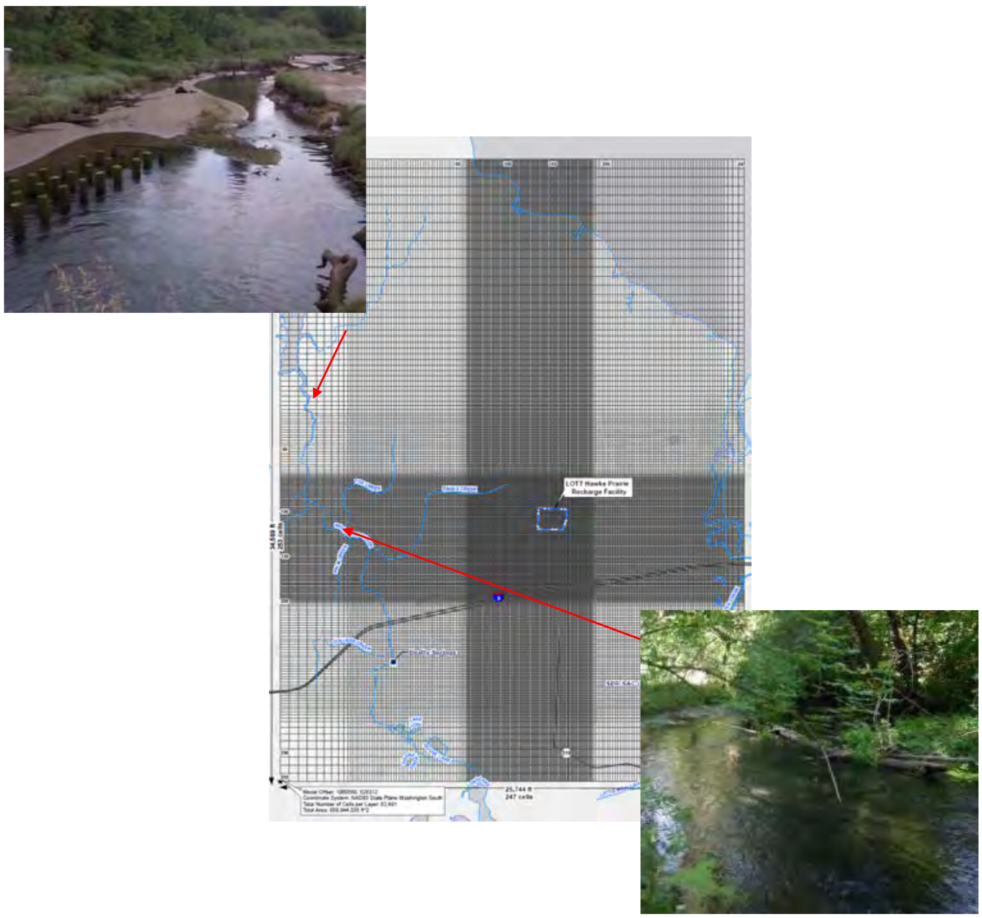
Technical Memorandum
Steady-State Groundwater Model Development and Calibration (Task 2.1.4)

LOTT Clean Water Alliance
Reclaimed Water Infiltration Study



October 22, 2021

Prepared by

HDR
905 Plum Street SE, Suite 200
Olympia, WA 98501

Prepared for

LOTT Clean Water Alliance
500 Adams Street NE
Olympia, WA 98501

Table of Contents

Tables

Figures

Appendices

Acronyms and Abbreviations

bgs	below ground surface
btoc	below top of casing
cfs	cubic feet per second
cm	centimeter
d_{10}	10% passing soil grain size
d_{50}	50% passing soil grain size
d_{90}	90% passing soil grain size
DEM	digital elevation model
°F	degrees Fahrenheit
ft	foot or feet
gpd	gallons per day
gpm	gallons per minute
hr	hour
ID	inside diameter
in	inch
LOTT	LOTT Clean Water Alliance
K_h	horizontal hydraulic conductivity
K_v	vertical hydraulic conductivity
mgd	million gallons per day
mm	millimeter
MSL	Mean Sea-Level
MWRWP	Martin Way Reclaimed Water Plant
N/A	not applicable
NRMSE	normalized root mean squared error
Qc	Pre-Vashon coarse deposits
Qf	Kitsap Formation
Qgof/Qgos	Late Vashon sediments in Woodland Creek Valley
Qvr/Qgo	Vashon Recessional Gravel Outwash
Qvt/Qgt	Vashon Till Formation
Qva/Qga	Vashon Advance Outwash Formation
RMSE	root mean squared error
RWIS	Reclaimed Water Infiltration Study
s	second
TQu	Tertiary unconsolidated and undifferentiated sediments
USCS	Unified Soil Classification System
USGS	United States Geological Survey
WAC	Washington Administrative Code
yr	year

1.0 Introduction and Background

The LOTT Clean Water Alliance (LOTT) provides services to treat and manage wastewater for the urban areas of Lacey, Olympia, and Tumwater in Thurston County, Washington (at the southern end of Puget Sound). Since 2006, LOTT has also produced reclaimed water at the Martin Way Reclaimed Water Plant (MWRWP) that is used for irrigation and other non-drinking purposes. Some of the reclaimed water is used to recharge (replenish) groundwater using rapid-infiltration basins at the LOTT Hawks Prairie Ponds and Recharge Basins property (referred to in this report as the LOTT Hawks Prairie property). The long-range plan for future wastewater management includes treating wastewater to a higher level at reclaimed water treatment plants for reuse and groundwater replenishment.

Some chemicals may remain in Class A reclaimed water even after going through advanced Class A required treatment (these chemicals remaining after reclaimed water treatment are hereinafter referred to as “residual chemicals”). These residual chemicals may include nutrients, pesticides/herbicides, pharmaceuticals, personal care products, cooking products, flame retardants, and other household chemicals not removed during treatment. In response to potential concerns regarding the residual chemicals in Class A reclaimed water, LOTT has initiated a study (Reclaimed Water Infiltration Study or RWIS). The purpose of the study is to quantify residual chemicals in reclaimed water and to assess their attenuation by Soil Aquifer Treatment and their fate and transport through the recharge infiltration basins, vadose zone and through groundwater to potential downgradient well water users or surface water discharge areas.

The study components include:

- Surface water, groundwater, and reclaimed water quality monitoring to determine water quality and evaluate occurrence and concentration of residual chemicals. Collected information will be used to assess the existing groundwater quality and the relative changes to groundwater quality that may occur from use of reclaimed water for groundwater replenishment.
- Tracer testing to identify dominant downgradient flow paths and travel times to monitoring wells as reclaimed water infiltrates the vadose zone to the water table and is then transported by groundwater.
- Groundwater flow and particle tracking modeling to estimate flow paths and travel times beyond the spatial and temporal extent identified through tracer testing and at a variety of recharge rates typical of full-scale build-out capacity of the reclaimed water recharge facility at Hawks Prairie. Fate and transport groundwater modeling to estimate residual chemical loading to downgradient receptors, under current and future reclaimed water aquifer recharge rates.
- Risk assessment to understand potential human health and ecologic risks posed by replenishing groundwater with reclaimed water.
- Evaluation of cost/benefit analysis of various options for treatment/disposal of reclaimed water.

1.1 Purpose and Scope of Groundwater Model Evaluation

The purpose of the groundwater modeling is to understand the fate and transport of residual chemicals in reclaimed water used for aquifer recharge. This document describes the numerical groundwater model development and calibration. After the model calibration is established and uncertainty in the model understood, the model will be used to predict flow paths and travel times of reclaimed water from the point of infiltration to downgradient discharge points (potential receptors such as wells or surface water bodies). Once calibrated, this numerical groundwater model has the ability to predict flow paths, travel times, and residual chemical transport beyond the spatial and temporal extent identified through the tracer testing and water quality monitoring conducted in 2018 (Task 2.1.3). The model will be used to determine the percentage of groundwater originally composed of reclaimed water that arrives at potential receptors (surface water springs, creeks or rivers, or a groundwater well). The model also will be used to predict the likely arrival concentration of residual chemicals which can be used to estimate residual chemical loading at the potential receptors. Model simulations to estimate residual chemical movement will be carried out for current reclaimed water infiltration rates (and residual chemical concentrations) and for future full-scale build-out capacity of the aquifer recharge facility at Hawks Prairie. The results of these model simulations, and analyses of residual chemical fate and transport will then be used to assess risk to human and ecological health.

The purpose of this report is to document the model development including data acquisition and steady-state flow model calibration to measured groundwater levels, baseflows of Woodland Creek and its tributaries and flow velocities calculated from tracer testing. A separate work plan, Draft Work Plan Groundwater Modeling Fate and Transport Assessment (HDR 2018a), has been developed to guide the modeling approach, process and methods used to support the risk assessment, including the approach to simulating and calculating travel times to, and percentage of reclaimed water and residual chemical concentrations arriving at, downgradient receptors.

1.2 Report Contents

This technical memorandum describes the approach and methods for groundwater model development and calibration. The contents are as follows:

- Section 2 summarizes previous reports referenced during this task, including previous tasks of the RWIS conducted by HDR, Inc. (HDR).
- Section 3 includes a description of the physical setting of the study area.
- Section 4 provides information on the hydrogeology of the study area including hydrogeologic reports by others.
- Section 5 is a summary of previous numerical groundwater models developed for the area.
- Section 6 describes the groundwater model development, calibration approach, and results.

2.0 Prior Investigations

The following reports were prepared by HDR as part of the ongoing LOTT RWIS study and are referenced in this technical memorandum for the development of the groundwater model.

- Scope of Services LOTT Clean Water Alliance Reclaimed Water Infiltration Study, Phase III – Study Implementation, HDR (2014). This is the document describing the initial study scope.
- Woodland Creek Stream Flow Measurement and Ground Water Inflow Analysis, HDR (2015). This technical memorandum documents a stream survey of Woodland Creek, Eagle Creek, and Fox Creek to assess low-flow conditions and characterize groundwater inflows and outflows (baseflows) from and to these creeks.
- Wastewater and Reclaimed Water Quality Characterization (Task 1.3), HDR (2016a). This report presents information on a quarterly sampling and laboratory analysis program to determine the residual chemicals present in LOTT's wastewater and the quality reclaimed water produced at the Budd Inlet Reclaimed Water Plant and the Martin Way Reclaimed Water Plant from November 2014 to October 2015.
- Surface Water Quality Characterization (Task 1.2), HDR (2016b). This report documents the surface water quality characterization completed by HDR in the Woodland Creek and Deschutes River watersheds. The monitoring study quantified surface water quality, including laboratory analysis for residual chemicals and conventional surface water quality parameters, with four sampling events between August and December 2015, including summer low flow, a fall storm event, and two winter high flow events.
- Groundwater Quality Characterization Report (Task 1.1), HDR (2017a). This report documents the groundwater quality sampling and analysis completed by HDR during 2015 with samples collected from residential, monitoring, and public supply wells and a spring in the Hawks Prairie and Tumwater areas. Samples were analyzed for nutrients, residual chemicals, metals, water quality indicator parameters, organic compounds, and other constituents of interest.
- Hydrogeologic Characterization Report, HDR (2017b). This report describes the hydrogeologic investigation undertaken at the vicinity of the LOTT Hawks Prairie property, including: collection of vadose zone soil samples and installation of six vadose zone borings and lysimeters to collect samples to characterize vadose-zone pore-water quality, installation of two soil moisture/temperature probes, the drilling of 14 soil borings below the water table, collection of saturated zone soil samples and laboratory analysis of soil properties (grain-size, mineralogy, organic carbon), and installation of 14 monitoring wells (10 wells were completed in the Shallow (Qva) Aquifer and 4 wells were completed in the Sea-Level (Qc) Aquifer). Depth to groundwater was measured in wells to determine groundwater elevations and horizontal and vertical groundwater gradients. Pumping tests and slug tests were performed and analyzed to estimate aquifer hydraulic properties. Pressure transducers were installed in the three sets of paired monitoring wells and recorded water levels every four hours from August through September, 2017.

- Tracer Testing and Water Quality Monitoring of Treatment Effectiveness (Task 2.1.3), HDR (2019a). This report documents the ten-month water quality and tracer testing program that started in January 2018 and continued through October 2018. This phase of the project included monitoring of reclaimed water, vadose zone pore-water, and groundwater quality. Groundwater levels were also measured at each sampling event and pressure transducers were installed in eighteen monitoring wells that recorded water levels every four hours from January to October 2018. The purpose of the monitoring is to determine the effects of reclaimed water infiltration on vadose zone and groundwater quality at the LOTT Hawks Prairie property. Tracer testing was completed to determine groundwater travel times from the infiltration basins through the aquifers.

A variety of hydrogeologic reports have been developed for water supply and resource protection projects in the greater Hawks Prairie and northern Thurston County area. These reports are referenced in the next section describing the physical setting of the study area.

3.0 Physical Setting

This section presents background information on the climate, topography, surface water features, and hydrogeology of the Hawks Prairie study area.

3.1 Climate

The area is characterized by mild cool/wet winters and warm/dry summers. Precipitation and temperature data from the Olympia Airport USW00024227 gauging station (about 10 miles southwest of the Hawks Prairie study area) is presented in **Table 1** and **Table 2**, respectively. Over the 1948 to 2016 period of record, during the summer period from June to October, the average low/high temperature ranged from 46.8 to 77.2 degrees Fahrenheit (°F) and average total monthly precipitation ranged from 0.7 to 4.8 inches (in). During the winter period from December to February, over the same period of record, the low/high temperature ranged from 31.8 to 49.2°F and average total monthly precipitation ranged from 5.3 to 8.2 in. Total average annual precipitation was 51.0 in and average annual temperature was 50.0°F.

3.2 Topography and Surface Water Features

Figure 1 shows the land surface topography and the surface water drainage in the Hawks Prairie study area. The study area is located on the east side of a broad plateau that was formed by sediments deposited during past glaciations. The plateau is about eight miles wide, bounded by Budd Inlet (Puget Sound) to the west and McAllister Creek (within the Nisqually River valley) to the east.

The specific study area for this project is between the Nisqually River valley to the east and the Woodland Creek drainage basin and valley to the west. Ground surface elevation in the study area range from sea level to 315 feet (ft). The Nisqually River and McAllister Creek (to the east) are located in a valley deeply incised through the upper glacial deposits that forms a steep east-facing scarp valley wall. Woodland Creek and several tributaries (Eagle Creek, Fox Creek and others) drain the west side of the study area. Woodland Creek flows north from Long Lake to Henderson Inlet (Puget Sound). Woodland Creek has eroded through the upper geologic formations bisecting the plateau. Steep scarps and the Puget Sound bound the northern edge of the Hawks Prairie study area.

3.3 Surface Water Flow in Study Area

3.3.1 Woodland Creek

Woodland Creek flows north into Puget Sound and receives inflow from runoff and groundwater baseflow. Stream flow data for Woodland Creek from gauging stations at River Miles 1.5 to 3 are presented in **Figure 2**. Stream flow ranges from 0 to 62 cubic feet per second (cfs). Stream flow generally peaks during the winter to early spring when runoff and groundwater inflow is highest, and stream flow declines significantly through the late spring and summer. High stream flows from storm events may also occur in the spring and fall.

Woodland Creek and its tributaries are primarily gaining streams—groundwater discharges from the aquifer to the creeks. This is because the creek channels have incised into or through the upper geologic formations, including the Shallow (Qva) Aquifer, to below the water table, as well as the humid climate with high rainfall rates.

A stream flow survey on Eagle Creek, Fox Creek, and Woodland Creek was conducted by HDR during summer-time low-flow conditions on August 24 and 25, 2015, to characterize groundwater exchange within these streams (HDR 2015). Rainfall in the three months leading up to the measurements in 2015 was below average. Average rainfall for June, July and August are 1.26, 0.39, and 1.0 in; prior to the 2015 measurements, monthly rainfall amounts were 0.14, 0.15 and 0.93 in. **Figure 3a** shows that a cumulative groundwater inflow of 9.9 cfs was measured in Woodland Creek and groundwater flowed into the creek channel in eight out of the 18 stream reaches (**Table 3**). Fox Creek was dry at the two upstream measurement locations but further downstream towards its junction with Woodland Creek, with a cumulative gain of 0.51 cfs, as shown in **Figure 3b**. Eagle Creek was mostly dry but exhibited minor groundwater inflow of 0.09 cfs, as shown in **Figure 3c**. Observed stream flow and groundwater inflow between gauging locations is summarized in **Table 3**.

The only available stream flow records for Fox Creek and Eagle Creek were from Ecology (2018a) with stream flow records on June 21, 2002, of 0.54 and 0.31 cfs, and on October 31, 2002, of 0.35 and 0.17 cfs, respectively. It is generally expected that these streams flow during the winter and spring and are mainly dry in the late summer.

3.3.2 McAllister Creek and the Nisqually River Valley

The Nisqually River and McAllister Creek flow through the broad Nisqually River valley. Nisqually River flow generally peaks in the winter to early spring and declines through the summer and early fall as shown in **Figure 6**. Within the area of interest, the Nisqually River low-flow ranges from 550 to 1,000 cfs, and the high flow is usually above 2,500 to 3,000 cfs, based on gauging data at River Mile 3.5. Groundwater drains to the valley as evidenced by springs along the steep scarp along the toe of the western valley wall. Both McAllister Creek and the Nisqually River are tidally influenced in the study area. A stream flow record was not available for McAllister Creek.

4.0 Hydrogeology

The Hawks Prairie study area was heavily glaciated, resulting in a sequence of stratified sediments that are regionally correlated based on their water-bearing properties (Logan et al. 2003). The most recent glaciation occurred 15,000 to 13,500 years ago and is referred to as the Vashon Stade of the Fraser Glaciation (Drost et al. 1998). Regional geologic and hydrogeologic reports, including reports of groundwater supply studies and well installation and testing projects, were reviewed to assess the occurrence and extent of hydrostratigraphic units. These reports include Brown and Caldwell (2004, 2009), Drost et al. (1998, 1999), Golder Associates, Inc. (2011), Hart Crowser (1989), Landau (2016), Logan et al. (2003), NWLW (2008), PGG (1997, 2004), and Robinson and Noble, Inc. (2000, 2002, 2005). This information is in addition to the recently completed hydrogeologic characterizations for the study area (HDR 2017a, 2017b). A map showing the surface geologic units is presented in **Figure 7** (data from Washington Geological Survey (2017), nomenclature follows Logan et al. (2003)). Cross sections showing the stratigraphic units around the LOTT Hawks Prairie facility are shown in **Figures 6a** to **6c**. Compiled geologic cross sections from previous hydrogeologic reports from groundwater supply studies in the area are presented in **Appendix A**, and the locations of the cross sections are shown in **Figure 11**. HDR reviewed publically available well logs from the study area (Ecology 2018b) to gather additional information on hydrostratigraphic unit occurrence throughout the study area. Well locations and well logs compiled from this review are presented in **Appendix B** (available as electronic file).

4.1 Hydrostratigraphic Units

The hydrostratigraphic units present in the Hawks Prairie study area are discussed below from top to bottom. Unit nomenclature differs between two sources of data. In the descriptions below the hydrostratigraphic unit name is presented first and the geologic formation name is presented second (abbreviations in parenthesis are first from Drost et al. (1999) and second from Logan et al. (2003). For the purposes of this report, unit name abbreviations follow Drost et al. (1999).

The following four units comprise the vadose zone (where unsaturated) or the shallow aquifer (where saturated):

Late Vashon Sediments in Woodland Creek Valley (Qgof/Qgos). Late Vashon sediments were deposited in the Woodland Creek valley during inter-glacial periods (Landau 2003, Logan et al. 2003). Sediments consist of sand/silt up to 100 ft thick or more in the middle reach of Woodland Creek valley (HDR 2017a). This unit forms an unconfined aquifer within the Woodland Creek valley.

Alluvium and Vashon Recessional Gravel Outwash (Qvr, also known as Qgo). This unit is composed of alluvium and recessional glacial outwash sand and gravel. Throughout most areas the unit is unsaturated and forms the vadose zone and where saturated it forms part of the unconfined aquifer. Approximate thickness of the unit ranges from being absent (eroded) to over 100 ft thick in places. This is the upper-most water bearing unit in the Hawks Prairie study area.

