CITY OF JOHN DAY: PHASE 3 – FINAL GROUNDWATER MODELING REPORT

Project No. 2111001

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CwM-H2O
Complete Water Management

CwM

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1 Introduction

This Final Groundwater Modeling Report follows the preliminary report completed for the John Day Hydrogeologic Investigation, submitted to the City on August 9, 2021. The Hydrogeologic Investigation has been broken down into three phases of work to allow for review and comment among stakeholders, which include the City of John Day (City) and their consultants CwM-H2O (CwM), Kennedy-Jenks Consultants (KJC), and Flagline Engineering (Flagline), as well as Oregon Department of Environmental Quality (DEQ). Previous work in Phase 1 and 2 has been documented in the following technical memoranda and reports:

- Phase 1 – Field Investigation Plan, May 14, 2021
- Phase 1 – Preliminary Alluvial Aquifer Hydrogeologic Report, May 21, 2021
- Phase 2 – Field Investigation Technical Memoranda, August 9, 2021
- Phase 2 – Preliminary Groundwater Modeling Report, August 9, 2021
- Phase 2 – Aquifer Test Analysis Technical Memorandum, September 27, 2021
- Phase 2 – Groundwater Quality Investigation Technical Memorandum, October 19, 2021

Phase 2 groundwater modeling work was aimed at constructing a representative computer model of the John Day Alluvial Aquifer system based upon available desk-top data. A primary model was developed in MODFLOW-6 and was calibrated to existing field data from 2019 for initial simulations of various wastewater infiltration scenarios. Supporting models in VS2D and Mound Solv were designed to match the MODFLOW model structure and the functionality of the aquifer system. In Phase 3, these three groundwater models were refined based upon new site-specific data from well borings, groundwater monitoring, aquifer pump tests, water quality sampling during Site Visits 2 and 3, and from digitized historic City records. The ultimate goal of the modeling effort is to simulate the impact and fate of infiltrated wastewater, inform infiltration system design and placement, and to assist in optimizing operations of the planned wastewater facility.

In this final report, CwM presents a description of the computer groundwater model constructed to simulate groundwater flow in the dredge tailings and related deposits along the north side of the John Day River. CwM understands that the alluvial sand and gravel deposits, which have been altered by historic gold-dredging activity, will act as part of an infiltration system for treated effluent under a proposed Water Pollution Control Facility (WPCF) permitting pathway. The City is in the process of planning a new Wastewater Treatment Plant (WWTP) which will discharge treated effluent to an infiltration system, yet to be fully designed, but which is intended to meet the federal Environmental Protection Agency (EPA) Guidance and state required regulatory framework for permitting a WPCF permit. The evaluation covered in this report includes a summary of the latest modeling results from simulations of infiltration through the proposed subsurface infiltration galleries (SIG), as well as an alternative location on the adjacent property.

Modeling programs used in this evaluation include:

- MODFLOW-6 (Langevin et al., 2021) with Model Muse (Winston, 2020)
- Mound Solv (Duffield, 2021)
- VS2D-HI (Healy & Ronan, 1996)

Available data from previous site and regional studies (Chadwick, 1999; Schlicker & Brooks, 1975; Thayer, 1972) and data collected in the field during Site Visits 2 and 3 of this study were used to develop and refine a three-layer model of the alluvial aquifer within the Project Area (Figure 1: John Day Project Area Map and Figure 2: Map of Alluvial Aquifer Model Boundary) using the USGS computer program MODFLOW-6. The aquifer model area was defined by the John Day River to the south and the bedrock foothills on the north side of the valley, which together form a hydraulically bounded portion of the aquifer containing the current WWTP and the proposed SIG (Figure 2). The sensitivity analysis performed on the preliminary model identified the hydraulic conductivity of the upper model layer (Layer 1 – Dredge Cobbles, Section 3.1.1) as the highest-impact parameter. Hydraulic properties of the model layers and boundary conditions from the preliminary model (Preliminary Groundwater Modeling Report, August 9, 2021) were updated based on new aquifer test results and other field data. As in the preliminary model, the MODFLOW model was calibrated by comparing simulation results to available groundwater, pond, and river level measurements from 2019 field surveys.

A simplified cross-sectional model was constructed in the heat transport model VS2D based on the same aquifer dimensions, layers, and properties as the MODFLOW model. The VS2D model was used to simulate the thermal effects of infiltration on the down-gradient aquifer and the hyporheic zone of the John Day River. Hydraulic and thermal properties in the VS2D model were also updated to reflect the changes to the final MODFLOW model. The simple mounding program MoundSolv was used to quickly evaluate various configurations of the SIG, the effects of seasonal groundwater gradients, and aquifer properties in relation to groundwater mounding.

1.1 Site Conditions and Summary of Results

The aquifer pump test study completed in Phase 2 yielded a range of transmissivity estimates for the dredged alluvial aquifer within the range of published estimates for similar materials (Phase 2 – Aquifer Test Analysis Technical Memorandum). The upper estimate for transmissivity was used in models simulating fate and transport to generate conservative (shorter/faster) estimates of travel distance and time. In contrast, models simulating mounding were run using the lower end estimates of transmissivity to provide maximum mounding estimates for use in planning and design.

Initial drawings of the proposed SIG include three closely set, parallel 61 x 1.25 x 1.5-m StormTech Chamber galleries located in the northwest portion of the former Oregon Pine Products site, approx. 360 m down-gradient of the existing percolation ponds (Figure 1). This study proposes and discusses an alternate location about 125 m northeast between the Iron Triangle and Oregon Pine properties (Figure 1). Both SIG locations were modeled.

The planned capacity of the SIG is 0.30 MGD (1,136 m^3/d), equivalent to an average rate of about 208 gallons per minute (gpm). At the primary proposed location, the final MODFLOW and MoundSolv models predict this infiltration rate will cause a maximum groundwater mound (low transmissivity estimate) of about 0.52 m directly below the center of the SIG after three years of continuous infiltration. Actual anticipated mounding is about 0.12-0.25 m. The predicted mounding at the alternate SIG location is greater (maximum of 0.80 m, anticipated of about 0.30 m) because the aquifer is thinner at that location. Both locations experienced maximum mounding less the approx. 1.2 m of available unsaturated zone beneath the SIG, and are therefore able to handle short periods of increased infiltration capacity if needed.

Tracking particles originating at the proposed SIG traveled approx. 990 – 1,140 m before discharging to the John Day River based on the final MODFLOW model MODPATH simulations. The flow path is expected to take a minimum of 32-36 days, with the longest flow path along the north side of the infiltration plume. Average groundwater flow velocity down-gradient of the SIG is approx. 0.0004 m/s, compared to summer low-flow velocity of about 0.5-1.0 m/s in the John Day River. The infiltrated water plume from the proposed SIG intercepts the river along an approx. 100-200-m wide reach of the channel. Unlike in the preliminary model, the location of the discharge reach does not vary significantly by season in the final model. The receiving reach of the river is most narrow in May when river levels peak. The flow path from the alternate location is 1,440 m to more than 2,000 m, with minimum travel times of 50 – 89 days. The area of potential discharge to the river produced by the alternate SIG was more than 800-m wide.

The MTD3MS extension in MODFLOW was used to simulate the transport of a conservative solute tracer from the SIG. The conservative tracer experienced only advection, dilution, dispersion, and slow decay. This very modest decay rate based on evidence of denitrification occurring down-gradient of the current percolation ponds. The model suggested that the concentration at discharge of between approx. 2-30% of the influent concentration released at the SIG, depending on the seasonal water table and location within the plume. The highest concentrations (20-30% of influent concentration) occur at the very center of the plume. Outer sections of the plume average about 10% or less of the influent concentration. Less than 5% of the solute load was removed through the decay function (denitrification) because of the relatively brief residence times. However, even a slight reduction in transmissivity, an increase in residence time, or an increase in decay rate due to improved biological conditions has the potential to increase decay reduction to 10-20%. Because of the effect of dispersion within the aquifer, the modeled tracer discharges to the river along a wider reach than the MODPATH tracking particles, which travel only according to groundwater gradients (Anderson, 1979).

The heat transport model VS2D was used to simulate the thermal effects of infiltration on the aquifer and groundwater that discharges to the John Day River. Assuming a constant initial influent temperature of 20°C, the preliminary heat transport model predicts that the center of the infiltrated water plume will be a maximum of approx. 2°C warmer than the background groundwater (groundwater at this location without any infiltration through the SIG) in the near-river environment after three years of continuous infiltration. During the summer, this temperature difference is around 1°C and groundwater in the plume discharge area remains cooler than river water. Temperatures away from the center of the plume are expected to be closer to background groundwater conditions, much like in the tracer plume. Once the plume enters the hyporheic zone of the river, the infiltration temperature signature is expected to be further reduced. The model assumed constant influent temperature year-round. Actual SIG operations would likely be able to reduce the temperature of the infiltration wastewater below 20°C during the winter when thermal effects on the river are of the greatest magnitude.

1.2 Limitations of the Groundwater Models

All groundwater models have limitations related to the availability of site-specific information, the degree of simplification necessary for very complex groundwater-surface water systems, and the capacity of the computer models themselves. The primary limitation in this modeling study is the availability of spatially and temporally diverse calibration data for the site (discussed in Section 3.1.3). The only site-specific calibration data available is from one year (2019) which may not be representative of future water years.

Most of the calibration data is also concentrated in the eastern third of the model area, leaving greater uncertainty in the down-gradient portion of the model.

Other limitations include subsurface heterogeneity and simulating groundwater-pond interactions. It is expected that heterogeneity exists within the alluvial aquifer's structure given its history of human alteration. The well logs and test pits available provide only point data across the study area. Certain assumptions of regularity and homogeneity must be made in the absence of continuous spatial information. The impacts of such assumptions on the model results, in this case, typically make for a more conservative model. The exact relationship between groundwater and the multiple log ponds in the study area has not been described. Available data suggests the level of the ponds is substantially higher than adjacent groundwater for at least a portion of the year. The information required to accurately model these ponds, which would include water depth, thickness and hydraulic conductivity of bed sediments, are not available. The groundwater model presented in this report is therefore unable to simulate these ponds in the groundwater flow field presented.

2 Geologic Description

The development of a groundwater flow model begins with an investigation of regional and local geologic conditions and controls. Before the modeling process, CwM completed a review of available maps and reports regarding the lithology and geologic structures of the John Day area. The hydrogeologic characteristics of the local alluvial aquifer frame the development of the preliminary groundwater model. However, recognizing the regional geologic history is key in understanding how the alluvial aquifer formed and how it will behave under the proposed operational conditions. The following information is from the Phase 1, Task 1.2 – Alluvial Aquifer Hydrogeology Conceptual Model (CwM-H2O, 2021).

2.1 Regional Geology

The City of John Day and the John Day River Valley mark the boundary between two major geologic and physiographic provinces. Much of the state north of the river is dominated by the Columbia River Flood Basalts in the Columbia Plateau region. To the south are the upper reaches of the Basin and Range, which is characterized by extensional fault-block mountain ranges and its own distinct volcanic activity. Paralleling the John Day River and reinforcing this regional border is the John Day Fault, which juxtaposes the geologies of these two provinces in the area of the City. Much of the following geologic description is based on Thayer, 1972 and Schlicker & Brooks, 1975.

The oldest rocks exposed at the surface in the immediate John Day area are Paleozoic meta-sedimentary rocks that form the core of the Strawberry and Aldrich Mountains just south of the river valley. Mud and silt that were deposited on a shallow continental shelf about 350 – 400 million years ago (my) have been altered by the tectonic activity that followed and now appear as shale, schist, and amphibolite. These ancient deposits are usually logged as shale or slate in the deep well logs in southern John Day but are also exposed at the surface just west and south of the Grant County Regional Airfield. Between 200 – 250 my ago, metal-rich mafic magmas erupted to the surface of the sea floor, burying the older sediments. The next 100 my saw repeated phases of regional uplift, subsidence, erosion, and volcanic activity which formed the Canyon Mountain Complex. The mafic lavas from this period have been altered to serpentinite and soapstone, which can also be seen in deep well logs in the area and in road-cuts along Highway 395 (Wagner, 1957).

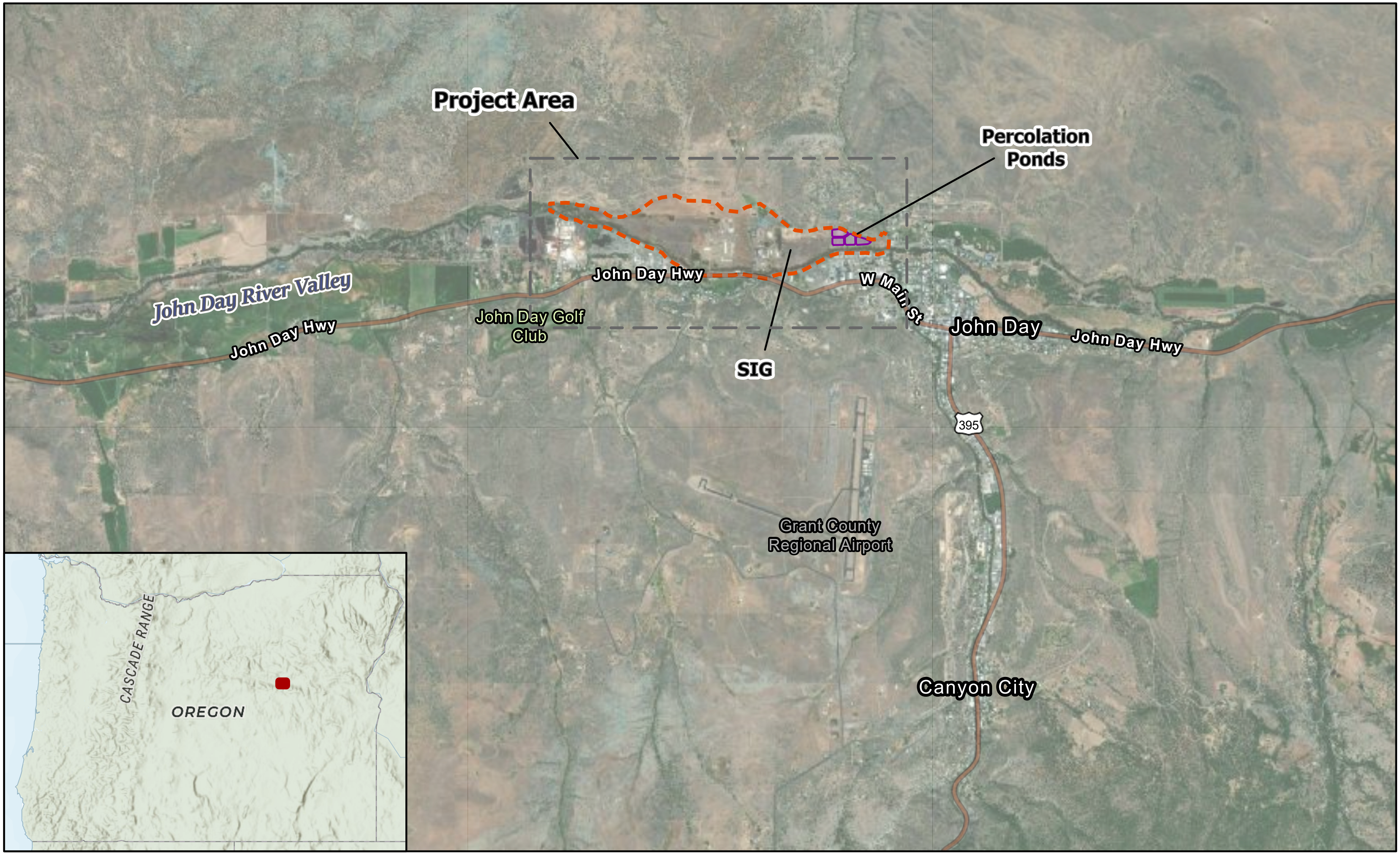

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Figure 1
John Day Project Area Map

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Scale: 1" = 5,410 ft

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Alluvial Aquifer Model Boundary
City Percolation Ponds

Between 100 – 145 my ago, a large igneous intrusion was formed about 20 miles northeast of John Day near Dixie Butte. The hydrothermal activity associated with this intrusion was the source of gold and other heavy metals that were placer mined along the John Day for half a century. Erosion has exposed the heart of this intrusion at the surface. The volcanic arc that formed west of the region between 40 – 60 my ago laid hundreds to thousands of feet of ash, sand, and andesite/rhyolite lavas of the Clarno and John Day Formations. The Clarno is exposed in the hills just northwest of downtown John Day and underlies parts of the John Day River at a relatively shallow depth. The Picture Gorge member of the Columbia River Basalt Group (CRBG) flooded the entire John Day Basin with hundreds of feet of lava starting about 20 my ago. Soon after, a series of volcanos erupted in the location of the Strawberry Mountains and contributed ash-fall tuffs and andesite lava flows (Steiner, 2016). This continuous cap of recent volcanics was broken in the last few million years when compressional forces folded and faulted the region. The John Day Fault formed along the river valley and lifted the area south of the river upward. Relative movement was as great as two miles in some areas of the Strawberry Mountains. Continued erosion exposed the older rocks in the hills south of John Day and filled the river valley with silt, sand, and gravel (Thayer, 1972).

2.2 Model-Area Hydrogeology

The planned location of the new WPCF facility is approx. ¼ mi downstream (west) of the current percolation ponds in the middle of the John Day River Valley (Figure 2). The location is dominated by recent, shallow alluvial deposits from the erosion of the surrounding mountains. It is in this alluvial material that gold was found in the mid-19th century. In addition to hosting gold, the alluvial deposits hold significant groundwater. In many parts of the John Day Valley, the 10 – 50 ft-thick near-river alluvium is the only reliable groundwater source (Frank & Oster, 1979).

