generated to quantify the calibration set:

- Mean error (ME) – The mean difference between the observed head and the corresponding simulated head for a number of data pairs
- Root mean square error (RMSE) – The square root of the average of the squared differences between the simulated head and the corresponding observed head for a number of data pairs
- RMSE % – The RMSE divided by the range of observed heads across the model domain.

The calibration metrics are summarized per aquifer zones and for the entire model domain in the table in Figure 9.

Figures 10 show the simulated and observed water levels for the transient simulation period. The fit between the observed and simulated hydrographs is generally good for this preliminary calibration and indicates that the model can reproduce the major recharge mechanisms impacting water levels.

This preliminary calibration will be further adjusted as part of the model refinement following completion of additional investigations such as a pumping test.

4. SIMULATED GROUNDWATER FLOW FIELD AND BUDGET

The groundwater flow model provides a tool for assessing and predicting the groundwater flow field under varying conditions. In particular, the groundwater flow model can be used to generate potentiometric surfaces and flow vectors at various times and at multiple depths within the flow system. The potentiometric surfaces provide a means to assess the variation in the flow field with depth and to evaluate the timing and distribution of historical shifts in the flow regime.

The groundwater flow model can also be used to evaluate the water balance. The water balance provides an accounting of the various components of water inflow to, and outflow from, the model domain. The steady-state values of these components are indicative of the primary drivers of the flow field.

4.1 Simulated Flow Dynamics and Particle Tracking

The simulated water level contours for the steady-state model for the three main aquifer zones are shown in Figure 11.

The groundwater flow field from the Shallow Zone Aquifer at one source area as an example, EFR, is illustrated with forward particle tracking in Figure 12. Particles are released at the EFR in Layer 1. The simulated water level contours and groundwater flow field show that the model is consistent with the conceptual model of groundwater flow:

- Northeasterly flow in the Shallow Zone Aquifer from the EFR
- Northernly flow in the A Zone Aquifer
- Downward flow from the Shallow Zone to A Zone Aquifers between the EFR and monitoring well COI-MW6

4.2 Water Balance

The simulated steady-state water balance is provided below.

	cubic feet per day
Inflow	
Southern Inflow	144,000
Western Margin Inflow	127,000
Eastern Margin Inflow	101,000
Areal Recharge	622,000
River	
North Fork Issaquah Creek	138,000
East Fork Issaquah Creek	6,000
Issaquah Creek	99,000
Tibbetts Creek	127,000
Total Inflow	**1,364,000**
Outflow	
Discharge to Lake Sammamish	766,000
Production Wells	514,000
River	
North Fork Issaquah Creek	0
East Fork Issaquah Creek	2,000
Issaquah Creek	79,000
Tibbets Creek	3,000
Total Outflow	**1,364,000**

As noted in Section 2.3.4, City production well pumping has changed for three wells, and the pumping rates will be adjusted as part of model refinement and the resultant water balance will also be updated.

5. CONCLUSIONS

This memo documents the preliminary development and calibration of the numerical groundwater flow model for the LIV. The current groundwater flow model provides a robust basis for the next phase of the project. Following additional data collection, the numerical groundwater flow model will be further refined and calibrated under steady-state and transient conditions, including calibration using transducer data and refinement of layering based on additional boring logs. PFAS transport will be added to the MODFLOW model using MT3DMS to allow for simulations of up to three PFAS compounds. Fate and transport calibration will be quantitatively adjusted by varying transport parameters such as the sorption coefficients to match historical observations of PFAS plumes and transient PFAS concentrations at different locations.

6. REFERENCES

Geosyntec Consultants (Geosyntec), 2021. Groundwater Flow and PFAS Transport Modeling Report, Issaquah, Washington. September 2021.

Geosyntec, 2022a. Critical Aquifer Recharge Area (CARA) Mapping and Assessment Report, Issaquah, Washington. November (*revision publication date pending*).

Geosyntec, 2022b. Draft Regional Conceptual Hydrogeological Model. October 7.

Geosyntec, 2022c. Draft Data Gaps Investigation Work Plan Addendum 1 – Hydrogeological Characterization Well Installation. October 7.

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Attachments

Table 1	Observation Locations and Average Groundwater Elevations
Figure 1	Model Domain, Grid and Boundary Conditions
Figure 2	Lake Sammamish Stage
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Figure 12	Forward Particle Tracking from EFR

ATTACHMENTS

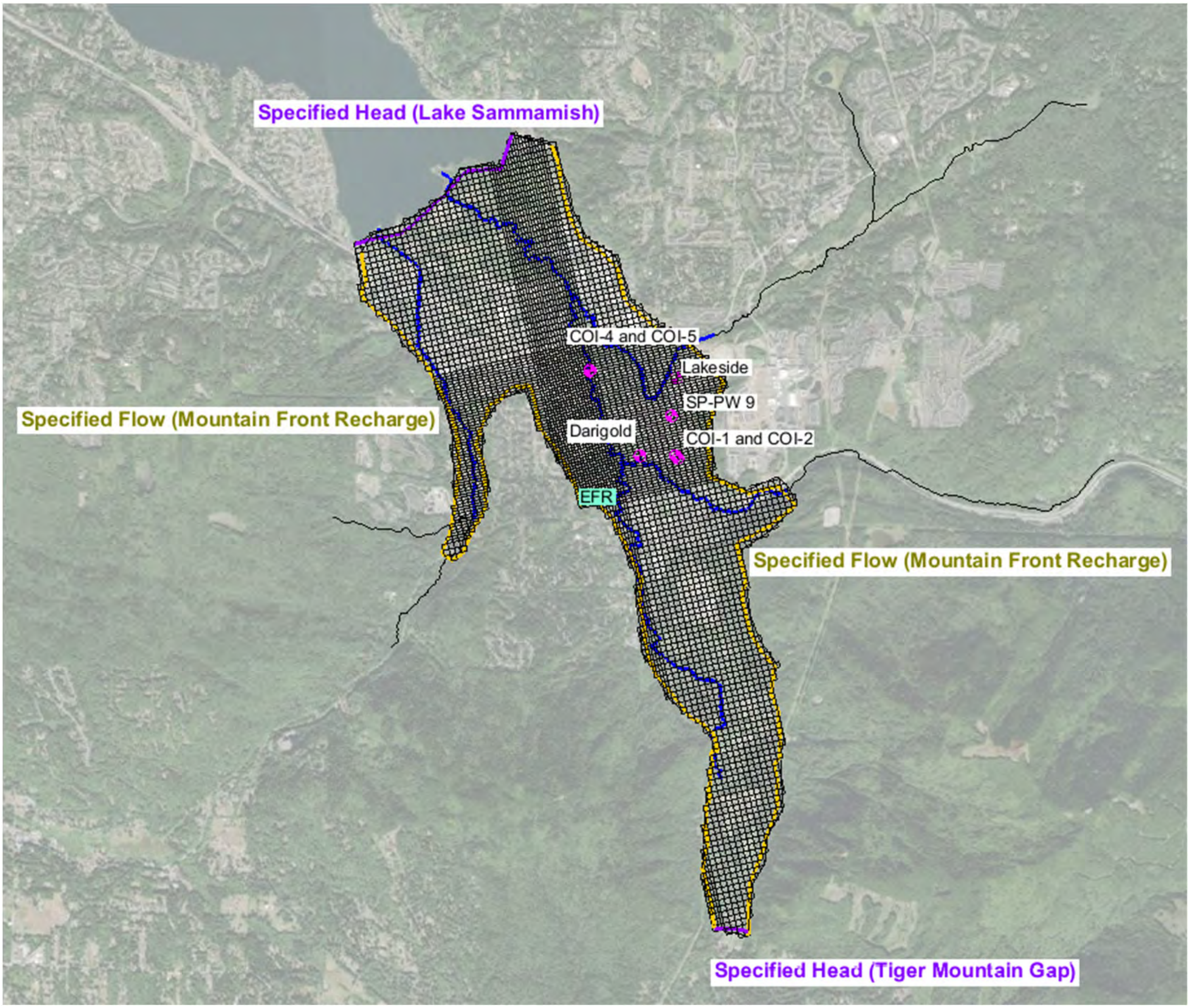
Table 1 - Observation Locations and Average Groundwater Elevations