Vashon Till (Qvt, also known as Qgt). Deposits of dense (compacted) unsorted silt, clay, sand and gravel form a regional unit which sometimes impedes the vertical flow of groundwater if the sediments above it are saturated. The till unit is absent throughout most of the LOTT Hawks Prairie property, but is present nearby to the south and north of the site. Approximate thickness of the unit ranges from being absent to over 50 ft thick, with appearances at the surface and at varying depths.

Vashon Advance Outwash (Qva, also known as Qga). The Vashon Advance Outwash is a regional aquifer composed of sand and gravel. This is the upper-most water bearing unit where Qvr is not saturated. The Qvr and Qva units are sometimes grouped together and called the Shallow (Qvr/Qva) Aquifer in previous studies. The depth to the bottom of the Shallow (Qva) Aquifer is generally less than 150 ft below ground surface (bgs), although may be deeper in places. In the vicinity of the LOTT Hawks Prairie property the Shallow (Qva) Aquifer is generally unconfined, although in places the groundwater level may rise into the glacial till and become confined.

The following four units underlying the shallow aquifer include:

Upper Confining Unit, Kitsap Formation (Qf). The Kitsap Formation is generally a low-permeability clay, silt and sand formation that is a regional Upper (Qf) Confining Unit up to 150 ft thick between the Shallow (Qva) Aquifer and the Sea-Level (Qc) Aquifer. The top of the Kitsap formation was generally observed at depths of 110 to 160 ft in well logs in the study area. Significant thicknesses of fine sand beds have been observed in some locations, which may cause the confining unit to behave as a leaky confining unit. During the tracer test conducted at the Hawks Prairie Recharge basins in 2018, bromide and sulfur hexafluoride tracer were observed in monitoring wells screened in the Sea-Level (Qc) Aquifer, further supporting the understanding of the Kitsap Formation as a leaky confining unit or is not continuous. Furthermore, PGG (2004) states that the permeability of the Kitsap Formation can vary quite widely. The Kitsap Formation appears to be absent near the west side of the Thurston County Landfill, as illustrated in cross sections in **Figures 6a** through **6c** and **Appendix A** (HDR 2017b, NWLW 2008, and PGG 2004).

Sea-Level (Qc) Aquifer, Pre-Vashon Coarse Deposits (Qc). This thick (up to 150 ft) sequence of stratified coarse sand and gravel forms a regional aquifer used in places for public supply wells. These aquifer deposits are often distinguishable in the field during drilling because of the reddish-orange color (whereas the overlying Kitsap Formation is black or dark gray in color). The aquifer is also sometimes called the Sea-Level (Qc) Aquifer in previous studies. The top of the Sea-Level (Qc) Aquifer was generally observed at depths of 190 to 260 ft bgs in well logs. The aquifer is almost always confined because groundwater levels are above the top of the overlying Kitsap Formation confining unit. The coarse-grained deposits are usually found in beds overlain and underlain by finer-grained sediments that act as confining units or low-permeability units within the aquifer. The coarse-grained sediments are often correlated to be at or below current Sea-Level elevation, but are not necessarily uniform in depth or extent.

Lower Confining (TQu) Unit, Tertiary Unconsolidated and Undifferentiated Sediments (TQu): The Tertiary Unconsolidated and Undifferentiated Sediments include layers of clay, silt, sand and gravel of glacial and non-glacial origin. Below the Sea-Level (Qc) Aquifer where these sediments are fine-grained, the unit known locally as the Lower Confining Unit exists. The fine sediments of the Lower Confining Unit generally appear 250 to 350 ft bgs.

Deep (TQu) Aquifer, Tertiary Unconsolidated and Undifferentiated Sediments (TQu): Throughout the TQu strata occur layers of sand and gravel. In some places, deep public supply wells have been completed in the coarse TQu sand and gravel units which form a deep confined aquifer called the Deep (TQu) Aquifer in previous studies. The top of the coarse sediments of the Deep Aquifer appeared between approximately 350 and 530 ft bgs in well logs. The occurrence, extent, and connectivity of these coarse sediments throughout the study area is not well characterized due to lack of deep wells or borings.

4.2 Groundwater Levels and Flow Directions

Groundwater levels at monitoring wells near the LOTT Hawks Prairie property were measured monthly from January to October, 2018, as part of the recent groundwater quality and tracer testing study (HDR 2019a). **Table 4a**, **4b**, and **4c** show the measured groundwater levels and corresponding elevations as of June, 2018. **Figures 8a** to **8c** show the groundwater potentiometric elevations and estimated groundwater flow directions for the Shallow (Qva) Aquifer, Sea-Level (Qc) Aquifer, and Deep (TQu) Aquifer, respectively. **Figures 9a** to **9j** present hydrographs showing groundwater levels monitored during the January to July or October, 2018, period in LOTT monitoring wells and in City of Lacey water supply wells and monitoring wells.

4.2.1 Shallow (Qva) Aquifer Groundwater Levels and Flow Direction

Groundwater elevations in the Shallow (Qva) Aquifer are shown on **Table 4a**. Groundwater flows laterally from a groundwater divide located between the Nisqually River valley and the Woodland Creek valley. This causes groundwater to flow from a high point (approximately 160 ft in elevation) north of the LOTT Hawks Prairie property either to the southwest or west towards Woodland Creek or to the east or southeast towards McAllister Creek or north toward Puget Sound. Groundwater in the immediate vicinity of the LOTT Hawks Prairie property flows southwest from an elevation of about 150 ft from the northeast of the property to about elevation 95 ft in the area southwest of the property. Groundwater gradients then become flatter to the southwest as groundwater flows west towards the middle reach of Woodland Creek where groundwater discharges to a spring/wetland complex. The reason for the steeper groundwater gradients in the area north of and including the LOTT Hawks Prairie property and the flatter groundwater gradients to the southwest of the property is likely because the Upper (Qf) Confining Unit (composed of the lower-permeability Kitsap Formation silt/sand) dips down from the north to the southwest across the LOTT property toward the area where it is absent to the west of Thurston County Landfill, before flattening out to the southwest where it transitions into the Woodland Creek alluvium.

To the east of the LOTT property, groundwater flows east or southeast and discharges from springs and to McAllister Creek in the Nisqually River valley. There are numerous springs emanating along the base of the western scarp of the Nisqually River valley.

Groundwater levels were recorded in monitoring wells installed on and in the vicinity of the LOTT Hawks Prairie property completed in the Shallow (Qva) Aquifer and in the Sea-Level (Qc)

Aquifer, as shown on hydrographs from **Figures 9a** through **9e**. The groundwater level data indicate approximately 5 to 15 ft of fluctuation in the Shallow (Qva) Aquifer, partially as a result of the increase in precipitation throughout the winter and partially because of LOTT recharge activities. Hydrographs at monitoring wells near infiltration Basins 4 and 5 are presented with infiltrated reclaimed water volume in **Figure 25** showing the influence of infiltrated reclaimed water volumes on groundwater levels. The groundwater levels in the City of Lacey well S16 in the Shallow (Qva) Aquifer are shown in **Figure 9f** which also indicates approximately 5 to 10 ft of seasonal groundwater level fluctuation.

4.2.2 Sea-Level (Qc) Aquifer Groundwater Levels and Flow Direction

Groundwater in the Sea-Level (Qc) aquifer at the LOTT Hawks Prairie property flows from the west to the east towards and discharges into McAllister Creek, as shown in **Figure 8b**. Regional well logs to the north and west of the property indicate that groundwater in that area, within the Sea-Level (Qc) Aquifer, flows to the north, likely discharging into Puget Sound. The high groundwater elevations to the west and southwest of the LOTT Hawks Prairie Facility, as seen in **Figure 8b**, are in the vicinity of the window in the Upper Confining Unit (Qf) and suggest the Sea-Level (Qc) Aquifer is receiving recharge from the Shallow (Qva) Aquifer in this area.

Groundwater hydrographs presented in **Figures 9a** to **9e** for wells installed near the LOTT site and in **Figure 9g** for City of Lacey Well S29 indicate that groundwater levels in the Sea-Level (Qc) Aquifer also have up to about 10 ft of seasonal fluctuation. The groundwater levels for the paired wells in the Shallow (Qva) Aquifer and Sea-Level (Qc) Aquifer show that the deeper aquifer is hydraulically influenced by recharge from the upper aquifer, and that groundwater levels in each aquifer fluctuate similarly in magnitude and timing.

4.2.3 Deep (TQu) Aquifer Groundwater Levels and Flow Direction

Groundwater in the Deep (TQu) Aquifer flows from the south to the north, discharging to Puget Sound as shown in **Figure 8c**. The Deep (TQu) Aquifer is hydraulically connected to Puget Sound. The water level fluctuations observed in the hydrographs in **Figures 9h** to **9j** are likely due to the influence of pumping wells cycling on and off.

4.3 Aquifer Hydraulic Properties

Previous hydrogeologic studies were reviewed to estimate aquifer hydraulic properties for the hydrostratigraphic units. Aquifer hydraulic properties include hydraulic conductivity, storage coefficient, and effective porosity. The storage coefficient determines the amount of water in storage in the aquifer, and how quickly it can be released or added. The groundwater flow model is a steady-state solution, so storage is not accounted for in the groundwater flow equation. These hydraulic properties are respectively used to calculate the rate at which water can flow through the porous media, and the average linear velocity of groundwater or constituents of interest in groundwater. These properties are necessary for the development of groundwater flow and fate and transport models.

Previous pumping tests were completed on water supply wells and monitoring wells in the study area (Hart Crowser 1989, HDR 2017b, Landau 2008, 2016, NWLW 2008, PGG 1997, and Robinson and Noble, Inc. 2005). The calculated hydraulic properties from those tests are summarized in **Tables 5a** and **5b**. Hydraulic conductivity calculated from grain size analysis of soil samples in the Hawks Prairie vicinity are presented in **Appendix C** and summarized in **Table 6** (HDR 2017b). A summary of hydraulic conductivity values calculated from specific capacity data reported on well logs by Drost et al. (1999) is summarized in **Table 7**.

Aquifer transmissivity was also estimated from short term pumping tests to estimate well yield as reported on well logs and is presented in **Appendix D**. Transmissivity was calculated using the specific capacity equation from Driscoll (1986):

$$T = C\frac{Q}{s}$$

Where:

Q = Well pumping rate (gpm)

s = Groundwater decline (drawdown) during pumping (ft)

T = Transmissivity (gpd/ft)

C = Aquifer coefficient; 1,500 for unconfined aquifers, or 2,000 for confined aquifers.

Wells completed in the Shallow (Qva) Aquifer were assumed to be unconfined and the Sea-Level (Qc) and Deep (TQu) Aquifers were treated as confined for the analysis. Transmissivity calculated using the Driscoll equation is a rough estimate and highly influenced by well efficiency. Furthermore, pumping tests conducted during well installation to estimate yield often do not fully stress the aquifer and therefore aquifer transmissivity calculated from these tests is likely an underestimate of field conditions. Hydraulic conductivity, which is the value used by groundwater flow codes to solve the groundwater flow equation, was then calculated by dividing transmissivity by the average hydrostratigraphic unit saturated thickness observed in well logs referenced in development of the hydrostratigraphic model. Average hydrostratigraphic unit thicknesses are presented in **Table 8**. Maps showing the spatial distribution of hydraulic conductivity are presented for aquifer units (Qva, Qc, TQu) in **Figures 11a** through **11c**. These figures show hydraulic conductivity as determined from pumping tests for water supply wells (**Table 5a**) and estimated from pumping tests as reported on well logs (**Appendix D**).

Aquifer hydraulic properties by hydrostratigraphic unit are discussed below. The hydraulic property values presented are the horizontal hydraulic conductivity values (K_h)[1] and total porosity.

<u>Alluvium and Vashon Recessional Gravel Outwash (Qvr, also known as Qgo).</u> This is the upper-most water bearing unit in the Hawks Prairie study area. Because it is shallow and mostly unsaturated, it is not used for domestic or groundwater supply wells. Hydraulic conductivity estimates range from 14 to 2,100 ft per day (ft/day) with a median value of 150 ft/day, as shown on **Table 7** (Drost et al. 1999). Soil borings collected from underneath Basin 4 observed total porosity ranging from 15 to 24 percent using method ASTM D7263 (HDR

[1] Vertical hydraulic conductivity (K_v) is typically less than horizontal hydraulic conductivity (K_h) because of the tendency for natural deposits to settle in horizontal alignment and because geologic units may be composed of layered materials with differing hydraulic conductivity; both of which causes the vertical flow of water to be slower than the horizontal flow rate.

2017b). Total porosity, sample depth, grain size fraction and soil classification are provided in **Table 9**.

<u>Vashon Till (Qvt, also known as Qgt).</u> Estimates of hydraulic conductivity for this regional confining unit by Drost et al. (1999) range from 5 to 89 ft/day, and have a median value of 14 ft/day (**Table 6**). These values are likely biased high and reflect the hydraulic conductivity values from well pumping tests for wells completed in the Shallow (Qva) Aquifer, because the Vashon Till is known to be a dense, low-permeability unit (Drost et al. 1998, Logan et al. 2003).

<u>Shallow (Qva) Aquifer.</u> The Vashon Advance Outwash is a regional aquifer that is used for domestic and public water supply. Production well yields within the Hawks Prairie study area for the Shallow (Qva) Aquifer range from 170 and 275 gallons per minute (gpm) with rates reported up to 810 gpm on well logs, as listed in **Table 10**. Estimates of median hydraulic conductivity are 180 ft/day, reported by Drost et al. (1999). Pumping tests in the study area for water supply well projects, and by HDR for this project, indicates a geometric mean hydraulic conductivity of 56 ft/day and an upper hydraulic conductivity value of 235 ft/day, as summarized in **Table 5a** and **5b**. Grain-size analysis yielded similar results with most of the samples from the Shallow (Qva) Aquifer having hydraulic conductivity values between 100 and 363 ft/day (**Appendix C**). The spatial distribution of hydraulic conductivity values calculated from well logs and from water supply well pumping tests is shown in **Figure 26a**.

<u>Upper (Qf) Confining Unit.</u> The Kitsap Formation is a low-permeability formation that is a regional confining unit. Because wells are not completed in the formation, there is no pumping test data to calculate hydraulic conductivity. Hydraulic conductivity estimates range from 0.05 to 62 ft/day with a median of 17 ft/day, as reported by Drost et al. (1999). Estimated hydraulic conductivity values from grain-size analysis of samples collected by HDR in 2017 using the Hazen Method found hydraulic conductivity values between 0.015 and 8 ft/day with a geometric mean value of 0.2 ft/day (**Table 6** and **Appendix C**).

<u>Sea-Level (Qc) Aquifer.</u> This thick sequence forms a regional aquifer used in places for public supply wells. Well yields of up to 1,680 gpm have been reported on well logs and City of Lacey supply wells (S19, S21, S22, S28) produce 1,000 gpm to 1,600 gpm (Carollo Engineers 2013, Ecology 2018b). Estimates of median hydraulic conductivity are 150 ft/day by Drost et al. (1999). The geometric mean of hydraulic conductivity values from pumping tests in water supply wells in the study area is 87 ft/day, as shown on **Table 5b**. The spatial distribution of hydraulic conductivity values calculated from well logs and from water supply well pumping tests is shown in **Figure 11b**.

<u>Lower (TQu) Confining Unit</u>. Little hydraulic property information is available for the Lower (TQu) confining unit. Only one soil boring penetrated into the lower confining unit during the field investigations in 2017, which showed the presence of silty-clay deposits; grain size analysis estimated a hydraulic conductivity of 0.002 ft/day, as presented in **Appendix C**.

<u>Deep (TQu) Aquifer</u>. In a few locations in the project area, the City of Lacey has drilled deep public supply wells in the deep confined aquifer. This aquifer is composed of deep coarse sand and gravel, and well yields of up to 1,800 gpm have been reported (Carollo Engineers 2013). The geometric mean of the hydraulic conductivity values for this aquifer from Drost et

al. (1999) is 78 ft/day. The geometric mean hydraulic conductivity calculated from specific capacity tests from well logs in the area is 24 ft/day (up to 91 ft/day), as listed in **Table 5b**. The spatial distribution of hydraulic conductivity values calculated from well logs and from water supply well pumping tests is shown in **Figure 11c**.

This page intentionally left blank.

5.0 Previous Groundwater Flow Models in Study Area

Four numerical groundwater models have been developed in the Hawks Prairie study area. Some of these models have undergone revisions/modifications which are discussed below. Figures and tables showing previously implemented recharge and hydraulic conductivity are presented in **Appendix E**.

5.1 USGS Groundwater Model of Thurston County

This model was prepared in the 1990s as part of the U.S. Geological Survey's (USGS) efforts to simulate groundwater flow in Thurston County aquifers. The hydrogeologic data for the model is presented in Drost et al. (1998), and the numerical model is presented in Drost et al. (1999). This modeling study characterized the groundwater system in northern Thurston County, including: identification of groundwater recharge and discharge areas, quantification of water budget components, and simulation of flow paths. The model was used to simulate the possible effects of increased groundwater withdrawals and inform management concerns. This model served as the basis for subsequent models developed in the area. The model has a uniform cell size 3,000 ft by 3,000 ft.

5.2 Groundwater Flow Model Prepared by the Cities of Lacey and Olympia (McAllister Model)

The McAllister Model was originally developed for the City of Olympia to analyze regional hydrology and the planning of a well field to be located near McAllister Springs. The model grid and layers were based on the model developed by the USGS for Thurston County (Drost et al. 1999), described above. The original model was developed by CDM for planning and a water right application for the McAllister well field water supply project for the City of Olympia. Since that time, the model has been updated, modified and used by the Cities of Lacey and Olympia for water supply planning, including an update in 2010 that was used by the cities of Olympia, Lacey, and Yelm to evaluate impacts from water rights development. The 2010 version of the model has been modified and used by others for multiple projects. These series of models generally share the following characteristics: model area between Nisqually River and Deschutes River and from Puget Sound to Yelm, grid cell size ranging from of 100 ft to 1,250 ft, steady-state and transient calibration and simulation of pumping of numerous public water supply wells in the area. Model layers are included that simulate all of the major water supply aquifers and confining units in the study area.

The following reports document model updates and completed analyses:

- Interim and Final Report Model Report for McAllister Well Field by CDM (2002a, 2002b)
- Groundwater Modeling of Water Right Applications and Transfers, Golder Associates, Inc. (2006)
- McAllister Groundwater Model Updates, Golder Associates, Inc. (2007)
- Groundwater Modeling of Madrona and Evergreen Estates, Well Water Right Applications, Golder Associates, Inc. (2008a)

- Groundwater Modeling of Betti and Hawks Acres Well Pumping Increases, Golder Associates, Inc. (2008b)
- Groundwater Modeling of New Hawks Prairie Area Pumping, Golder Associates, Inc. (2008c).
- Groundwater Modeling Files for the 2009 Water System Plan City of Lacey, Washington, Shannon and Wilson, Inc. (2012).

5.3 LOTT Groundwater Modeling by Brown and Caldwell

A groundwater model was prepared for the design and permitting of the LOTT Hawks Prairie reclaimed water aquifer recharge project. This included two models, one developed in 2004 and a revision completed in 2009 (Brown and Caldwell 2004, 2009). The models were used to simulate the infiltration of reclaimed water into the subsurface and to evaluate the travel paths and time as reclaimed water mixed with groundwater and traveled downgradient. The models include the water supply aquifers and confining units down to the Sea-Level (Qc) Aquifer; the Lower (TQu) Confining Unit and the Deep (TQu) Aquifer are not included. The model domain extends to the west to Woodland Creek, and to the east to the Nisqually River valley, approximately 1.9 miles north and 1.9 miles south of the LOTT Hawks Prairie property. The grid cell size ranges between 40 to 1,080 ft. The model was calibrated to steady-state (static) groundwater level conditions. The model simulated well pumping only at Lacey well S29.