The WPCF site is located in a hydrologically bounded portion of the river valley alluvial aquifer where the John Day River bends south as the toe of the bedrock foothills curve north (Figure 2). On the east end, the John Day River nearly meets the northern CRBG and Clarno Formation foothills at Davis Creek. To the west, the river meets the foothills again north of Malheur Lumber. The John Day River acts as a flux-boundary and hydraulic control to the south, while the low-permeability bedrock in the foothills forms a no-flow boundary to the north (Figure 2). The basalts, tuffs, and mafic lavas underlying the alluvium are typically altered to clays, forming a low-permeability confining unit below the aquifer. The result of the geographic and geologic constraints is an oval-shaped segment of the aquifer, widest in the middle (approx. 0.5 miles) and tapering out towards the west and east (approx. 1.5 miles). This area defines the groundwater model boundary. Within the model area the groundwater flow direction is generally from the east to west.

2.2.1 The Impacts of Dredging and Grading on Hydrogeology

The depositional history of the alluvial aquifer within the model domain includes recent dredging of the native materials. The entirety of the model area was dredged for gold starting in the 1890s. Small independent placer miners had been gold mining in the valley since the 1862. Starting in 1898, the Burns Consolidated Placer Mining Company began buying up claims and leases that covered most of the valley floor around the City. This included the Luce and Trowbridge farms, which are the namesakes of two major irrigation ditches on the southwest and northeast sides of the model area (BLM, 1955).

In 1899, the Pomeroy Dredging Company out of Portland, Oregon announced the construction of a large dredge on the John Day River. This machine operated in the area around the City for two years until a larger dredge (40 ft by 110 ft) was put in place in 1901. This was the largest gold dredge in the Western United

States at the time. Reports from the Pomeroy Company suggest an average depth of the alluvium of about 18 ft, with serpentinite and slate underlying sections of the river (Lindgren & Jackson, 1901), in agreement with modern well logs and borings completed as part of this investigation (CwM Well Installation Technical Memorandum, August 2021). Dredges excavated anywhere from 10 to 20 ft below the natural land surface (Lindgren & Jackson, 1901). The Burns and Pomeroy Companies were active in John Day until about 1915.

The same area was selectively reworked between 1915 and about 1930 by immigrant miner groups from China. The Walter W. Johnson Dredging Company operated an even larger dredge across the region, dredging from Mt. Vernon up to John Day, between 1937 and about 1948. This dredge was capable of digging to a depth of 23 ft and was highly effective at separating fines and discharging them to the river (Mining World, 1939). During this period, lower Canyon Creek was also dredged at least twice, potentially including part of what is now downtown John Day.

Due to the long history of dredge mining and redeposition, the valley geology in the model area is now effectively three distinct units, which are described here based on conditions observed during well installation in Site Visit 2: Dredged cobbles and gravel, dredged sand and gravel, and a lower confining unit.

- Dredged Cobbles & Gravel – predominantly boulders, cobbles, and gravel with little sand and minimal fines (Dyksterhuis, 1981). Estimated to have a high hydraulic conductivity, possibly on the order of an inch per second or more.

- Dredged Sand & Gravel – a layer of dredged alluvium where fine material was redeposited during mining activities. This layer appears to be absent where the alluvium was not dredged. Usually described in well logs as silty or sandy gravel with primarily pea gravel. This layer likely has moderate conductivity and varies in thickness from absent to 9 ft or more, as seen in the log for City Monitoring Well #5 (GRAN-50156).

- Lower Confining Unit – undisturbed clay-matrix alluvial or floodplain deposits, glacial till, and highly-weathered basalt and ultramafic bedrock which all act as a lower confining unit for the younger valley deposits. These formations all share a very low hydraulic conductivity 3-6 orders of magnitude less than the overlying alluvium (estimated around 4.7x10-8 m/s by Chadwick, 1999).

The dredging activity also altered the natural channel of the John Day River. Some reaches of the river probably still overlay original channel sediments, though much of the river flows directly over and through dredge tailings (Reclamation, 2008). For this reason, the river and alluvial aquifer are suspected to be in relatively close connection. This is clearly suggested by river level and groundwater depth data collected from the City's monitoring wells and the wells constructed during this field investigation. Groundwater levels in wells throughout the aquifer vary by 0.05-0.08 ft each day in response to river level changes (Phase 2 – Aquifer Test Analysis Technical Memorandum). On a seasonal timescale, river levels directly south of the percolation ponds typically vary by 1.5 to 2.0 ft, which is echoed in the alluvial aquifer by about a 1.0 ft variation in the nearby monitoring wells (MW-5 and MW-6). Many shallow ponds and wetlands were formed by dredging and still exist in the Project Area. There is evidence that these ponds, because of the low permeability soil beds and vegetation communities that have developed within them over the last century, may maintain high spring water levels throughout much of the summer after groundwater levels drop (Reclamation, 2008). For this reason, pond water levels may not represent true groundwater elevations as accurately as levels obtained from monitoring wells or recently excavated test pits.

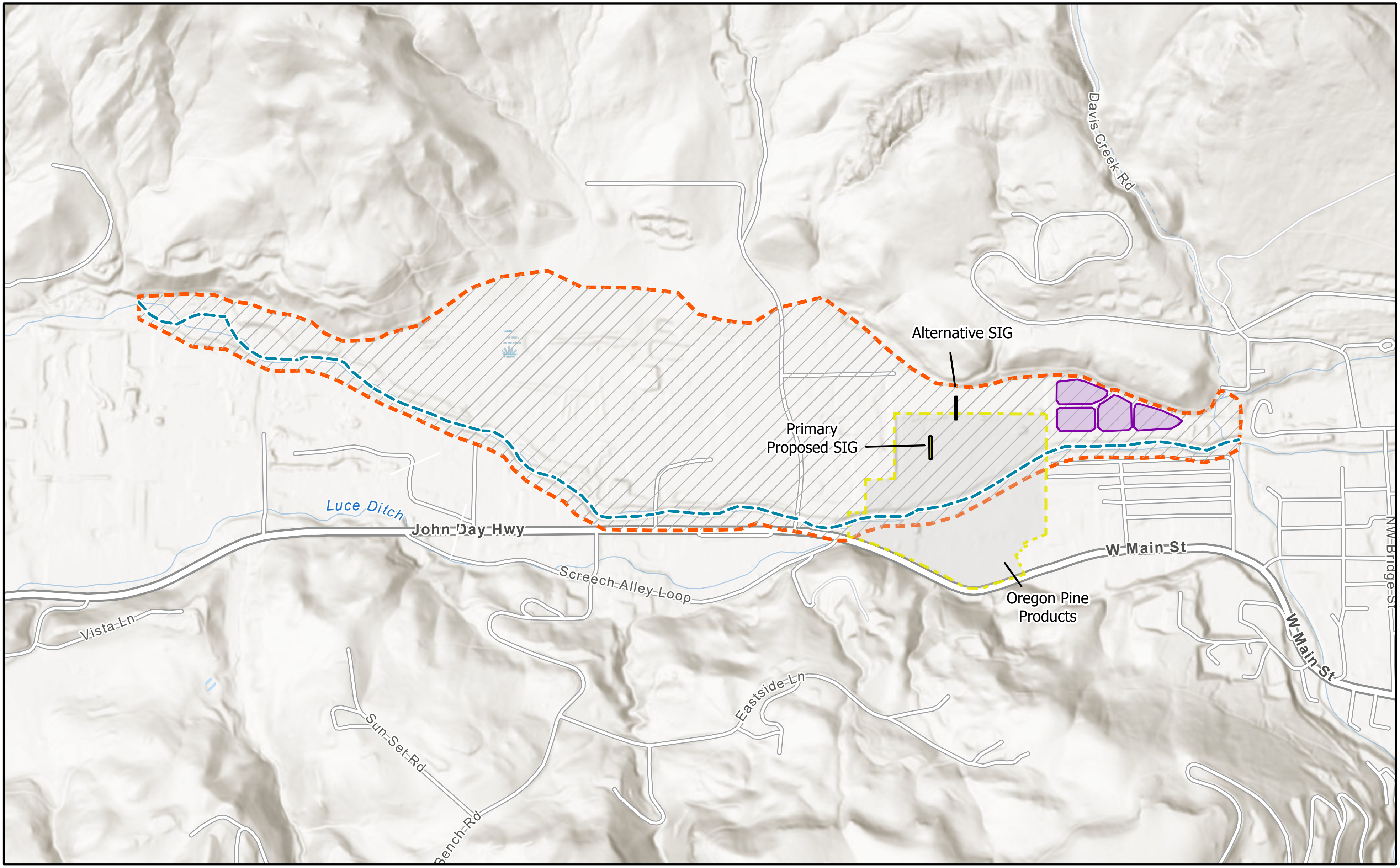

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Figure 2
Map of Alluvial
Aquifer Model Boundaries

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1	DATE	AUTH	DRAFT

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Alluvial Aquifer Model Boundary
City Percolation Ponds
River CHD Boundary

The physical removal of fine sand, silt and clay caused by the dredging activity has a major impact on the hydraulics of the proposed SIG. The coarseness and high conductivity of the dredge tailings are ideal for infiltrating water at a high rate with minimal groundwater mounding. However, these factors result in shorter residence times for the infiltrated effluent before discharge to the John Day River, as well as a lower potential for further in-ground treatment. The relative interconnection of the aquifer to the river also has implications for seasonal variability in groundwater flow velocity, flow direction of infiltration water from the facility, and thermal controls of the river on the aquifer.

3 Modeling Methods

CwM employed three modeling programs to evaluate the various infiltration scenarios for the proposed SIG: MODFLOW-6, MoundSolv, and Variably-Saturated 2D (VS2D). The primary three-dimensional groundwater flow model was developed in MODFLOW-6 (Langevin et al., 2021) using the graphical user interface ModelMuse (Winston, 2020), both developed by the United States Geological Survey (USGS). The MODFLOW model incorporates the entire active extent of the alluvial aquifer, i.e., the portion of the alluvial aquifer that controls and is affected by the proposed operation of the SIG. The MODFLOW model was responsible for simulating groundwater levels, groundwater flow paths (using the MODPATH package), and contaminant transport (using the MT3DMS package).

MoundSolv, a simple box-aquifer model, was used to quickly assess the impacts of SIG size, design, and local conditions on groundwater levels (Duffield, 2021). The results from MoundSolv were used to check the precision of the larger-scale, coarser-grid MODFLOW model results.

Finally, the USGS program VS2D (Healy & Ronan, 1996) was used to model the extent of heat transport throughout the aquifer and to surface water discharge zones. VS2D is a two-dimensional, cross-sectional model of groundwater systems and does not model flow or heat distribution in the river channel itself. Instead, the VS2D model is aimed at understanding the travel time of the infiltration heat signature through the alluvial aquifer and the long-term impact of infiltration on groundwater temperature in the hyporheic environment of the John Day River. The VS2D model was used to assess operational methods for reducing thermal impacts to the river.

3.1 MODFLOW-6 Model Construction

Many of the features used to construct the MODFLOW-6 model domain were first developed in ArcGIS-Pro (ESRI, 2019). For example, features such as the percolation ponds, SIG, monitoring wells, test pit and log pond groundwater checkpoints were first created in ArcGIS-Pro. The spatial elements were imported into MODFLOW as shapefiles and a model grid of 5 by 5-m cells was created based on the alluvial aquifer model boundary.

The model boundary was defined based on the active extent of the aquifer from topographic maps and aerial images (Figure 2). The alluvial sand and gravel aquifer straddles the John Day River, extending up to a kilometer north or south beyond the current banks. The east end of the aquifer model was defined by the confluence of Davis and Canyon Creeks with the John Day River, near the current WWTP. The point where the John Day River pinches out the alluvial aquifer deposits against the north side of the valley defines the west end of the model. The north side of the model is marked by the slopeward extent of the alluvium and dredging, and the John Day River defines the southern model boundary. The model boundary extends roughly 30 m to the south of the river to reduce edge-effects in the model results. All model domain edges were modeled as no-flow boundaries. The model configuration of the John Day River boundary condition is discussed in Section 3.1.2.

3.1.1 Model Layers

The model consists of three layers which were defined based on data from borings completed as part of this investigation, local well logs, test pit observations (CwM, 2021; Chadwick, 2019), geologic maps, and mining reports (Figure 3: Alluvial Aquifer Stratigraphy and Model Conceptualization). Layer 1 (from ground surface downward) is the dredged and washed alluvium consisting of course cobbles and gravels with little sand and trace silt. The dredged cobbles and gravel layer in the three CwM wells installed at the proposed SIG location was 5.2-5.8 m (17-19 ft) thick. The top surface of Layer 1 was defined by the surface elevation (3-m DEM data from USGS). Extensive alteration of the land surface has created artificial piles of tailings as well as deep pits and trenches up to 4 m higher or lower than the surrounding land surface. Therefore, the thickness of Layer 1 was not defined downward from the land surface (i.e., Surface Elevation – X-m) to avoid creating a highly variable layer-bottom not representative of true conditions. The bottom of Layer 1 was instead defined at seven transects across the model, roughly corresponding to field data points (monitoring wells, test pits, other well logs), and interpolated as a fitted surface over the rest of the model (Table 1). Layer 1 therefore ranges from about 2 m (within existing pits or trenches like the one just west of the proposed SIG) to 10 m (at existing tailing piles and mounds) but averages 5.0-6.0 m (approx. 16.5-20 ft) over the model area (Figure 3).

Table 1 – Layer 1 Thickness Transect Reference Points

Parameter	Transect 1	Transect 2	Transect 3	Transect 4	Transect 5	Transect 6	Transect 7
Reference Point[1]	GRAN-51028	GRAN-399	GRAN-51148/51157, GRAN-50583	CwM-1, CwM-2, and CwM-3	MW-6	MW-5	MW-7
Layer 1 Thickness at Transect	6.0 m	7.3 m	6.5 m	5.5 m	5.0 m	4.5 m	4.0 m
Notes	[1]The transects are ordered from west to east across the model domain.						

Layer 2 is a unit of finer dredge deposits and disturbed alluvium that underlies the large cobble and gravel tailings. Layer 2 consists of fine gravel, medium to coarse sand, with some silt and occasional cobbles. This material represents where washed fines were discharged during certain phases of dredging and is noted in many well logs in in the John Day River Valley where dredging took place. Layer 2 appears to be absent where the alluvium was not thoroughly dredged (such as in the Old Mill area south of the John Day River) but is probably continuous across the dredged area north of the river. The thickness of Layer 2 was observed to vary between about 0.7-2.5 m (approx. 2.5-8 ft) between the CwM wells (CwM-1, 2, and 3) and City monitoring wells (MW-5, 6, and 7), with an average of about 1.5 m (4.9 ft). For the purposes of the model, the bottom of Layer 2 was defined as 1.5 m below the bottom of Layer 1 and was consistent in thickness (Table 2, Figure 3).

Finally, Layer 3 is fine-grained, undisturbed alluvium or valley basement material. The bottom of this material, which appears as a compacted blue-gray gravelly silt, was not reached in any of the CwM wells or City monitoring wells. Area well logs suggest the gravelly silt and clay material ranges from 3.6 m (11.8 ft) (GRAN 427) to 25.3 m thick (83 ft) (GRAN 407), below which is weathered to competent igneous or metamorphic bedrock. Material corresponding to Layer 3 was observed in the CwM wells (CwM-1, 2, and

3) and in monitoring well borings south of the river (GRAN-51436-51438) to act as a lower confining unit for the alluvial aquifer. The material tended to be dry below a wetted upper margin approx. 0.1 – 0.2 m (4-8”) and appears to exhibit an extremely low hydraulic conductivity relative to the overlying units. Because of the stark difference in conductivities between the dredged alluvium and fine-grained deposits, Layer 3 is a functional barrier to groundwater flow. Matching the layer thickness to observed conditions will not significantly affect flows in the model. For this reason, a regular thickness of 10 m was applied to Layer 3 (Figure 3). The hydraulic properties of each layer in the final model were defined using estimates from site-specific field studies, when available, or previous local studies as described in the Preliminary Groundwater Modeling Report (Table 2).

Table 2 – MODFLOW Model Layers

Parameter	Layer 1	Layer 2	Layer 3
Layer Material	Dredged Cobbles and Gravel	Dredged Sand and Gravel	Confining Unit
Layer Thickness	Variable[1], ~2 – 10 m	1.5 m	10 m
Hydraulic Conductivity (m/s) Horizontal	0.0178	1.78×10^{-4}	5×10^{-8}
Hydraulic Conductivity (m/s) Vertical	0.0178	1.78×10^{-4}	5×10^{-9}
Specific Storage / Porosity	1×10^{-5} / 0.30		
Model Initial Head	Model Surface Elevation (fully saturated model)[2]		
Notes	[1]The thickness of Layer 1 averages about 5 to 6 m but varies based on the altered surface topography of the model area. [2]Though the model begins fully saturated, the influence of the RIV boundary causes the model to adjust during the initial steady-state modeling period.		

Table 3 – MODFLOW RIV Boundary Conditions for the John Day River

Season	Downstream Reach RIV Elevation	Upstream Reach RIV Elevation
December-January[1]	DEM elevation + 0.20 m	DEM elevation + 0.15 m
February-March[1]	DEM elevation + 0.35 m	DEM elevation + 0.30 m
April	DEM elevation + 0.55 m	DEM elevation + 0.50 m
May	DEM elevation + 0.65 m	DEM elevation + 0.60 m
June	DEM elevation + 0.25 m	DEM elevation + 0.20 m
July	DEM elevation + 0.10 m	DEM elevation + 0.05 m
August	DEM elevation + 0.05 m	DEM elevation
September	DEM elevation + 0.10 m	DEM elevation + 0.05 m
October-November	DEM elevation + 0.17 m	DEM elevation + 0.12 m
Constants	**RIV Conductivity Downstream of Diversion Structure**	**RIV Conductivity Upstream of Diversion Structure**
	10 m^2/s [2]	10 m^2/s [2]
	[1]No City data points from January and February, each month grouped with adjacent month. [2](Riverbed-K*Cell-length*Cell-width)/(Riverbed-thickness)	

3.1.2 Boundary Conditions

The John Day River is the primary boundary condition included in the MODFLOW model and was treated as a river flow boundary (RIV). Cells assigned to the RIV boundary maintain a specified effective water level and can be both a source and sink of groundwater flow in the model (Figure 4: MODFLOW Model Representation of Alluvial Aquifer-River System).