Well ID	X	Y	Aquifer	Top of Screen (feet bgs)	Bottom of Screen (feet bgs)	Midpoint Elevation (feet NAVD88)	Average Groundwater Elevation (feet NAVD88)	Simulated Steady-State Groundwater Elevation (feet NAVD88)
B-2	1339406	199916	Shallow Zone Aquifer	20	30	56	Not Available	Not Available
B-4	1340063	198862	Shallow Zone Aquifer	20	30	49	Not Available	Not Available
COI-MW01	1338949	201384	Shallow Zone Aquifer	28	38	25	54.5	52.7
COI-PW01	1344158	197898	Shallow Zone Aquifer	90	106	-5	Not Available	Not Available
COI-PW02	1344184	197865	Shallow Zone Aquifer	82	97	4	Not Available	Not Available
DF-MW01	1341733	197859	Shallow Zone Aquifer	5	15	68	67.1	68.9
DF-MW02	1341342	197988	Shallow Zone Aquifer	15	25	54	66.2	68.4
DF-MW03	1341663	198264	Shallow Zone Aquifer	20	30	49	65.8	67.5
IES-MW01	1341197	197783	Shallow Zone Aquifer	16	26	55	68.0	69.2
IES-MW02	1340885	197926	Shallow Zone Aquifer	15	25	54	67.2	68.6
IES-MW03	1340736	198407	Shallow Zone Aquifer	15	25	53	65.6	66.2
IES-MW04	1341051	198402	Shallow Zone Aquifer	15	30	50	65.7	66.5
IES-MW05	1341434	198390	Shallow Zone Aquifer	20	30	48	65.5	66.9
IES-MW07	1341387	199096	Shallow Zone Aquifer	20	30	45	63.4	63.7
IES-MW08	1341809	198349	Shallow Zone Aquifer	20	30	47	65.1	67.3
MF-MW01	1343913	195913	Shallow Zone Aquifer	16	26	82	68.2	71.1
MF-MW02	1343727	196215	Shallow Zone Aquifer	25	45	65	67.2	69.9
MF-MW03	1343967	196294	Shallow Zone Aquifer	35	50	62	67.2	69.5
NDS-MW01	1341326	197104	Shallow Zone Aquifer	22	32	58	67.9	72.0
NDS-MW03	1341935	197357	Shallow Zone Aquifer	25	35	52	68.2	70.8
NGB-MW01	1341021.8	200693.7	Shallow Zone Aquifer	20	30	37.96	55.1	56.7
NLS-MW01	1340501.3	199666.8	Shallow Zone Aquifer	19.5	29.5	42.12	61.1	60.1
NWN-MW01	1341269	196417	Shallow Zone Aquifer	15	30	68	71.0	74.5
NWN-MW02	1341462	196584	Shallow Zone Aquifer	15	30	67	69.3	73.7
NWN-MW03	1341264	196600	Shallow Zone Aquifer	15	30	69	69.8	73.9
NWN-MW04	1341096	196495	Shallow Zone Aquifer	13	23	72	78.8	74.8
NWN-MW05	1341075	196597	Shallow Zone Aquifer	7	17	78	76.5	74.8
NWN-MW06	1341125	196598	Shallow Zone Aquifer	15	25	71	75.7	74.5
NWN-MW07	1341204	196570	Shallow Zone Aquifer	16.5	26.5	69.4	70.8	74.1
NWN-MW09	1341257	196600	Shallow Zone Aquifer	45	50	44	69.6	73.4
NWN-MW10	1341148	196565	Shallow Zone Aquifer	10	25	73	74.2	74.4
NWN-MW11	1342184	196195	Shallow Zone Aquifer	15	25	71	71.9	75.4
NWN-MW12	1341146	196492	Shallow Zone Aquifer	8	23	75	78.2	74.5
NWN-MW13	1341046	196465	Shallow Zone Aquifer	3	18	79	81.5	75.2
NWN-MW14	1341141	196443	Shallow Zone Aquifer	7	22	76	77.8	74.7
NWN-MW15	1341234	196460	Shallow Zone Aquifer	15	30	68	70.4	74.4
NWN-MW16	1341235	196537	Shallow Zone Aquifer	15	30	68	70.1	74.1
NWN-PZ01	1341235	196537	Shallow Zone Aquifer	20	30	66	69.0	74.1
NWN-PZ02	1341243	196576	Shallow Zone Aquifer	20	30	65	69.7	74.0
RT-MW01	1343590	195910	Shallow Zone Aquifer	25	45	64	66.8	71.2
RT-MW03	1343676	195900	Shallow Zone Aquifer	25	45	64	66.4	71.1
RT-MW04	1343630	195466	Shallow Zone Aquifer	28	38	68	70.5	72.7
SP-VT1-1	1343702	199872	Shallow Zone Aquifer	28	38	40	62.2	61.8
SP-VT2-1	1341545	201239	Shallow Zone Aquifer	19	24	38	54.0	56.2
SP-VT2-2	1341579	201204	Shallow Zone Aquifer	34	39	25	56.3	56.2
SP-VT7-1	1344491	198956	Shallow Zone Aquifer	23	33	55	61.0	60.0
SP-VT7-2	1344491	198956	Shallow Zone Aquifer	43	53	35	60.8	60.0
SP-VT8-1	1344235	199055	Shallow Zone Aquifer	45	55	29.7	61.3	59.9
COI-MW02	1340781	201348	A Zone Aquifer	70	90	-17	59.5	54.2
COI-MW03	1341030	200668	A Zone Aquifer	78	98	-25	57.3	55.2
COI-MW04	1341895	199847	A Zone Aquifer	70	90	-7	62.9	59.1
COI-MW05	1341394	199048	A Zone Aquifer	70	90	-8	64.4	60.9
COI-MW06	1341319	197107	A Zone Aquifer	80	100	-4	68.1	66.8
COI-MW07	1342211	196184	A Zone Aquifer	100	110	-15	71.8	67.6
COI-PW04	1341271	200772	A Zone Aquifer	77	102	-23	Not Available	Not Available
COI-TMW1	1342570	197378	A Zone Aquifer	84	94	-7	Not Available	Not Available
DG-PW01	1342972	197877	A Zone Aquifer	81	96	-3	Not Available	Not Available
IES-MW06	1341204	197797	A Zone Aquifer	80	90	-9	66.1	64.5
IES-MW09	1341819	198351	A Zone Aquifer	75	85	-8	65.7	63.2
IES-MW10	1340747	198407	A Zone Aquifer	75	85	-7	64.5	62.8
IES-MW11	1341191	197794	A Zone Aquifer	120	130	-49	61.0	62.8
IES-MW12	1341460	199134	A Zone Aquifer	120	130	-58	58.0	59.5
Lakeside	1344222	200519	A Zone Aquifer	102	108	-65	Not Available	Not Available
MF-MW04	1343721	196214	A Zone Aquifer	65	75	30	67.3	69.4
NDS-MW02	1341398	197439	A Zone Aquifer	71	81	6	68.0	67.0
NDS-MW04	1341933	197337	A Zone Aquifer	72	82	5	67.6	67.5
NLS-MW02	1340495.3	199667.6	A Zone Aquifer	70	80	-8.12	60.7	58.4
NWN-MW08	1341456	196583	A Zone Aquifer	70	80	15	68.2	69.4
RBN-MW01	1342586	199284	A Zone Aquifer	70	80	-1	64.3	60.5
RBN-MW02	1343631	197109	A Zone Aquifer	70	80	24	66.9	65.3
SP-MW07-1	1343024	200205	A Zone Aquifer	35	58	26	Not Available	Not Available
SP-MW07-2	1343024	200205	A Zone Aquifer	135	220	-105	Not Available	Not Available
SP-MW07-3	1343022	200507	A Zone Aquifer	85	150	-47	Not Available	Not Available
SP-PW07	1342984	200506	A Zone Aquifer	82.6	146.9	-44.6	Not Available	Not Available
SP-PW08	1343076	200077	A Zone Aquifer	105	179	-68	Not Available	Not Available
SP-VT1-2	1343702	199872	A Zone Aquifer	70	80	-2	61.8	60.8
SP-VT1-3	1343702	199872	A Zone Aquifer	150	160	-82	59.4	56.9
SP-VT2-3	1341592	201153	A Zone Aquifer	74	79	-14	54.3	55.5
SP-VT5-1	1342872	201253	A Zone Aquifer	75	85	-13.89	57.8	58.1
SP-VT7-3	1344491	198956	A Zone Aquifer	51	71	22	60.8	60.0
SP-VT7-4	1344491	198956	A Zone Aquifer	108	118	-30	60.7	59.7
SP-VT8-2	1344235	199055	A Zone Aquifer	83	93	-8.3	60.5	59.8
SP-VT8-3	1344235	199055	A Zone Aquifer	158	168	-83.3	60.4	59.0
COI-PW05	1341310	200669	B Zone Aquifer	323	405	-297	Not Available	Not Available
COI-TW03	1342444	197417	B/C Zone Aquifer	284	289	-205	Not Available	Not Available
COI-TW06	1342579	197291	B/C Zone Aquifer	258	362	-228	Not Available	Not Available
SP-PW09	1343953	199191	B/C Zone Aquifer	194	219	-129	Not Available	Not Available
SP-VT5-2	1342874	201247	B/C Zone Aquifer	180	190	-118.89	58.5	54.7
SP-VT8-4	1344235	199055	B/C Zone Aquifer	192	214	-123.3	60.4	58.6

Notes:

bgs = below ground surface

NAVD88 = North American Vertical Datum of 1988



SCALE: 1 INCH = 5,250 FEET

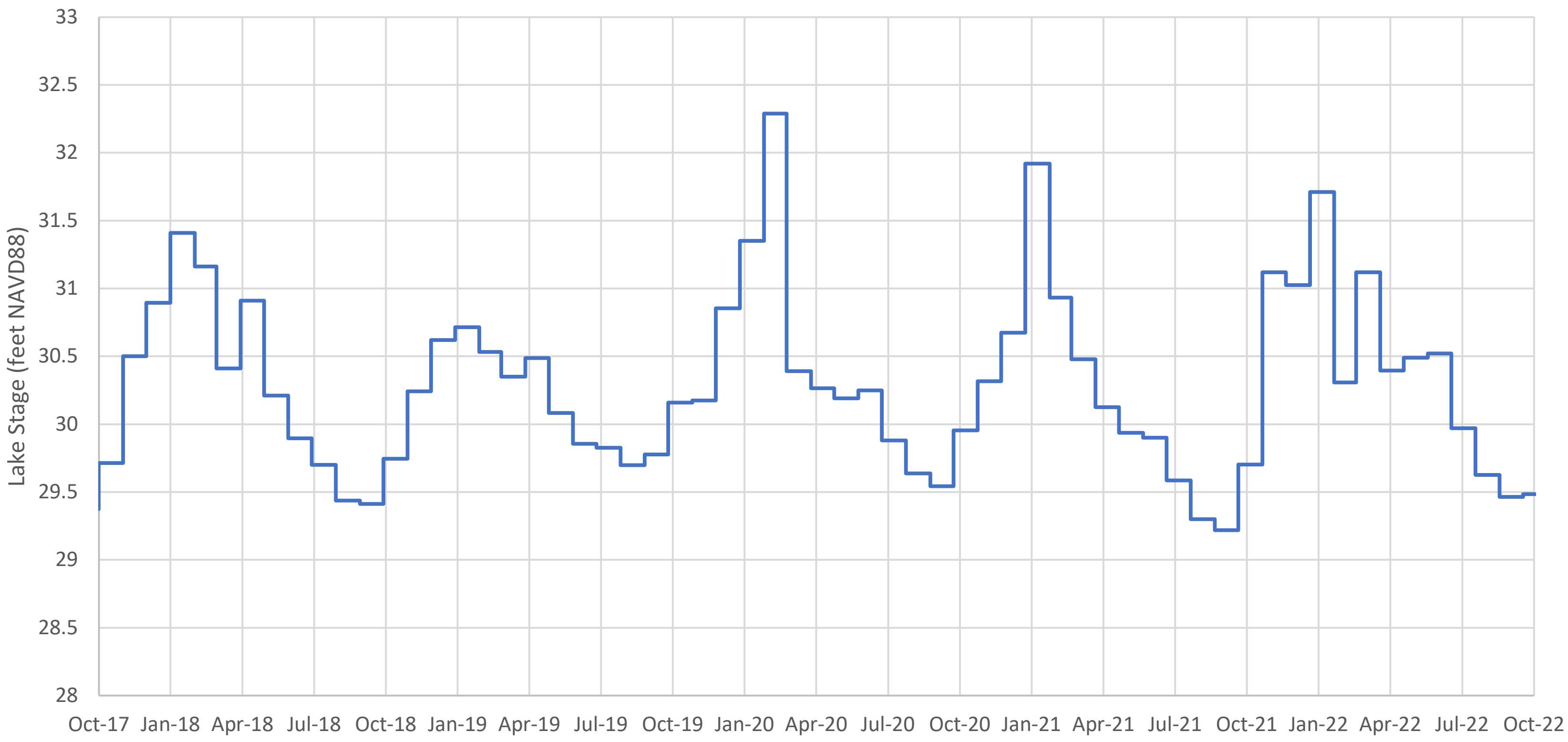
— Specified flow boundary condition
— Specified head boundary condition
— River boundary condition
⊕ Pumping well

Model Domain, Grid, and Boundary Conditions

Lower Issaquah Valley
Issaquah, Washington

Geosyntec consultants

PNG0989	December 2022	**Figure** 1



Lake stage from United State Geological Survey (USGS)

https://waterdata.usgs.gov/monitoring-location/12122000/#parameterCode=62614&startDT=2017-01-01&endDT=2022-11-14

Lake Sammamish Stage

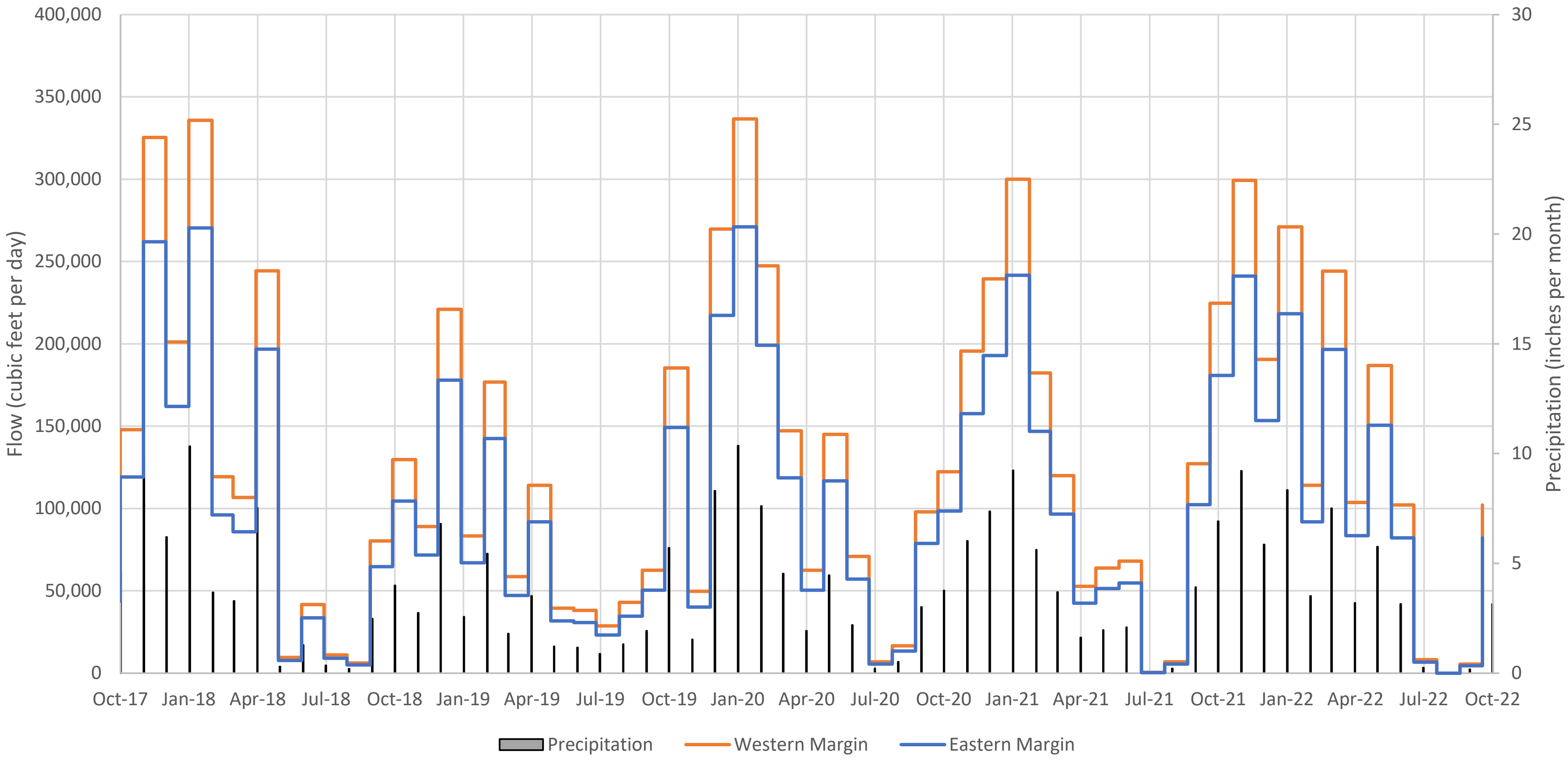
Lower Issaquah Valley
Issaquah, Washington

Geosyntec
consultants

PNG0989
November 2022

Figure

2



Precipitation from National Oceanic and Atmospheric Administration (NOAA)

Daily Summaries Station Details: ISSAQUAH 3.6 NW, WA US, GHCND:US1WAKG0059 | Climate Data Online (CDO) | National Climatic Data Center (NCDC) (noaa.gov)