5.4 Carpenter Ridge and Pleasant Glade Models

Two models were developed for a proposed water supply well for the Pleasant Glade and Carpenter Ridge development project. The purpose of the model was to develop the information required for a water right permit for a groundwater supply well and to evaluate the effects of groundwater pumping on groundwater levels and surface water flow. The models are documented in Landau (2008) and Massmann and Romero (2006).

6.0 Numerical Groundwater Flow Model

The purpose of the groundwater flow model is to estimate the travel times and concentrations of residual chemicals traveling from the LOTT Hawks Prairie property to downgradient surface water discharge points or potential groundwater users. This report documents the development and calibration of a numerical model that simulates the flow of groundwater through the study area. Model development and calibration follow the methods, procedures, and criteria outlined in the Draft Work Plan Groundwater Modeling Fate and Transport Assessment (HDR 2018a). This calibrated model is proposed to be used in the future evaluation of the fate and transport of residual chemicals moving through the groundwater flow system.

6.1 Model Code

The USGS modeling program, MODFLOW, solves the system of equations that quantify the flow of groundwater in three dimensions. The specific MODFLOW code chosen for the study is MODFLOW-NWT (Niswonger et al. 2011), a formulation of MODFLOW-2005 (Harbaugh 2005), designed to improve the stability of solutions involving drying and re-wetting under conditions present at the water table. Particle tracking and travel time analysis were conducted using the MODPATH version 5 (Pollock 2012). The model was developed using the groundwater model pre- and post-processing software, Groundwater Vistas (Environmental Simulations, Inc. 2017).

6.2 Model Domain and Grid

The model domain extends west-to-east from Woodland Creek and Henderson Inlet to McAllister Creek and from Sandy Point on Puget Sound to Long Lake to the south of the LOTT Hawks Prairie property (**Figure 1**). This model domain (an area of about 30 square miles) was chosen because it is large enough so that the model can simulate natural discharge boundaries at the north, east, and western model extents, and extends a sufficient distance to the south to minimize boundary effects on groundwater in the expected flow paths from the LOTT Hawks Prairie property.

The numerical model grid is shown in **Figure 29**. The grid consists of 253 rows and 247 columns, 7 layers, with cell dimensions ranging from 50 to 711 ft and a total of 62,491 cells per layer (59,998 active). Grid cell dimension are documented in **Appendix F**. The grid cell dimensions are refined in the area around the recharge facility so that greater detail can be incorporated into the model and allow for more precision during calibration and minimize numerical error in the advection-dispersion equation in risk assessment simulations. The cell size within the anticipated downgradient transport analysis area was 50 ft to provide sufficient numerical precision based on the anticipated dispersion of 10 percent of the total flow path, the anticipated groundwater velocity ranging between 25 to 50 ft/day, the anticipated travel times, and assuming a Peclet number[2] of 2 (Zheng and Bennett 2002). For computational efficiency, grid cell dimensions increase in size to approximately 500 ft outside the anticipated flow path transport analysis area, and a maximum cell size of 711 ft along the southern boundary. The maxim

[2] The Peclet number is a dimensionless number expressing the ratio of advective to diffusive transport. By limiting the Peclet number to 2, the numerical solution approaches the analytical solution, thus reducing the numerical dispersion created by the numerical model.

um increase between adjacent grid cells is constrained to a 1.4 multiplier for numerical stability.

6.3 Model Layers

Model layers were assigned for the following hydrostratigraphic units throughout the model domain:

- Layer 1. Vashon Recessional Outwash (Qvr)
- Layer 2. Vashon Till (Qvt)
- Layer 3. Shallow Aquifer (Qva)
- Layer 4. Upper Confining Unit (Qf)
- Layer 5. Sea-Level Aquifer (Qc)
- Layer 6. Lower Confining Unit (TQu)
- Layer 7. Deep Aquifer (TQu)

Layers representing the hydrostratigraphic units were generated using the 3-D geologic modeling software Leapfrog Hydro™ (version 2.8.3, ARANZ Geo Limited). Leapfrog Hydro™ uses interactive implicit modeling, a modeling technique that allows the development of surfaces (contacts between hydrostratigraphic layers) directly from the area hydrostratigraphy data and allows editing of layer surfaces to provide a representative hydrogeologic model.

The land surface elevation bounds the top of Layer 1 and was assigned based on a digital elevation model (DEM) (PSLC 2018). The bottom of layers were defined based on hydrostratigraphic unit contacts identified in well logs and previous hydrostratigraphic cross sections in the area, as shown in **Figure 11** (Brown and Caldwell 2004, HDR 2017b, Landau 2016, NWLW 2008, PGG 2004). Well logs considered included wells drilled to depths 150 ft and greater, reaching the Kitsap Formation (Qf). Well logs with data inconsistent with geologic cross sections or multiple nearby wells were not included in the model. Hydrostratigraphic unit contact elevations as determined from well logs were compared to the previously developed Brown and Caldwell (2009) model to aid in construction of layers consistent with previous work. This comparison is shown in the work plan (HDR 2018a). Well logs used in model construction are presented **Appendix G**. Well log location information and identified hydrostratigraphic unit contacts are given in **Appendix H**. Cross sections showing model layering are presented alongside previously published cross sections in **Appendix A**. Layer elevation contours for the Shallow (Qva) Aquifer through the Deep (TQu) Aquifer are depicted on site maps in **Appendix I**.

The geologic units identified in boring logs are not always continuous throughout the model domain and may be represented in the model as one or more layers, and with different hydraulic conductivity values to designate heterogeneity (spatial changes) of geologic units.

Once the 3-D geologic model was completed using Leapfrog Hydro™, it was exported into a format accessible for import into Groundwater Vistas, Version 7 (Environmental Simulations, Inc. 2017). In places where a unit was absent the minimum layer thickness was set to one foot and the model cells in that area were assigned to the correct hydrostratigraphic unit by using each unit's hydraulic conductivity zone number and associated values.

6.4 Aquifer Hydraulic Parameters

Aquifer hydraulic parameters defined in the steady-state flow model and particle tracking flow path simulation include hydraulic conductivity and effective porosity. Hydraulic conductivity describes the rate that groundwater flows through porous media (soil/rock). Porosity is the ratio of total pore (void) space to bulk volume of porous media. Effective porosity is the volume of the void spaces through which water travels divided by the bulk volume of porous media. Effective porosity is a portion of the total porosity, with the remainder of the total porosity being either dead-end pores or occupied by immobile water adhered to the aquifer matrix.

Hydraulic parameters were initially assigned in the model based on previous field testing of wells as discussed in Section 4.3, prior modeling investigations as discussed in Section 5 and **Appendix E** and literature values where data were unavailable. The ratio of horizontal to vertical hydraulic conductivity (K_h:K_v) was assigned such that it varies from 1:1 to 100:1 by aquifer and hydraulic conductivity zone within aquifers. The average K_h:K_v ratio by model layer ranges from approximately 11:1 for Layers 1 and 2, from 21 to 29:1 for Layers 5–7, and from 45 to 49:1 for Layers 3 and 4. This is generally consistent with ratios implemented in previous modeling efforts. Total porosity values were only available for the Vashon Recessional Outwash, represented by Layer 1. For unconfined conditions, specific yield, the ratio of the volume of water that drains under gravity to the bulk volume of the porous media, can be used as an approximation for effective porosity (Domenico and Schwartz 1990). Specific yield and total porosity based on sediment texture are presented in **Table 12**.

Hydraulic conductivity values assigned to the model are presented in **Appendix J** and **Table 13**. Effective porosity values were assigned uniformly throughout model layers; initial values assigned were slightly less than total porosity. Hydraulic conductivity and effective porosity values were adjusted during model calibration to better match simulated with observed groundwater levels and particle travel times. Simulated effective porosity values are given in **Table 14**.

6.5 Model Boundaries

6.5.1 Recharge

Groundwater recharge occurs from precipitation infiltration into the subsurface and from infiltration of reclaimed water introduced into the rapid infiltration basins at the LOTT Hawks Prairie facility. Recharge was assigned based on extent of development and land cover and was simulated using the Recharge package in MODFLOW.

Areas were designated as undeveloped low density development, or high density development, as shown in **Figure 30**. Development status was determined from zoning information and compared against satellite imagery from 2017 (Thurston GeoData Center 2016, ESRI et al. 2019). Residential development with 1 unit per two acres or less was classified as undeveloped. Individual parcels were reclassified if the satellite image showed significantly different land use than the original zoning classification.

Areas classified as undeveloped were assigned a recharge value from a recharge dataset developed by Thurston County (Hansen 2019). This data was calculated by applying empirical relationships based on precipitation and land use as defined in Bidlake and Payne (2001). The precipitation data is a combined dataset from county precipitation station records from 2007 to 2016, and a 30-year estimated annual cumulative precipitation dataset from the PRISM project. This combined precipitation dataset is documented in Kale (2016). Land use was determined from the national land cover database (Hansen 2019). This dataset was modified such that any recharge values greater than 31 inches per year (in/yr) were assigned as 31 in/yr based on the maximum expected recharge rate from 51 in/yr of precipitation, as defined in Bidlake and Payne (2001).

The recharge values developed by the county were not used in developed areas as they were based on outdated land cover information and did not reflect the extent of current development (Hansen 2019). Areas identified as high density development based on the zoning information were assigned a recharge rate of 7 in/yr, consistent with the Thurston County recharge dataset for high density development. Areas of low density development classification were primarily residential development and were assigned a value greater than the high density developed, as they include more permeable surfaces, but lower than recharge values applied in undeveloped areas based on Bidlake and Payne (2001). The simulated recharge value for low density development was 12 in/yr. The spatial distribution of recharge simulated in the numerical model is illustrated in **Figure 31** and summarized in **Table 15**.

The property directly north of the Hawks Prairie recharge basins was undergoing development during 2018, including the period of tracer testing and water levels used for calibration. Clearing of the site began October 24, 2017, and satellite imagery shows much of the site was cleared as of May 2018 (Aviles-Ortiz 2019, Google Earth 2019). Construction of the main building began March of 2018 and was completed October, 2018 (Aviles-Ortiz 2019). As of July 2018, the total foot print of development was cleared but still unpaved; paving began after June 26, 2018, and was completed by August, 2018 (Aviles-Ortiz 2019). For the steady-state calibration, previous recharge values from the Thurston County recharge dataset were applied in the cleared and unpaved and uncleared areas of the property. The area of the new building was applied with the recharge value assigned to high density development to be consistent with other high density development in the model. For predictive simulations recharge in this area will be updated based on final paved surfaces and available stormwater management information for the site (to reflect the shallow dry well infiltration gallery, infiltration pond, and wetland mitigation area). The stormwater system became fully operational after January 16, 2019 (Aviles-Ortiz 2019).

6.5.2 Inflow from LOTT Hawks Prairie Property Recharge Basins

The inflow from the LOTT Hawks Prairie Property Recharge Basins was simulated as a specified flux (flow/time) into the upper saturated model layer. This was implemented using the Recharge package in MODFLOW. Recharge simulated at the LOTT Hawks Prairie Facility was modified to reflect operations of the wetland ponds and rapid infiltration basins. No recharge was applied under wetland ponds 1, 2, and 4, since they are lined (Steffensen 2019). Pond 3 is lined with a mixture of low permeability clay and topsoil (Steffensen 2019). Pond 3 was empty as of June 15, 2018, which is approximately the time period from which groundwater elevations used for steady-state calibration were collected, so no recharge was applied under pond 3 for calibration (Steffensen 2019). Pond 5's sides are lined and native glacial till underlies the footprint of the pond; lab testing found a permeability of 10^{-5} centimeters per second (0.28 ft/day) for the till (Steffensen 2019). Pond 5 is represented in the groundwater flow model using the River package which computes leakage to the aquifer based on conductance and thickness of the liner, bottom elevation of the pond, and pond stage. For steady-state model calibration, recharge rates applied to Basins 4 and 5 were based on reclaimed water volumes infiltrated for May and June of 2018, since water levels used for calibration collected in mid-June of 2018. Recharge rates assumed a uniform recharge rate over individual cells in which reclaimed water was applied, each cell selected based on the location of the headers supplying water and area appearing saturated or with ponded water during operations as visible on satellite imagery and from photographs during the tracer test. The higher recharge rates, representing infiltrated reclaimed water, were assigned to five grid cells in the western part of Basin 4, four grid cells Basin 4's eastern part, and eight grid cells in Basin 5, covering a combined area of 42,500 ft^2.

Different steady-state recharge rates were simulated for Basins 4 and 5 for particle tracking simulations than simulated for steady-state flow model calibration. Different recharge rates were assigned because reclaimed water application rates were higher in January, February, and March, which was the main period of tracer transport to monitoring wells. The average recharge rate for January 16 to February 22, 2018 (tracer test days 1 to 35) was used for the particle tracking simulation of the tracer test. That time period was chosen because day 35 was the first detection observed at MW-25, one of the farthest away wells where the tracer was detected. Daily recharge rates for Basins 4 and 5 for January through October 2018 are given in **Appendix K.** Recharge rates for the steady-state flow model water level calibration and for the particle tracking simulations are presented in **Table 16**. Only the eastern half of Basin 5 was assigned the higher reclaimed water infiltration recharge rates for particle tracking simulation because only this half was utilized during the application of the tracer.

6.5.3 Hydrologic Boundaries

The model domain was defined to be bounded by natural discharge boundaries. This includes Woodland Creek and Henderson Inlet to the west, Puget Sound to the north, and McAllister Creek and the Nisqually Valley to the east. Flow model boundary conditions are shown in **Figure 32** and summarized in **Table 17**. The implemented boundary conditions are discussed for each aquifer in the following text.

6.5.3.1 Shallow (Qva) Aquifer

Groundwater in the shallow aquifer flows radially out from a high to the northeast of the LOTT Hawks Prairie property. Flow to the north discharges to springs along the bluffs that overlook Puget Sound, in the west the shallow aquifer discharges to Woodland Creek and its tributaries, in the east flow exits to springs in the east along the scarp above McAllister Creek or as baseflow discharge directly to McAllister Creek. Woodland Creek and its tributaries, as well as springs are represented using the Drain package. This boundary condition is active in layers 1 to 5 depending on the elevation that the streams/springs intersect model layers. Drain stages (and layer assignment) was based on elevations 2 ft lower than minimum land surface elevations within each grid cell from the LiDAR-based DEM (PSLC 2018). Puget Sound in the northwest and north is represented using the Constant Head package. The General Head Boundary package was implemented on the west and south boundaries of the model domain to allow water in and out of the domain, based on the difference between assigned stage and simulated head and conductance, as those boundaries do not represent a groundwater divide or hydrologic boundary. The General Head Boundary stage and conductance were initially assigned based on nearest groundwater and stream elevations, and hydraulic conductivity information, respectively, and were adjusted during calibration.

6.5.3.2 Sea-Level (Qc) Aquifer

Near the LOTT Hawks Prairie recharge basins groundwater in the Sea-Level (Qc) Aquifer flows east, discharging to McAllister Creek and the Nisqually River which are tidally controlled within the model domain. In the northern and northwestern areas of the model domain, groundwater flows to the north, likely discharging into Puget Sound. Puget Sound and the boundary to the east (McAllister Creek/Nisqually valley) are represented using the Constant Head package. The General Head Boundary package was implemented on the west and south boundaries of the model domain to allow water in and out of the domain as those boundaries do not represent a groundwater divide or hydrologic boundary. The General Head Boundary stage and conductance were initially assigned based on nearest groundwater and stream elevations, and hydraulic conductivity information, respectively, and were adjusted during calibration. In the downstream most reach of Woodland Creek, the channel is deeply incised and the creek elevation coincides with the Sea-Level Aquifer, for this reason in some reaches drains representing Woodland Creek are assigned to model layers 4 and 5. Drain stages (and layer assignment) was based on elevations 2 ft lower than minimum land surface elevations within each grid cell from the LiDAR-based DEM (PSLC 2018).

6.5.3.3 Deep (TQu) Aquifer

Groundwater in the Deep (TQu) Aquifer flows from the south to the north, discharging to Puget Sound as shown in **Figure 8c**. Puget Sound is represented using the Constant Head package. The General Head Boundary package was implemented on the west, east and south boundaries of the model domain to allow water in and out of the domain as those boundaries do not represent a groundwater divide or hydrologic boundary. The General Head Boundary stage and conductance were assigned based on nearest groundwater and stream elevations, and hydraulic conductivity information, respectively, and were adjusted during calibration.

6.5.4 Pumping Wells

Wells in the model domain were included as they remove water from the groundwater flow system. Wells were represented using the MODFLOW Well package implemented via the grid-independent analytic element well option in Groundwater Vistas. A well dataset including commercial, domestic, fishery, industrial, irrigation, and public supply wells was provided by Thurston County (Hansen 2019). Wells were implemented in the model based on the provided location, withdrawal rate, and screened interval information. The following adjustments were made when implementing the wells in the model: 1) wells that were screened across an aquitard layer and an aquifer layer were only assigned to the aquifer layer; and 2) wells screened entirely in an aquitard layer were assigned to the nearest aquifer layer. A total of 867 wells were assigned to the model domain with pumping rates ranging from 0.15 gpm to 88.03 gpm, as shown in **Figure 33** and summarized in **Table 18**. The following City of Lacey supply wells in the model domain were included: S07, S15, S16, S19, S21, S22, S28, S29, and S31. Pumping rates for the City of Lacey supply wells were assigned based on the annual average pumping rates for 2017–2018, which range from 55 to 911 gpm, as summarized in **Table 19** (Rector 2018).

This page intentionally left blank.

7.0 Model Calibration

Model calibration is the process of adjusting boundary conditions and hydraulic parameters to achieve an acceptable match between simulated and observed conditions. Model parameters were initially assigned within reasonable ranges based on measured field data, previous studies, literature values, and hydrogeological analysis.

7.1 Flow Model Calibration Targets

The steady-state groundwater flow model was calibrated to 67 measured groundwater elevations collected by HDR, the City of Lacey, and the Thurston County Landfill staff (HDR 2017a, 2017b, Rector 2018, Tousley 2018), and 110 groundwater elevations estimated from well logs (Ecology 2018b). Travel times as observed in the tracer test (HDR 2019a), and observed groundwater discharge to streams (HDR 2015), were also used to guide groundwater model calibration.

7.1.1 Groundwater Elevation Targets

The steady-state flow model was calibrated to 47 water levels from April, May and June 2018, and 20 water levels from previous HDR sampling in 2015 and 2017. This includes 42 groundwater elevations in the Shallow (Qva) Aquifer, 18 in the Sea-Level (Qc) Aquifer, and 7 in the Deep (TQu) Aquifer. Of these 67 measured water levels, 65 are spring measurements (made between April and June). These groundwater elevation targets are presented in **Figures 8a** through **8c** and **Tables 4a**, **4b** and **4c**.

Nine of these targets are City of Lacey production wells and are simulated as pumping wells in the model. Since these nine wells are simulated as pumping wells this invalidates the reported water levels as targets, because pumping draws down the water level. Pumping water levels cannot be considered as targets due to representation of the model including use of average annual pumping rate (instead of operating pumping rate at time of water level measurement) and head losses. However, these water levels are still included as targets since they are often the only data point in the area, as is the case for S07, but the residuals between measured water level and simulated water level should be considered as more of a qualitative indicator, rather than a quantitative indicator of model calibration.

An additional 110 groundwater elevations were estimated from well logs using the reported depth to water and the ground surface elevation. These estimated groundwater elevations were used to guide model calibration, though there is uncertainty associated with these water levels. This uncertainty comes from: 1) date water level was taken—some of these water levels date back to 1962; 2) location of the well—the Washington State Department of Ecology (Ecology) publishes well locations to the centroid of the quarter-quarter section (Ecology 2018b)—when available, well locations were relocated to the address listed on the well log; and 3) ground surface elevation—the ground surface elevation used to calculate the groundwater elevation is from the DEM (PSLC 2018) at the well location rather than a surveyed measuring point, or even measured elevation using a GPS. The DEM has a horizontal resolution of 3.25 ft.