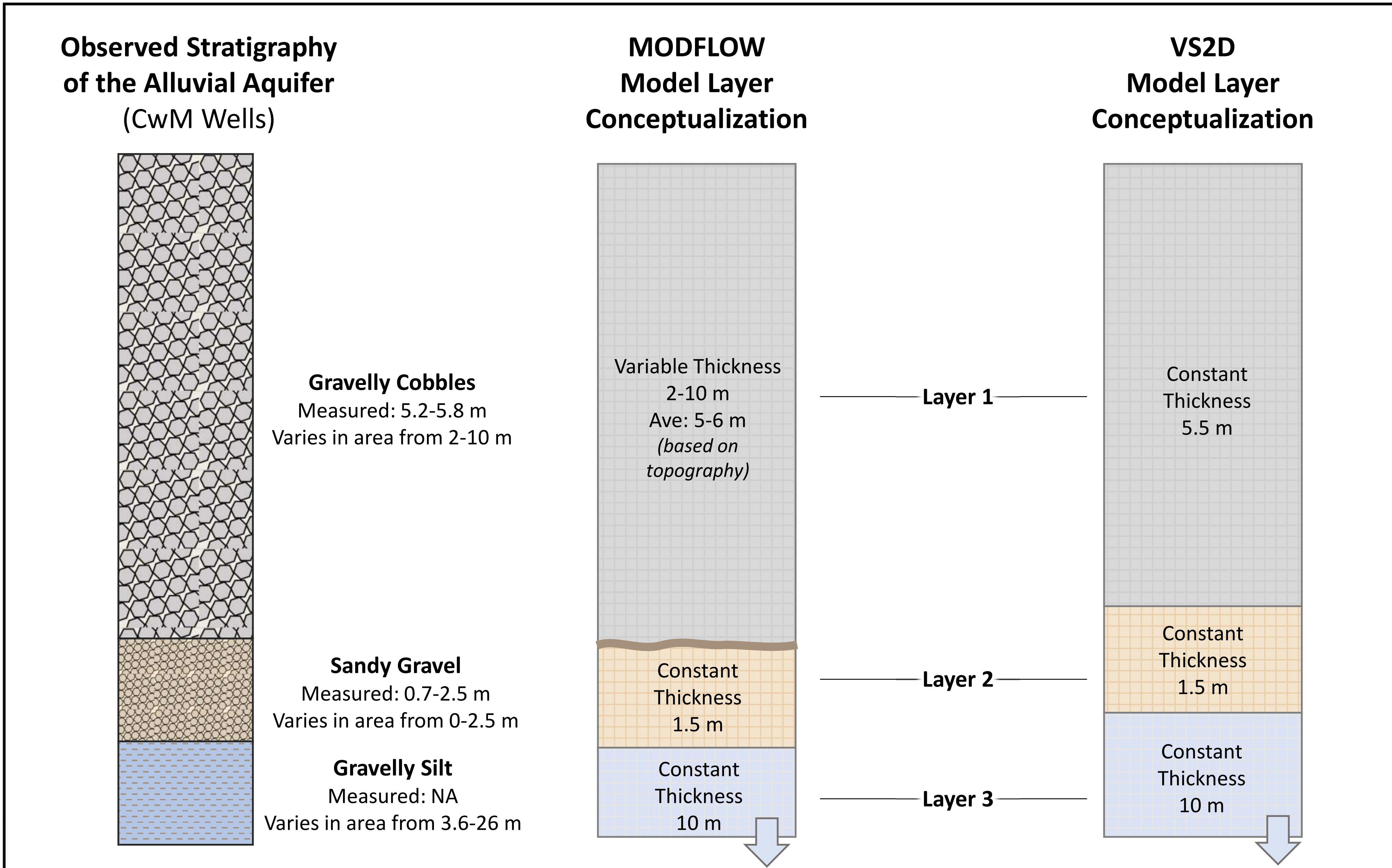

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Figure 3
Alluvial Aquifer Stratigraphy and Model Conceptualizations

The location of this boundary was determined from the DEM data which defined the model surface. The model cells with the lowest DEM elevation value within the John Day River channel (corresponding to the water surface) were selected as RIV cells. The bottom of the river channel at each RIV cell was defined as half of the Layer 1 thickness (i.e., (Model_Top + Layer1_Bottom)/2)), which allows for possible underflow beneath the river (Figure 4).

It is important to note that the default elevations of the river cells within the model are dependent on the river level at the time the DEM dataset was collected. The actual river level and the corresponding values of the RIV cells should vary seasonally. The values of the RIV boundary cells were changed from the preliminary model values to more closely resemble a representative hydrograph for the John Day River (Table 3).

The approximate river stage in January, April, and October of 2019 relative to the DEM dataset elevations were determined from previous survey measurements (Chadwick, 2019; CwM-H2O, 2021). These site-specific values were also compared to discharge measurements from the USGS river gage approx. 3 miles upstream on the John Day River (USGS 14038530). The DEM dataset elevations appear to closely resembled low-flow river conditions from July or August. The relative seasonal change in water level from 2004-2018 City measurements at two points along the river (City stations SW-5 and SW-6) were averaged to create a typical hydrograph of the river in the Project Area relative to the DEM elevation values (Figure 5).

From the 2019 river level data, two river reaches were defined with slightly different stage corrections (Table 3, Figure 5). The break in stage correction corresponds with the Luce Irrigation Ditch diversion structure on the John Day River directly south of the planned SIG. The RIV boundary was divided into 11 separate reaches (8 downstream and 3 upstream of the diversion) to allow for better observation of river loss or gain relative to the aquifer.

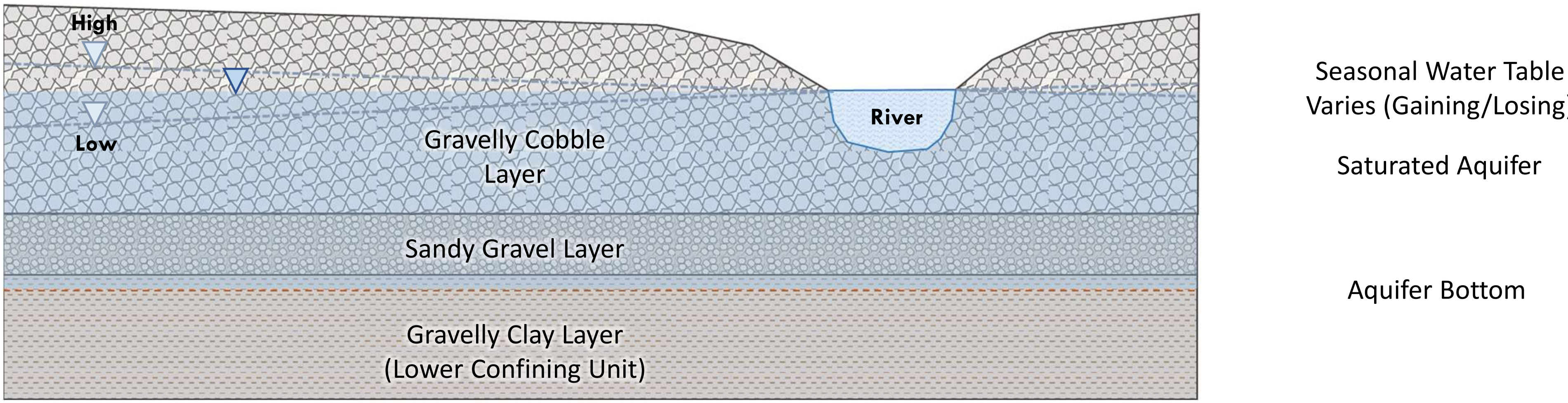
For the purposes of calibrating the model to existing conditions, a recharge boundary (RCH) was added to the model at the location of the City percolation ponds. The details of this boundary are explained in Section 3.1.3. During simulation of infiltration through the proposed SIG system, the SIG was also added as a RCH boundary with the dimensions and depth of the proposed structure. The pond RCH boundary was not modeled during simulated operations of the SIG.

3.1.3 Model Calibration

To calibrate the model, the model results needed a field measurement comparison. A previous City study included 22 water level measurement points, including wells, ponds, and test pits, with data over three seasons (Section 3.1.2). However, these measurements were collected while the current percolation ponds were in operation as they are today. The percolation ponds act as an additional input compared to the base model described in Section 3.1.2. To account for the percolation ponds, a recharge boundary condition (RCH) was added at percolation pond #2 (which appears to maintain continuous perched water) with a representative 0.30 MGD (1135.6 m^3) of recharge per day over the pond area for the purpose of model calibration. The model was run with this configuration and the RIV and RCH boundary conditions active. Modeled water levels were compared to measured levels at the 22 monitoring points with river stage adjusted based on seasonal data.

Riverbed conductivity, the level of the RIV boundary, and the Layer 1 transect thicknesses were adjusted slightly to achieve the best outcome with the other variables held constant. This model calibration process determined that the model accounted for 98.6-98.7% of the variation in groundwater levels observed in

Conceptualized Aquifer-River System



Modeled Aquifer-River System

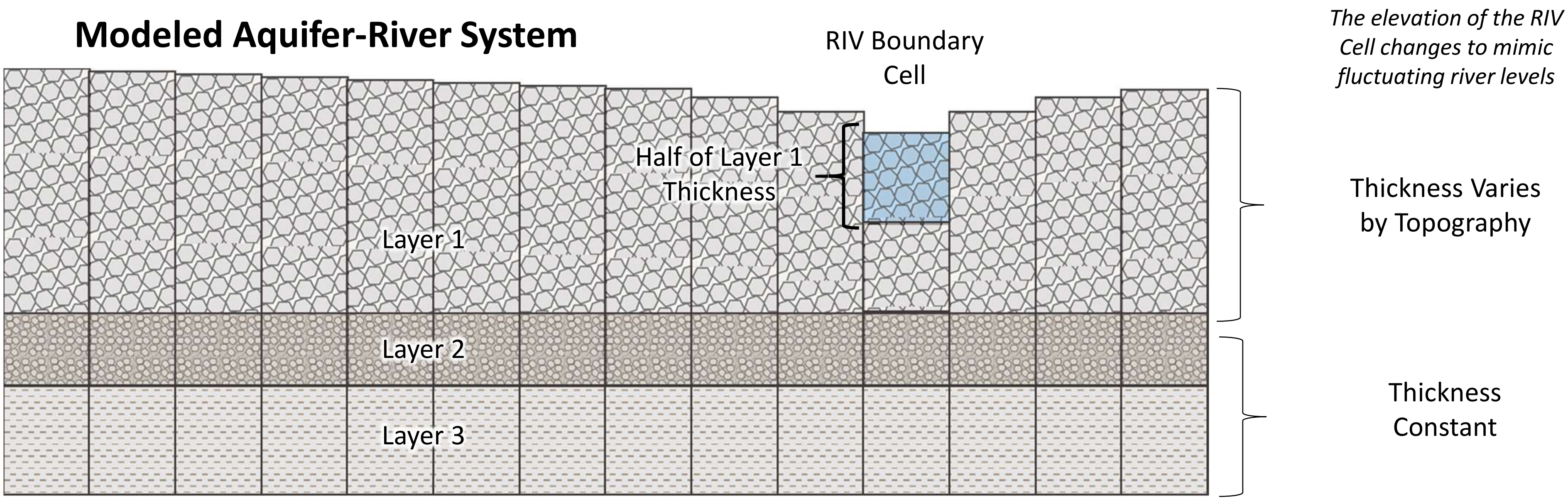


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Figure 4
MODFLOW Model Representation of Alluvial Aquifer-River System

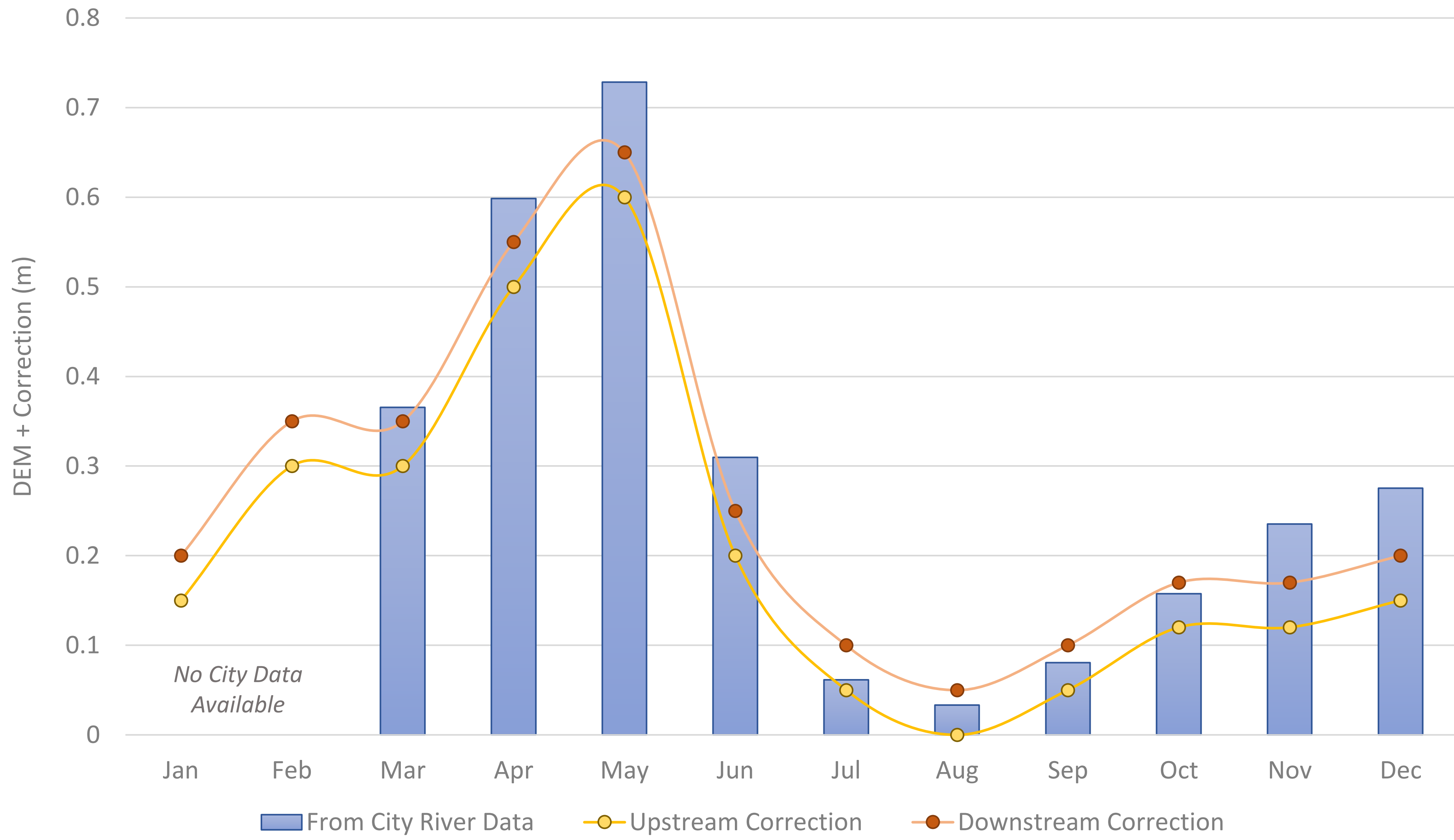

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Figure 5
Final MODFLOW Model RIV-Boundary Updated Hydrograph

the reference survey (Figure 6: MODFLOW Model Calibration Plots). The model predicted 40% of monitoring points to within 20 cm (8 in) of the observed levels, with April model predictions having the greatest error (average residual of ± 10.5 cm). The average residual across all seasons and calibration points ranged from ± 1.5 – 10.5 cm with root mean squared error (RMSE) of 39.1 – 45.6 cm.

The seven log ponds included in the calibration consistently had the largest discrepancies and were underpredicted significantly by the model (up to 1.13 m lower than measured). It is possible that the ponds have developed significant low-permeability sedimentation layers that hold water above the water table for much of the year (Reclamation, 2008). Ponds 1 and 2 (ponds on the US Forest Service property), pond 4 (Patterson Pond), and pond 5 (small u-shaped pond in the northwest portion of the model) all averaged more than 0.57 m lower than measured in the field. There is also evidence that some of these ponds may be used as water sources for other water rights, while others may receive pond maintenance water deliveries. The bowed contours on the hand-drawn groundwater level maps from the 2019 City study also suggest the ponds exhibit elevated levels relative to groundwater (Chadwick, 2019).

The model was most accurate in predicting groundwater levels in the wells and test pits closest to the proposed SIG area (note the low residuals in upstream data points on Figure 6). These results are satisfactory given that it is common for the stage of the John Day River to vary by up to 10 – 20 cm per day over winter and spring (based on date from Gauge USGS 14038530), which could translate to several centimeters of variation in groundwater level during the two of the field surveys that the calibration is based on. It must also be considered that the river hydrograph used in the model is an average of data spanning about 14 years, while the calibration data are all from 2019. The calibrated model is therefore representative of typical conditions, even if it does not perfectly match the conditions observed in the 2019 water year.