Specified Flow at Western and Eastern Margins

Lower Issaquah Valley
Issaquah, Washington

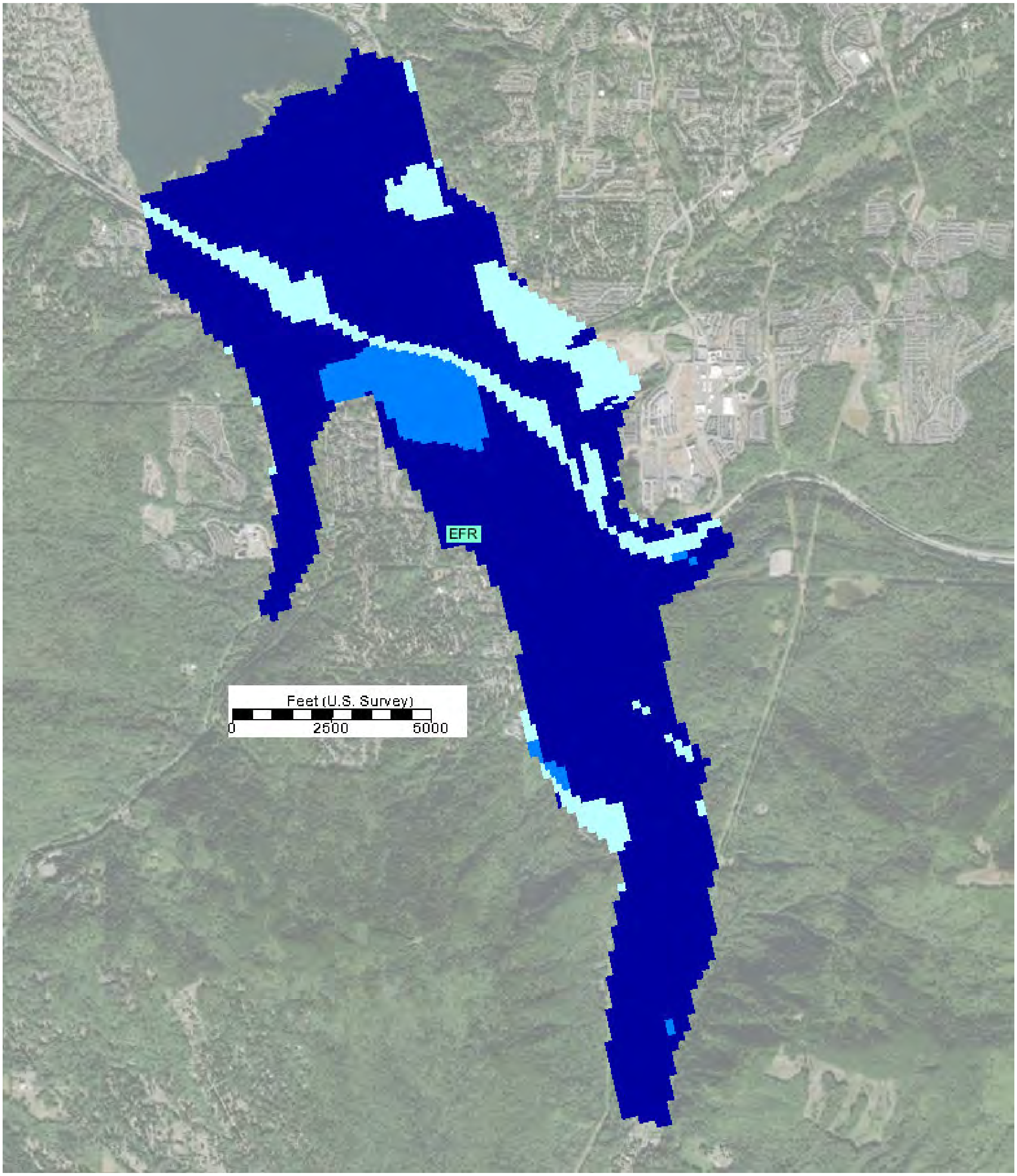
Geosyntec consultants

PNG0989

November 2022

Figure

3



Recharge Rate

🟦 Low (6.8 inches per year)

🟦 Medium (12.5 inches per year)

🟦 High (23.0 inches per year)

Recharge Rate

Lower Issaquah Valley
Issaquah, Washington

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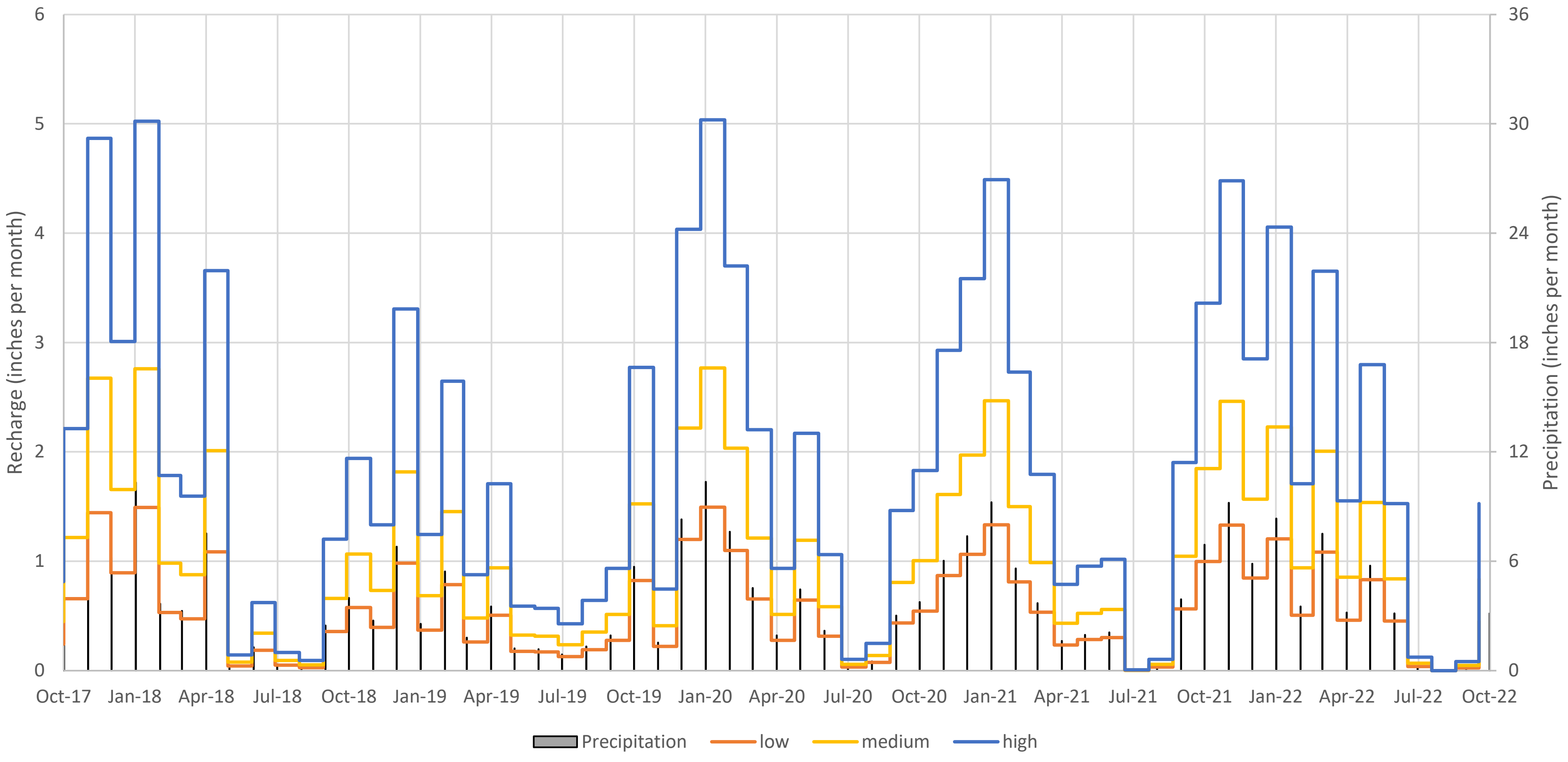
Figure

4



Precipitation from National Oceanic and Atmospheric Administration (NOAA)

Daily Summaries Station Details: ISSAQUAH 3.6 NW, WA US, GHCND:US1WAKG0059 | Climate Data Online (CDO) | National Climatic Data Center (NCDC) (noaa.gov)

Areal Recharge

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Issaquah, Washington

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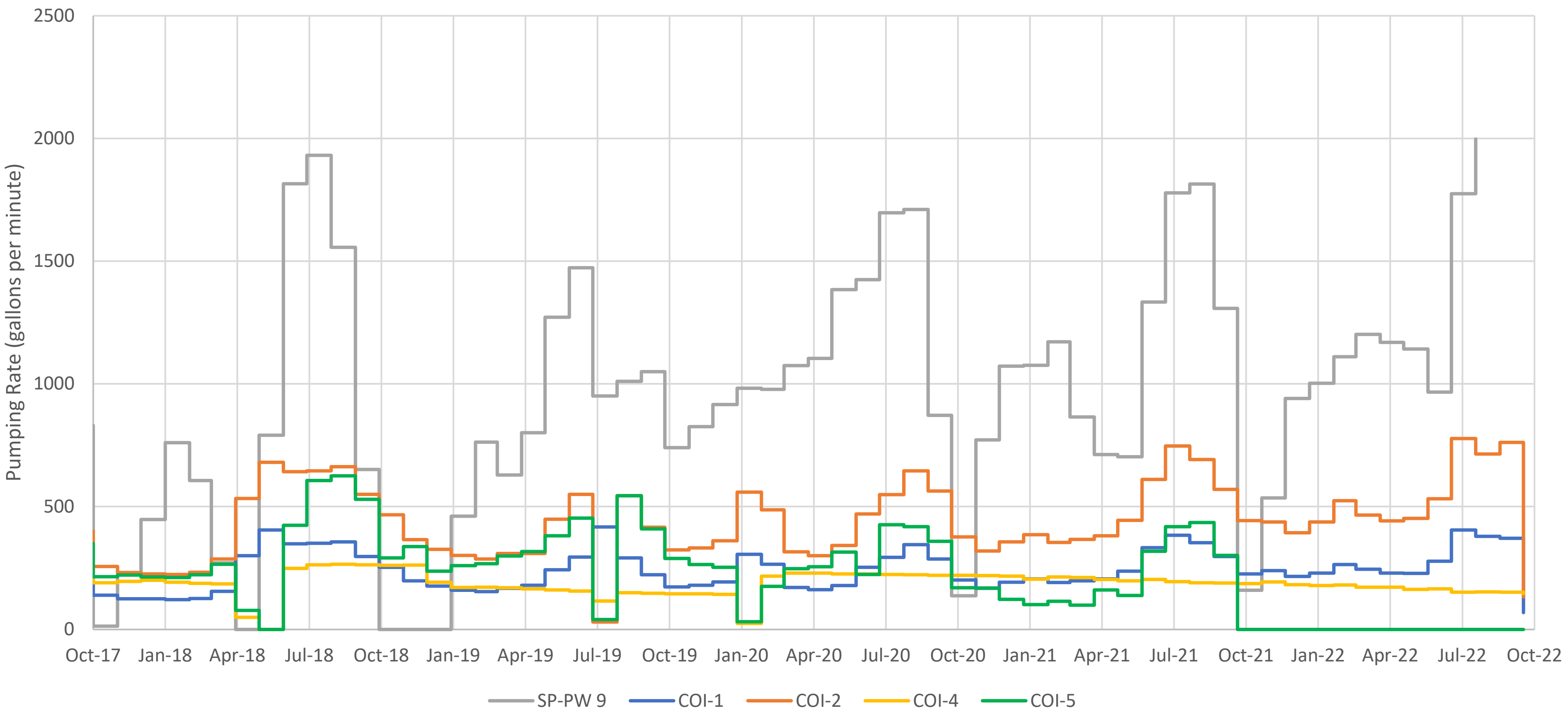
Figure