7.1.2 Tracer Test Travel Times

Travel times simulated using MODPATH were calibrated to observed travel times from the tracer test conducted at the LOTT Hawks Prairie recharge facility in 2018. MODPATH is a particle tracking program that simulates pathlines and time of travel for advective transport. The flow paths and travel times simulated by MODPATH are dependent upon the assigned hydraulic conductivity, effective porosity, and the groundwater flow field (gradients) simulated using the steady-state flow model. A separate model run was used to represent the tracer test. This separate run differs from the run calibrated to observed groundwater levels, only in that the recharge rates applied at the LOTT Hawks Prairie recharge basins, and effective porosity were adjusted. Note that effective porosity does not influence the calculated groundwater levels or gradients, and only affects the speed at which particles (or solutes) move through the groundwater system. As discussed in **Section 6.5.2** recharge rates applied to Basins 4 and 5 were the averages from days 1 to 35 of the tracer test, which is 36 percent larger than the rates applied in the calibrated flow model (1.055 mgd versus 0.774 mgd), since this was the primary period of tracer transport.

The tracer test is documented in the report *Tracer Test and Water Quality Monitoring (Task 2.1.3*) (HDR 2019a). For the test, two non-toxic, inert tracers, potassium bromide and sulfur hexafluoride, were added to the reclaimed water applied to the recharge basins at the land surface. Nearby monitoring wells were sampled to observe the arrival and breakthrough of tracer. Only the monitoring well arrival times of potassium bromide (bromide) was used for the calibration to tracer test travel times since sulfur hexafluoride was retarded in transport (HDR 2019a).

To simulate time of travel, as was observed in the tracer test, particles were introduced at monitoring wells at the mid-point elevations of their screened intervals within the appropriate layer (so either Layer 3 for the Shallow (Qva) Aquifer, or Layer 5 for the Sea-Level (Qc) Aquifer) and backwards particle tracking was run, tracing flow paths backwards from the monitoring wells to Basins 4 and 5.

Simulated travel time is compared to time of first arrival for bromide. Only wells with clear bromide breakthrough curves were considered. This includes wells: MW-3a, MW-5, MW-8, MW-9, MW-11, MW-13, MW-15, MW-16, MW-25, and MW-27 in the Shallow (Qva) Aquifer, and MW-12 and MW-14 in the Sea-Level (Qc) Aquifer.

Observed time of travel includes travel time from the surface of the recharge basins where reclaimed water is introduced, through the vadose zone and aquifer to the monitoring wells. Since travel time includes transport through the vadose zone, which is not represented in the groundwater flow model, observed travel times were treated as an upper bound.

7.1.3 Observed Stream Flow

Simulated groundwater discharge to creeks was compared to observed stream flow as described in **Section 3.3** and documented in *Woodland Creek Stream Flow Measurement and Ground Water Inflow Analysis* (HDR 2015). A stream flow survey on Eagle Creek, Fox Creek and Woodland Creek was conducted during summer-time low-flow conditions in August, 2015, to characterize groundwater exchange within these streams (HDR 2015). Groundwater inflow to

Woodland Creek, between stream gauging locations and cumulative groundwater inflow are presented in **Figure 3a** and **Table 3**. Observed inflow between stream gauging locations and cumulative inflow for Fox Creek is shown in **Figure 3b**. Eagle Creek was mostly dry but exhibited minor groundwater inflow of 0.09 cfs, as shown in **Figure 3c**. Observed stream flow and groundwater inflow between gauging locations is summarized in **Table 3**.

7.2 Steady-State Flow Model Calibration

The calibrated flow model is assumed to represent steady-state flow conditions for the site under long-term, average conditions. The initial trial-and-error calibration assumed homogeneous hydraulic conductivity within each hydrostratigraphic unit. Since recharge was constrained based on the data provided by Thurston County (Hansen 2019) and estimates from Bidlake and Payne (2001), adjustments to the model were made to hydraulic conductivity zones and values, as shown in **Appendix J**. The basis for delineating the zones in this way was to obtain the best local calibration using hydraulic conductivity values within the range of spatially measured hydraulic conductivity as summarized in **Table 13**. The steady-state model was first calibrated to the groundwater elevation targets and baseflow estimates before calibrating to observed tracer travel times. Hydraulic conductivity and effective porosity were adjusted during particle tracking calibration and both groundwater levels and travel times were considered during the adjustment of aquifer properties.

Model calibration is discussed below with respect to commonly accepted criteria (Anderson and Woessner 1992, ASTM 1996, Hill and Tiedeman 2007, Reilly and Harbaugh 2004, USACE 1999), as presented in the work plan (HDR 2018a). This includes summary statistics such as the absolute mean residual, root mean squared error, and qualitative measures such as the visual comparison of residuals at groundwater elevation targets and groundwater level contours. The calibration criteria outlined in the work plan (HDR 2018a) sets forth an absolute mean residual (or the absolute average of the difference between observed groundwater levels and simulated groundwater levels) that is less than 15 percent of the total groundwater change across the model domain, not including outliers or potentially erroneous data. Another industry standard is to achieve a root mean squared error (RMSE) (the average of the squared differences in observed and simulated water levels) less than 10 percent of the total groundwater elevation change across the model domain. Calibration to tracer travel times using particle tracking is not an industry standard and does not have established calibration criteria, and baseflow observations were only used to guide calibration. Therefore, the results associated with these model components are qualitatively discussed.

7.2.1 Comparison of Model Steady-State Results to Groundwater Elevations

Simulated groundwater elevations and flow directions generally agree with observed groundwater elevation data in the Shallow (Qva) Aquifer as shown in **Figure 34a**. Groundwater flows radially from a high to the north of the site toward Woodland Creek in the west, College and Beatty Springs in the southwest, the bluffs over Puget Sound in the north, and the Nisqually Valley in the east. A map showing the residuals (differences between observed and simulated groundwater elevations) is presented in **Figure 17b**. Considering only measured groundwater elevations (either by HDR, City of Lacey, or Thurston County Landfill) in the Shallow (Qva) Aquifer, the mean residual is -0.57 ft, and the mean absolute residual is 4.01 ft. The minimum resi dual for wells with measured water levels was -10.93 ft, and the maximum residual was 13.74 ft.

Simulated groundwater elevations in the Sea-Level (Qc) Aquifer are shown in **Figure 36a.** In the Sea-Level Aquifer groundwater recharges through the window in the Kitsap to the south of the Hawks Prairie recharge basins, and discharges to Puget Sound in the north and McAllister Creek in the Nisqually Valley in the east. A map showing the residuals and the simulated groundwater elevation is presented in **Figure 18b**. Considering only measured groundwater elevations in the Sea-Level (Qc) Aquifer, the mean residual is -0.07 ft, and the mean absolute residual is 2.44 ft. The minimum residual for wells with measured water levels was -5.72 ft and the maximum residual was 6.44 ft.

Contours of simulated groundwater elevation are shown for the Deep (TQu) Aquifer in **Figure 38a**. A map showing the residuals and the simulated groundwater elevations is presented in **Figure 19b**. Considering only measured groundwater elevations in the Deep (TQu) Aquifer, the mean residual is 1.24 ft, and mean absolute residual is 10.85 ft. The minimum residual for wells with measured water levels was -20.83 ft and the maximum residual was 19.98 ft.

Observed and simulated groundwater levels (post-calibration) are compared in **Table 20** and in **Figure 40**. The observed and simulated groundwater elevations plotted against a line with a slope of one show that error is close to normally distributed. Summary statistics are presented for all groundwater levels (included those estimated from well logs) and measured groundwater levels in **Table 21**. The square root of the average squared error (RMSE) is 13.41 ft for all water levels, and 6.19 ft for measured water levels. The model calibration goal is an RMSE less than 10 percent of the change in head across the model domain. The ratio of the average RMSE to total measured head change is the normalized root mean squared error (NRMSE). The NRMSE of the calibrated model is 6.4 percent for all water levels and 3.9 percent for measured water levels. Likewise, the calibration goal of 15 percent for the normalized absolute mean residual is met, with the calibrated model achieving 4.4 percent for all water levels, and 2.7 percent for measured water levels.

The results of this evaluation show that simulated groundwater flow directions and contours generally agree with observed groundwater elevations and the model satisfies the established calibration criteria.

7.2.2 Comparison of Model Steady-State Results to Geometric Mean Groundwater Elevations

In addition to comparing simulated and observed groundwater elevations at a point in time (primarily spring of 2018), simulated groundwater levels were also compared to the geometric mean of observed levels where time-series data are available for non-pumping wells. This comparison is useful as the geometric mean water level is a representative water level for the flow system over time. Time-series data were available for 29 wells including LOTT and Thurston County Landfill monitoring wells sampled and monitored during the tracer test and City of Lacey monitoring wells. Wells included in this comparison are screened in the Shallow (Qva), Sea-Level (Qc), and Deep (TQu) Aquifers.

Three analyses were completed. The first evaluates whether the simulated water level at an observation point lies within an acceptable range of observed water levels. This range is defined as the arithmetic mean minus two standard deviations (the lower bound) to the arithmetic mean plus two standard deviations (the upper bound). Groundwater levels simulated at 20 of the 29 wells fell within their associated observed water level range, as presented in **Table 22**.

The second analysis is a measure of the model as a whole to simulate representative groundwater levels. This involves a comparison of the RMSE, using the geometric mean of observed water levels minus the simulated water levels, to two times the root mean square of the standard deviation of observed groundwater levels. Here the expected natural variability is quantified by two times the standard deviations calculated from observed groundwater levels at each well, and then is represented in a combined statistic using the root mean square of the standard deviations. If the RMSE of the residuals is less than two times the RMS of the observed standard deviations, then the model simulates groundwater levels within the observed natural variability. Two times the RMS of the observed standard deviations at each well is 8.09. The RMSE for these 29 wells equals 6.85 ft, thus the described calibration criteria has been met. Considering the 25 wells near the site (those wells sampled during the tracer test and LOTT monitoring wells), two times the RMS of the observed standard deviations is equal to 7.68 ft, while the RMSE equals 5.01 ft, again fulfilling the calibration criteria. The RMSE of the June 2018 residuals and standard deviations are shown in **Table 23**.

The third analyses is the calculation of summary statistics using the geometric mean water level as the target water level (instead of the June 2018 water levels). These results are presented in **Table 23**. The mean residual is -0.50 ft; the absolute residual mean is 5.07 ft. For close wells the mean residual is -2.35 ft; the absolute residual mean is 4.11 ft. These are similar values compared to the residual mean and absolute residual mean calculated for the June 2018 water levels for these wells. The NRMSE of the calibrated model is 5.7 percent for these 29 wells, and 5.0 percent for the 25 wells nearest the recharge basins. The normalized absolute residual mean is 4.2 percent for all 29 wells, and 4.1 percent for wells close to the recharge basins, both of which are lower than the criteria set in the work plan (HDR 2018a) of a normalized absolute residual mean of 15 percent or less.

These three analyses support that the calibrated model reasonably simulates observed groundwater elevations.

7.2.3 Comparison of Model Steady-State Results to Stream Flow

The drain cells simulating streams receiving groundwater inflow, compared with reaches where groundwater inflows have been measured (HDR 2015), are presented in **Figure 41**. Groundwater flow is simulated as discharging to Woodland Creek and its tributaries generally in downstream reaches, where the stream channels have incised through the upper hydrostratigraphic units. The greatest amount of groundwater inflow to Woodland Creek occurs at Beatty Springs (River Mile 4.0) and further downstream. The steady-state water budget by boundary condition type is listed in **Table 24**. A subset water budget corresponding to the stream flow measurement locations is presented in **Table 25**, with corresponding reach numbers used to calculate the water budget shown in **Figure 42**.

The simulation does not show groundwater flow to the most upstream reaches of Fox Creek and Eagle Creek. This is consistent with stream flow gauging results which observed Fox Creek to be dry at its most upstream measurement location, and Eagle Creek to be dry at the four upstream measurement locations. The model simulates groundwater discharge to Eagle Creek upstream of gauging points Eagle 9 and Eagle @ Carpenter, which is consistent with observations. The model simulated groundwater discharging in College Creek and Woodland Creek upstream and at College Springs and Beatty Springs. The model simulates slightly less groundwater discharge to Eagle Creek than observed over the first two gaining reaches, and does well to simulate no discharge for the reach ending on its downstream end at Woodland Creek; the latter was observed as a losing reach (**Table 25**). Groundwater was simulated as discharging to Fox Creek in all three observed gaining reaches, and is of a similar magnitude as observed flow, the total simulated amount only slightly greater (within 20 percent).

The model simulates less groundwater discharge to Woodland Creek than observed (excluding Woodland Creek to Henderson Inlet), within 17 percent. Groundwater is simulated as discharging to Woodland Creek in all nine of the observed gaining reaches, including at College Springs and Beatty Springs (Reaches 1, 2, 4, 5, 8, 9, 10, 12, 24 and 26—see **Figure 22** and **Table 25**), and is of similar magnitude as observed flow, with exceptions of Reaches 2, 5, and 26, where the simulated discharges are between about 23 and 38 times lower than observed. Low simulated flows to Woodland Creek, including to Beatty and College Springs, may be due to underestimating local recharge, but could also be due to uncharacterized subsurface heterogeneity, such as buried paleo-channels or other localized high-permeability features with converging flow paths at springs and potential features that extend to greater depths than are simulated by the Drain package.

Overall, the model simulates groundwater discharging to streams in observed gaining reaches, and no (or extremely little) groundwater discharge to streams in losing stream reaches. Simulated groundwater elevations compare favorably to observed elevations around Fox Creek, Eagle Creek and Woodland Creek, as shown by the low residuals in **Figure 17b**, with a few exceptions, but only where compared to groundwater levels reported on well logs. The stream water budgets are reasonable and sufficient for the modeling purpose.

7.2.4 Comparison of Model Steady-State Results to Tracer Test Travel Times

Simulated travel time is compared to observed time of first arrival and maximum concentration (peak) for potassium bromide in **Table 26** and **Figure 43**. The time of first arrival, and time of arrival of the maximum concentration, for bromide and sulfur hexafluoride tracers are all included for reference. Travel times observed for bromide are considered more representative since sulfur hexafluoride was retarded in transport compared to bromide (HDR 2019a).

The simulated travel times agree well with observed travel times established based on the maximum bromide concentrations at wells located some distance away from Basins 4 and 5. The average residual for MW-5, MW-8, MW-9, MW-11, MW-13, MW-25, and MW-27 is 18.6 days, (29 percent shorter than the observed average of 65.2 days), geometric mean of the residuals is 6.1 days, and the absolute average residual is 24.1 days. Excluding MW-11 from the above list of wells screened in the Shallow (Qva) Aquifer, which had an observed travel time of 260 days, the average residual equals 0.0 days. For wells in the Sea-Level Aquifer, MW-12 and MW-14, the calibrated model matched the observed travel times reasonably well, with residuals of -5.4 days and 7.0 days, and simulated travel times equaling -9 and 19 percent of observed, respectively.

The comparison of observed and simulated travel times must be qualified, as the observed travel times include vertical transport from the land surface through the vadose zone, whereas simulated travel times only represent travel through the saturated Shallow Aquifer, Kitsap Formation, and Sea-Level Aquifer. Therefore, observed travel times are treated as the upper bound, and the resulting positive average residual (simulated travel times less than observed) is appropriate, and errs towards a conservative simulation of transport velocities, if not an accurate representation.

This page intentionally left blank.

8.0 Model Assumptions and Limitations

Limitations, based on necessary assumptions, will be inherent within the completed groundwater flow and transport model. Where data was unavailable, use of published literature values, appropriate assumptions and professional judgment are routinely employed in modeling and are necessary to complete model construction and simulations. The following list provides details on model assumptions and limitations:

- The hydrostratigraphy model relied upon well logs completed by multiple individuals with varying degrees of detail. It is possible that geological interpretations are not uniform.
- The development of the hydrostratigraphy model requires interpretation of geologic units and interpolation of units between boreholes that may be inaccurate despite professional judgment and reasonable interpretations.
- Previous studies have noted a thinning or absence of the Kitsap (Qf) Formation to the southwest of the LOTT Hawks Prairie Recharge Facility. The extent of this window in the Kitsap formation is unknown, and degree of hydraulic connection between the Shallow (Qva) Aquifer and Sea-Level (Qc) Aquifer is not entirely known, but recently reviewed drill logs and hydraulic head measurements indicate a window is present and that the Sea-Level (Qc) Aquifer groundwater levels fluctuate in sync with those in the Shallow (Qva) Aquifer. The vertical hydraulic conductivity of the Shallow (Qva) Aquifer, Kitsap (Qf) Formation (where present but thin), and Sea-Level (Qc) Aquifer appear to be sensitive model parameters.
- Recharge rates in developed areas are unknown and have not been tested. Simulated recharge rates are based on analogous studies (Bidlake and Payne 2001) and professional judgment.
- Hydraulic conductivity values are sparse throughout the model domain and are not likely fully representative of each hydrostratigraphic unit since units in the area are heterogeneous. Hydraulic conductivity values calculated using the information reported on well logs and the specific capacity equation may underestimate the actual value since these short-term tests were conducted to estimate well yield and not for determining aquifer properties.
- Site-specific effective porosity values are not known and were initially based on literature values for specific yield and available total porosity values. Values of effective porosity were adjusted lower during calibration to observed tracer travel times. Variability in effective porosity influences groundwater velocities, which are thought to be either matched accurately with the model, or are conservative (faster than observed), overall.
- Measured groundwater levels at model boundaries in the Shallow (Qva), Sea-Level (Qc), and Deep (TQu) aquifers are limited, and general head boundaries at the edges of the model domain are defined based on inferred groundwater elevations.
- Groundwater levels in the far-field at remote distances from the LOTT Hawks Prairie Recharge Facility, are estimated from historic information such as groundwater levels encountered when wells were installed. The accuracy of these groundwater levels is

uncertain, and largely the measurement time periods do not match the time period represented in the simulation.

- The model represents steady-state conditions and does not account for storage, changes in recharge, or changes in groundwater gradients over time.
- Observed travel times used for calibration of travel time includes flow through the vadose (unsaturated) zone, which is not represented in the simulation of groundwater flow. It was assumed that the observed travel times are an upper bound for target values to compensate, resulting in conservative assumptions for the adjusted transport model parameter (lower effective porosity and faster advective transport results).

9.0 Future Work - Model Predictive Simulations

The steady-state groundwater flow model as described above will be used for predictive simulations to inform risk assessment analysis. A work plan is being developed that identifies the specifics of that approach (HDR 2019b).

This page intentionally left blank.

10.0 Summary

This technical memorandum describes the approach and methods for groundwater model development and steady-state flow calibration, including calibration to travel times from a dye tracer test conducted with the recharge basins in operation. The model was developed in accordance with the work plan (HDR 2018a). The steady-state flow model documented in this technical memorandum satisfies the calibration criteria of: 1) an absolute mean residual that is less than 15 percent of the total groundwater change across the model domain (the calibrated model achieves a normalized absolute residual mean of 2.7 percent for measured water levels); and, 2) a NRMSE less than 10 percent (the calibrated model achieves a NRMSE of 3.9 percent for measured water levels). Additionally, the calibrated model reasonably approximates baseflow to Woodland Creek and its tributaries, and matches observed potassium bromide tracer travel times.

This page intentionally left blank.

11.0 References

Anderson, M. and W. Woessner. 1992. Applied Groundwater Modeling Simulation of Flow and Advective Transport. Academic Press, Inc. San Diego, California.

ASTM (American Society for Testing and Materials). 1996. ASTM Standards on Analysis of Hydrologic Parameters and Ground Water Modeling. ASTM Publication Code Number 03-418096-38.

Aviles-Ortiz, Carlos. 2019. City of Lacey. Stormwater Infrastructure Code Specialist. Personal Communication. May 23.

Bidlake, W.R. and K.L. Payne. 2001. Estimating Recharge to Ground Water from Precipitation at Naval Submarine Base Bangor and Vicinity, Kitsap County, Washington. U.S. Geological Survey. Water-Resources Investigations Report 01-4110.