The down-gradient, western portion of the model did not include any well or test pit measurement points. The log ponds in this part of the model exhibited higher percent errors than the wells and test pits in the east. The model typically underpredicted pond levels, suggesting that the model was allowing faster transport of groundwater (higher gradient) than observations of pond water elevations would suggest. It is possible the higher margin of error corresponds to a change in aquifer conditions in this half of the model. However, given the history of dredging in the project area, the aquifer properties in this section of the aquifer are assumed to be nearly equivalent to the east portion of the model. If the observed level data for the ponds are accurate, then the underpredicting model will be conservative in terms of fate and transport predictions. The model would be simulating an increased gradient in the western part of the aquifer, resulting in faster travel times, less contaminant attenuation, and a lesser degree of dilution compared to what the observed pond levels would suggest.

3.1.4 Model Sensitivity Analysis

A basic model sensitivity analysis was performed on the calibrated preliminary model in order to determine which parameters have the greatest impact on model results. This was meant to inform development of the final model by identifying which parameters were most in need of field verification and which parameters could be held at a constant representative value. Twelve parameters were assessed in this process. The value of each parameter was varied so that the corresponding variation in model results could be determined. Parameters with a theoretically infinite range, such as hydraulic conductivity and vertical/horizontal anisotropy, were varied by two degrees of magnitude around the value in the base model. Parameters with plausible or absolute bounds, like porosity, were varied within their reasonable range (Table 4). The results of the sensitivity analysis performed in the preliminary study were assumed to be applicable to the final MODFLOW model, which was not drastically changed from the preliminary model. The transmissivity values determined in the field and applied to the final model were within the ranges tested for in the preliminary model sensitivity analysis.

Table 4 – Sensitivity Analysis from the Preliminary Model

Parameter	Min Value	Max Value	Range in Model Results[1]	Model Sensitivity
Layer 1 – Hydraulic Conductivity[2]	*$3.3x10^{-4}$ m/s*	*$3.3x10^{-2}$ m/s*	2.01	High
Layer 2 – Hydraulic Conductivity	$5.0x10^{-6}$ m/s	$5.0x10^{-4}$ m/s	0.18	Moderate
Layer 1 – Anisotropy[2]	*0.01 Kv/Kh*	*1.0 Kv/Kh*	<0.01	Low
Layer 2 – Anisotropy[2]	*0.01 Kv/Kh*	*1.0 Kv/Kh*	0.01	Low
Layer 1 – Specific Storage	$1x10^{-6}$	$1x10^{-4}$	<0.01	Low
Layer 2 – Specific Storage	$1x10^{-6}$	$1x10^{-4}$	<0.01	Low
Layer 1 - Porosity	5%	50%	<0.01	Low
Layer 2 - Porosity	5%	50%	<0.01	Low
Riverbed Conductivity – Up-stream Reach	$1x10^{-5}$ m/s	$1x10^{-3}$ m/s	0.20	Moderate
Riverbed Conductivity – Down-stream Reach	$1x10^{-5}$ m/s	$1x10^{-3}$ m/s	<0.01	Low
River Level Elevation[2]	*DEM – 0.25m*	*DEM + 0.15m*	0.24	Moderate

[1]Range in model results is shown as a factor of the deviation from observed values, or max error/min error.

[2]These values were tested in the sensitivity analysis for the preliminary model but were made static in the final model based upon field data gathered during Site Visits 2 and 3.

The hydraulic conductivity (K) of Layer 1, the target material for wastewater infiltration at the proposed facility, was found to be the most significant parameter in the preliminary model. Residuals between observed and modeled groundwater levels varied by more than a factor of 2 across the tested range of Layer 1 K. The effect of varying Layer 1 K was eight times greater than the second most significant parameter, river stage. The hydraulic conductivity of the Layer 1 material was estimated at 0.46-1.78 cm/s in the aquifer pump test (Phase II – Aquifer Test Analysis Technical Memorandum, September 27, 2021). These field-derived values are within the range tested for in the preliminary model sensitivity analysis (Table 4). For the purpose of maintaining a conservative model, the higher-end estimate of Layer 1 K (1.78 cm/s) will be used in the final MODFLOW model (Table 2). Based on the aquifer test and infiltration test data, the dredged materials of Layers 1 and 2 likely exhibit little to no vertical anisotropy. In the final model, both layers were simulated with a 1.0 Kv/Kh anisotropy. River levels were also adjusted based on the latest field data on river stage (Section 3.1.2).

The K of Layer 2 also had a moderate impact on the model results. Other moderate-impact factors are riverbed conductivity in the up-stream reach of the RIV boundary, and river stage. Seven of the tested factors had such a small influence on model results that they were kept constant in further iterations of this model, including the final model presented here.

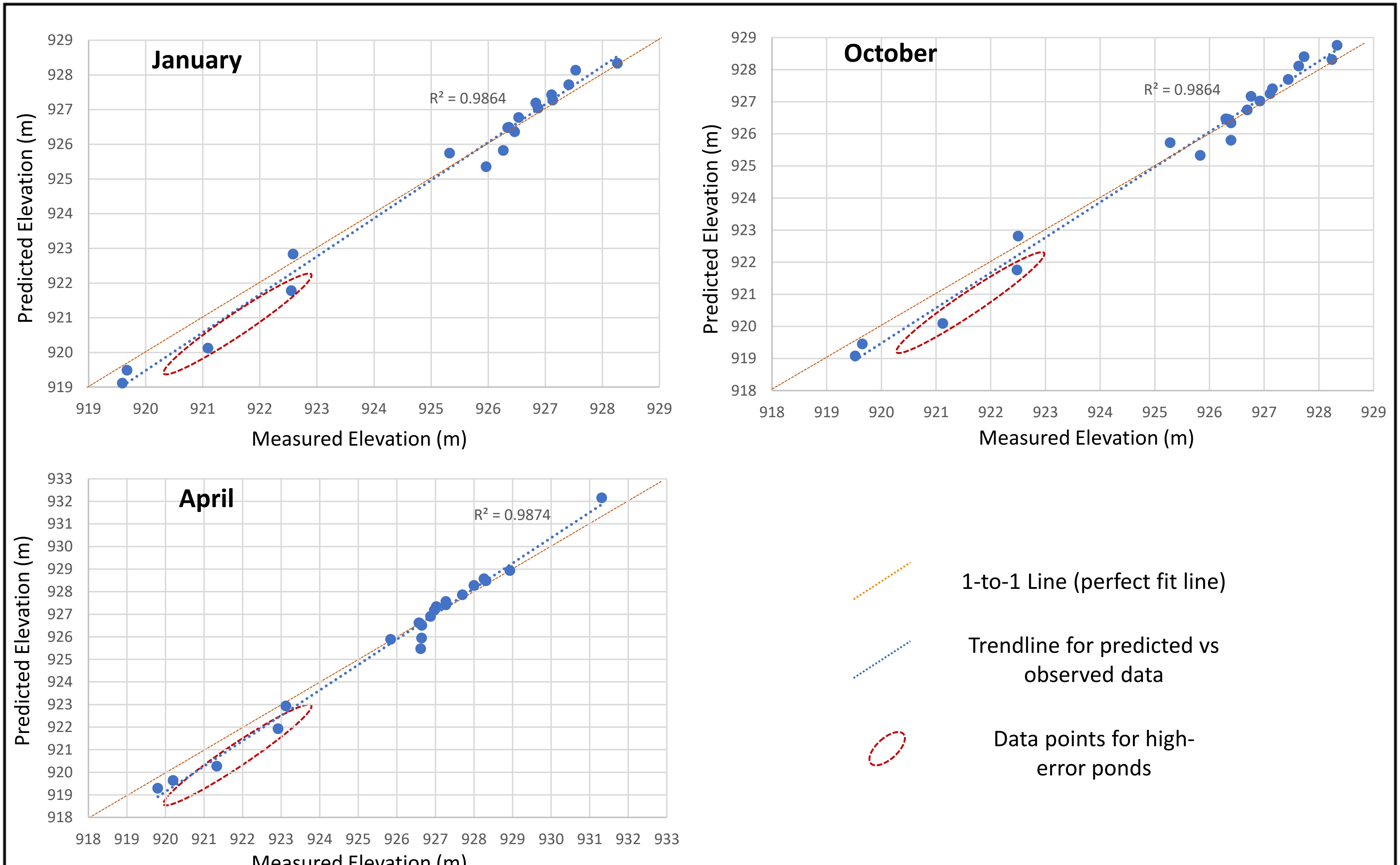

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Figure 6
MODFLOW Model Calibration Plots with Layer 1 K=1.78cm/s

Varying the conductivity of the riverbed for the RIV boundary cells was only significant in the upstream portion of the river (the three river reaches upstream of the Luce Ditch Diversion). This fact is due to the proximity of most of the 22 calibration points to this portion of the river. All but 6 of the checkpoints are cross- or up-gradient of part of the three upstream reaches. The six checkpoints closer to the downstream river reaches are all log ponds which, as explained above, were consistently underpredicted by the model across all parameter value ranges. Moderate adjustments to the riverbed conductivities, Layer 1 and 2 K, and even the values of the downstream transects that define Layer 1 thickness were unable to account for the underpredicting of these particular log pond checkpoints.

3.2 MoundSolv Model

The MoundSolv program is a simple box model that allows for rapid adjustment of aquifer and infiltration system properties to simulate groundwater mounding under various simplified scenarios. MoundSolv allows for visual assessment of mounding from above (plan view) and in cross-section. The same model parameters used to define the dredged alluvial aquifer material in the final MODFLOW model were used to create a model of the infiltration system in MoundSolv. With aquifer properties defined, MoundSolv makes it easy to change the size and shape of the infiltration system, as well as background conditions like static water level and gradient. This model will provide estimates of mounding using much finer cells than the MODFLOW model, making it a good source of check data for the large-scale model.

The SIG facility was initially designed in MoundSolv based on available plan drawings. Though the early proposed system consisted of three narrow, parallel trenches, the MoundSolv model treated these as one wide trench with a total width of 7.6 m (25 ft) and a length of 61 m (200 ft). Based on field observations from the construction of the CwM wells, the base aquifer configuration was as follows:

- Saturated thickness = 3.9 m (12.8 ft)
- Unsaturated zone thickness = 3.1 m (10.2 ft)
- Westward groundwater gradient of 0.007 m/m.

The saturated thickness of the aquifer and groundwater gradient were adjusted slightly (± 0.3 m, 0.006-0.008 m/m) between model runs to evaluate effects of seasonal groundwater changes on mounding. Assessment of alternative SIG locations also required changes to the saturated thickness based on the position within the aquifer.

3.3 VS2D Model Construction

VS2D is a two-dimensional model for groundwater flow and heat transport in variably-saturated aquifers. MODFLOW with MT3DMS is capable of modeling contaminant transport but is not configured for simple simulation of energy transport. VS2D is designed specifically for this function.

VS2D was used to construct a representative cross-sectional model of heat transport through the alluvial aquifer (Figure 7: VS2D Heat Transport Model Profiles: Cross-section Along General Flow Path). The cross-section was aligned with the primary east-to-west flow path from the proposed facility to the main discharge area to the John Day River (1,000 m in length). This cross-sectional configuration was chosen based on preliminary MODFLOW model runs and is applicable to the final MODFLOW model results, as well (see Section 4.2). The VS2D model layers were defined based on the final MODFLOW model layers, with some adjustments to dimensions in order to simplify the cross-sectional model (Table 5). The primary difference is that the VS2D model layer surfaces are planar and not reflective of actual site topography captured in the DEM data for the MODFLOW model.

3.3.1 Model Design

The VS2D cross-sectional model domain is a parallelogram 17 m deep and 1,400 m in length (Figure 7). The trench of the SIG was placed 1,000 m up-gradient of the river at the west end of the model. The surface elevation differs by 12 m from one end to the other, representative of the surface elevation along the flow path from the primary proposed SIG site to the river. The initial water table was placed 3 m below the surface at the SIG site (based on initial state water levels measured in the three CwM monitoring wells) sloping to the level of the river on the west side of the model, with a representative gradient of approx. 0.007 m/m. In order to gain greater vertical resolution in the cross-sectional model, rectangular grid cells approx. 0.6 m high and 2.0 m wide were used.

3.3.2 Boundary Conditions

The final VS2D model was arbitrarily started in April with an initial temperature throughout the model domain of 7°C. Two boundary conditions were defined: a constant-head boundary (CHD) on the east end of the model (400 m up-gradient of the SIG, representing the river and ponds) defining an initial water table 3 m below the surface, and a CHD boundary representing the John Day River level at the west end (Figure 4). The elevations of the CHD boundaries changed seasonally in the same manner as the MODFLOW model (Section 3.1.2, Table 3). Unlike in the MODFLOW model, the RIV boundaries in VS2D are also able to function as constant temperature boundaries (CT). In the case of the final model, both CHD boundaries were also defined as a CT boundary with an initial value of 6°C for April conditions.

The temperature value of water flowing into the model from the upgradient CHD and at the river-aquifer interface CHD varied throughout the year. The CT boundary temperatures were updated in the final model based upon available site data from the City and to match the final river hydrograph cycle used in the MODFLOW model (Section 3.1.2). The final model more accurately represents monthly peaks in temperature in the river than the preliminary model. CT boundary values varied as follows: 6°C (Apr), 11°C (May), 16°C (Jun), 18°C (Jul), 19°C (Aug), 13°C (Sep), 7°C (Oct-Nov), 4°C (Dec-Jan), and 3°C (Feb-Mar). The CT temperature values represent average river temperature and do not represent short-term (daily/weekly) peaks like observed during Site Visits 2 and 3. This model is not intended to simulate water temperatures within the river channel itself, but instead it models groundwater temperatures as flow approaches the river. The river must be modeled at a defined, representative, seasonal temperature to accurately model the river's influence on the hyporheic environment.

The final VS2D model was allowed to run for a two year background period before the introduction of the infiltration source (SIG). Groundwater temperatures within the model over the first two simulated years were monitored and are considered to represent background conditions without infiltration. Because the model is a 2D cross-section through the SIG and aquifer, a recharge rate of approx. 2.9×10^{-5} m/s was applied to account for infiltration from just a 1-m (one length unit) thick cross-section of the SIG (Figure 7). The model cross-section represents the center of the gallery and its infiltration plume. Infiltrated water was initially set with a constant temperature of 20°C, compared to a starting background temperature of 7°C. In this model, infiltration was simulated for a period of three years with the goal of determining the temperature at discharge into the John Day River under proposed conditions and designs.

Table 5 – Final VS2D Model Layers and Properties

Parameter	Layer 1	Layer 2	Layer 3
Layer Material	Dredged Cobbles & Gravel	Dredged Sand & Gravel	Confining Unit
Layer Thickness	5.5 m	1.5 m	10 m
Hydraulic Conductivity (m/s) Horizontal	0.0178	1.78×10^{-4}	5×10^{-8}
Hydraulic Conductivity (m/s) Vertical	0.0178	1.78×10^{-4}	5×10^{-9}
Specific Storage	1×10^{-5}		
Specific Yield	0.30		
Model Initial Head	Model Surface Elevation – 3.0 m		
Dispersivity (Long/Trans/Vert)[1]	15 / 1.5 / 15	20 / 2 / 20	10 / 1 / 1
Heat Capacity at RML (J/m^3°C)[2]	2.4×10^6	2.2×10^6	1.8×10^6
Heat Capacity at Sat (J/m^3°C)[2]	2.6×10^6	2.4×10^6	2.1×10^6
Thermal Cond. of Dry (W/m°C)[2,3]	1.70	1.70	1.70
Thermal Cond. of Water (W/m°C)[4]	4.20		

1. Values derived from Waldrop et al., 1985
2. Values derived from Hamdhan & Clark, 2010 and Markle et al., 2006
3. Values derived from Dalla Santa et al., 2017
4. Value from USGS Water Science School

4 Groundwater Modeling Results

The following section outlines the results from the final MODFLOW, MoundSolv, and VS2D groundwater models. The proposed SIG design and operations scenario is simulated using the site drawing in Figure 4 of Chadwick, (2019) and assuming subsurface StormTech Chambers (as shown in the Anderson Perry & Associates drawings, 2019). This scenario includes three closely-set, north-south aligned StormTech Chamber galleries, each 61 m (200 ft) long and 1.3 m (4.25 ft) wide, set approx. 2.75-3 m (8-10 ft) apart, and excavated to 1.5 m (4.5 ft) in depth.

For the final modeling runs presented here (like in the preliminary models), an average daily infiltration rate of 0.30 MGD (1136 m^3/d) was used year-round. Infiltration volume was equally split among the three parallel galleries, which operated full time for a model period of three years with no interruptions. River levels were varied seasonally throughout the three year period (Figure 5). The RCH boundary at the current WWTP percolation ponds, which currently acts as an input source to the aquifer, was removed for these runs under the assumption that the ponds will not operate in their current capacity once the new SIG system is installed.

The previous engineering drawings provided to CwM by the City included an alternative location and configuration for the SIG structure. This alternative SIG was located approx. 375 m (1,230 ft) to the west of the primary location modeled in this study. Instead of the three StormTech Chambers being in parallel, the alternate location had the three trenches in a linear series along the west side of Patterson Bridge Road. Based on the preliminary modeling results from the primary SIG location, it was clear that this alternative SIG would result in far less favorable flow paths, travel times, and changes in wastewater concentrations before discharge to the John Day River. For these reasons, this western alternative location was not modeled for this final report. Instead, CwM proposes an alternate location approx. 125 m (420 ft) northeast of the primary SIG, covering parts of the former Oregon Pine and Iron Triangle properties, with the same parallel trench configuration (Figure 2). Modeling results for this alternate location are also presented in sections 4.1-4.4 below.