5



Pumping rates at Lakeside and Darigold are constant at 475 and 150 gallons per min, respectively

Pumping Rates at Production Wells

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Issaquah, Washington

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Figure

6

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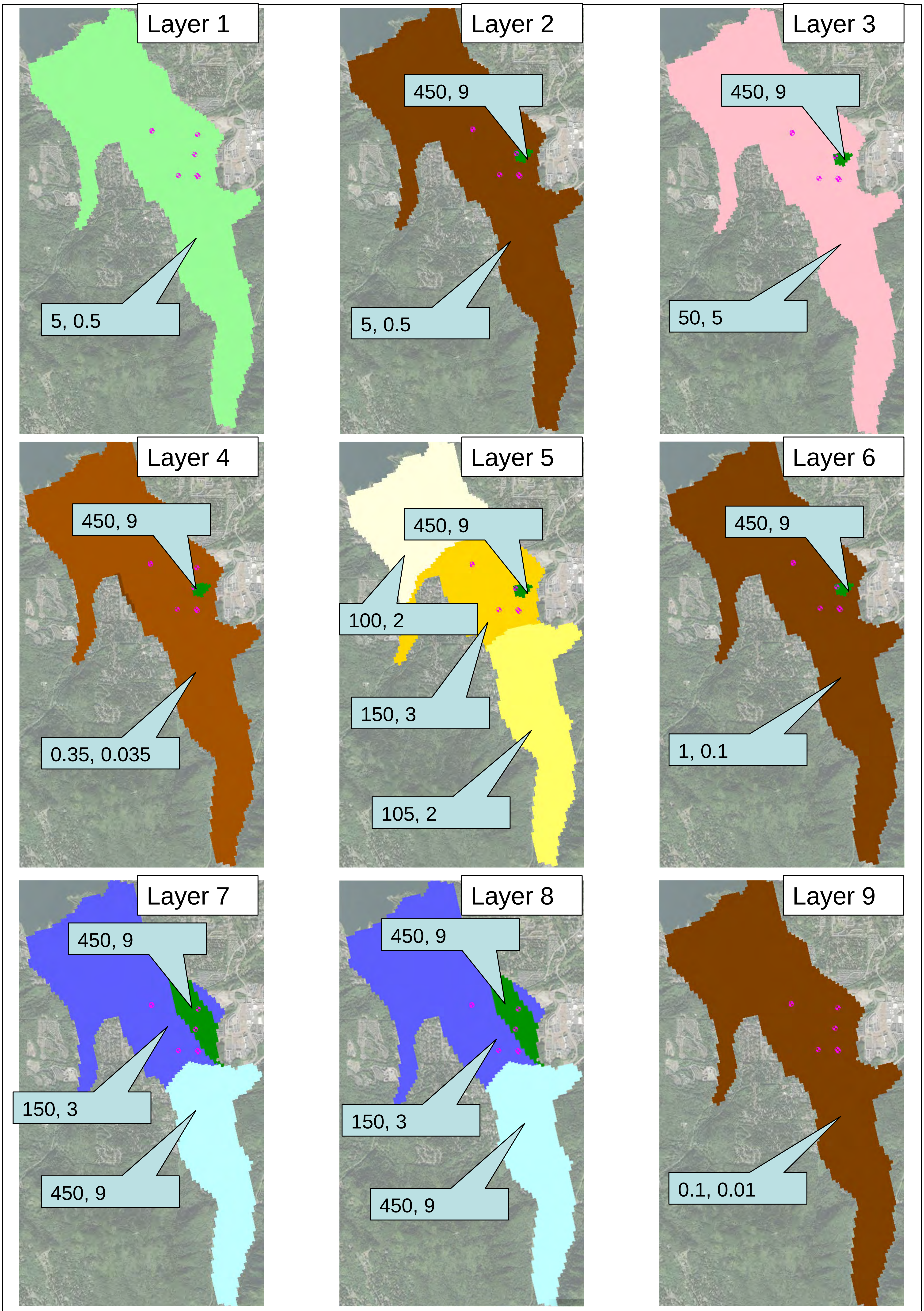

Notes:
Specific yield = 0.15
Specific storage = 10^{-6} feet^{-1}

Kh, Kv in feet per day

Hydraulic Properties

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Issaquah, Washington

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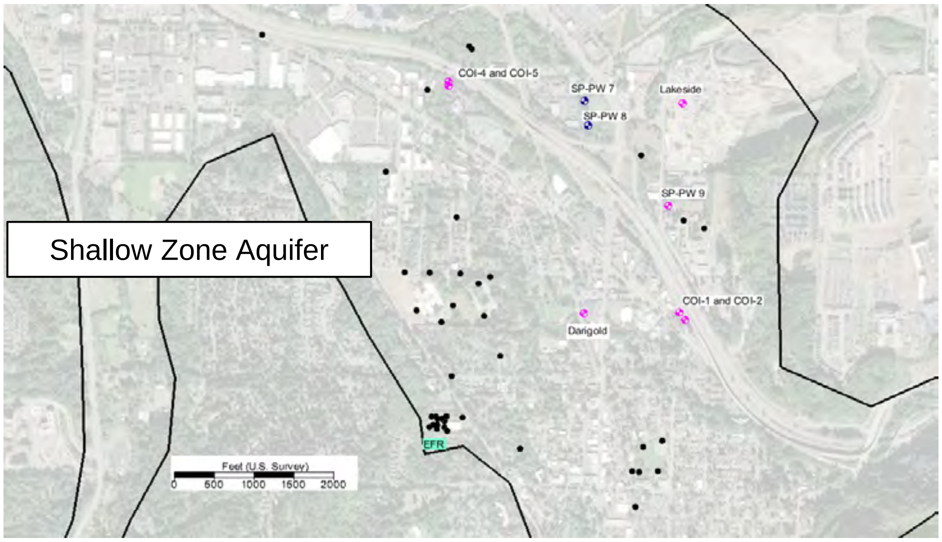
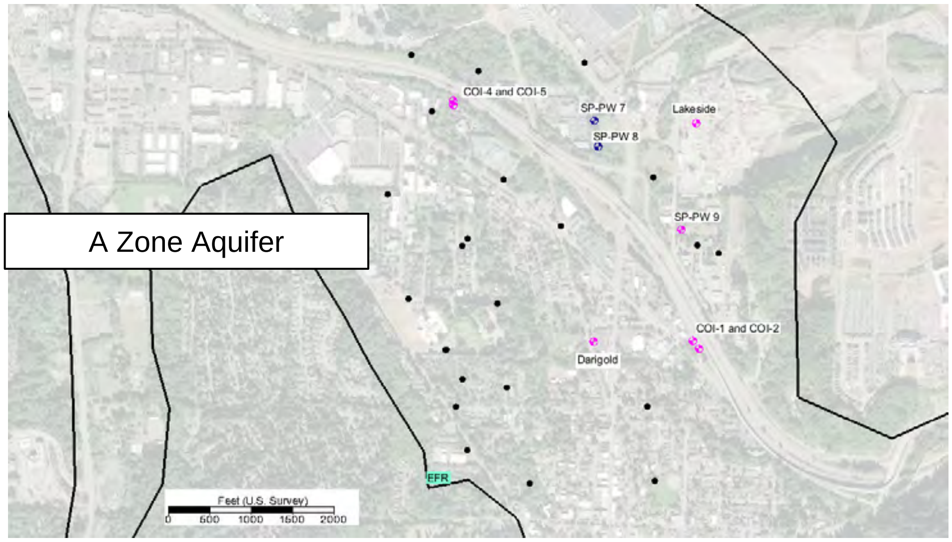
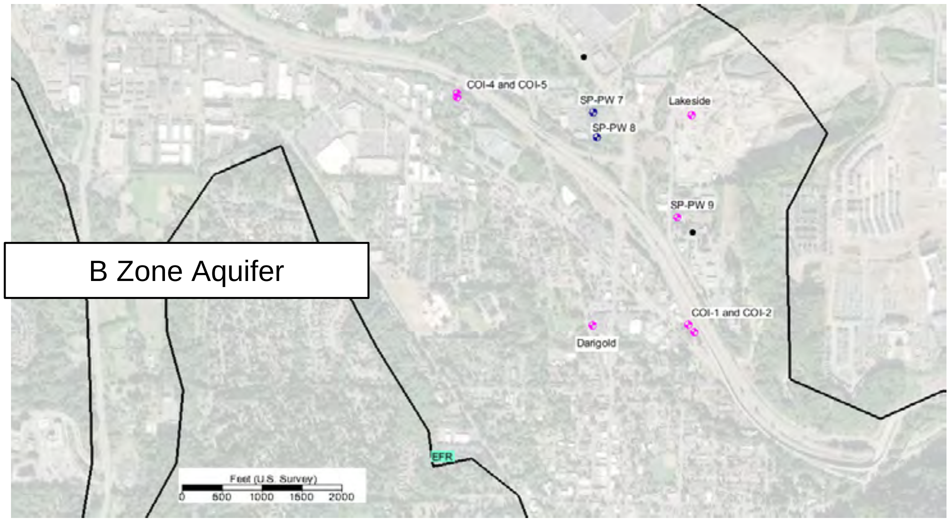
Figure

7







Legend
- ● Observation Location
- ◕ Active Production Well
- ◕ Inactive Production Well