Brown and Caldwell. 2004. Hawks Prairie Reclaimed Water Satellite Final Groundwater Flow Modeling Results. Prepared for LOTT Wastewater Alliance. January.

Brown and Caldwell. 2009. LOTT Hawks Prairie Groundwater Modeling Update. Prepared for LOTT Alliance, Thurston County WA.

Carollo Engineers. 2013. City of Lacey Water System Comprehensive Plan Update. Prepared for the City of Lacey. February.

CDM. 2002a. Interim Report Model Construction and Steady-State Calibration McAllister Wellfield Numerical Model. Prepared for the City of Olympia Public Works Department. Olympia, Washington. April.

CDM. 2002b. Final Report – DRAFT (Section 5-8) McAllister Wellfield Numerical Model. Prepared for City of Olympia Public Works Department. Olympia, Washington. July.

Ecology (Washington State Department of Ecology). 2018a. Environmental Information Management System. Accessed September 9, 2018. https://fortress.wa.gov/ecy/eimreporting/Download/Download.aspx?DownloadType=EIM&MapLocationPolygon=1058948+630333%2c1058948+660434%2c1086813+660434%2c1086813+630333%2c1058948+630333&ResultParameterName=Flow&ResultParameterNameSearchType=Equals.

Ecology (Washington State Department of Ecology). 2018b. Washington State Well Report Viewer. Accessed September 2018. https://fortress.wa.gov/ecy/wellconstruction/map/WCLSWebMap/default.aspx.

Ecology (Washington State Department of Ecology). 2018c. Study ID AMS001E. Environmental Information Management System. Accessed September 6, 2018. EIMSearchResults.

Domenico, P.A. and F.W. Schwartz. 1990. Physical and Chemical Hydrogeology. New York, NY: John Wiley and Sons.

Driscoll, F.G. 1986. Groundwater and Wells. 2nd Ed., Johnson Screens. St. Paul, Minnesota.

Drost et al. 1998. Hydrology and Quality of Ground Water in Northern Thurston County, Washington. U.S. Geological Survey. Prepared in cooperation with Thurston County Department of Health. Tacoma, Washington.

Drost et al. 1999. Conceptual Model and Numerical Simulation of the Ground-Water-Flow System in the Unconsolidated Sediments of Thurston County, Washington. U.S. Geological Survey. Prepared in cooperation with Thurston County Health Department. Tacoma, Washington.

Environmental Simulations, Inc. 2017. Groundwater Vistas, Version 7.

ESRI, Digital Globe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGrid, and IGN. 2019. Background Satellite Imagery. Accessed May 10, 2019.

Fetter, C.W. 2001. Applied Hydrogeology. Fourth Edition. Prentice-Hall, Inc. Upper Saddle River, NJ.

Golder Associates, Inc. 2006. Groundwater Modeling of Water Right Applications and Transfers. Prepared for the City of Lacey. February 16.

Golder Associates, Inc. 2007. McAllister Groundwater Model Updates. Prepared for the City of Lacey. November 16.

Golder Associates, Inc. 2008a. Groundwater Modeling of Madrona and Evergreen Estates, Well Water Right Applications. Prepared for the City of Lacey. February 15.

Golder Associates, Inc. 2008b. Groundwater Modeling of Betti and Hawks Acres Well Pumping Increases. Prepared for the City of Lacey. March 25.

Golder Associates, Inc. 2008c. Groundwater Modeling of New Hawks Prairie Area Pumping. Prepared for the City of Lacey. August 15.

Golder Associates, Inc. 2011. City of Lacey Wellhead Protection Report for the Water System Plan Update 2011. Submitted to Carollo Engineers.

Google Earth. Map showing Hawks Prairie Area. Accessed May 2019. Imagery from 2017 and 2018. https://www.google.com/earth/.

Hansen, Kevin. Thurston County. County Hydrogeologist. Personal Communication May 1, 2019.

Harbaugh, A.W. 2005. MODFLOW-2005, The U.S. Geological Survey Modular Ground-Water Model – the Ground-Water Flow Process. U.S. Geological Survey Techniques and Methods 6-A16.

Hart Crowser. 1989. Hydrogeologic Report, Hawks Prairie Production Well. Prepared for City of Lacey. Lacey, Washington. April 11.

HDR. 2014. Scope of Services LOTT Clean Water Alliance. Reclaimed Water Infiltration Study Phase III – Study Implementation. July 31.

HDR. 2015. Woodland Creek Stream Flow Measurement and Ground Water Inflow Analysis. September 10.

HDR. 2016a. Wastewater and Reclaimed Water Quality Characterization (Task 1.3). Reclaimed Water Infiltration Study. Prepared for LOTT Clean Water Alliance. March 18.

HDR. 2016b. Surface Water Quality Characterization (Task 1.2). Reclaimed Water Infiltration Study. Prepared for LOTT Clean Water Alliance. May 17.

HDR. 2017a. Groundwater Quality Characterization. Reclaimed Water Infiltration Study. Prepared for LOTT Clean water Alliance. February 7.

HDR. 2017b. Draft Hydrogeologic Characterization Report On-Site Wells and Lysimeter Installation (Task 2.1.1.A) Off-site Monitoring Wells (Task 2.1.2.C) Hawks Prairie Area. Reclaimed Water Infiltration Study. Prepared for LOTT Clean Water Alliance.

HDR. 2018a. Draft Work Plan, Groundwater Modeling Fate and Transport Assessment (Task 2.1.4). Reclaimed Water Infiltration Study. Prepared for LOTT Clean Water Alliance. October 9.

HDR. 2018b. Work Plan, Tracer Testing and Water Quality Monitoring of Treatment Effectiveness (Task 2.1.3) Hawks Prairie Area. Reclaimed Water Infiltration Study. Prepared for LOTT Clean Water Alliance. January 5.

HDR. 2019a. Draft Work Plan, Groundwater Modeling Predictive Simulations (Task 2.1.4 continued) and Residual Chemical Fate and Transport (Task 2.1.5). Reclaimed Water Infiltration Study. Prepared for LOTT Clean Water Alliance. October 10.

HDR. 2019b. Tracer Test and Water Quality Monitoring (Task 2.1.3). Reclaimed Water Infiltration Study. Prepared for LOTT Clean Water Alliance. June 28.

Hill, M. and C. Tiedeman. 2007. Effective Groundwater Model Calibration. John Wiley & Sons, Inc., Hoboken, New Jersey.

Kale, N. 2016. Thurston County, Washington, Thurston County Water Resources Technical Memorandum #4. December.

Landau (Landau Associates, Inc.). 2003. Hydrogeologic Assessment and Water Supply Pumping Evaluation Pleasant Glade Development, Lacey, Washington. Prepared for Century Pacific. July.

Landau (Landau Associates, Inc.). 2008. Preliminary Permit Report for Groundwater Applications G2-29951 and G2-30137 Thurston County, Washington. Prepared for Century Pacific, Inc. March.

Landau (Landau Associates, Inc.). 2016. Monitoring Well Installation and Testing. Prepared for the City of Lacey, Lacey, Washington. February.

Logan, R., T. Walsh, H. Schasse, and M. Polenz. 2003. Geologic Map of the Lacey 7.5-minute Quadrangle, Thurston County, Open File Report 2003-9. Washington Division of Geology and Earth Resources, Olympia, Washington.

Niswonger, R.G., Panday, S., and Ibaraki, M. 2011. MODFLOW-NWT, A Newton formulation for MODFLOW-2005: U.S. Geological Survey Techniques and Methods 6-A37, 44 p.

Massmann, J. and N. Romero. 2006. Numerical Simulation of the Groundwater Flow System in the Woodland Creek watershed. Prepared for Natural Resources Department Squaxin Island Tribe, Shelton Washington. May.

NWLW (Northwest Land and Water, Inc.). 2008. Hawks Prairie Area Hydrogeologic Characterization Report. Prepared for the City of Lacey.

PGG (Pacific Groundwater Group). 1997. Results of Well Installation and Testing Lacey Production Well C at Madrona Park. Prepared for the City of Lacey.

PGG (Pacific Groundwater Group). 2004. Final Results of Well Construction and Testing, Betti Test Well. Prepared for City of Lacey, Washington.

Pollock, D.W. 2012. MODPATH v6.0: A particle-tracking model for MODFLOW. U.S. Geological Survey Software Release. http://dx.doi.org/10.5066/F70P0X5X.

PSLC (Puget Sound LiDAR Consortium). 2018. Thurston County LiDAR. Thurston GeoData Center. Data Collected July 2011. Accessed August 28, 2018. http://pugetsoundlidar.ess.washington.edu/lidardata/restricted/nonpslc/thurston2011/thurston2011.html.

Rector, Julie. 2018. City of Lacey. Personal Communication. November 26 and July 20.

Reilly T. and A. Harbaugh. 2004. Guidelines for Evaluating Ground-Water Flow Models. Scientific Investigations Report 2004-5038. U.S. Geological Survey.

Robinson and Noble, Inc. 2000. Technical Memorandum 200F H.P. Area, LOTT Wastewater Resource Management Plan, Hydrogeologic Investigation of the Finley and Corners Properties. Prepared for LOTT Wastewater Alliance, Olympia, Washington.

Robinson and Noble, Inc. 2002. Technical Memorandum 18763.400, LOTT Wastewater Alliance, Monitor Well Drilling and Construction at Groundwater Recharge Basin A. Prepared for LOTT Wastewater Alliance, Olympia, Washington.

Robinson and Noble, Inc. 2005. Construction and Testing of Betti Site Production Well Source No. 29. Prepared for City of Lacey.

Shannon and Wilson, Inc. 2012. Groundwater Modeling Files for the 2009 Water System Plan City of Lacey, WA. Prepared for the City of Lacey.

Steffensen, Wendy. 2019. LOTT Clean Water Alliance. Environmental Project Manager. Personal Communication.

Thurston County. 2018. Water Quality Monitoring. Public Health and Social Services. Accessed September 28, 2018. https://www.co.thurston.wa.us/cm-ehswat/station.asp?site=HENWL0030

Thurston GeoData Center. 2016. Thurston Zoning. https://gisdata-thurston.opendata.arcgis.com/datasets/thurston-zoning.

Tousley, Gerald. 2018. Thurston County Waste and Recovery Center. Personal Communication.

USACE (U.S. Army Corps of Engineers). 1999. Engineering and Design Groundwater Hydrology. Manual No. 1110-2-1421. Department of the Army. Washington, DC.

Washington Geological Survey. 2017. Surface geology, 1:24,000-GIS data, September 2017: Washington Geological Survey Digital Data Series DS-10, version 3.0, previously released November 2016. https://www.dnr.wa.gov/programs-and-services/geology/publications-and-data/gis-data-and-databases.

Zheng, C. and G.D. Bennett. 2002. Applied Contaminant Transport Modeling, Second Edition. Wiley Interscience, Maryland.

This page intentionally left blank.

Tables

Table 1. Average Precipitation for the 1948 to 2016 record from the Olympia Airport Gauging Station

Date	Average Precipitation over Period of Record (1948-2016) (in/month)	Monthly Percentage of Average Annual Precipitation
January	7.87	15.4
February	5.69	11.1
March	5.28	10.3
April	3.37	6.6
May	2.17	4.3
June	1.54	3.0
July	0.7	1.4
August	1.17	2.3
September	2.13	4.2
October	4.78	9.4
November	8.22	16.1
December	8.12	15.9
Total Annual	51.04	100

Notes:
Precipitation data from GHCND Station USW00024227, Olympia Airport.

Table 2. Average Temperature for the 1948 to 2016 record from the Olympia Airport Gauging Station

Date	1948-2016 Monthly Average High (°F)	1948-2016 Monthly Average Low (°F)	1948-2016 Monthly Average Temperature (°F)
January	44.7	31.8	38.3
February	49.2	32.5	40.8
March	53.3	33.9	43.6
April	58.8	36.6	47.7
May	65.7	41.7	53.7
June	70.9	46.8	58.8
July	77.2	49.6	63.4
August	77.2	49.7	63.4
September	71.6	45.4	58.5
October	60.5	40	50.2
November	50.4	35.5	43
December	44.8	32.6	38.7

Notes:
Temperature Data from GHNCD Station USW00024227, Olympia Airport.

Table 3. Observed Stream Flow

Location	Creek	Date	River Mile	Total Flow (cfs)	Ground-water Inflow Between Reaches (cfs)	Cumulati-ve Ground-water Inflow (cfs)	Source	X	Y
Eagle @ Stormwater Ponds	Eagle	8/25/2015	1.97	0	0	0	HDR 2015	1072896	644472
Eagle 2	Eagle	8/25/2015	1.32	0	0	0	HDR 2015	1069565	644311
Eagle 3	Eagle	8/25/2015	1.16	0	0	0	HDR 2015	1068799	644188
Eagle 4	Eagle	8/25/2015	1.1	0	0	0	HDR 2015	1068606	643994
Eagle 9	Eagle	8/25/2015	0.46	0.21	0.07	0.07	HDR 2015	1067736	640790
Eagle @ Carpenter	Eagle	8/25/2015	0.33	0.36	0.15	0.21	HDR 2015	1066917	640659
Eagle @ Woodland	Eagle	8/25/2015	0	0.24	-0.12	0.09	HDR 2015	1065529	641162
North Spring Flow	North Springs	8/25/2015	0.46	0.14			HDR 2015	1067994	640329
Fox @ Hawks Prairie RD	Fox	8/25/2015	1.64	0	0	0	HDR 2015	1066815	647799
Fox @ Carpenter RD	Fox	8/25/2015	1.28	0.05	0.05	0.05	HDR 2015	1066841	645953
Fox @ Pleasant Glade RD	Fox	8/25/2015	0.23	0.24	0.19	0.24	HDR 2015	1064310	643229
Fox @ Woodland	Fox	8/24/2015	0	0.51	0.28	0.51	HDR 2015	1063919	642370
Jorgensen Creek Flow	Jorgensen	8/25/2015	1.19	0.7			HDR 2015	1061975	644021
Flow 4 Rail Grade	Woodland	8/24/2015	5.63	0.67	0.12	0.12	HDR 2015	1071355	628863
Flow 1 Wetland	Woodland	8/24/2015	5.23	2.53	1.86	1.98	HDR 2015	1069504	629446
Flow 3 Pacific	Woodland	8/24/2015	4.86	0.34	-2.18	-0.2	HDR 2015	1067896	630456
Flow 6 USFWS	Woodland	8/24/2015	4.24	0	0	-0.55	HDR 2015	1065685	632320

Location	Creek	Date	River Mile	Total Flow (cfs)	Ground-water Inflow Between Reaches (cfs)	Cumulati-ve Ground-water Inflow (cfs)	Source	X	Y
Flow 9 US College	Woodland	8/24/2015	3.44	5.41	5.41	4.86	HDR 2015	1066774	635586
Flow 8 Woodland Creek (DSC)	Woodland	8/24/2015	3.43	7.29	-0.06	4.8	HDR 2015	1066782	635626
College Springs Flow	College Springs	8/24/2015	3.43	1.94			HDR 2015	1066709	635520
Flow 11 Woodland Creek Upper	Woodland	8/24/2015	3.36	4.26	-3.02	1.78	HDR 2015	1066617	635927
Flow 10 Woodland Creek I-5	Woodland	8/24/2015	3.25	10.39	6.12	7.9	HDR 2015	1066635	636457
Woodland @ 50' DS Draham RD	Woodland	8/24/2015	2.92	8.43	-1.95	5.94	HDR 2015	1066145	638465
Woodland @ 500' DS Draham RD	Woodland	8/24/2015	2.85	7.58	-0.85	5.09	HDR 2015	1065989	638800
Woodland @ 3000' DS of Draham RD	Woodland	8/24/2015	2.64	8.9	1.32	6.41	HDR 2015	1065049	639248
Eagle Creek Flow	Woodland	8/25/2015	2.25	0.24			HDR 2015	1065701	641120
Woodland @ 300' DS Eagle	Woodland	8/24/2015	2.2	9.45	-0.56	6.72	HDR 2015	1065385	641470
Woodland @ 100' US Palm	Woodland	8/24/2015	1.96	9.88	0.43	7.16	HDR 2015	1064427	641843
Woodland @ 100' US Fox	Woodland	8/24/2015	1.81	9.47	-0.63	6.53	HDR 2015	1063916	642294
Woodland @ Pleasant Glade RD	Woodland	8/24/2015	1.62	11.43	1.44	7.97	HDR 2015	1063099	642443
Woodland @ 100' US Jorgensen	Woodland	8/25/2015	1.19	13.41	1.99	9.95	HDR 2015	1062060	644073
Dobbs Creek @ Johnson Point Road (Db0.1)	Dobbs	6/23/2014		1.3			Ecology 2018a	1062652	652320
Woodland Creek @ Hawks Prairie Road (Wl0.2)	Woodland	6/23/2014		26			Ecology 2018a	1061990	649246

Notes:
Location information is given in the Washington State Plane NAD 83 South coordinate system.

Table 4a. Groundwater Elevation Measurements, Shallow (Qva) Aquifer, April–August 2018

Well Name or Study ID	Measuring Point Elevation (ft, NAVD88)	Screened Interval (ft bgs)	Date	Groundwater Elevation (ft, NAVD88)
LOTT MW-1	219.46	87 - 97	06/14/2018	136.13
LOTT MW-11	228.00	150 - 160	06/15/2018	96.62
LOTT MW-13	226.80	118.7 - 148.7	6/15/2018	108.57
LOTT MW-15	219.20	75 - 95	06/12/2018	137.77
LOTT MW-16	219.34	74.5 - 94.5	06/13/2018	137.09
LOTT MW-2	218.27	97 - 107	6/14/2018	136.90
LOTT MW-20	219.22	120 - 150	06/12/2018	96.51
LOTT MW-24	204.90	65 - 90	6/14/2018	144.26
LOTT MW-25	228.95	118 - 168	06/12/2018	96.73
LOTT MW-26	233.18	175 - 105	06/11/2018	154.36
LOTT MW-27	220.16	95 - 120	06/11/2018	122.85
LOTT MW-28	224.85	130 - 170	06/12/2018	98.38
LOTT MW-3a	219.17	77 - 127	06/13/2018	131.85
LOTT MW-5	219.09	76 - 96	06/14/2018	135.18
LOTT MW-6	218.97	83 - 103	06/14/2018	139.33
LOTT MW-7	218.91	100 - 120	06/14/2018	137.63
LOTT MW-8	218.70	105 - 125	06/14/2018	117.84
LOTT MW-9	218.69	89 - 109	06/14/2018	127.92
Lacey MW-11	232.12	130 - 115	06/15/2018	110.17
Lacey S15	235.66	115 - 140	06/28/2018	159.36
Lacey S16	238.82	113 - 138	06/28/2018	160.02
Landfill MW-1	220.58	No screen, total depth 195	06/13/2018	90.80
Landfill MW-10S	228.09	125 - 135	6/13/2018	124.13
Landfill MW-11	225.07	90 - 105	04/27/2018	122.62
Landfill MW-14	226.35	98 - 108	4/24/2018	123.90
Landfill MW-15	226.41	No screen information, total depth 222.74	4/24/2018	131.63

Well Name or Study ID	Measuring Point Elevation (ft, NAVD88)	Screened Interval (ft bgs)	Date	Groundwater Elevation (ft, NAVD88)
Landfill MW-9S	253.24	130 - 145	04/23/2018	123.94
Hogum Bay (Study ID 1224)	251.34	No screen information, total depth 139 ft	09/13/2017	151.42
24	164.48	154 - 163	05/07/2015	85.48
70	78.98	89 - 93	05/07/2015	72.04
196	268.76	145 - 158	05/07/2015	154.66
226	161.75	135 - 145	04/24/2015	95.04
667	132.75	75 - 80	06/02/2015	89.10
722	202.60	141.75 - 153.75	09/13/2017	88.54
782	104.86	68.75 - 72.5	04/30/2015	71.11
962	33.63	37 - 47	04/29/2015	27.81
963	77.90	84 - 88	04/23/2015	3 4.07
972	70.70	111 - 119	06/04/2015	50.58
980	86.54	110 - 120	04/28/2015	50.06
983	87.73	86 - 90	05/11/2015	52.00
1160	98.93	66 - 76	05/01/2015	66.73
1215	252.13	133 - 143	05/07/2015	159.86

Notes:
Elevation datum is NAVD88 (ft).