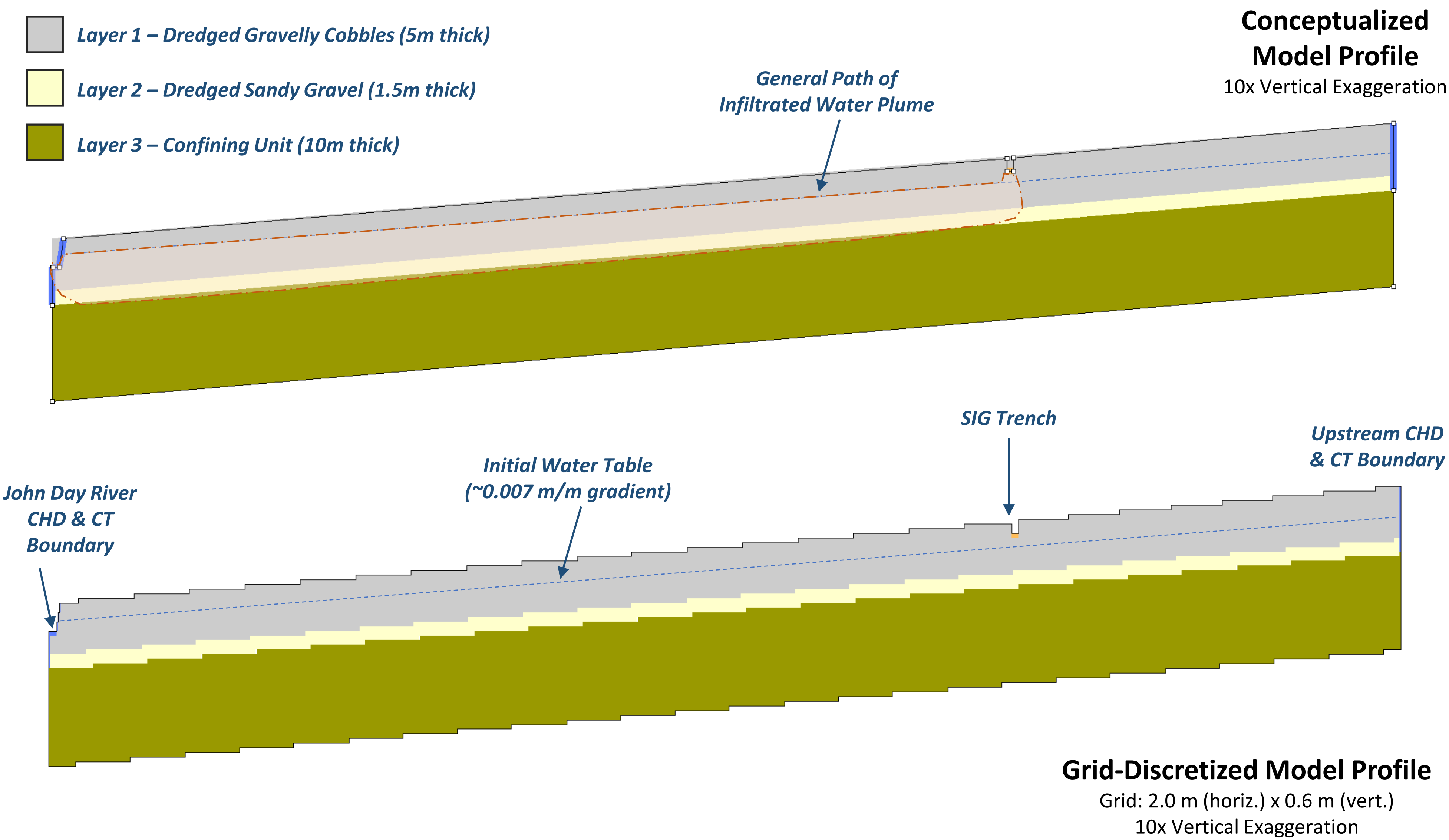

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Figure 7
Final VS2D Heat Transport Model Profiles: Cross-section Along General Flow Path
Facing Northward

4.1 Groundwater Mounding and Gradient

A critical factor determining the successful operations of the SIG is the maximum groundwater mounding incurred under and around the galleries. With the bottom of the galleries at a depth of about 1.5 m and the typical groundwater table at approx. 3.0-3.2 m, there is only about 1.5 m of head space available mounding for this design. During spring high-groundwater levels, the available head space may decrease to about 1.2 m. Mounding exceeding about 1.2 m could result in flooding of the gallery chambers.

Mounding estimates were calculated using the low- and high-end hydraulic conductivity values derived from the aquifer pump test (CwM Aquifer Test Analysis Technical Memorandum, 2021). The mounding estimates from the low-end value (K=0.46 cm/s) are considered the maximum anticipated mounding. Higher mounding within the operation limits of the galleries may be beneficial for water quality, as a higher mound will result in greater initial dispersion of the infiltrated water.

4.1.1 MoundSolv Model Results

Mounding was evaluated at two proposed SIG sites, the primary site from Anderson Perry and a site proposed by CwM northeast of the primary site.

4.1.1.1 Primary SIG Location

The MoundSolv model was set up to simulate infiltration at 1136 m^3/d through a single 7.6 m-wide SIG that represented the three parallel galleries until stead-state was achieved (more than 5 years). Monitoring points were set in the model at the center of the SIG, and at various distances up, down, and cross-gradient from the SIG.

The final model suggests that the maximum mounding at the center of the primary SIG location is estimated at approx. 0.52 m. Mounding of more than 0.25 m was observed as far as 175 m down-gradient, 125 m up-gradient, and 150 m directly cross-gradient from the SIG with the low-end transmissivity estimate (Figure 8 – Groundwater Mounding and Gradient below the Proposed SIG Location). This degree of mounding creates a zone of flat or very low gradient groundwater about 40-50 m up-gradient of the SIG (Figure 8). The low-gradient zone effectively reduces the rate at which fresh groundwater mixes with the infiltrated water plume. Greater mounding therefore limits dilution immediately down-gradient of the SIG. However, greater mounding increases dispersion of wastewater constituents immediately around the SIG.

With the aquifer transmissivity estimates used in the MODFLOW model (Section 4.1.2), mounding at the center of the SIG peaks at about 0.14 m. In this case, mounding at a distance of more than 100 m in any direction were below 0.08 m and the up-gradient effects were very reduced (Figure 8).

4.1.1.2 Alternate SIG Location

The alternate SIG location is anticipated to have a thinner alluvial aquifer based on soil borings on the Iron Triangle Property and its closer proximity to the valley wall. The MoundSolv model was run with a saturated aquifer only 2.5-m thick for the alternate location (compared to 3.9 m at the primary location). Maximum mounding at the center of the SIG was estimated at approx. 0.80 m. The increased mounding creates a larger low-gradient groundwater zone above the SIG that extends up to 60-70 m up-gradient.

The higher-end transmissivity suggested mounding of only approx. 0.22 m (Figure 9 – Groundwater Mounding and Gradient below the Alternate SIG Location). The maximum head space for mounding of about 1.2 m is not exceeded until the saturated aquifer in the model is reduced to just 1.0-m thick, even with the conservative transmissivity estimate.

4.1.2 MODFLOW Model Groundwater Gradients

The preliminary model suggested that the mounding caused by the SIG operations significantly altered the groundwater gradients up- and down-gradient of the facility. The gradient between the SIG and the river to the east changed by as much as 9-10%, for example. This leveling out of the groundwater regime resulted in a reduction of net recharge from the upstream reach of the river equivalent to about half of the infiltrated water volume (about 0.15 MGD less recharge from the river).

The final model suggests that the impact is somewhat reduced from the preliminary estimates. The gradient between the SIG and river to the east decreased by approx. 3-8% in the final model during maximum (May) and minimum river levels (August). Recharge from the up-stream river reaches decreased by about 0.10-0.11 MGD from current conditions. This effect is expected to be similar between the primary and alternate SIG locations.

4.2 Groundwater Flow Path and Travel Time

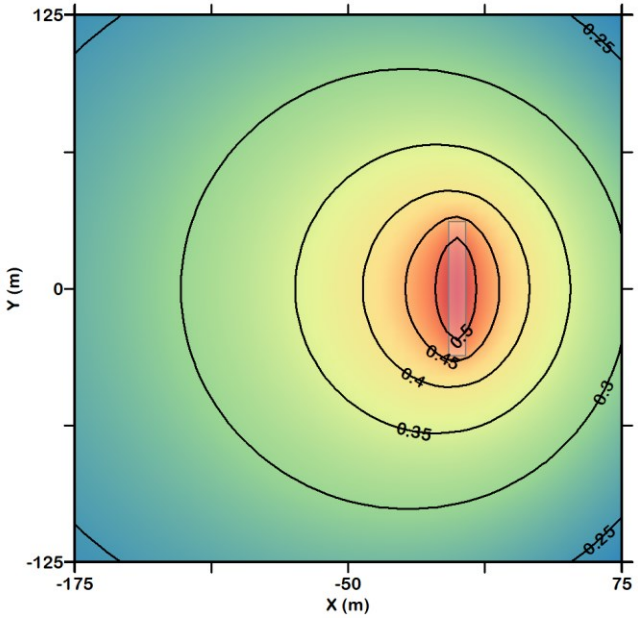
The MODFLOW-6 add-on package MODPATH was used to assess groundwater flow direction in the alluvial aquifer. Tracking particles were placed at three depths within each of the model cells that comprised the SIG feature within the model grid, totaling about 150 particles. MODPATH tracking particles flow along with groundwater based solely on gradients. Tracking particles therefore do not exhibit any retardation factor, adsorption, dispersion, or chemical reactions and therefore represent a very conservative tracer. The model was run with 0.30 MGD of infiltration through the SIG to simulate anticipated average operation.

Multiple model runs were completed, each running for a full three years, but starting in different seasons. The purpose of this was to determine how the flow path of infiltrated water varies depending on the release season. In the preliminary groundwater modeling study, particle tracks were simulated starting in January, April, and October based on the three month of calibration data used. The RIV boundary hydrograph was updated for the final model to better represent available river data, allowing particle track simulations starting in May (maximum river levels) and August (minimum river levels). These two months, along with the intermediate month of January, will be presented in this final report.

Unlike in the preliminary model, flow path directions, path lengths, and travel times in the final model generally did not vary considerably by season in which the particles were released. Instead, the groundwater flow from the SIG behaved nearly the same throughout the year for both the primary and alternate SIG locations. This change is due to the increase in aquifer transmissivity between the preliminary and final models, which reduced the overall travel time from the SIG to the river as well as the seasonal change in river levels on flow paths.

4.2.1.1 Primary SIG Location

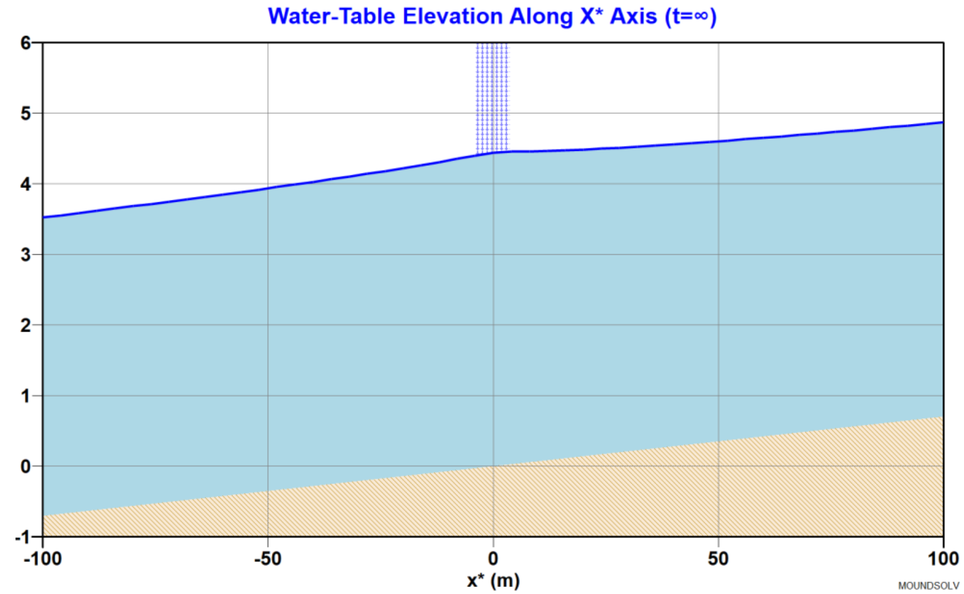
The higher transmissivity in the final model reduced the effects of mounding on the initial travel paths of the tracking particles. Particles do not spread out up- and cross-gradient of the SIG upon infiltration as was shown in the preliminary model, and instead flow directly down gradient (Figure 10 - Groundwater Flow Paths from Proposed SIG Location). The maximum width of the particle plume was approx. 120-125 m (Table 6). The distance travelled by tracking particles from infiltration to discharge at the river ranged from approx. 990 – 1,140 m (3,250 – 3,740 ft) from the south to north side of the plume.

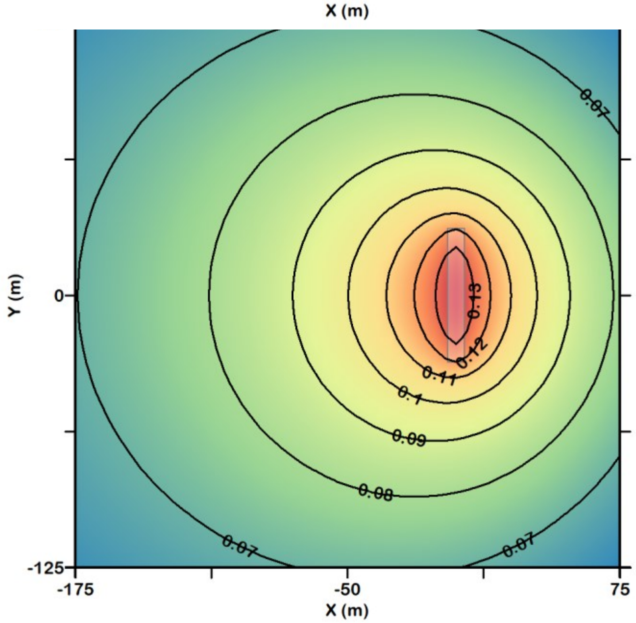


Water-Table Rise (t=∞)
K = 397 m/d
h_0 = 3.9 m
i = 0.007 m/m
γ = 0°
L = 7.6 m
W = 61 m
ϕ = 0°
Q = 1136 m^3/d

Low-end K

0 62.5 m
contour interval = 0.05 m





Water-Table Rise (t=∞)
K = 1538 m/d
h_0 = 3.9 m
i = 0.007 m/m
γ = 0°
L = 7.6 m
W = 61 m
ϕ = 0°
Q = 1136 m^3/d

High-end K

0 62.5 m
contour interval = 0.01 m

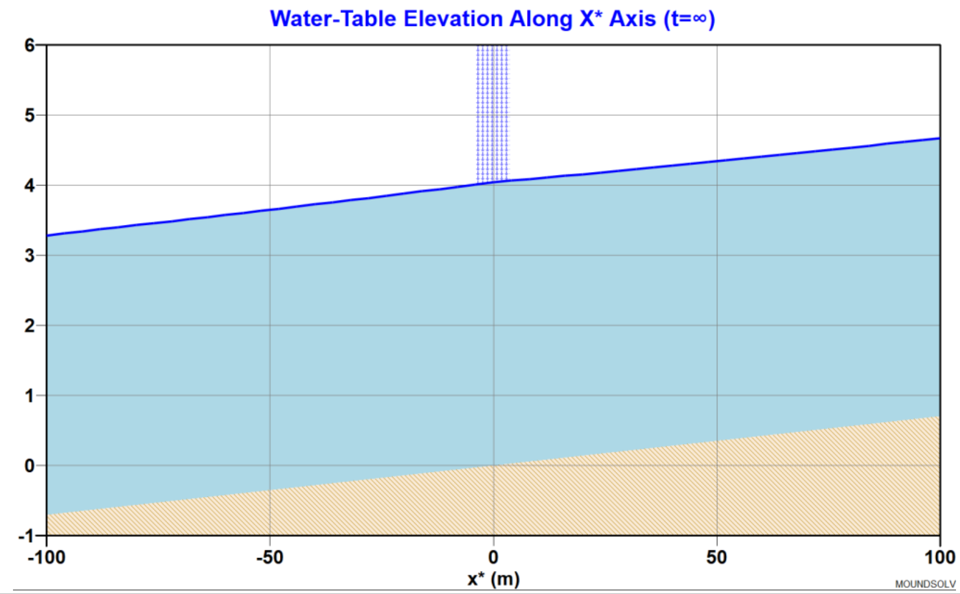


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Figure 8
Groundwater Mounding and Gradient below the Proposed SIG Location
Layer 1 K=0.46 cm/s and K=1.78 cm/s