Observation Locations

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Issaquah, Washington

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Figure

8

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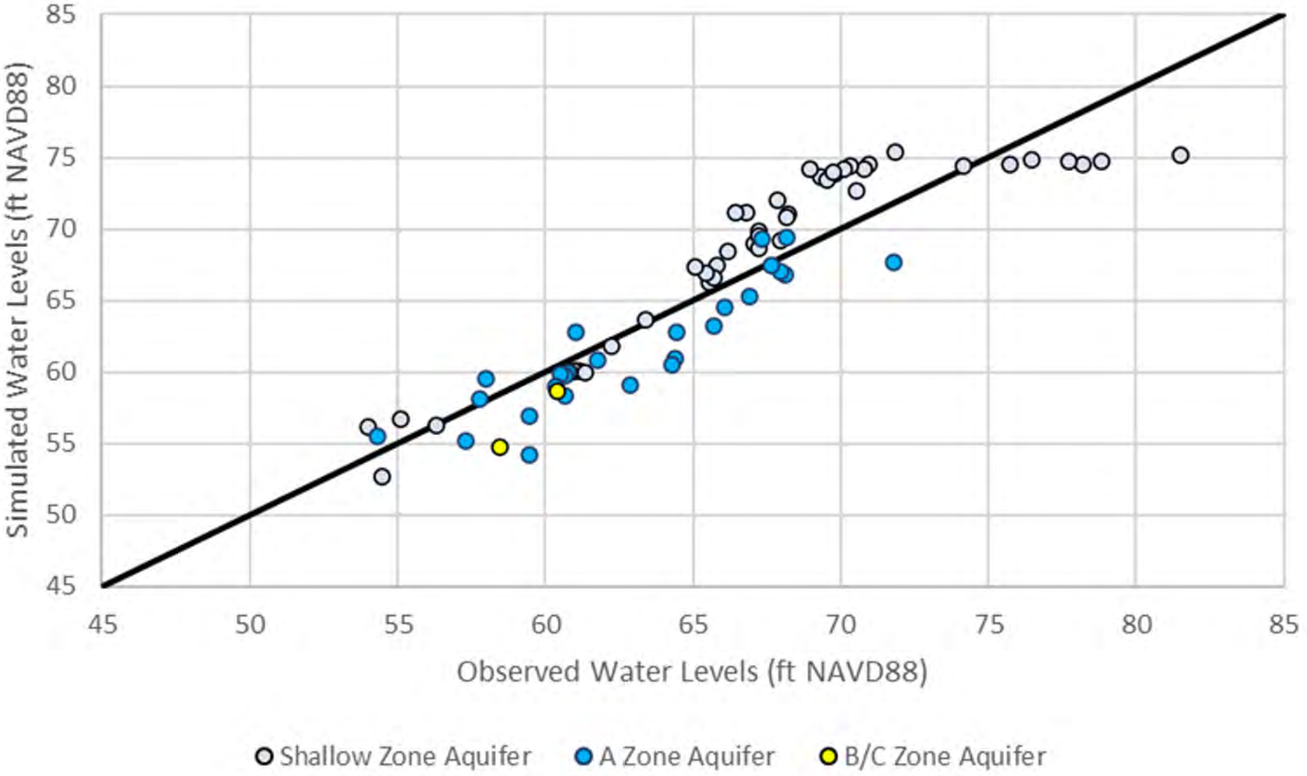

	All	Shallow Zone Aquifer	A Zone Aquifer	B/C Zone Aquifer
Number	72	44	26	2
Min Head (ft)	53.99	53.99	54.34	58.46
Max Head (ft)	81.50	81.50	71.81	60.42
Range (ft)	27.51	27.51	17.47	1.96
Mean residual (ft)	-0.25	-1.31	1.31	2.76
RMSE (ft)	2.7	2.9	2.3	2.9
% RMSE	**10%**	**11%**	**13%**	**Not Applicable**

ft = feet
RMSE = root mean square error

Simulated vs. Observed Groundwater Levels for Steady State Simulation

Lower Issaquah Valley
Issaquah, Washington

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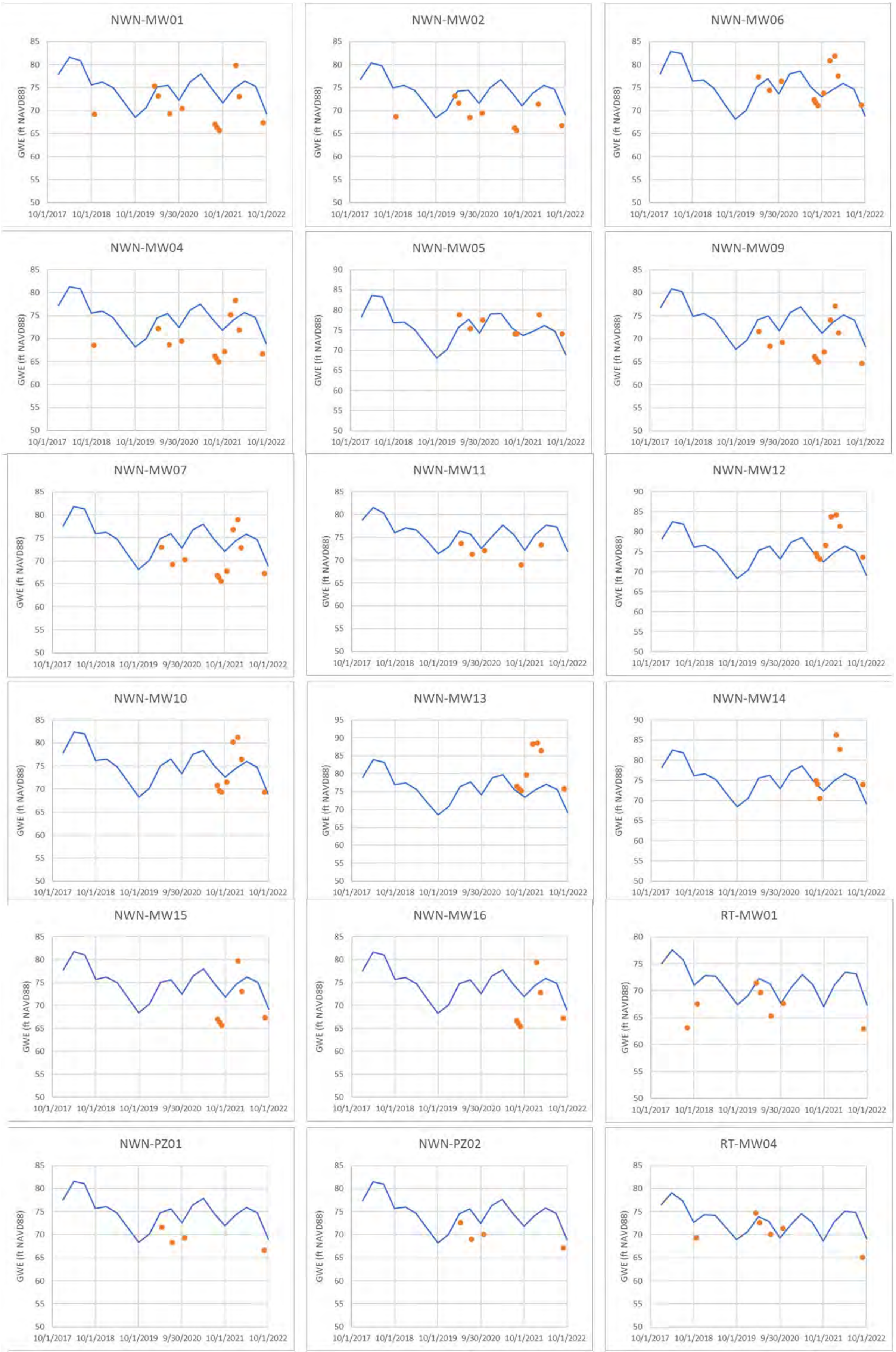
Figure