Table 4b. Groundwater Elevation Measurements, Sea-Level (Qc) Aquifer, April - August 2018

Well Name or Study ID	Measuring Point Elevation (ft, NAVD88)	Screened Interval (ft bgs)	Date	Groundwater Elevation (ft, NAVD88)
LOTT MW-12	227.00	284.7 - 304.7	06/15/2018	93.61
LOTT MW-14	218.04	310 - 330	06/12/2018	64.32
LOTT MW-21	227.16	220 - 240	06/14/2018	92.71
LOTT MW-23	204.54	259.8 - 289.8	06/14/2018	55.99
Lacey S21	264.90	263 - 271, 279.5 - 292.5, 313 - 324	6/28/2018	38.80
Lacey S22	266.07	265 - 282, 294 - 306	6/28/2018	38.57
Lacey S28	265.35	262.5 - 277.5, 286.5 - 325.5	6/28/2018	38.55
Lacey S29	230.62	293.6 - 309.25, 332.5 - 347.9, 354.9 - 375	06/28/2018	83.92
Landfill MW-10D	227.51	253 - 258	04/23/2018	38.96

Landfill MW-12D	220.18	238 - 248	04/24/2018	58.20
Landfill MW-13D	214.04	218 - 228	04/23/2018	33.34
Landfill MW-6R	227.87	No screen information, total depth 224.34 ft	04/24/2018	36.61
Landfill MW-9D	252.53	248 - 258	04/23/2018	30.65
27	241.88	274.8 - 283.6	05/07/2015	18.18
536	224.90	250 - 255	05/07/2015	21.98
882	232.82	253 - 258	05/07/2015	17.00
1082	64.56	93 - 98	4/23/2015	2.11
1088	106.27	134 - 139	04/27/2015	7.33

Notes:
Elevation datum is NAVD88 (ft).

Table 4c. Groundwater Elevation Measurements, Deep (TQu) Aquifer, May - June 2018

Well Name or Study ID	Measuring Point Elevation (ft, NAVD88)	Screened Interval (ft bgs)	Date	Groundwater Elevation (ft, NAVD88)
Lacey S07	187.44	430 - 481	06/28/2018	121.94
Lacey S19 (HP1)	305.23	585 - 643	05/31/2018	42.43
Lacey S31 (HP2)	302.52	498 - 525, 573 - 598, 629 - 648	06/28/2018	5.92
Lacey SMW	113.08	325 - 442, 468 - 536	06/14/2018	29.98[3]
Lacey TW-BC3	230.00	523 - 530, 540 - 547	06/14/2018	27.722
Lacey TW-MC	242.70	497 - 533, 564 - 574, 607 - 617, 647 - 657	06/14/2018	24.732
Lacey TW-MR	282.80	507.5 - 527.5, 566 - 568.5, 601.5 - 611.5, 616.5 - 624.5	06/14/2018	24.192

Notes:
1. Elevation datum is NAVD88 (ft).
2. For wells with significant water level fluctuations, the median value for that day is reported.
3. Groundwater elevation reflective of upper screen only.

Table 5a. Aquifer Properties as Estimated from Pumping Tests

Owner	Well ID	Screened Zones (ft bgs)	Aquifer	Aquifer Thickness (ft)	Type of Analysis	Pumping Rate (gpm)	Specific Capacity (gpm/ft)	Transmissivity (ft^2/day)	Hydraulic Conductivity (ft/day)	Storage Coefficient (unitless)	Citation	Notes
LOTT	MW-2	97 - 107	Qva	31	Pumping Test	30	10.5	282 - 976	68 - 235	0.00018 - 0.000062	HDR 2017b	
LOTT	MW-13	118.7 - 148.7	Qva	6.2	Pumping Test	3.3	6	165	82		HDR 2017b	
LOTT	MW-16	74.5 - 94.5	Qva	13.9	Pumping Test	17	14	283 - 624	68 - 151	0.012 - 0.00014	HDR 2017b	
City of Lacey	MW-11	119.3 - 129.3	Qva	5	Pumping Test	0.55	0.3	8	12		Landau 2016	
City of Lacey	MW-12	71.5 - 81.5	Qva	10	Pumping Test	1.6	0.5	14	11		Landau 2016	
LOTT	MW-12	284.7 - 304.7	Qc	110	Pumping Test	2.9	12	15	29		HDR 2017b	
LOTT	MW-14	310 - 330	Qc	60	Pumping Test	3	1	8	4		HDR 2017b	
City of Lacey	Betti Test Well	338 - 348, 366 - 386	Qc	50	Pumping Test	500	12	5,882 - 6,417	118 - 128		PGG 2004	
City of Lacey	S29	293.6 - 309.25, 332.5 - 347.9, 354.9 - 375	Qc	96.5	Pumping Test	1,200	5	6,550 - 8,021	76	0.02	Ecology 2018b, Robinson and Noble, Inc. 2005	2
City of Lacey	S22	265 - 282, 294 - 306, 313 - 326	Qc	61	Pumping Test	1,025	460	408,060	6,690		PGG 1997	3
Miller Land and Timber LLC	Carpenter Ridge	361 - 371	Qc		Pumping Test	200	2	126 - 9,625	28 - 212	0.0002 - 0.0005	Landau 2008	4
Miller Land and Timber LLC	Pleasant Glade	543 - 553	TQu		Pumping Test	33	0.3	43,144	0.4 - 2.8		Landau 2008	4, 5
City of Lacey	TW-MC	497 - 533, 564 - 574, 607 - 617	TQu	85	Pumping Test	448	11	4,010	47		NWLW 2008	1, 2
City of Lacey	TW-BC	447 - 472, 523 - 547	TQu	54	Pumping Test	361	4	896	13		NWLW 2008	1, 2
City of Lacey	S19 (Hawks Prairie Production Well)	585 - 592, 603 - 608, 625 - 645	TQu	56	Pumping Test	860	6	5,080	91		Hart Crowser 1989	
City of Lacey	TW-HP1	585 - 608, 623 - 642	TQu	62	Pumping Test	745	10	2,941	43-65	0.00003	NWLW 2008	1, 2
City of Lacey	TW-HP2	498 - 525, 573 - 598, 629 - 648	TQu	103	Pumping Test	1,488	16	4,679	31-51	0.0003	NWLW 2008	1, 2
Silver Hawk Development Company	Silverhawk (ID-312)	535 - 575	TQu	85	Pumping Test	750	16	4,144	49	0.0002	NWLW 2008	1, 2
City of Lacey	TW-MR	507 - 527.5, 566 - 586.5, 602.5 - 624.5	TQu	96	Pumping Test	432	18	4,946	62	0.0004-0.0005	NWLW 2008	1, 2

Notes:

1. Reported transmissivity was the best fit analyzed.
2. Hydraulic conductivity was an average of high and low values.
3. Reported transmissivity is an average of previously reported values.
4. Calculated hydraulic conductivity assuming aquifer thickness of 34 ft which is the average thickness reported.
5. Identified by Landau as screened in the Qc. NWLW (2008) and HDR reinterpreted it as screened in the TQu, which was identified from 534 to 553 ft bgs.

This page intentionally left blank.

Table 5b. Summary of Hydraulic Conductivity Calculated from Pumping Tests by Aquifer Unit

Aquifer	Hydraulic Conductivity (ft/day)			
	Minimum	Geometric Mean	Arithmetic Mean	Maximum
Shallow Aquifer (Qva)	11	56	90	235
Sea Level Aquifer (Qc)	4	53	84	212
Deep Aquifer (TQu)	0.4	24	42	91

Notes:
Lacey S22 was not included in the calculation of statistics for the Sea-Level (Qc) Aquifer because it is an outlier and not representative of hydraulic properties.

Table 6. Summary of Hydraulic Conductivity Calculated from Grain Size Analysis

Formation Name	Hydraulic Conductivity (ft/day)		
	Minimum	Geometric Mean	Maximum
Shallow Aquifer (Qva)	0.1	112	523
Kitsap Formation (Qf)	0.002	0.2	16
Sea Level Aquifer (Qc)	0.2	25	1,429
Lower Confining Unit (TQu)	0.002		

Table 7. Summary of Hydraulic Conductivity Determined from Well Logs in Northern Thurston County (Drost et al. 1999).

Hydrostratigraphic Unit	Number of Wells Tested	Hydraulic Conductivity (ft/day)		
		Range		Median
Qvr	43	14	2,100	150
Qvt	22	5.2	89	14
Qva	370	6.8	130,000	180
Qf	41	0.052	62	17
Qc	321	1.9	12,000	150
TQu	132	1.2	4,200	78
Tb	38	0.0025	450	0.88

Notes:
Tb is characterized in Drost et al. (1999) as the poorly permeable base of unconsolidated sediments, mostly Tertiary claystones, siltstones, and sandstones with some basalt, and is older than TQu. The unit Tb is an unreliable source of groundwater and many wells drilled into this unit in Thurston County have been abandoned due to insufficient yield or poor-quality water (Drost et al. 1998).

Table 8. Average Unit Thickness Observed in Well Logs Used to Construct Geology Model

Hydrostratigraphic Unit	Average Thickness (ft)
Qvr	24
Qvt	59
Qva	64
Qf	74
Qc	45
TQu (**L**ower **C**onfining **U**nit)	89
TQu	81

Table 9. Porosity as Determined from Laboratory Analysis

Sample Number	Porosity (%)	Grain-Size Fractions[3]				Soil Classification
		Gravel (%)	Sand (%)	Silt (%)	Clay (%)	
West Lysimeter (22'-25')	23.8	6	79.6	11.3	3.2	Fine sand, some silt, trace clay and gravel
West Lysimeter (42'-45')	19.3	28.8	55.8	10.4	5.1	Fine sand and gravel, some silt, trace clay
East Lysimeter (32'-35')	15.2	63.3	26.8	7	2.9	Fine to medium sand and gravel, trace silt and clay
East Lysimeter (42'-45')	18.2	36.8	37.3	18.5	7.4	Fine to medium sand and gravel, some silt, trace clay

Notes:
Size Fractions based on the following:
Gravel = material between 4.75 mm and 760 mm
Sand = material between 0.075 mm and 4.75 mm
Silt = material between 0.002 mm and 0.075 mm
Clay = material less than 0.002 mm
Source: HDR 2017b.

Table 10. Summary of Hydraulic Conductivity Estimated from Pumping Tests as Reported on Well Logs

Aquifer	Maximum Pumping Rate (gpm)	Hydraulic Conductivity (ft/day)			
		Minimum	Maximum	Geometric Mean	Average
Qva	810	0.1	373	5	18
Qc	1680	0.2	4,159	20	341
TQu	860	0.1	85	14	43

Notes:
1. See Appendix D for complete table of hydraulic conductivity as estimated from pumping tests reported in well logs.
2. Transmissivity calculated using the specific capacity equation from Driscoll (1986).
3. Hydraulic conductivity was calculated from transmissivity using the average hydrostratigraphic unit thickness from well logs used to construct the geology model, equal to 64 ft for Qva, 45 ft for Qc, and 81 ft for TQu.

Table 11. Summary of Hydrostratigraphic Unit Hydraulic Conductivity Observed in the Field and Implemented in Previous Models

Hydrostratigraphic Unit	Hydraulic Conductivity Observed in Field (ft/day)		Hydraulic Conductivity Implemented in Previous Models (ft/day)	
	Range		Range	
Qvr	14	2,100	1	640
Qvt	5.2	89	1	320
Qva	0.1	130,000	1	640
Qf	0.002	62	0.1	100
Qc	0.1	12,000	7.5	640
TQu (Lower Confining Unit)	0.002		1	1
TQu	0.4	4,200	40	250

Table 12. Specific Yield and Total Porosity Ranges based on Sediment Texture

Sediment Texture	Specific Yield (%)		Porosity (%)
	Range	Average	
Silt	3 - 12	7	35-50
Fine Sand	10 - 28	21	-
Medium Sand	15 - 32	26	-
Gravelly Sand	20 - 35	25	20 - 35

Source: Fetter (2001)

Table 13. Summary of Hydrostratigraphic Unit Hydraulic Conductivity Observed in the Field and Implemented in Previous Models

Hydrostrati-graphic Unit	Model Layer	Simulated Horizontal Hydraulic Conductivity (ft/day)	Simulated Vertical Hydraulic Conductivity (ft/day)	Hydraulic Conductivity Observed in Field (ft/day)		Hydraulic Conductivity Implemented in Previous Models (ft/day)	
				Range		Range	
Qvr	1	0.07, 1, 7, 20, 80, 120, 200	0.1, 0.7, 2, 8, 12, 20	14	2,100	1	640
Qvt	2	1, 7, 20, 80, 120, 200	0.1, 0.7, 2, 8, 12, 20	5.2	89	1	320
Qva	3	0.07, 1, 3, 7, 10, 15, 20, 30, 50, 60, 80, 100, 120, 140, 200, 225	0.1, 0.3, 0.5, 0.7, 0.8, 1.5, 2, 10, 12, 14, 20, 22, 25	0.1	130,000	1	640
Qf	4	0.07, 0.2, 0.8, 1, 7, 10, 20, 80	0.0007, 0.02, 0.08, 0.1, 0.2, 0.7, 2, 5, 8	0.002	62	0.1	100
Qc	5	0.5, 3, 10, 30, 80, 120, 500	0.3, 0.5, 8, 10, 12, 50,	0.1	12,000	7.5	640
TQu (Lower Confining Unit)	6	0.07, 0.1, 7	0.0007, 0.01, 0.7	0.002		1	1
TQu	7	7, 13, 23, 50, 75, 100	0.5, 0.7, 1.3, 2.3, 7, 10	0.4	4,200	40	250

Table 14. Implemented Effective Porosity by Model Layer

Unit	Model Layer	Effective Porosity
Qvr	1	15%
Qvt	2	15%
Qva	3	11%
Qf	4	0.2%
Qc	5	1.5%
TQu (Lower Confining Unit)	6	15%
TQu	7	15%

Table 15. Model Recharge Summary Table

Recharge Category	Recharge (in/yr)	Source
Undeveloped	8 - 31	Hansen 2019
Low Density Development	12	Based on Bidlake and Payne 2001
High Density Development	7	Based on Bidlake and Payne 2001

Table 16. Recharge Rates for Basins 4 and 5 Used in Steady-State Water Level Calibration and Particle Tracking Simulations

Model Units	Steady-state Flow Model		Particle Tracking Simulation of Tracer Test	
	MGD	*ft/d*	*MGD*	*ft/d*
LOTT Basin 4	0.584433	3.472324	0.648985	3.855852
LOTT Basin 5	0.189451	1.266298	0.405686	5.423232
Source	Average recharge rate for May - June		Average recharge rate for days 1-35, (time of first detection for MW-25)	

Table 17. Surface Water Bodies and the Corresponding Model Boundary Package

Surface Water Body	MODFLOW Package	Active in Layers
Puget Sound	*Constant Head*	*3, 5, 7*
McAllister Creek	*Constant Head*	*5*
Woodland Creek, Beatty Springs, Lake Lois, Tributary Creeks, Little McAllister Creek	*Drain*	*1 - 5*
Springs on bluffs over Nisqually River Valley	*Drain*	*3 - 5*
Wetland Pond 5	*River*	*1 - 2*
Other Boundary Conditions		
General Head Boundary, Western Boundary	*General Head*	*3, 5, 7*
General Head Boundary, Eastern Boundary	*General Head*	*7*
General Head Boundary, Southern Boundary	*General Head*	*3, 5, 7*

Table 18. Summary of Simulated Pumping Wells

Layer	Number of Wells	Minimum Pumping Rate (gpm)	Maximum Pumping Rate (gpm)	Average Pumping Rate (gpm)
1	10	0.16	1.2	0.73
3	483	0.16	59	1.3
5	341	0.15	414	6.0
7	42	0.16	911	45

Table 19. Pumping Rates for City of Lacey Supply Wells

Well ID	Well Name	X	Y	Top of Casing or Measuring Point Elevation (ft, NAVD88)	Average Annual Pumping Rate 2017–2018 (gpm)	Screened Interval (ft bgs)	Aquifer	Model Layer
S15		1079909	652456	235.66	59	115.5 - 140.8	Qva	3
S16	Beachcrest 2	1079938	652480	238.82	55	113 - 138	Qva	3
S21		1078330	629868.3	264.9	114	263 - 271, 279.5 - 292.5, 313 - 324	Qc	5
S22		1078300	629883.4	266.07	414	265 - 282, 294 - 306, 313 - 326	Qc	5
S28		1078260	629870.4	265.35	128	262.5 - 277.5, 286.5 - 325.5	Qc	5
S29	Betti Well	1073552	643379	230.62	343	293.6 - 309.25, 332.5 - 347.9, 354.9 - 375	Qc	5
S07		1064830	630020	187.4	911	430 - 481	TQu	7
S19	Hawks Prairie No. 1	1072577	648745	305.23	379	585 - 592, 603 - 608, 625 - 645	TQu	7
S31	Hawks Prairie No. 2	1072737	648609.6	302.52	216	498 - 525, 573 - 598, 629 - 648	TQu	7

Notes:
Average annual pumping rates were calculated using the total gallons pumped in 2017 and 2018.

This page intentionally left blank.