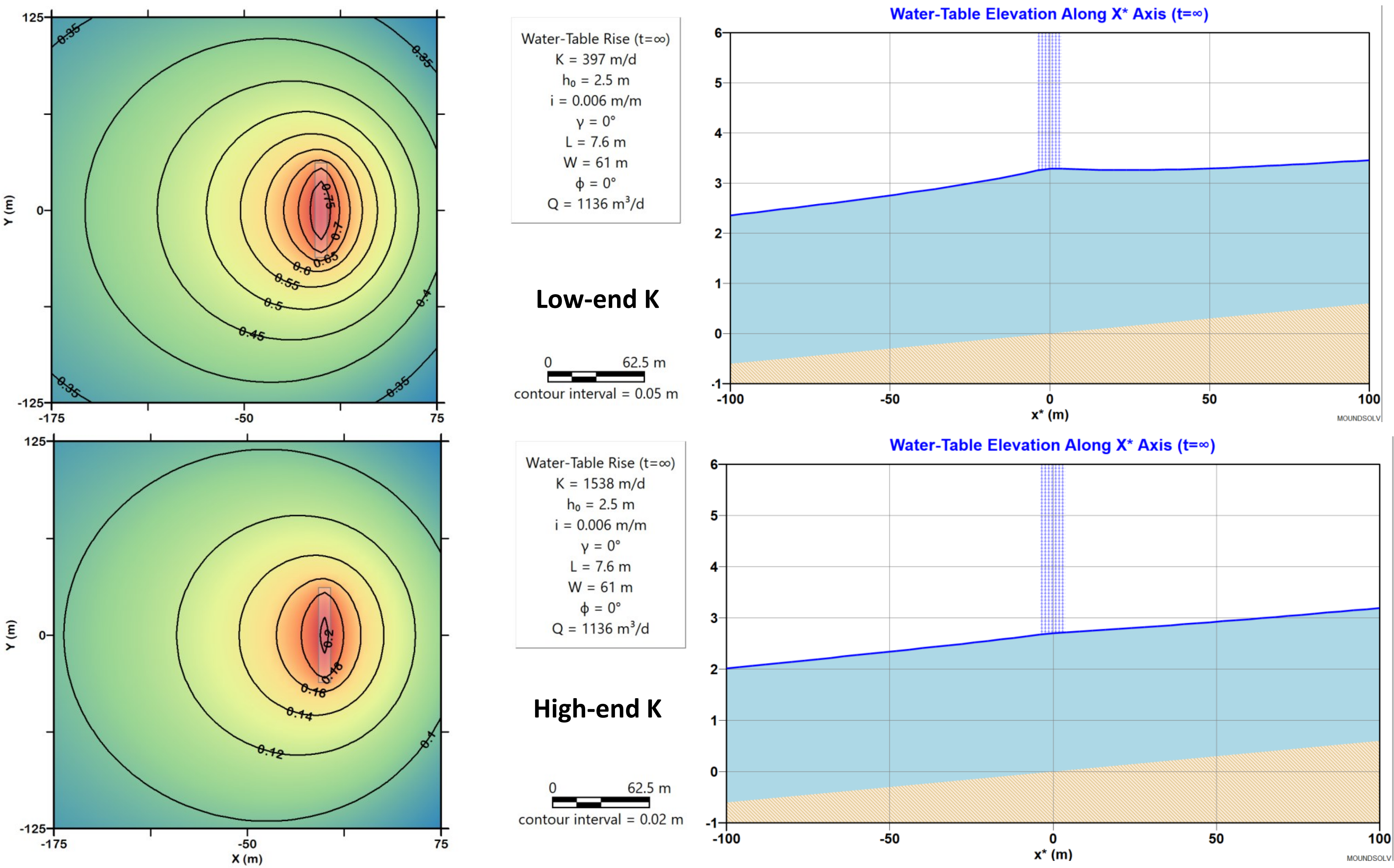

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Figure 9
Groundwater Mounding and Gradient below the Alternate SIG Location
Layer 1 K=0.46 cm/s and K=1.78 cm/s

Estimates of travel time from the SIG to the river ranged from approx. 32 days to 36 days depending on the location within the infiltration plume (Figure 10). Particles released from the southern side of the SIG always discharged to the river before particles from the north side. Travel times in the conservative model were consistent throughout the year. All particle paths ended at discharge points along the northern bank of the John Day River.

4.2.1.2 Alternate SIG Location

The alternate SIG's location further up-gradient increases the maximum flow path length possible from the SIG to the river. Being further north, the westward flow path intercepts the river farther away from the SIG, further lengthening the maximum path length (Table 7). The groundwater gradients at the alternate SIG location are more west-northwest, compared to directly west at the primary location. This means the infiltration plume is initially pushed against the northern edge of the aquifer, resulting in a curving path.

The distance travelled by tracking particles from infiltration to discharge at the river ranged from approx. 1,440 – 2,240 m (4,725 – 7,350 ft) from the south to north side of the plume. Some tracking particles reached the western extent of the modeled aquifer where the river abuts the northern slope of the valley (Figure 11 - Groundwater Flow Paths from Alternate SIG Location). Estimates of travel time from the SIG to the river ranged from approx. 50 days to 89 days depending on the location within the infiltration plume. Particles released from the southern side of the SIG always discharged to the river before particles from the north side. Three tracking particles released in January were able to cross underneath the John Day River to the south side of the alluvial aquifer. This is the only case of cross-over in the simulations, and these three particles then discharged to the river through the south bank (Figure 11).

Table 6 – Conservative Final MODFLOW Particle Tracking Results – Primary SIG Location

Parameter	January Release (mod. river level)	May Release (max. river level)	August Release (min. river level)
Min Travel Time to River	33 days	34 days	32 days
Max Travel Time to River	36 days	36 days	36 days
Min Path Length to River	990 m	1,075 m	990 m
Max Path Length to River	1,140 m	1,135 m	1,140 m
Length of River Reach Receiving Tracking Particles	195 m	105 m	190 m
Max Width of Particle Plume	120 m	120 m	125 m
Particles Flow Under RIV Boundary?	NO	NO	NO
	Due to the rate of groundwater flow, the seasonal variation in river level has less effect on the transport of the infiltrated wastewater.		

The tracking particles in the model move according to groundwater gradients and exhibit no lag or retardation factor in their transport. For this reason, the travel times predicted in the model runs described here represent a conservative range of travel times based on the assumed transmissivity. Reactive and even weakly reactive constituents of the influent water can be expected to exhibit retardation and/or decay factors which could reduce concentrations along the flow path and increase travel time relative to the tracking particles.

It must also be considered that constituents within the infiltrated wastewater travel according to both groundwater gradients and concentration gradients, as well as molecular dispersion. This means the constituents within the water can disperse to a larger area of the aquifer than the tracking particle plumes suggest. This is addressed in Section 4.3.

Table 7 – Conservative Final MODFLOW Particle Tracking Results – Alternate SIG Location

Parameter	January Release (mod. river level)	May Release (max. river level)	August Release (min. river level)
Min Travel Time to River	51 days	50 days	51 days
Max Travel Time to River	88 days	89 days	88 days
Min Path Length to River	1,460 m	1,440 m	1,460 m
Max Path Length to River	2,240 m	2,240 m	2,240 m
Length of River Reach Receiving Discharge	910 m	850 m	910 m
Max Width of Particle Plume	175 m	175 m	180 m
Particles Flow Under RIV Boundary?	YES	NO	NO
	Due to the rate of groundwater flow, the seasonal variation in river level has less effect on the transport of the infiltrated wastewater.		

4.2.2 Groundwater Discharge Area

The groundwater discharge area is the area of river reach that has the potential to receive waters infiltrated from the SIG. Two locations, the primary and alternate, were evaluated in the modelling scenarios.

4.2.2.1 Primary SIG Location

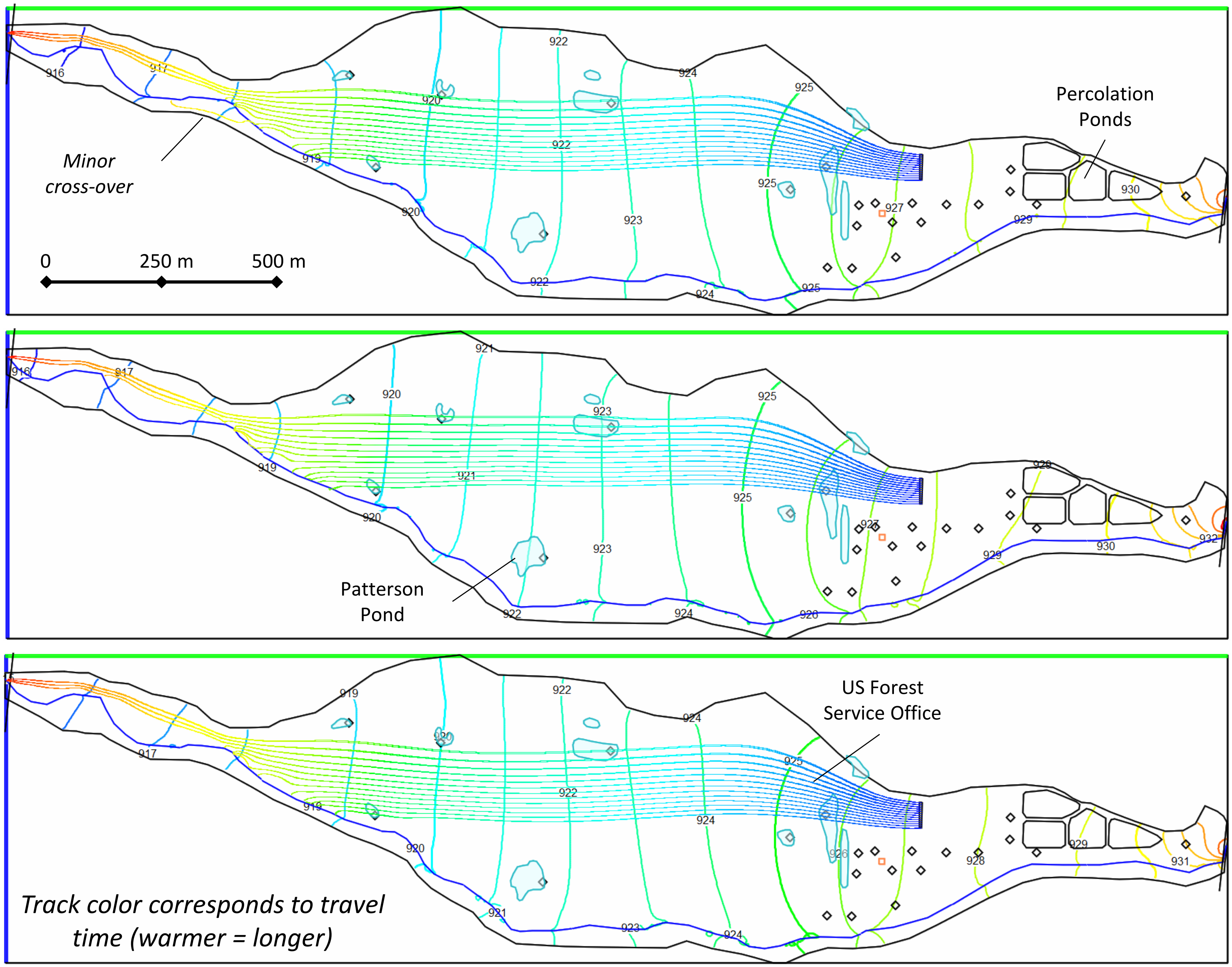
The MODPATH results also define the geometry of the infiltrated water discharge area to the John Day River. During infiltration of 0.30 MGD through the proposed SIG, the infiltrated water discharged to a reach of the river that varied only slightly in length and location depending on the season. The primary westward flow path from the SIG intercepts the river north of the end of Apple Road and west of Patterson Pond. Over most of the year, the discharge area is about 190-200 m wide (Table 6). However, the discharge area narrows to just over 100 m during high river levels in April and May (Figure 10).

Tracking particles were released from the SIG at three depths within the model, equally spaced across the Layer 1. Particles of all three depths discharged to the river along the north bank, despite the fact that the river channel cuts only half-way through Layer 1. The model suggests discharge to the riverbank is likely distributed along the wetted perimeter of the river channel on the receiving side. This amounts to approximately 350 – 600 m^2 of river channel over which the infiltrated water is diffusing into the river.

4.2.2.2 Alternate SIG Location

The tracking particles released from the alternate SIG location discharge to the river over a much wider area than for the primary SIG (Table 7) because the groundwater contours immediately down-gradient of the alternate SIG curve significantly due to the shape of the north valley wall. Particles released from the south end of the SIG follow a due west flow path (Figure 11). However, since the alternate SIG is further north, these particles intercept the river father to the west near the end of Wilderness Road. Particles towards the north end of the SIG are pushed up against the northern edges of the aquifer before flowing westward. These particles intercept the river between Wilderness Road and north of Carpenter Pond.

A small percentage of tracking particles continued through the narrow alluvial aquifer band near Malheur Lumber before discharging at the west end of the model. For this reason, the discharge area from the south to north end of the plume exceeds approx. 850 m year-round. In the January-release simulation, a few particles crossed underneath the John Day River channel and discharged along the south bank of the river. This represents a very small fraction of the infiltrated water and did not occur during other simulations. Overall, infiltrated water from the alternate SIG appears to diffuse into the river through approximately 1,800 – 5,000 m^2 of river channel.



Particles Released in January

Particles Released in May

Particles Released in August

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Figure 11
Groundwater Flow Paths from Alternate SIG Location with Layer 1 K=1.78cm/s
January, May, and August Paths

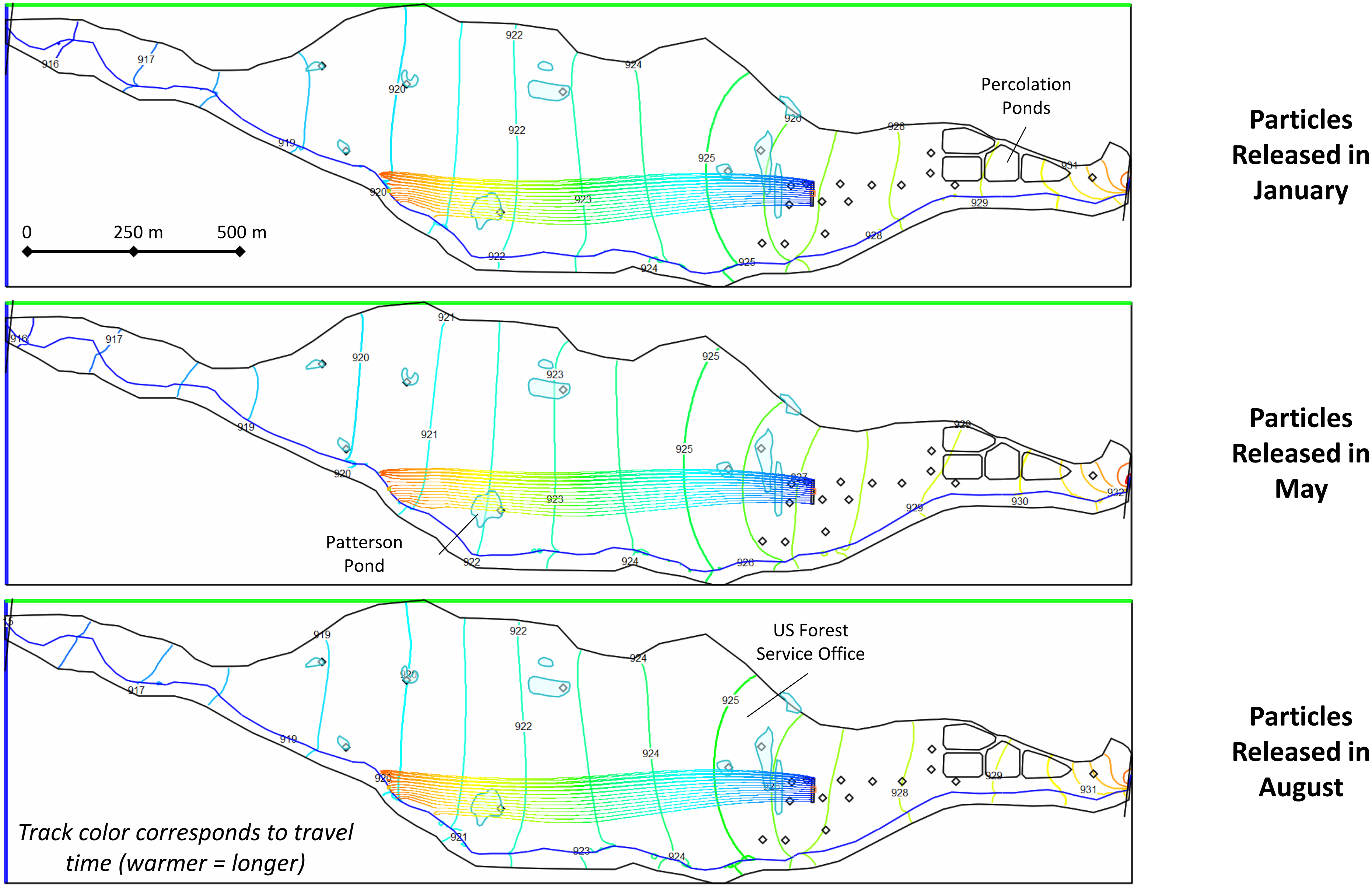

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Figure 10
Groundwater Flow Paths from Proposed SIG Location with Layer 1 K=1.78cm/s
January, May, and August Paths

4.3 Dilution and Dispersion of Infiltrated Water Constituents

The same model setup outlined in Section 3.1 and used in the particle tracking and flow path simulations was used to examine contaminant transport within the alluvial aquifer. The only change made to the model was the addition of the MT3DMS transport package to the MODFLOW model (Bedekar et a., 2016). Using this package, the SIG was made a constant concentration (CC) source of the wastewater constituent being modeled. For the purposes of this study, nitrate-nitrogen is considered the primary constituent of concern and was the representative tracer in the MT3DMS program.

The model did not simulate retardation or binding to the aquifer material as many wastewater constituents would experience to varying degrees. However, a decay factor was simulated based on evidence of denitrification within the aquifer collected in the field (Phase 2 – Groundwater Quality Investigation Technical Memorandum). Field data suggest significant denitrification in the current City percolation ponds and in the aquifer down-gradient of the ponds. For this model, a much lower first-order decay rate ($1.5 \times 10^{-9}\ s^{-1}$) was chosen as a highly conservative estimate based on denitrification rate from a survey of studies in similar aquifer systems (DeSimone & Howes, 1998; Hantush & Wang, 2003; Hojberg et al., 2017; Klapperich, 2004; Korom, 2007; Szymkiewicz, et al., 2020; Tesoriero & Puckett, 2011; Welches et al., 2011). The SIG CC source was set to 10 ppm (mg/L), equivalent to 1.14 kg/d of loading via 0.30 MGD of simulated infiltration.

The models were run to simulate plumes created by infiltration starting in January, May (maximum river level), and August (minimum river level). The model runs simulated three years of continuous infiltration at 0.30 MGD and 10 ppm.