9



— Simulated groundwater elevation

● Observed groundwater elevation

Notes:
Hydrographs shown for Shallow Zone Aquifer

Hydrographs

Lower Issaquah Valley
Issaquah, Washington

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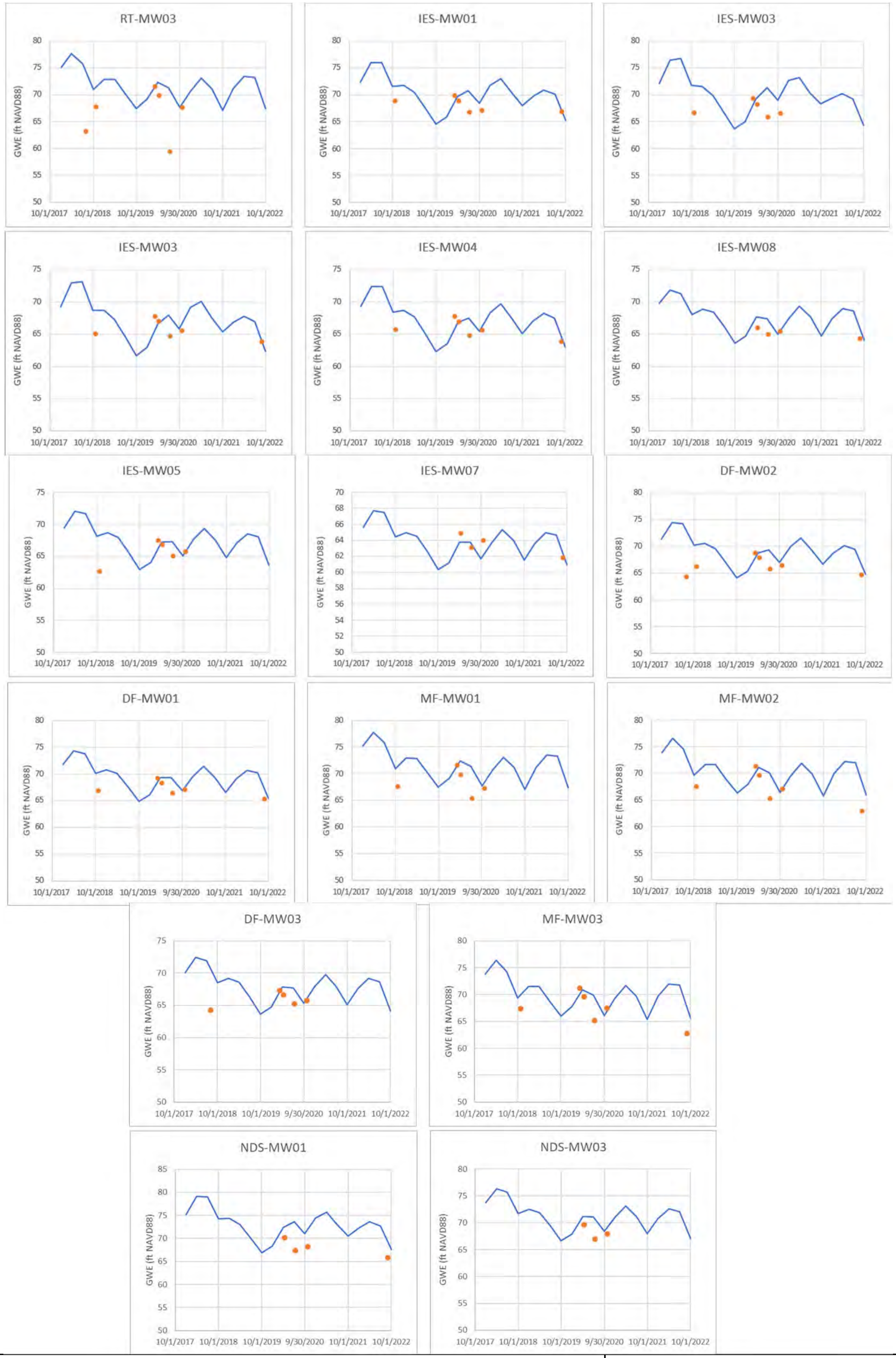
Figure

10a

PNG0989	December 2022



― Simulated groundwater elevation

● Observed groundwater elevation

Notes:
Hydrographs shown for Shallow Zone Aquifer

Hydrographs

Lower Issaquah Valley
Issaquah, Washington

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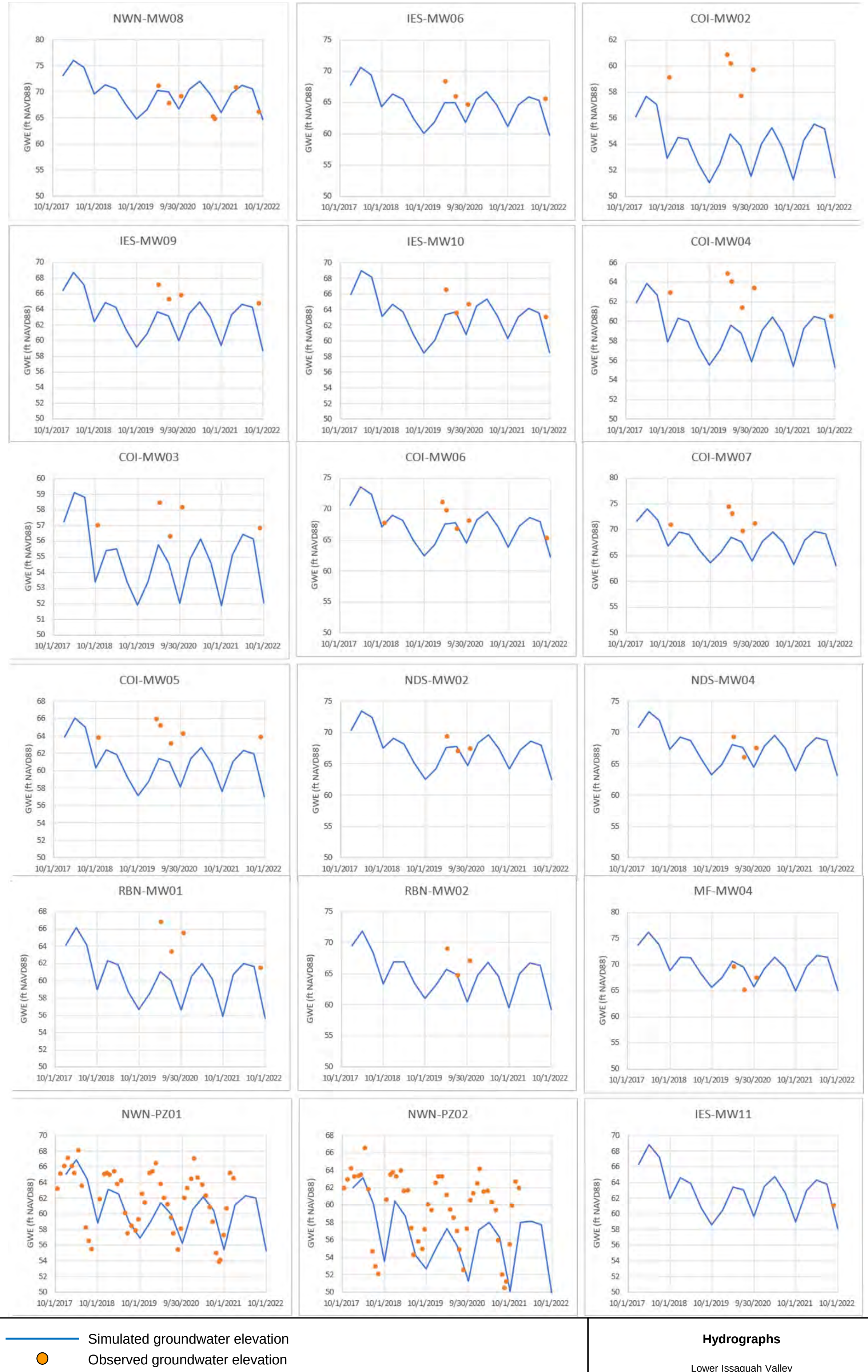
Figure

10b

PNG0989

December 2022



Notes:
Hydrographs shown for A Zone Aquifer

Hydrographs

Lower Issaquah Valley
Issaquah, Washington

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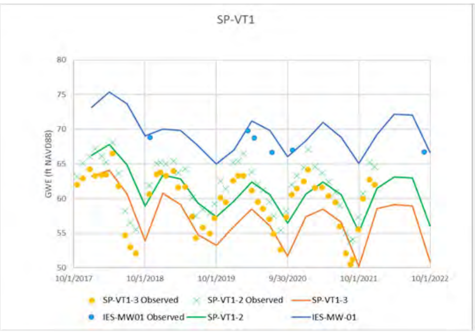
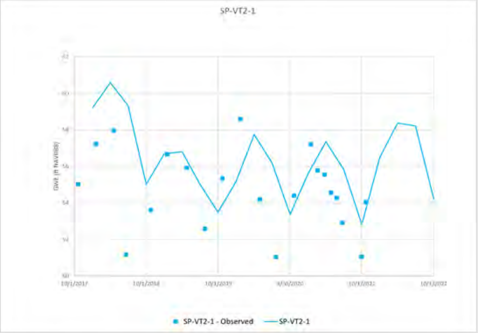
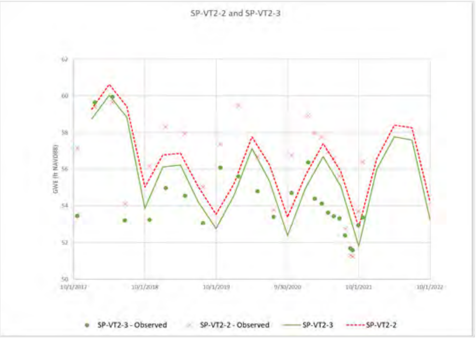
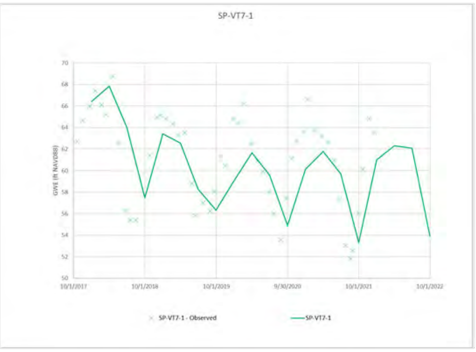
Figure
10c