Table 20. Groundwater Elevation Calibration Targets, Simulated Groundwater Elevations and Residuals

Study ID	Owner	Well Name	Ecology ID	X Coordinate	Y Coordinate	Observed Groundwater Elevation (ft)	Simulated Groundwater Elevation (ft)	Residual	Water Level Confidence	Aquifer	Model Layer	Water Level Date	Citation or Source
24	VIRCE		41117	1065837	648629	85.48	96.41	-10.93	Measured	Qva	3	05/07/2015	Ecology 2018b
70	OMAN SALAZAR	Salazar	27975	1065375	639488	72.04	72.32	-0.28	Measured	Qva	3	05/07/2015	Ecology 2018b
196	F. MORRIS	Forest Park	43614	1068854	651639	154.66	156.11	-1.45	Measured	Qva	3	05/07/2015	Ecology 2018b
226	KEN RIGGERS	Huard/ Fife	333351	1066989	648262	95.04	99.4	-4.36	Measured	Qva	3	04/24/2015	Ecology 2018b
667	PARAMOUNT BUILDERS | RICHARDSON WELL DRILLING	Whittaker	737252	1066867	646779	89.1	81.58	7.52	Measured	Qva	3	06/02/2015	Ecology 2018b
699	Lacey	Lacey S15	36278	1079908	652456	159.36	146.28	13.08	Measured	Qva	3	06/28/2018	City of Lacey
700	Lacey	Lacey S16	37941	1079937	652480	160.02	146.28	13.74	Measured	Qva	3	06/28/2018	City of Lacey
722	EDDIE TRUE	Eagle Estates	24137	1069718	644272	88.54	89.06	-0.52	Measured	Qva	3	09/13/2017	Ecology 2018b
782	SHAWN AND DENISE BROWNLEE	Thompson	386847	1068119	644980	71.11	78.08	-6.96	Measured	Qva	3	04/30/2015	Ecology 2018b
962	MC CONST. (RUSSELL)	Bhagia	32096	1062074	645714	27.81	28.27	-0.46	Measured	Qva	3	04/29/2015	Ecology 2018b
963	JOHN FRIEND | FRIEND AND FRIEND	Doran	301152	1062770	644454	34.07	36.65	-2.58	Measured	Qva	3	04/23/2015	Ecology 2018b
972	MC CONSTRUCTION	Benjamin	333232	1062588	642343	50.58	48.82	1.77	Measured	Qva	3	06/04/2015	Ecology 2018b
980	CHANCE & SON CONST.	Waits	32026	1061676	642691	50.06	47.32	2.74	Measured	Qva	3	04/28/2015	Ecology 2018b
983	NORA JEWETT		380547	1062894	642178	52	52.47	-0.47	Measured	Qva	3	05/11/2015	Ecology 2018b
1160	JAMES SMITH LLC	Shoemaker	392707	1064143	654284	66.73	57.15	9.58	Measured	Qva	3	05/01/2015	Ecology 2018b
1215	SOUTH SOUND UTILIITES	Foxhall		1068115	652560	159.86	152.3	7.56	Measured	Qva	3	05/07/2015	Ecology 2018b
1224	GEORGE WELLING	Hogum Bay	24805	1077301	644064	151.42	155.21	-3.79	Measured	Qva	3	09/13/2017	Ecology 2018b
1237	LOTT	MW-25		1075647	641496	96.73	103.22	-6.49	Measured	Qva	3	06/12/2018	HDR 2018a
1238	LOTT	MW-26		1077568	644799	154.36	156.87	-2.51	Measured	Qva	3	06/11/2018	HDR 2018a
1239	LOTT	MW-27		1075465	642077	122.85	121.76	1.09	Measured	Qva	3	06/11/2018	HDR 2018a
1240	LOTT	MW-28		1074790	641129	98.38	99.3	-0.92	Measured	Qva	3	06/12/2018	HDR 2018a
1250	LOTT	MW-1		1076316	642684	136.13	141.07	-4.94	Measured	Qva	3	06/14/2018	HDR 2018a
1251	LOTT	MW-2		1076140	642770	136.9	140.78	-3.88	Measured	Qva	3	6/14/2018	HDR 2018a
1252	LOTT	MW-3a		1075924	642566	131.85	134.64	-2.79	Measured	Qva	3	06/13/2018	HDR 2018a

Study ID	Owner	Well Name	Ecology ID	X Coordinate	Y Coordinate	Observed Groundwater Elevation (ft)	Simulated Groundwater Elevation (ft)	Residual	Water Level Confidence	Aquifer	Model Layer	Water Level Date	Citation or Source
1253	LOTT	MW-5		1076096	642379	135.18	133.82	1.36	Measured	Qva	3	06/14/2018	HDR 2018a
1254	LOTT	MW-6		1076201	643157	139.33	138.4	0.93	Measured	Qva	3	06/14/2018	HDR 2018a
1255	LOTT	MW-7		1075959	642881	137.63	135.59	2.04	Measured	Qva	3	06/14/2018	HDR 2018a
1256	LOTT	MW-8		1075400	642506	117.84	126.27	-8.43	Measured	Qva	3	06/14/2018	HDR 2018a
1257	LOTT	MW-9		1075575	642394	127.92	127.51	0.41	Measured	Qva	3	06/14/2018	HDR 2018a
1259	LOTT	MW-11		1074897	642391	96.62	102.6	-5.98	Measured	Qva	3	06/15/2018	HDR 2018a
1260	LOTT	MW-13		1074897	642684	108.57	108.1	0.47	Measured	Qva	3	6/15/2018	HDR 2018a
1261	LOTT	MW-15		1076002	642742	137.77	138.86	-1.09	Measured	Qva	3	06/12/2018	HDR 2018a
1262	LOTT	MW-16		1076203	642738	137.09	141.48	-4.39	Measured	Qva	3	06/13/2018	HDR 2018a
1263	LOTT	MW-20		1074874	641507	96.51	100.21	-3.7	Measured	Qva	3	06/12/2018	HDR 2018a
1265	LOTT	MW-24		1077296	643021	144.26	145.41	-1.15	Measured	Qva	3	6/14/2018	HDR 2018a
1266	Landfill	Landfill MW-1		1075984	639615	90.8	96.38	-5.58	Measured	Qva	3	06/13/2018	Tousley 2018
1268	Landfill	MW-9S		1079966	639812	123.94	128.37	-4.43	Measured	Qva	3	04/23/2018	Tousley 2018
1269	Landfill	Landfill MW-10S		1077481	640752	124.13	120.87	3.26	Measured	Qva	3	6/13/2018	Tousley 2018
1270	Landfill	Landfill MW-11		1078000	639554	122.62	122.29	0.33	Measured	Qva	3	04/27/2018	Tousley 2018
1272	Landfill	MW-14		1080079	640233	123.9	128.47	-4.57	Measured	Qva	3	4/24/2018	Tousley 2018
1273	Landfill	MW-15		1079401	642174	131.63	135.1	-3.47	Measured	Qva	3	4/24/2018	Tousley 2018
1274	Lacey	Lacey MW-11		1073816	642533	110.17	103.66	6.51	Measured	Qva	3	06/15/2018	HDR 2018a
4	JAMES CLARK		25532	1069600	643746	82.6	88.53	-5.93	Estimated from well log	Qva	3	07/17/1990	Ecology 2018b
13	JAMES & KATHERINE HART		36480	1071219	647689	163.4	159.73	3.67	Estimated from well log	Qva	3	07/17/1990	Ecology 2018b
29	JIM BAIN		30794	1066340	645878	64.37	67.47	-3.1	Estimated from well log	Qva	3	07/04/1995	Ecology 2018b
180	BOB DROHMAN		41585	1071787	650972	148.58	156.78	-8.2	Estimated from well log	Qva	3	01/22/1995	Ecology 2018b
197	FRANK MORRIS & SHANNON MORRIS		42680	1069163	651073	162.44	158	4.43	Estimated from well log	Qva	3	09/02/1998	Ecology 2018b
206	GARY ALLISON		24622	1066110	637880	76.13	86.4	-10.27	Estimated from well log	Qva	3	06/04/1987	Ecology 2018b
207	JOHN KOOKER		26202	1066110	637880	45.4645.457001	74.243568	-28.7866	Estimated from well log	Qva	3	08/14/1988	Ecology 2015

Study ID	Owner	Well Name	Ecology ID	X Coordinate	Y Coordinate	Observed Groundwater Elevation (ft)	Simulated Groundwater Elevation (ft)	Residual	Water Level Confidence	Aquifer	Model Layer	Water Level Date	Citation or Source
208	ROBERT PETROZZI		301165	1066110	637880	82.457001		-3.94	Estimated from well log	Qva	3	01/11/2001	Ecology 2018b
209	WILFRED KOVER		381426	1066110	637880	85.71	86.4	-0.69	Estimated from well log	Qva	3	06/27/2001	Ecology 2018b
210	WOODLAND CREEK WAER ASSOCIATION		30661	1065566	637764	76.6	86.38	-9.78	Estimated from well log	Qva	3	07/31/1963	Ecology 2018b
215	PAUL & BEVERLY RICHARDSON		28062	1081908	637349	149.7	139.64	10.06	Estimated from well log	Qva	3	06/12/2008	Ecology 2018b
315	WASHINGTON WATER		461138	1069614	644125	75	88.61	-13.61	Estimated from well log	Qva	3	12/05/2006	Ecology 2018b
331	JEWELL PAIGE		25805	1070001	635091	136.2	118.73	17.47	Estimated from well log	Qva	3	11/04/1968	Ecology 2018b
413	BOB KRANCE		33448	1083675	650529	113.03	149.8	-36.77	Estimated from well log	Qva	3	09/21/1980	Ecology 2018b
414	GREG LAWRENCE		311820	1083675	650529	160.7	149.8	10.9	Estimated from well log	Qva	3	04/04/2001	Ecology 2018b
415	PAUL & TONYA WOLFE		42068	1083675	650529	112.03	149.8	-37.77	Estimated from well log	Qva	3	05/13/1994	Ecology 2018b
430	DAVE PIER		272793	1064795	637931	103.33	86.61	16.71	Estimated from well log	Qva	3	07/10/1980	Ecology 2018b
432	DAVID & ISABELLE PIER		23376	1064795	637931	101.33	86.61	14.71	Estimated from well log	Qva	3	07/20/1964	Ecology 2018b
471	PAT HEITZMANN		386846	1069924	632457	100.36	108.76	-8.4	Estimated from well log	Qva	3	02/19/2004	Ecology 2018b
472	MAURICE JACOBSEN		38147	1065099	648575	95.98	94.05	1.93	Estimated from well log	Qva	3	05/26/1962	Ecology 2018b
529	ROLLIE THOMPSON		39879	1073181	653558	138.2	139.74	-1.54	Estimated from well log	Qva	3	07/24/1997	Ecology 2018b
531	ROWLAND CRAIG		249910	1083562	647894	141.22	142.1	-0.88	Estimated from well log	Qva	3	11/22/1999	Ecology 2018b
539	OLE ERIKSEN		27950	1082119	643962	135.16	136.73	-1.56	Estimated from well log	Qva	3	12/28/1976	Ecology 2018b
540	VERNON BIRCHER		30222	1082119	643962	140.16	136.73	3.44	Estimated from well log	Qva	3	02/17/1977	Ecology 2018b
541	ALAN ANDERSON		21673	1082119	643962	130.25	136.73	-6.48-3.48353	Estimated from well log	Qva	3	07/12/2012	Ecology 2015
542	ALICE ESTES		21725	1082119	643962	138.164993	133.731857	4.433136	Estimated from well log	Qva	3	08/11/1976	Ecology 2015
543	BILLIE PHILLIPS		22172	1082119	643962	132.164993	133.731857	-1.56686	Estimated from well log	Qva	3	05/01/1978	Ecology 2015
550	JAMES CLARK		25533	1071723	645074.1	95.2	98.584862	-3.38486	Estimated from well log	Qva	3	06/02/1971	Ecology 2015Ecology 2018b
601	ROBERT DROHMAN		39629	1069116	649752	131.6	144.71	-13.11	Estimated from well log	Qva	3	08/09/2007	Ecology 2018b
623	SCHILTER FAMILY FARM INC		487812	1084809	635971	103.91	100.67	3.24	Estimated from well log	Qva	3	07/23/2007	Ecology 2018b
661	JESS CROFT		25790	1081595	635898	162.9	148.26	14.64	Estimated from well log	Qva	3	12/18/1995	Ecology 2018b
670	BILLY RECTOR		33377	1076923	646847	212.76	186.95	25.81	Estimated from well log	Qva	3	06/21/1980	Ecology 2018b

Study ID	Owner	Well Name	Ecology ID	X Coordinate	Y Coordinate	Observed Groundwater Elevation (ft)	Simulated Groundwater Elevation (ft)	Residual	Water Level Confidence	Aquifer	Model Layer	Water Level Date	Citation or Source
780	RANDY POND		28394	1067634	644492	67.21	75.36	-8.16	Estimated from well log	Qva	3	06/08/1984	Ecology 2018b
783	DAVID HILL & GOSPEL OUTREACH OF OLYMPIA		23418	1082923	638635	137.37	129.78	7.59	Estimated from well log	Qva	3	07/25/1991	Ecology 2018b
802	DIXON ROBERT		34762	1083618	649212	162.17	153.06	9.11	Estimated from well log	Qva	3	05/02/1991	Ecology 2018b
803	RANDY ROVGHTON		39286	1083618	649212	168.17	153.06	15.11	Estimated from well log	Qva	3	09/10/1997	Ecology 2018b
804	WILLIALM DJUDY BELENSKI		443811	1083618	649212	171.17	153.06	18.11	Estimated from well log	Qva	3	06/25/2006	Ecology 2018b
805	WILLIAM AND JUDY BELENSKI		443114	1083618	649212	129.17	153.06	-23.89	Estimated from well log	Qva	3	06/14/2006	Ecology 2018b
838	TOM BRUSS		40822	1081065	651952	150.31	150.65	-0.34	Estimated from well log	Qva	3	03/30/1988	Ecology 2018b
840	MANCE AND SONS DEVELOPERS INC		401815	1070515	652343	152.4	155.03	-2.63	Estimated from well log	Qva	3	01/27/2005	Ecology 2018b
841	MANCE AND SONS DEVELOPERS INC		401816	1070515	652343	152.4	155.03	-2.63	Estimated from well log	Qva	3	01/28/2005	Ecology 2018b
844	RALPH WHITE		275062	1070781	646589	140.5	133.45	7.05	Estimated from well log	Qva	3	06/11/1997	Ecology 2018b
937	DENNIS THOMPSON		34680	1083509	646572	139.81	131.31	8.51	Estimated from well log	Qva	3	07/24/1977	Ecology 2018b
940	JOHN BURRELL		41583	1067704	647161	75.1	88.71	-13.61	Estimated from well log	Qva	3	06/30/1994	Ecology 2018b
944	MIKE WILLIS		38461	1067704	647161	84.1	88.71	-4.61	Estimated from well log	Qva	3	09/12/1985	Ecology 2018b
946	ADRIAN GABLES		256405	1067704	647161	82.1	88.71	-6.61	Estimated from well log	Qva	3	04/15/2000	Ecology 2018b
1031	Don Fisher		923943	1063480	637981	100.03	88.97	11.06	Estimated from well log	Qva	3	07/03/2014	Ecology 2018b
1098	NORM GOODRUM		38677	1065374	657823	74.3	62.62	11.68	Estimated from well log	Qva	3	08/13/1991	Ecology 2018b
1107	MANCE AND SON RD		314204	1070655	657610	47.8	68.33	-20.53	Estimated from well log	Qva	3	12/14/2000	Ecology 2018b
1120	BARALYN GRANT		387450	1073350	658821	32.95	39.99	-7.04	Estimated from well log	Qva	3	05/27/2004	Ecology 2018b
1128	MANCE & SON RD / MARVIN GARDENS WATER SYSTEM		274779	1071941	656233	168.23	117.1	51.13	Estimated from well log	Qva	3	06/18/1986	Ecology 2018b
1159	ASSOCIATION OF OUTDOOR RECREATION CLUBS		33128	1064325	653923	52.2	56.24	-4.04	Estimated from well log	Qva	3	05/04/1970	Ecology 2018b
1162	DELBERT MC CANN		34635	1062612	653952	47.8	27.84	19.97	Estimated from well log	Qva	3	10/03/1978	Ecology 2018b
71	OMAN SALAZAR		27976	1066212	640525	70.5	72.29	-1.79	Estimated from well log	Qva	3	06/03/1998	Ecology 2018b
27	HUDSON ENGINEERING, INC.	Classic Heights	25295	1082689	645541	18.18	16.22	1.96	Measured	Qc	5	05/07/2015	HDR 2017a
536	CONSOLIDATED CONST.	White Fir	23029	1081546	643433	21.98	21.77	0.21	Measured	Qc	5	05/07/2015	HDR 2017a
882	JOHN THOMPSON	Thompson	26320	1082947	641529	17	17.57	-0.57	Measured	Qc	5	05/07/2015	HDR 2017a
1082	MC CONSTRUCTION	Mena	38231	1085410	652625	2.11	0	2.11	Measured	Qc	5	4/23/2015	HDR 2017a
1088	PETER FIELD	Toyanbee	427861	1085428	651675	7.33	0.88	6.44	Measured	Qc	5	04/27/2015	HDR 2017a

Study ID	Owner	Well Name	Ecology ID	X Coordinate	Y Coordinate	Observed Groundwater Elevation (ft)	Simulated Groundwater Elevation (ft)	Residual	Water Level Confidence	Aquifer	Model Layer	Water Level Date	Citation or Source
1074	Lacey	Lacey S21	31684	1078305	629705	38.8	39.25	-0.45	Measured	Qc	5	6/28/2018	City of Lacey
1075	Lacey	Lacey S22	32323	1078300	629883	38.57	39.25	-0.68	Measured	Qc	5	6/28/2018	City of Lacey
1076	Lacey	Lacey S28	251552	1078256	629870	38.55	39.25	-0.7	Measured	Qc	5	6/28/2018	City of Lacey
237	Lacey	S29 (Betti Well)	405357	1073552	643379	83.92	81.38	2.54	Measured	Qc	5	6/28/2018	City of Lacey
1247	TC-Landfill	Landfill MW-10D		1077481	640752	38.96	42.13	-3.17	Measured	Qc	5	04/23/2018	Tousley 2018
1271	Landfill	Landfill MW-12D		1076508	642983	58.2	63.92	-5.72	Measured	Qc	5	04/24/2018	Tousley 2018
1248	TC-Landfill	Landfill MW-13D		1079237	640600	33.34	33.01	0.33	Measured	Qc	5	04/23/2018	Tousley 2018
1267	Landfill	Landfill MW-6R		1078030	639491	36.61	39.99	-3.38	Measured	Qc	5	04/24/2018	Tousley 2018
1246	TC-Landfill	Landfill MW-9D		1079966	639812	30.65	31.36	-0.71	Measured	Qc	5	04/23/2018	Tousley 2018
1229	LOTT	MW-12		1074893	642690	93.61	88.07	5.54	Measured	Qc	5	06/15/2018	HDR 2018a
1230	LOTT	MW-14		1075991	642641	64.32	67.95	-3.63	Measured	Qc	5	06/12/2018	HDR 2018a
1234	LOTT	MW-21		1073574	641077	92.71	90.54	2.17	Measured	Qc	5	06/14/2018	HDR 2018a
1236	LOTT	MW-23		1077296	643061	55.99	59.54	-3.55	Measured	Qc	5	06/14/2018	HDR 2018a
10	TOM LUDRTIN		29998	1074734	638255	51.3	60.14	-8.84	Estimated from well log	Qc	5	08/27/1974	Ecology 2018b
11	ALVIN THOMPSON		272572	1073654	635007	40.4	52.12	-11.72	Estimated from well log	Qc	5	03/11/2000	Ecology 2018b
17	BOB SMITH		22292	1083238	639278	16.5	20.29	-3.79	Estimated from well log	Qc	5	11/06/1981	Ecology 2018b
20	OLYMPIA SAND & GRAVEL CO.		27970	1068172	639794	37.84	65.2	-27.36	Estimated from well log	Qc	5	04/06/1992	Ecology 2018b
21	OLYMPIA SAND & GRAVEL CO.		273373	1067860	640127	45.7	65.43	-19.73	Estimated from well log	Qc	5	04/06/1992	Ecology 2018b
22	ALVIN THOMPSON		272571	1078994	638359	32.1	36.57	-4.47	Estimated from well log	Qc	5	03/11/2000	Ecology 2018b
182	WILBUR LENARD		30510	1069981	646304	42.4	52.73	-10.33	Estimated from well log	Qc	5	02/26/1991	Ecology 2018b
195	YOUR HOME BUILDERS		30684	1068670	635138	35.2	72.3	-37.1	Estimated from well log	Qc	5	07/31/1963	Ecology 2018b
258	JOHN KEYES		273154	1079301	637446	32	35.91	-3.91	Estimated from well log	Qc	5	12/15/1986	Ecology 2018b
322	DAVID SIMONSEN		550336	1064895	640570	56.3	58.36	-2.06	Estimated from well log	Qc	5	08/20/2008	Ecology 2018b
329	ROBERT HALL		28847	1080520	634763	26.3	32.44	-6.14	Estimated from well log	Qc	5	06/09/1978	Ecology 2018b
332	MARK SHATTUCK		825295	1070001	635091	49.2	69.13	-19.93	Estimated from well log	Qc	5	05/27/1994	Ecology 2018b
333	MARY DAVIS		27367	1070001	635091	41.2	69.13	-27.93	Estimated from well log	Qc	5	10/22/1970	Ecology 2018b
334	ANTANAS MINELGA		272576	1070001	635091	88.22	69.13	19.09	Estimated from well log	Qc	5	05/02/2007	Ecology 2018b
355	OLYMPIA SAND & GRAVEL		273372	1067534	640479	13.1	65.1	-52	Estimated from well log	Qc	5	03/14/2000	Ecology 2018b
479	BRADLEY-NOBLE		41980	1080932	647998	48.7	32.61	16.09	Estimated from well log	Qc	5	03/25/1994	Ecology 2018b