4.3.1.1 Primary SIG Location

The contaminant plume from the primary SIG location generally resembles the westerly particle flow paths predicted based purely on groundwater gradients. Due to dispersion, the edge of the plume (defined by the 1 ppm or 90% dilution contour) extended approx. 50-60 m north and south of the particle tracks, forming a contaminant plume roughly 200-225 m wide in the middle. The plume reached this north-south extent after just a few months and remained stable through the entire 3-year modeling period (Figure 12 - Conservative Tracer Plumes from Proposed SIG Location).

From the first year to second year of infiltration, the westerly extent of the plume increased by less than 50 m, as shown by the 1 ppm contour (Figure 12). Similarly, the core of the plume extended westward by about 50-100 m between the first and second years, as shown by the 6 and 7 ppm contours (orange and red in Figure 12). Neither of these trends continues after the second year, and the extent and structure of the plume appears to remain stable after about two years.

The concentration of the groundwater at the center of the plume (following the particle tracks) was approx. 1.0-2.7 ppm at the hyporheic zone along the north bank of the John Day River. A steep concentration gradient forms in the hyporheic zone due to more rapid groundwater flow velocities and significant exchange with the river. Outside of the 200 m central discharge area, concentrations of the groundwater ranged from 0.1-1.0 ppm over an approx. 950 – 1000-m wide reach of the river. This can be compared to the approx. 0.4-0.8 ppm of nitrate observed in the river in the summer of 2021 (Phase 2 - Groundwater Quality Investigation Technical Memorandum). Due to dilution and dispersion, the approx. 1.14 kg/d of loading from the SIG disperses to the John Day River through about 1,000 m of riverbank.

4.3.1.2 Alternate SIG Location

The contaminant plume from the alternate SIG location is very different due to a distinct groundwater flow regime along the northern edge of the alluvial aquifer. For the primary SIG location, groundwater contours down-gradient of the facility were relatively straight, reducing overall dispersion and keeping the groundwater flow paths and plume paths similar. Tracking particles and wastewater constituents follow different patterns when originating from the alternate SIG location.

Much like the primary SIG, the plume from the alternate location appears to reach a stable structure and extent after about two years of continuous infiltration (Figure 13 - Conservative Tracer Plumes from Alternate SIG Location). At this stable point, the edge of the plume spans nearly the entire north-south extent of the aquifer, or about 420 m. Dispersion away from the primary flow path is much greater than in the plume from the primary SIG (Figure 13).

The concentration of the groundwater at the center of the plume (following the particle tracks) is similar to the plume from the primary SIG. Concentrations peak at about 3.0 ppm at the hyporheic zone along the north bank of the John Day River. Outside of the 800 m discharge area at the west end of the model, concentrations of the groundwater ranged from $\leq$0.1-1.0 ppm over an approx. 1,000-m wide reach of the river. At the end of the three year infiltration period, the MT3DMS model mass balance shows that the contaminant load entering the river is approx. 56% of the loading at the SIG source.

4.4 Groundwater Temperature at Discharge to River

The same model parameters used to create the 3D MODFLOW model were used to construct a simplified 2D representation of the alluvial aquifer cross-section to model heat transport (Table 5). The VS2D model cross-section line cut from the proposed SIG to the middle of the general flow path as determined from the MODFLOW simulations, or a model distance of 1,000 m. The model included 400 m of aquifer flow up-gradient of the SIG to represent the distance to the upstream reaches of the John Day River.

Simulated temperatures of groundwater within the aquifer were monitored for three full years of continuous infiltration and were compared to two years of background flow with no infiltration through the SIG. The aquifer was set at an initial groundwater temperature of 7°C with the SIG infiltration water set at 20°C. The temperature of the river boundary and up-gradient CHD boundary (also simulating the river) varied seasonally (Section 3.3.2). Groundwater temperature was primarily assessed at a distance of 15 m (49 ft) from the river CHD/CT boundary which simulates the river bank (Table 8). At this distance from the river, the hyporheic thermal regulating effects are minor and thermal changes are due primary to heat dispersion along the flow path within the aquifer.

During the months of May through October, the groundwater discharging to the John Day River from the alluvial aquifer is typically cooler than the river water. In the peak temperature months of July and August, background groundwater discharging to the river was 6-7°C colder than the river itself. In the third year of continuous infiltration at 20°C, groundwater at the center of the infiltration plume was still cooler than the river from June through September and roughly equal in temperature in May (Figure 14 – Final VS2D Model Groundwater Thermal Curves). The median temperature increase from May to October relative to background ranged from 2.7 to 3.9°C. These values are the maximum estimated thermal loads and are confined to the core of the plume as it approached the discharge area.

From October to November, the groundwater at the center of the plume 15 m from the riverbank was warmer than background and the average river temperature. From late fall through the spring, groundwater discharging to the river is typically warmer than the river (Figure 14). Between November and April, the groundwater at the center of the thermal plume was 2.2-2.9°C above background temperatures and less variable than in the summer months. The thermal profiles of the aquifer during infiltration are shown in Figure 15 - Final VS2D Heat Transport Model: Heat Distribution Profiles.

Table 8 – Maximum Groundwater Temperature Increase Near Discharge to River

	Apr	May	Jun	Jul	Aug	Sep	Oct-Nov	Dec-Jan	Feb-Mar
Difference in Median Groundwater Temp[1]	2.3°C	3.9°C	3.4°C	2.7°C	2.7°C	2.9°C	2.9°C	2.5°C	2.2°C
Notes	[1]Difference between infiltration period and background period.								

The two-dimensional VS2D model is a conservative thermal transport model in several respects. The model simulates the center or core of the infiltration plume where heat dispersion laterally through the aquifer is limited by the surrounding warm waters. Just like dispersion and dilution of the solute plume simulated by the MT3DMS package, heat will disperse more rapidly towards the edges of the plume. It can be reasonably expected that the 2-4°C maximum increase at the terminus of the plume core would be greatly reduced over the outside portions of the plume. Over the width of the infiltration plume, increases on the order of approx. 0.5-1.5°C are likely more representative.

The results presented in Figures 14-15 and Table 8 do not show the thermal influence of the river in the hyporheic zone. Constant interchange between the river channel and the groundwater in the near-river environment (within several meters of the riverbank) exerts a regulatory effect on the temperature of groundwaters discharging to the river. Groundwater gradients also increase very close to the river-groundwater interface, leading to higher flow velocities and greater thermal dispersion. Such effects will likely suppress the thermal impact of the center of the plume below the values presented in Table 8.

The model also assumes that the water infiltrating through the SIG will be at a constant temperature of 20°C. Real-world operations of the SIG will likely lead to variability including lower influent temperatures in the winter and spring. Efforts to acclimate influent wastewater to seasonal conditions could drastically reduce the thermal impacts to the river below those predicted here.

Finally, the VS2D model boundaries function as no-flux boundaries for water flow and for heat flow. This means that heat introduced to the aquifer from the river or from the SIG in the model cannot leave the model through the upper (land surface) or lower (confining unit) boundaries of the domain. Real world conditions would allow for continued heat dispersal downward into the confining unit, as well as evaporative and radiative heat loss from the land surface. The model, in effect, keeps more heat in the groundwater than should be the case. For these reasons, the estimates of warming in the near-river environment should be treated as conservative maximums.

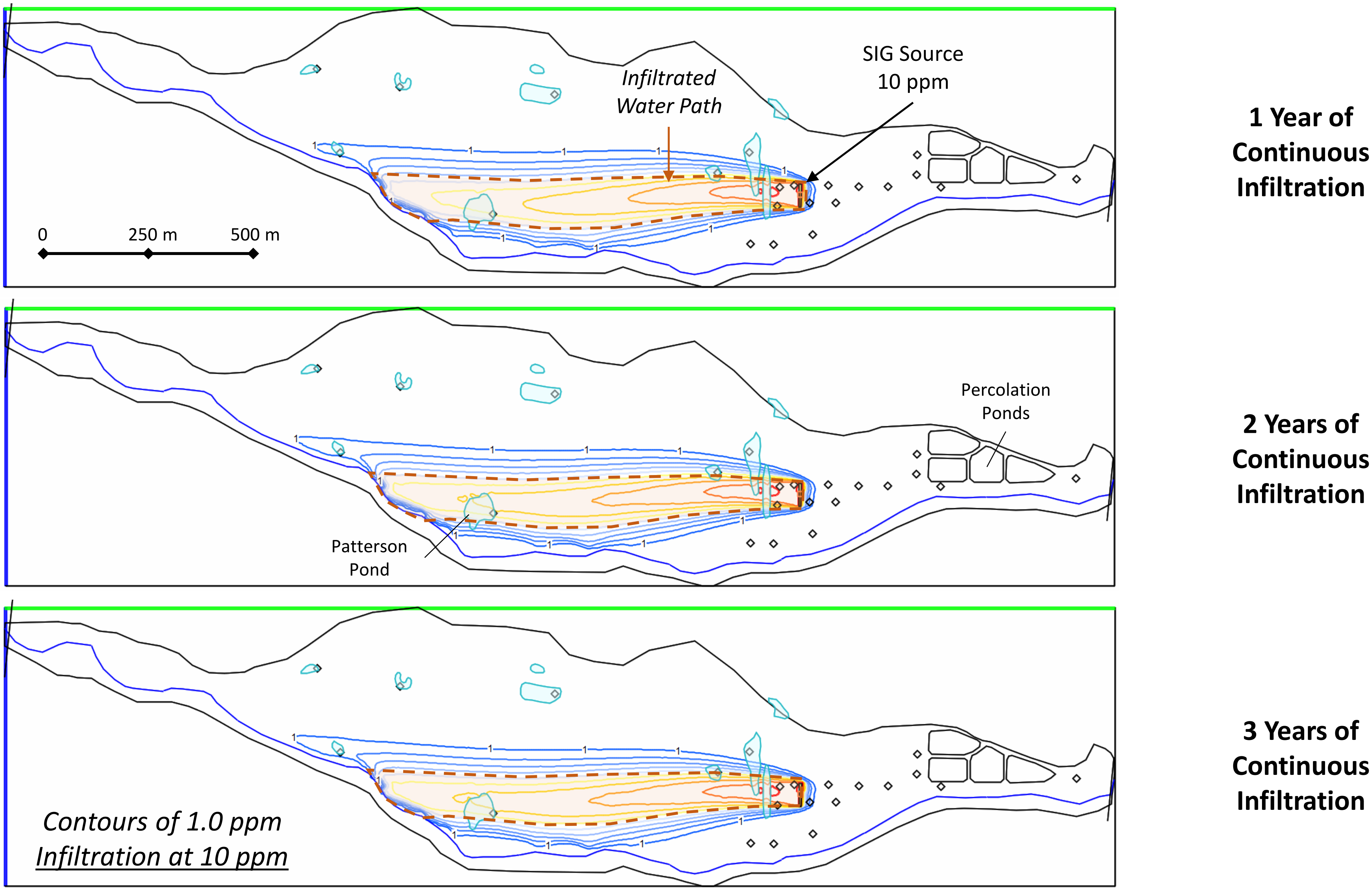

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Figure 12
Conservative Tracer Plumes from Proposed SIG Location:
Dilution, Dispersion, and Low Denitrification

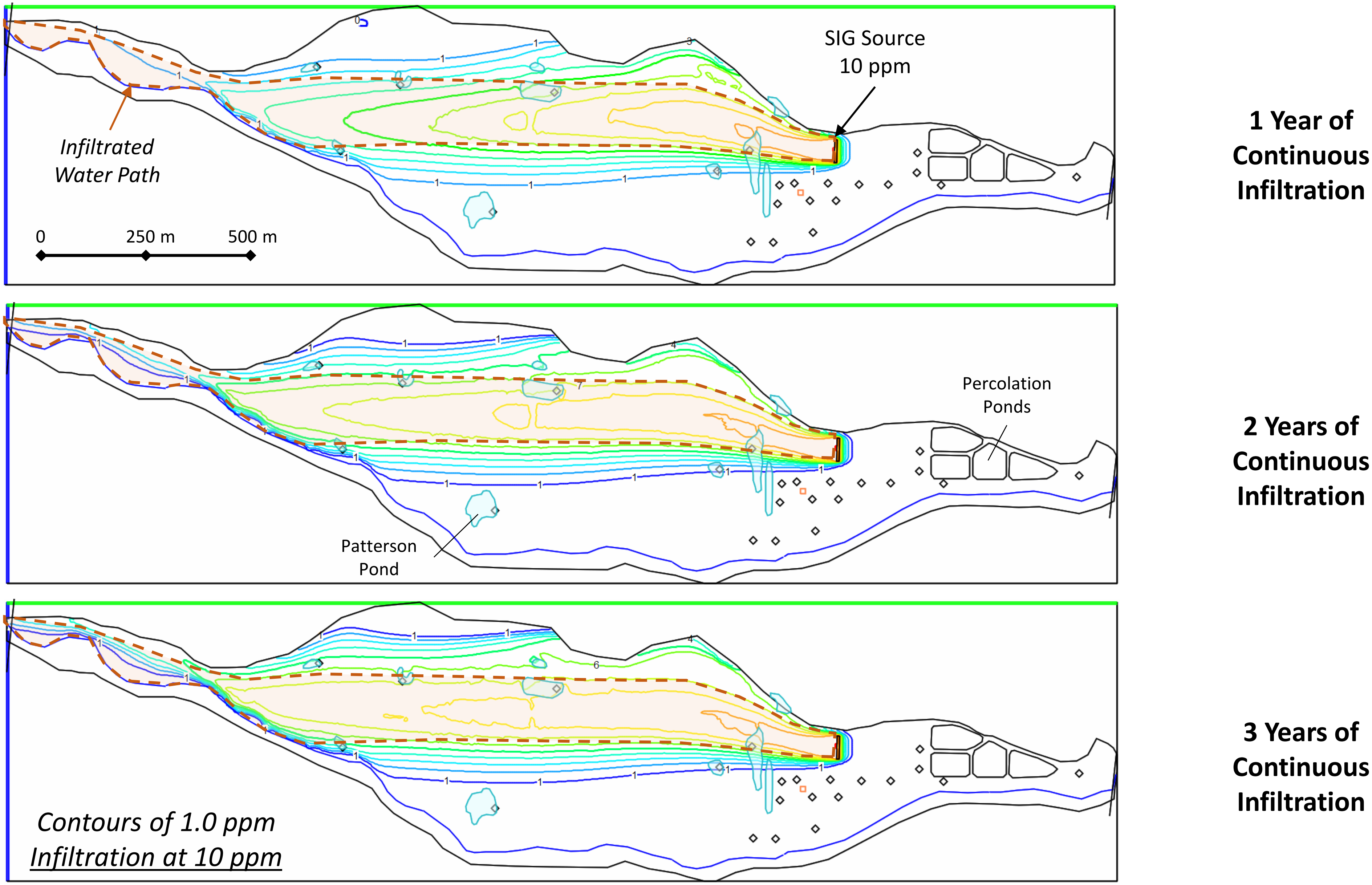

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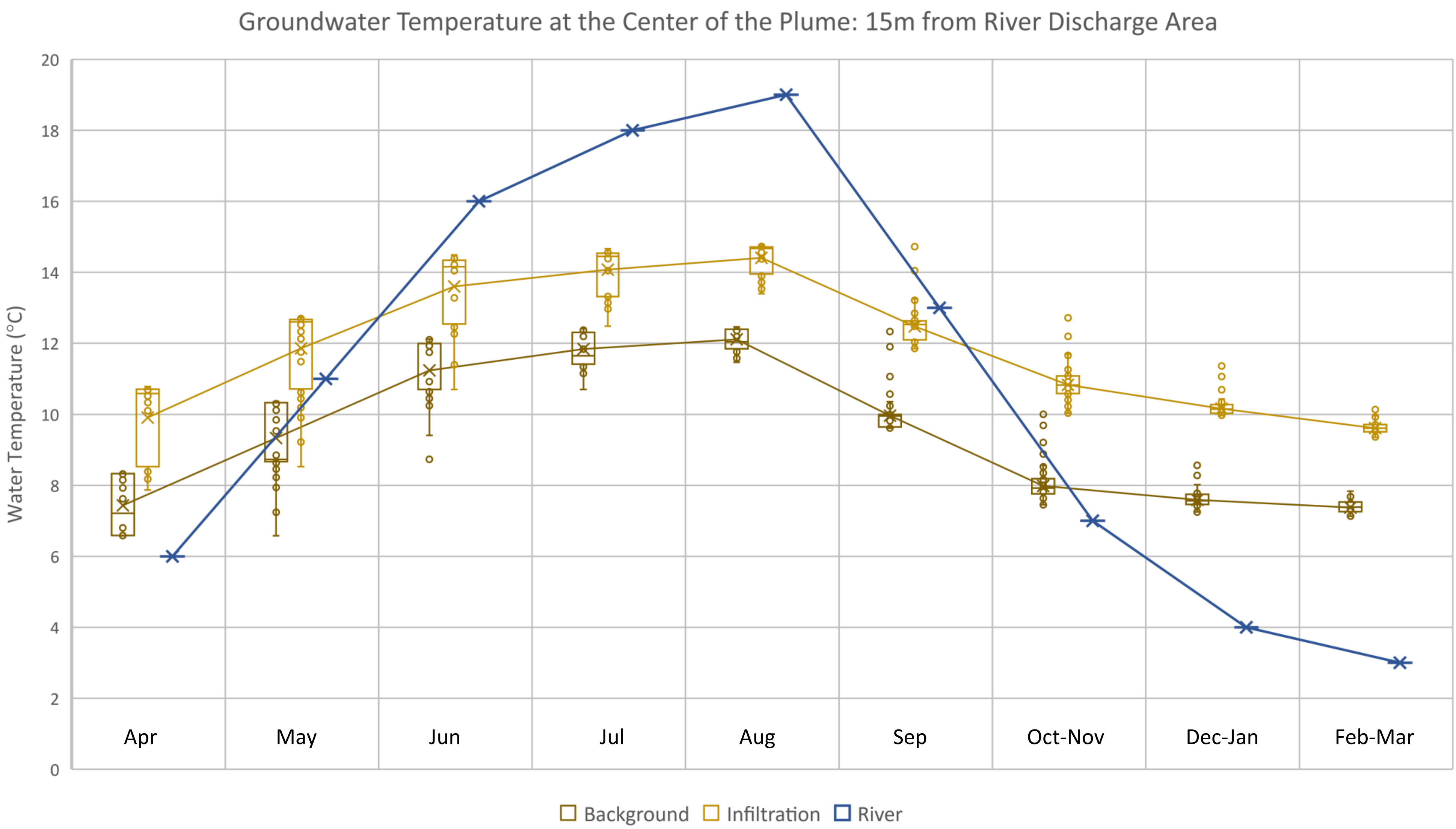
Figure 13
Conservative Tracer Plumes from Alternate SIG Location:
Dilution, Dispersion, and Moderate Denitrification



River temperature based on data from 40 City measurements collected 2004-2019. Measurements were generally quarterly but with many gaps. Data do not include times of measurement or weather conditions, so it is unclear how representative these values are of true peaks and lows.