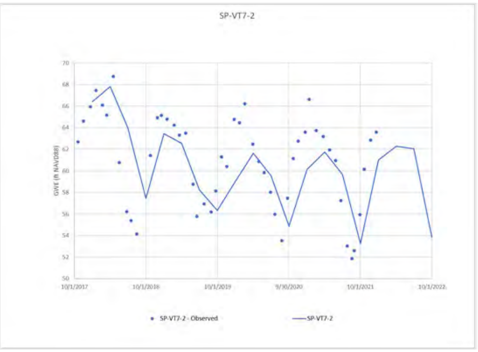
PNG0989 December 2022

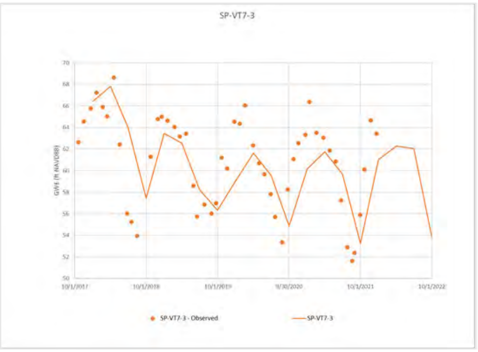


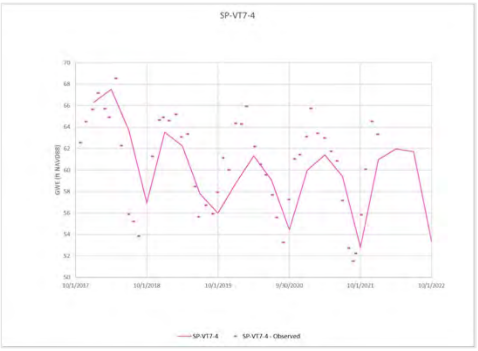


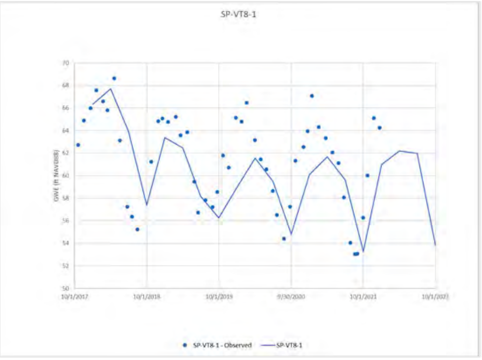


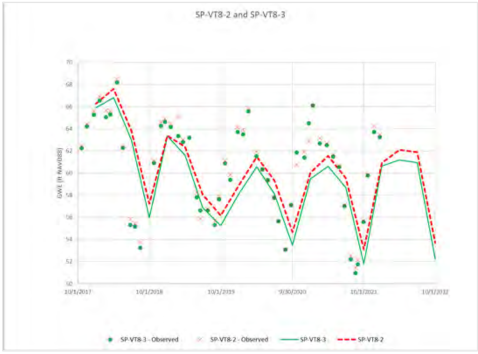












Notes:
Hydrographs shown for Cluster Wells

Hydrographs

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Issaquah, Washington

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Figure

10d

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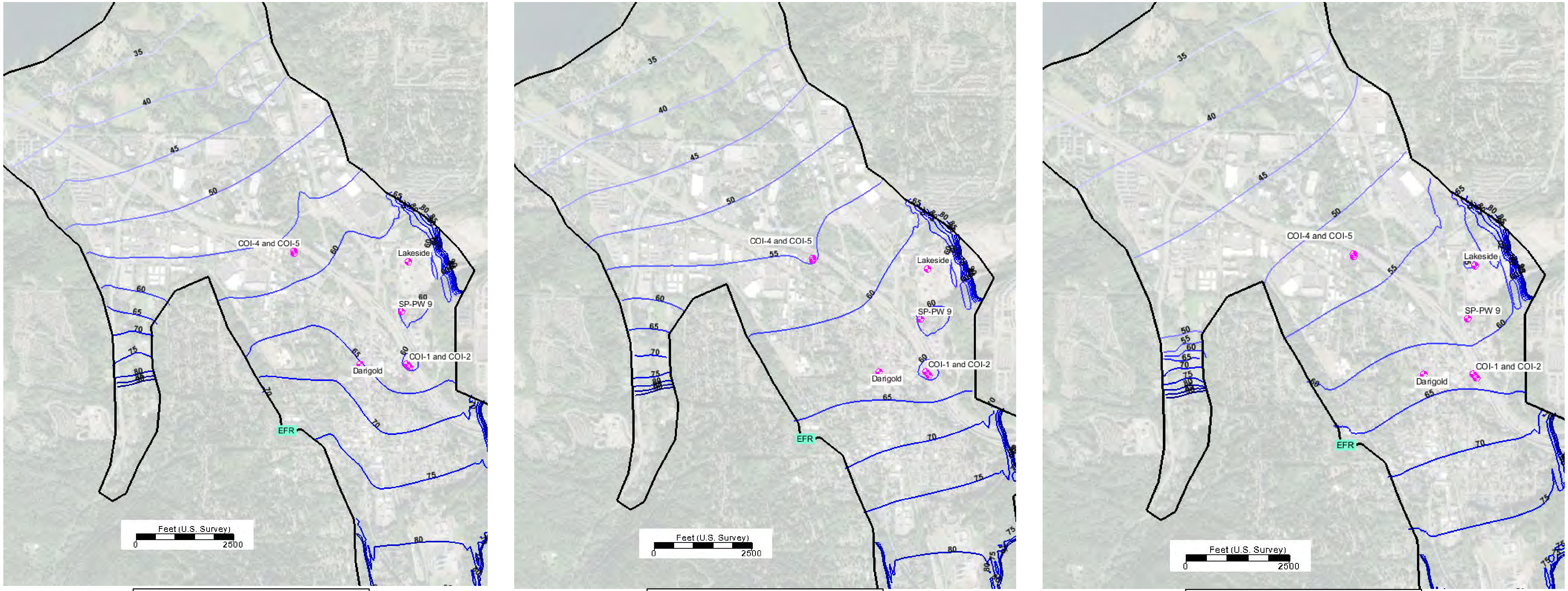

Shallow Zone Aquifer (Layer 3)

A Zone Aquifer (Layer 5)

B Zone Aquifer (Layer 8)

Notes:

Simulated groundwater elevation contour in feet NAVD88 (5-feet interval)

Simulated Groundwater Elevation Contours (Steady-State)
Lower Issaquah Valley
Issaquah, Washington

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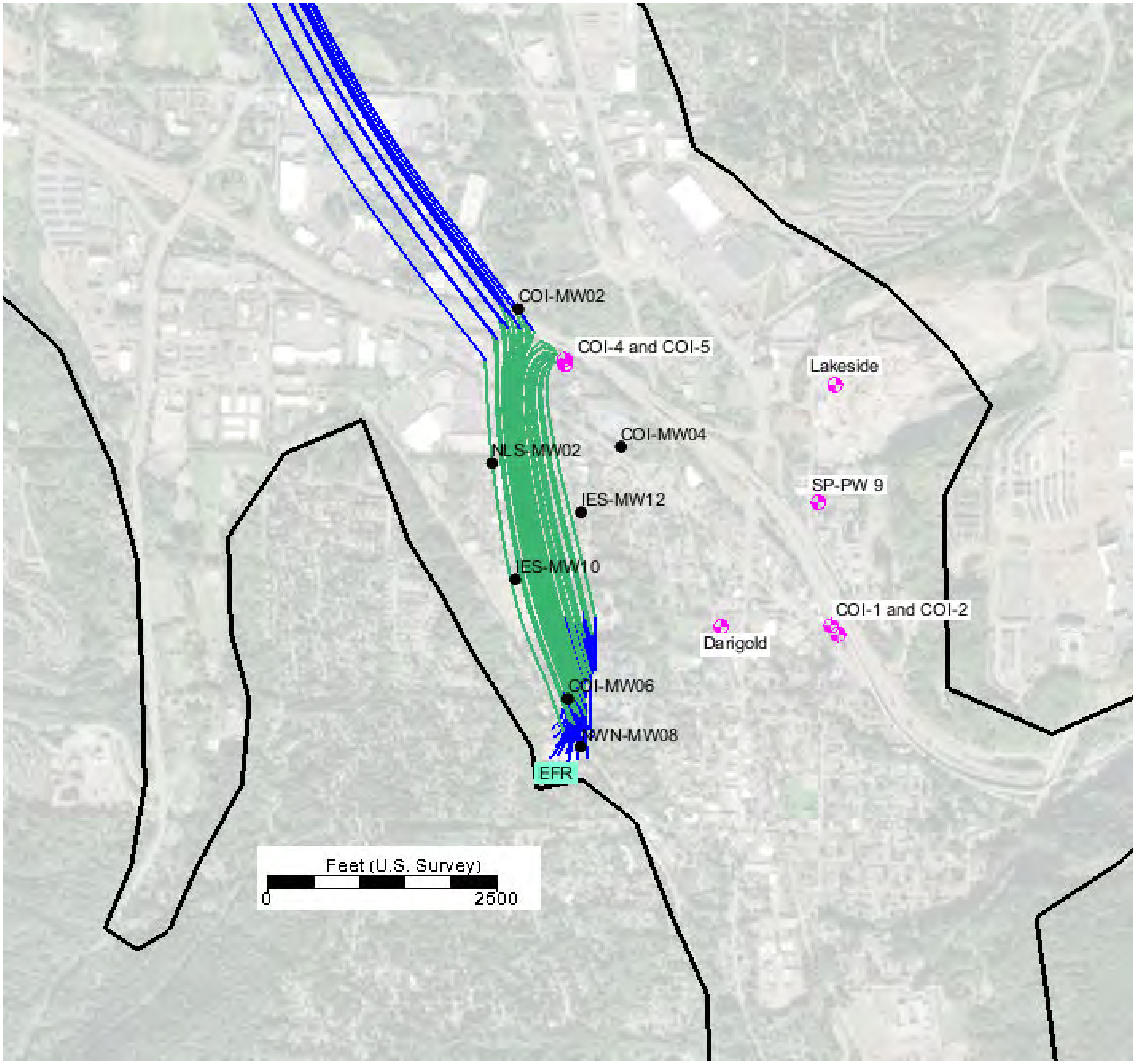
Figure 11



Select monitoring wells screened in the A Zone Aquifer are displayed for orientation.
Blue = particle flows in the Shallow Zone Aquifer (Layers 1-4)
Green = particle flows in the A Zone Aquifer (Layers 1-4)

Forward Particle Tracking from EFR

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Issaquah, Washington

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Figure

12