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Figure 14
Final VS2D Model CT Boundary and Groundwater Temperature Curves

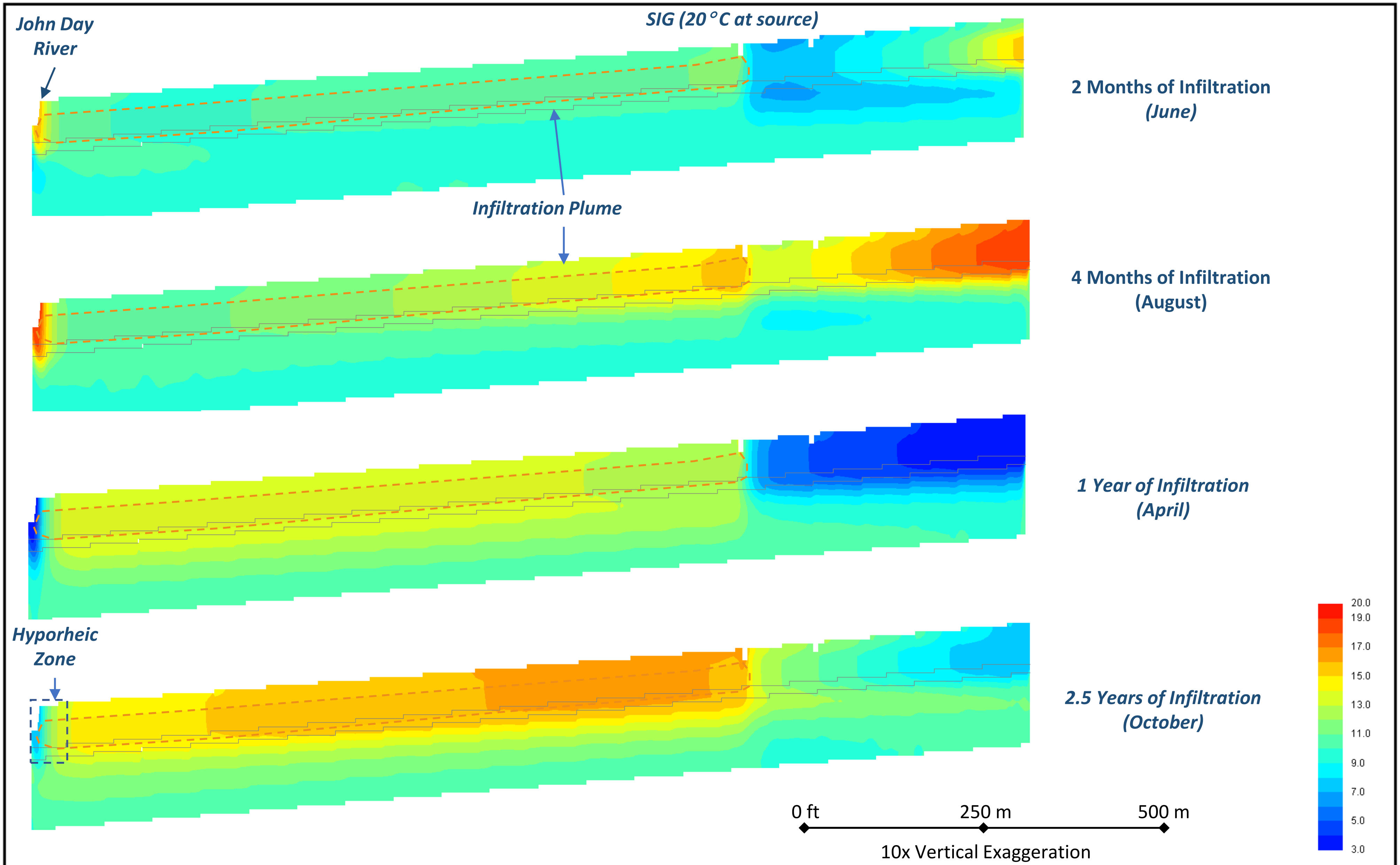

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Figure 15
Final VS2D Heat Transport Model:
Heat Distribution Profiles
Facing Northward

5 Discussion

5.1 Groundwater Model Application to the Maui Factors

The following section outlines the results from the final MODFLOW, MoundSolv, and VS2D groundwater models as they relate to factors under current litigation due the United States Supreme Court County of Maui v. Hawaii Wildlife Fund Decision. (Sept. 16, 2021). At the time of this project publication the U.S. Environmental Protection Agency (EPA) has rescinded the guidance document entitled "Applying the Supreme Court's County of Maui v. Hawaii Wildlife Fund Decision (Maui) in the Clean Water Act Section 402 National Pollutant Discharge Elimination System Permit Program" that was issued on January 14, 2021. Informed by the factors identified in the Maui Decision, ODEQ and the EPA continue to apply site specific science-based evaluations to determine whether a discharge from a point source through groundwater to a jurisdictional surface water, in this case the John Day River, is the function equivalent of a direct discharge. This discussion seeks to present the science-based facts of the proposed infiltration of treated groundwater based on the factors of the Maui Decision and its relative potential impact, if any, to the John Day River.

5.1.1 Time of Travel from Source to WOTUS

The travel times from the proposed SIG facility to the John Day River presented in this report are considered the minimum expected travel times. The MODFLOW model utilized the highest estimate of aquifer transmissivity obtained from field measurements, yielding the fastest groundwater flow velocities. In reality, the transmissivity of the aquifer deposits between the SIG and the river likely varies within the predicted range. Using the median transmissivity estimate instead of the maximum would result in 55-60% longer travel times than those presented in this report, for example.

That being said, the travel times from the two SIG locations evaluated in this study ranged from 31 to 89 days. Typical groundwater flow velocities in the alluvial aquifer of approx. 0.0004 m/s, or about 34.5 m/d. In comparison, flow velocities measured in the John Day River were more than 1,000 times this rate at a time of near record low river levels. The one to three months of minimum residence time within the aquifer provides an opportunity for natural attenuation of wastewater constituents through biogeochemical processes within the aquifer sediments, as well as dilution through groundwater mixing and dispersion. Wastewater directly discharged into the John Day River would not experience these diminishing processes.

5.1.2 Distance Traveled from Source to WOTUS

The MODFLOW model demonstrated that the placement of the SIG system has a major role in travel distance to discharge at the river. The average flow path through the alluvial aquifer from the primary SIG location was about 1,100 m in length at the center of the wastewater plume. The shortest flow path from the primary SIG to the river is about 990 m. This does not appear to vary significantly by season and river conditions. The average flow path increases to more than 1,700 m from the alternate SIG location, with a minimum flow path of about 1,440 m.

Longer flow paths mean greater contact between the infiltrated wastewater and the surfaces of the aquifer material. Chemical reactions with aquifer sediments and adsorption onto binding sites, neither of which were simulated in this conservative model, could further reduce the concentration of many wastewater constituents. Interactions between wastewater constituents and natural alluvial groundwater components, such as phosphorus and iron, are also expected to some degree. The beneficial effects of of these processes would increase as the flow path lengthens.

Again, these values are based on a conservative, high-transmissivity model. Models with a lower transmissivity value will yield similar average flow path estimates, but with shorter minimum and longer maximum flow paths. Lower hydraulic conductivity would result in a wider wastewater plume that would intercept the river along a wider reach.

5.1.3 Nature of the Aquifer Material

The physical and chemical characteristics of the alluvial aquifer were documented in the field through well logs, test pits, and water quality sampling. The majority of groundwater flow in the alluvial aquifer is through the upper layer of coarse cobbles, gravel, and sand which was heavily altered by gold dredging in the late 19th and early 20th centuries. Some groundwater flow occurs in a thinner layer of gravel and sand which underlying the coarse dredge tailings. Due to the confining nature of the underlying dense silt, groundwater flow in the alluvial aquifer is restricted to about 3-6 m of coarse deposits.

Cobbles and gravels are not an ideal material for optimizing physical (filtering) or chemical (adsorption) treatment of infiltration wastewater because of large pore spaces and low surface area. However, field measurements demonstrated low oxygen conditions within the aquifer. Furthermore, isotope data suggests denitrification is occurring in and down-gradient of the current percolation ponds. These factors indicate that conditions appropriate for biological cycling of wastewater nutrients are already present within the aquifer or will likely form once the SIG is in operation.

5.1.4 The Extent of Dilution and Chemical Change

Dilution and dispersion are primarily responsible for the decrease in concentration from SIG to discharge area. Denitrification is known to occur, may reduce nitrate load by several percent even over short residence time in the aquifer. Several processes that were not modeled, like adsorption and other biological processes, likely reduce and transform major wastewater constituents. These interactions occur within a groundwater or treatment wetland settings. None of these processes would occur in a direct release to surface water.

5.1.5 The Amount of Pollutant Entering WOTUS vs Amount at Discharge

Dilution and dispersion decrease concentration but not reduce contaminant load. Processes like biological uptake, denitrification, adsorption, and precipitation do remove many contaminants during residence within the aquifer. These processes would not occur for a direct discharge to the river.

5.1.6 Manner by Which Pollutant Enters WOTUS

The MODFLOW model suggests that all of the wastewater infiltrated through the SIG (in either location) will discharge to the John Day River near the western end of the study area. Particle tracking models using MODPATH indicated that the vast majority, if not all, of the infiltrated water will discharge along the north bank of the river and riverbed over an area between about 100 and 800 m wide. Groundwater naturally discharges to the river in this region through dispersed seepage through the river channel. The infiltrated water would enter the river in this manner over a large area of the riverbed.

5.1.7 Degree to Which Pollutant Maintains Specific Identity

Transformation of nitrate via denitrification in aquifer will change the nature of the pollutant and thermal diffusion through aquifer material will mitigate the potential thermal load that a direct release to the John Day River would experience. Together with dilution and dispersion few, if any, of the chemical or physical elements that define the treated effluent would remain unchanged. Transformation the treated effluent to near background or below background concentrations currently observed in the John Day River is likely with a groundwater infiltration system. The original effluent will be close to current conditions experienced in the river and may not be detected as significantly different from river conditions if monitored at the near river-environment within 15 meters of the river's edge.

5.2 Design and Operation of the Infiltration System

This modeling project provides insight to options under consideration in the design and construction of the infiltration system. The effect of the size, shape, orientation, and operations of the SIG are discussed in the sections that follow.

5.2.1 Size and Shape of the SIG

CwM utilized the MoundSolv and base MODFLOW models to briefly assess the impacts of the size and shape of the SIG facility on its performance. Shape and orientation of the SIG relative to groundwater flow has a larger potential effect on mounding than the size of the system. The proposed SIG is much longer north-south (cross-gradient) than it is wide. This is the ideal configuration given the east-to-west flow regime in the aquifer. At the expected aquifer transmissivities in the areas currently considered for SIG construction, reducing the width of the SIG infiltration area by 50% results in less than 1 cm (< 2%) of increased maximum mounding. In contrast, reducing the north-south length of the SIG infiltration area by 50% increases maximum mounding by about 7 cm (12%).

The cross-gradient orientation of the proposed SIG is the most ideal configuration for dispersing infiltrated water across the aquifer. For example, a square infiltration basin with the same infiltration area as the proposed SIG will experience about 16 cm (29%) greater maximum mounding under the same aquifer conditions. The long trench design also maximizes the width of the infiltration water plume, which is related to dilution and dispersion potential, as well as the width of the discharge are to the river.

Greater mounding below the SIG leads to greater initial dispersion of wastewater through the aquifer. Therefore, it may be beneficial to decrease the size of the SIG to increased mounding (within engineering limits) to encourage dispersion. However, according to CwM's model simulations, doing so is not effective. The reduction in SIG size required to significantly increase initial dispersion is so great that the effects balance out, i.e., the increased dispersion area is smaller than the original SIG. It is more effective to use a larger SIG with a greater margin of safety when it comes to mounding.

Maximum mounding for the proposed SIG design and location does not exceed 1.0 m until the infiltration rate is raised to approx. 2,100 m^3/d (0.55 MGD). This suggests the design safely allows for short periods of nearly double the average infiltration rate.

5.2.2 Location of the SIG

This final modeling report focused on the initially proposed SIG location and one alternate location just to the north and east. This alternate location is simply meant to demonstrate the potential benefits and downsides of moving the SIG away from the John Day River. Shifting the proposed SIG any distance to the north and east from the primary SIG location will increase travel times, flow paths, the discharge area to the river, and the potential for denitrification and other natural attenuation within the aquifer. The proposed SIG sits just south of a break or change in groundwater gradient orientation. Moving the SIG north will result in more of the infiltrated water being pushed initially away from the river for a longer flow path.

There is a likely downside to the alternate location or to moving the SIG north. The aquifer is expected to become thinner to the north closer to the valley wall. A thinner aquifer has a lower transmissivity, causing in a trade-off between more favorable flow paths and increased mounding. The models suggest the maximum mounding for the current SIG design would be less than the 1.2-m limit even with a 1.5-m thick aquifer (40% the thickness observed at the proposed SIG site). Additional field observations may be required to measure the aquifer thickness in the alternate location.

5.2.3 Alternating Infiltration Between Multiple SIG Systems

The current SIG design includes three infiltration galleries in a close parallel configuration. These three trenches were modeled as one 7.6-m wide infiltration area in the MODFLOW and MoundSolv models. However, as discussed in Section 5.2.1, MoundSolv suggests that reducing the west-east width of the SIG area does not significant increase mounding. In fact, a single 1.5-m wide gallery infiltrating the full 0.30 MGD of wastewater experiences only 6 cm greater maximum mounding than the three galleries sharing the capacity. This suggests that alternating between these galleries, or slightly modified galleries, is possible within the anticipated operational limits.

Alternating between multiple, separated SIGs allows for distinct wetting and drying period of the gallery itself and the underlying unsaturated/mounding zone. Wetting and drying periods are beneficial for promoting biological breakdown of wastewater constituents within the unsaturated zone, especially cycling of nitrate-N (Subramaniam et al., 2014; Pan et al., 2017). Alternating monthly between two or multiple SIGs could significantly increase aquifer treatment potential and make routine gallery maintenance easier.

Multiple SIGs could be oriented in two ways: west-to-east along gradient, or north-to-south across gradients. MODFLOW model simulations suggest that an arrangement along groundwater gradients does not significantly reduce the peak solute or thermal loading at the river discharge area. Multiple SIGs in this arrangement share the same plume area, meaning the infiltration plume would develop in more-or-less the same manner as a single gallery. However, alternation between galleries would allow for brief “flushing effects” where native groundwater would flow under the gallery recently under operation. The result would be a reduced-load pulse through the plume during each alternation period. The MODFLOW model did not consider the likely increase in natural attenuation due to wetting and drying, which would result in a lower peak concentration at discharge.

A series of SIGs spread out north-south across groundwater gradient would have a different result. Alternating between galleries in this orientation increases the time it takes for peak plume concentrations to develop. If alternation occurred monthly, for example, a large percentage of the water infiltrated through any one gallery would have reached the discharge point by its next operational period. For this reason, each period is essentially starting a nearly new plume. The build-up rate depends on the alternation period, location of each SIG, and the overlap of the plumes from each SIG. However, plume build up and stabilization could potential take much longer than the 2-3 years for the single SIG. The downside of this orientation is that a larger cross-section of the aquifer would be receiving wastewater, ultimately resulting in a greater range of flow path lengths, residence times, and discharge points, including less favorable ones.

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Figure 16
Potential Multiple-SIG Layouts

No.	Date	By	Revisions
1	DATE	AUTH	DRAFT

0 150 300 600 ft

1:3,600

Proj#: 2111001
John Day Hydrogeologic Investigation
City of John Day
Oregon

N

Multiple-SIG Systems
John Day River Area
Current Percolation Ponds

5.2.4 Monitoring of Surface Water Bodies Down-gradient of the SIG

If a groundwater and surface water monitoring system is required as proof-of-concept as part of a permitting path, the following elements are recommended as guidance for all potential monitoring. There are four primary monitoring considerations:

- Source Water- Either treated effluent or identifiable tracer. The concentrations, temperature, volume, rate duration of infiltration waters must be recorded.
- Log ponds – These surface water bodies may influence the path of infiltrated waters.
    - Only ponds that are not lined are appropriate for monitoring
    - Ponds within the groundwater flow path require upgradient and downgradient elevation and water quality measurements as well as surface water elevations and water quality.
    - Pumping from ponds and filling of ponds must be identified and measured if ponds operate as sources of water for other uses or are filled to maintain water levels.
- John Day River
    - In-stream sampling along the discharge zone as well as up gradient and downgradient of the modeled discharge area.
- Hyporheic Zone
    - Shallow groundwater sampling/monitoring in the hyporheic zone along the discharge area. Monitoring wells should be installed within approximately 15 meters of the river's natural highwater mark.

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