Study ID	Owner	Well Name	Ecology ID	X Coordinate	Y Coordinate	Observed Groundwater Elevation (ft)	Simulated Groundwater Elevation (ft)	Residual	Water Level Confidence	Aquifer	Model Layer	Water Level Date	Citation or Source
480	BRUNO BETTI		22414	1072894	642960	82.8	83.96	-1.16	Estimated from well log	Qc	5	10/19/1972	Ecology 2018b
503	RICHARD BERGT		28553	1077565	637178	21.3	43.49	-22.19	Estimated from well log	Qc	5	10/27/1964	Ecology 2018b
504	RICHARD NOBEL CORROLL		273526	1077465	637478	39.2	43.02	-3.82	Estimated from well log	Qc	5	05/30/1979	Ecology 2018b
530	BRUCE MORRISON		43060	1083659	649679	13.2	13.54	-0.34	Estimated from well log	Qc	5	10/31/1996	Ecology 2018b
564	OSTROMS MUSHROOM FARM		494838	1076557	633571	57.5	49.11	8.39	Estimated from well log	Qc	5	08/13/2007	Ecology 2018b
565	P. U. D. #1 OF THURSTON COUNTY		273380	1070970	634066	48.5	61.98	-13.48	Estimated from well log	Qc	5	06/20/2007	Ecology 2018b
624	ALVIN THOMPSON		21759	1071375	636365	72.4	64.36	8.05	Estimated from well log	Qc	5	03/11/2000	Ecology 2018b
655	DONAHUE CONST. CO.		23853	1081867	636034	52.2	29.57	22.63	Estimated from well log	Qc	5	09/20/1978	Ecology 2018b
656	DORIS BURTON		418741	1082068	635725	32.5	28.57	3.93	Estimated from well log	Qc	5	09/28/2005	Ecology 2018b
662	M & R CONSTRUCTION		27165	1081867	636034	32.2	29.57	2.63	Estimated from well log	Qc	5	06/09/1981	Ecology 2018b
697	PETER AND SUNNY PARK		479083	1074010	636291	42.2	51.29	-9.09	Estimated from well log	Qc	5	04/12/2007	Ecology 2018b
701	DOROTHY THORPE		301366	1069024	647109	60.3	49.21	11.09	Estimated from well log	Qc	5	12/19/2000	Ecology 2018b
703	RIPTIDE BUILDERS		410233	1069632	646795	26.7	49.61	-22.91	Estimated from well log	Qc	5	05/31/2005	Ecology 2018b
709	OLYMPIA CHEESE CO LLC		32285	1075812	644585	52.8	55.71	-2.91	Estimated from well log	Qc	5	11/03/1997	Ecology 2018b
768	WASH. LAND YACHT HARBOR		30380	1080488	633442	54.7	37.96	16.74	Estimated from well log	Qc	5	05/21/1980	Ecology 2018b
769	WASH. LAND YACHT HARBOR		273775	1080488	633442	37.2	37.96	-0.76	Estimated from well log	Qc	5	05/21/1980	Ecology 2018b
858	BRUNO BETTI		22415	1073819	642196	59.1	86.36	-27.26	Estimated from well log	Qc	5	10/19/1972	Ecology 2018b
881	JOHN NULY		26251	1082978	641270	22.8	17.9	4.9	Estimated from well log	Qc	5	05/11/1990	Ecology 2018b
1024	DARRYL SELNESS		23288	1064795	637931	75.3	78.81	-3.51	Estimated from well log	Qc	5	11/30/1978	Ecology 2018b
1035	HOOVER CONST. CO.		273001	1077794	630447	34.2	42.82	-8.62	Estimated from well log	Qc	5	2/8/1969	Ecology 2018b
1039	ST. MARTINS ABBEY		273623	1063756	631235	118.6	122.38	-3.78	Estimated from well log	Qc	5		Ecology 2018b
1087	FIELD, PETER		256818	1085051	651796	32.9	2.19	30.71	Estimated from well log	Qc	5	09/07/2000	Ecology 2018b
1090	SIERRA MADRE DEV LLC		361365	1084895	651166	30.9	2.59	28.31	Estimated from well log	Qc	5	01/22/2003	Ecology 2018b
1091	SIERRA MADRE DEV LLC		361934	1084895	651166	29.9	2.59	27.31	Estimated from well log	Qc	5	01/28/2003	Ecology 2018b
1117	DENNIS BURKE		274345	1074683	658781	14.5	14.44	0.06	Estimated from well log	Qc	5	8/26/1988	Ecology 2018b

Study ID	Owner	Well Name	Ecology ID	X Coordinate	Y Coordinate	Observed Groundwater Elevation (ft)	Simulated Groundwater Elevation (ft)	Residual	Water Level Confidence	Aquifer	Model Layer	Water Level Date	Citation or Source
1155	ROBERT DAYTON		494376	1064320	654612	47.42	20.02	27.4	Estimated from well log	Qc	5	08/09/2007	Ecology 2018b
1202	MEADOW WATER CO		398089	1082070	632548	47	28.3	18.7	Estimated from well log	Qc	5	03/30/1989	Ecology 2018b
1203	GRAYS HARBOR ENTERPRISES INC		398091	1081764	632076	24.8	30.39	-5.59	Estimated from well log	Qc	5	02/15/1983	Ecology 2018b
1204	HODGES HOMES INC		398090	1081764	632076	38.14	30.39	7.75	Estimated from well log	Qc	5	11/24/1986	Ecology 2018b
535	Lacey	Lacey S19 (HP1)	34019	1072576	648745	42.43	25.92	16.51	Measured	TQu	7	05/31/2018	City of Lacey
1216	Lacey	Lacey S07		1064747	629970	121.94	122.95	-1.01	Measured	TQu	7	06/28/2018	City of Lacey
1242	Lacey	Lacey TW-BC3		1079977	652463	27.72	21.86	5.86	Measured	TQu	7	06/14/2018	City of Lacey
1244	Lacey	Lacey TW-MC		1080072	645688	24.73	33.16	-8.43	Measured	TQu	7	06/14/2018	City of Lacey
1245	Lacey	Lacey TW-MR		1072315	649392	24.19	27.56	-3.37	Measured	TQu	7	06/14/2018	City of Lacey
1275	Lacey	Lacey S31 (HP2)		1072735	648609	5.92	26.75	-20.83	Measured	TQu	7	06/28/2018	City of Lacey
1276	Lacey	SMW		1079642	656028	29.98	10	19.98	Measured	TQu	7	06/14/2018	City of Lacey
15	HAWKS PRAIRIE GOLF COURSE, LLC		825289	1075004	648877	45.1	30.41	14.69	Estimated from well log	TQu	7	09/04/1984	Ecology 2018b
256	Lacey	8R (Lacey)	22851	1078653	638234	28	44.52	-16.52	Estimated from well log	TQu	7	01/25/1996	Ecology 2018b
312	MANKE LUMBER CO INC		517569	1074499	653513	12.8	22.75	-9.95	Estimated from well log	TQu	7	12/18/2007	Ecology 2018b
321	CLEARWATER UTILIITIES INC.		22969	1064895	640570	60.3	65.69	-5.39	Estimated from well log	TQu	7	03/30/1980	Ecology 2018b
346	MILLER LAND AND TIMBER		492258	1067664	645831	51.6	45.61	5.99	Estimated from well log	TQu	7	07/11/2007	Ecology 2018b
384	J. D. SHOTWELL COMPANY		25381	1077718	639805	15.5	43.64	-28.14	Estimated from well log	TQu	7	08/31/1970	Ecology 2018b
726	JOHN KELLEHER		26194	1062030	641770	77.5	72.63	4.87	Estimated from well log	TQu	7	12/15/1986	Ecology 2018b
727	MILLER LAND AND TIMBER		510237	1065088	643899	74.6	55.13	19.47	Estimated from well log	TQu	7	11/02/2007	Ecology 2018b
779	JOSEPH AND LORI WARGACKI		428522	1067530	643919	59.8	52.52	7.28	Estimated from well log	TQu	7	10/25/2005	Ecology 2018b
774	GLACIER PARK CO	Glacier Park	35933	1075684	649516	45	29.26	15.74	Estimated from well log	TQu	7	09/04/1984	Ecology 2018b
964	ANITA HARKINS		484671	1062926	644506	58.2	56.7	1.5	Estimated from well log	TQu	7	05/02/2007	Ecology 2018b

Notes:
Location coordinates in NAD 1983 Washington State Plane South, groundwater elevations in NAVD88.

This page intentionally left blank.

Table 21. Calibration Summary Statistics

Statistic	All Observed Water Levels	Measured Water Levels
Number of Observations	177	67
Residual Mean	-0.76	-0.24
Absolute Residual Mean	9.21	4.30
Residual Standard Deviation	13.39	6.19
Sum of Squares	31830.9	2567.7
RMSE	13.41	6.19
Min Residual	-52.00	-20.83
Max Residual	51.13	19.98
Min Observation	2.11	2.11
Max Observation	212.76	160.02
Range in Observations	210.65	157.91
Normalized Residual Std. Deviation	0.0636	0.0392
Normalized Absolute Residual Mean	0.0437	0.0273
Normalized RMSE	0.0637	0.0392
Normalized Residual Mean	-0.0036	-0.0015

Notes:
“All Observed Water Levels” refers to both those measured, and estimated from well logs.

This page intentionally left blank.

Table 22. Comparison of the Geometric Mean of Observed Water Levels to Simulated Water Levels

Monitoring Well	Aquifer	Geometric Mean Water Level (ft, NAVD88)	Average Water Level (ft, NAVD88)	Standard Deviation of Observed Water Levels (ft)	Lower Bound of Observed Range (ft, NAVD88)	Upper Bound of Observed Range (ft, NAVD88)	June 2018 Water Level (ft, NAVD88)	Simulated Water Level (ft, NAVD88)	Residual: June 2018 - Simulated Water Level (ft)	Residual: Geometric Mean - Simulated Water Level (ft)	Is the Simulated Water Level between the Upper and Lower Bounds?	Comment
MW-1	Qva	136.94	136.98	3.37	130.25	143.71	136.13	141.07	-4.94	-4.13	Yes	water levels collected every 4 hours with pressure transducer, includes 1 hand measurement for October
MW-2	Qva	136.78	136.84	4.12	128.60	145.08	136.90	140.78	-3.88	-4.00	Yes	water levels collected every 4 hours with pressure transducer
MW-3A	Qva	131.04	131.14	5.07	120.99	141.29	131.85	134.64	-2.79	-3.60	Yes	well sampled during tracer testing and water quality monitoring work 2018, water levels collected every 4 hours with pressure transducer
MW-5	Qva	135.01	135.19	7.03	121.14	149.25	135.18	133.82	1.36	1.19	Yes	well sampled during tracer testing and water quality monitoring work 2018, water levels collected every 4 hours with pressure transducer
MW-6	Qva	139.37	139.43	4.17	131.09	147.77	139.33	138.40	0.93	0.97	Yes	water levels collected every 4 hours with pressure transducer
MW-7	Qva	137.56	137.62	4.06	129.51	145.73	137.63	135.59	2.04	1.97	Yes	water levels collected every 4 hours with pressure transducer
MW-8	Qva	116.79	116.84	3.43	109.98	123.69	117.84	126.27	-8.43	-9.48	No	well sampled during tracer testing and water quality monitoring work 2018, water levels collected every 4 hours with pressure transducer
MW-9	Qva	127.32	127.97	5.14	117.69	138.25	127.92	127.51	0.41	-0.19	Yes	well sampled during tracer testing and water quality monitoring work 2018, water levels collected every 4 hours with pressure transducer
MW-11	Qva	93.06	127.40	4.04	119.31	135.49	96.62	102.60	-5.98	-9.54	No	well sampled during tracer testing and water quality monitoring work 2018
Lacey MW-11	Qva	110.11	110.11	0.49	109.13	111.09	110.17	103.66	6.51	6.45	No	well sampled during tracer testing and water quality monitoring work 2018, water levels collected every 4 hours with pressure transducer
MW-12	Qc	93.13	93.16	2.17	88.82	97.49	93.61	88.07	5.54	5.06	No	well sampled during tracer testing and water quality monitoring work 2018, water levels collected every 4 hours with pressure transducer, includes 4 hand measurements for July - October
MW-13	Qva	104.70	107.17	3.45	100.27	114.08	108.57	108.10	0.47	-3.40	Yes	well sampled during tracer testing and water quality monitoring work 2018, water levels collected every 4 hours with pressure transducer, includes 2 hand measurements for September - October
MW-14	Qc	70.44	71.06	3.82	63.43	78.69	64.32	67.95	-3.63	2.49	Yes	well sampled during tracer testing and water quality monitoring work 2018, water levels collected every 4 hours with pressure transducer
MW-15	Qva	137.24	137.71	4.32	129.06	146.35	137.77	138.86	-1.09	-1.62	Yes	well sampled during tracer testing and water quality monitoring work 2018, water levels collected every 4 hours with pressure transducer
MW-16	Qva	137.13	137.20	4.27	128.65	145.75	137.09	141.48	-4.39	-4.35	Yes	well sampled during tracer testing and water quality monitoring work 2018, water levels collected every 4 hours with pressure transducer
MW-20	Qva	92.61	92.71	4.21	84.29	101.13	96.51	100.21	-3.70	-7.60	Yes	well sampled during tracer testing and water quality monitoring work 2018
MW-21	Qc	89.26	89.35	3.88	81.58	97.11	92.71	90.54	2.17	-1.28	Yes	well sampled during tracer testing and water quality monitoring work 2018, water levels collected every 4 hours with pressure transducer

Monitoring Well	Aquifer	Geometric Mean Water Level (ft, NAVD88)	Average Water Level (ft, NAVD88)	Standard Deviation of Observed Water Levels (ft)	Lower Bound of Observed Range (ft, NAVD88)	Upper Bound of Observed Range (ft, NAVD88)	June 2018 Water Level (ft, NAVD88)	Simulated Water Level (ft, NAVD88)	Residual: June 2018 - Simulated Water Level (ft)	Residual: Geometric Mean - Simulated Water Level (ft)	Is the Simulated Water Level between the Upper and Lower Bounds?	Comment
MW-23	Qc	54.43	54.48	2.39	49.70	59.26	55.99	59.54	-3.55	-5.11	No	well sampled during tracer testing and water quality monitoring work 2018, water levels collected every 4 hours with pressure transducer
MW-24	Qva	144.35	144.42	4.46	135.49	153.34	144.26	145.41	-1.15	-1.06	Yes	well sampled during tracer testing and water quality monitoring work 2018, water levels collected every 4 hours with pressure transducer
MW-25	Qva	93.26	93.32	3.41	86.51	100.13	96.73	103.22	-6.49	-9.96	No	well sampled during tracer testing and water quality monitoring work 2018
MW-26	Qva	154.12	154.13	1.48	151.17	157.09	154.36	156.87	-2.51	-2.75	Yes	well sampled during tracer testing and water quality monitoring work 2018
MW-27	Qva	123.03	123.05	2.12	118.80	127.30	122.85	121.76	1.09	1.27	Yes	well sampled during tracer testing and water quality monitoring work 2018
MW-28	Qva	94.84	94.96	4.63	85.70	104.22	98.38	99.30	-0.92	-4.46	Yes	well sampled during tracer testing and water quality monitoring work 2018
TC Landfill MW-10S	Qva	123.42	123.43	1.75	119.93	126.93	124.13	120.87	3.26	2.55	Yes	well sampled during tracer testing and water quality monitoring work 2018
TC Landfill MW-1	Qva	88.22	88.26	2.72	82.82	93.70	90.80	96.38	-5.58	-8.16	No	well sampled during tracer testing and water quality monitoring work 2018
Lacey TW-BC	TQu	33.78	34.39	6.21	21.97	46.81	27.72	21.86	5.86	11.92	No	Water levels collected every hour with pressure transducer, time series from June 2017 - June 2018
Lacey TW-MC	TQu	35.26	34.41	3.81	26.79	42.04	24.73	33.16	-8.43	2.10	Yes	Water levels collected every hour with pressure transducer, time series from June 2017 - June 2018
Lacey TW-MR	TQu	34.69	34.11	6.41	21.28	46.94	24.19	27.56	-3.37	7.13	Yes	Water levels collected every hour with pressure transducer, time series from June 2017 - June 2018
Lacey SMW	TQu	33.13	33.30	3.30	26.70	39.90	29.98	10.00	19.98	23.13	No	Water levels collected every hour with pressure transducer, time series from September 2017 - June 2018, manual water levels from June 2017 - June 2018, packer installed to separate screened intervals, water level represents upper zone

Table 23. Summary Statistics Using the Geometric Mean Water Level as Observed Water Level

Statistic	June 2018 Water Levels (Non Pumping Wells)	Geometric Mean Water Levels (Non Pumping Wells)	June 2018 Water Levels (Proximal Wells)	Geometric Mean Water Levels (Proximal Wells)
Residual Mean	-0.73	-0.50	-1.41	-2.35
Absolute Residual Mean	4.15	5.07	3.31	4.11
Residual Standard Deviation	5.55	6.83	3.70	4.42
Sum of Squares	908.34	1359.77	392.42	627.48
RMSE	5.60	6.85	3.96	5.01
Min Residual	-8.43	-9.96	-8.43	-9.96
Max Residual	19.98	23.13	6.51	6.44
Number of Observations	29	29	25	25
Min Observation	24.19	33.13	55.99	54.43
Max Observation	154.36	154.12	154.36	154.12
Range in Observations	130.17	120.99	98.37	99.69
Normalized Residual Std. Deviation	0.0426	0.0564	0.0376	0.0444
Normalized Absolute Residual Mean	0.0319	0.0419	0.0337	0.0412
Normalized RMSE	0.0430	0.0566	0.0403	0.0503
Normalized Residual Mean	-0.0056	-0.0041	-0.0143	-0.0236
Statistics of Observed Water Level Standard Deviations				
Sum of Squares		474.00		368.86
RMS		4.04		3.84
2 * (RMS)		8.09		7.68
Number of Observations		29		25

Table 24. Steady-State Water Budget

Component	Inflows(ft^3/day)	Outflows (ft^3/day)
Well	-	866,885
Constant Head	26,343	3,114,160
General Head Boundary	2,565,377	155,640
River	3,063	-
Drain	-	1,583,268
Recharge	3,125,175	-
Total	5,719,958	5,719,952
Percent Error		1.14E-04

Table 25. Simulated Water Budget at Streams Compared to Gauging Data

Location	Creek	Date	River Mile (miles)	Total Stream Flow (cfs)	Observed Groundwater Inflow by Reach (cfs)	Observed Cumulative Groundwater Inflow (cfs)	Stream Reach Number shown in Figure 22	Simulated Groundwater Inflow by Reach (cfs)	Simulated Cumulative Groundwater Inflow (cfs)
Eagle @ Stormwater Ponds	Eagle	8/25/2015	1.97	0	0	0	Reach 14	0	0
Eagle 2	Eagle	8/25/2015	1.32	0	0	0	Reach 14	0	0
Eagle 3	Eagle	8/25/2015	1.16	0	0	0	Reach 14	0	0
Eagle 4	Eagle	8/25/2015	1.1	0	0	0	Reach 14	0	0
Eagle 9	Eagle	8/25/2015	0.46	0.21	0.07	0.07	Reach 15	0.04	0.04
Eagle @ Carpenter	Eagle	8/25/2015	0.33	0.36	0.15	0.21	Reach 16	0.11	0.15
Eagle @ Woodland	Eagle	8/25/2015	0	0.24	-0.12	0.09	Reach 17	0	0.15
Fox @ Hawks Prairie RD	Fox	8/25/2015	1.64	0	0	0	most upstream point	-	-
Fox @ Carpenter RD	Fox	8/25/2015	1.28	0.05	0.05	0.05	Reach 18	0.03	0.03
Fox @ Pleasant Glade RD	Fox	8/25/2015	0.23	0.24	0.19	0.24	Reach 19	02.6	0.29
Fox @ Woodland	Fox	8/24/2015	0	0.51	0.28	0.51	Reach 20	0.32	0.61
Flow 4 Rail Grade	Woodland	8/24/2015	5.63	0.67	0.12	0.12	Reach 1	0.09	0.09
Flow 1 Wetland	Woodland	8/24/2015	5.23	2.53	1.86	1.98	Reach 2	0.08	0.17
Flow 3 Pacific	Woodland	8/24/2015	4.86	0.34	-2.18	-0.2	Reach 3	0.00	0.17
Flow 5 Lake Lois Outlet	Woodland		4.55	0	-0.34	-0.55	Reach 3	0.00	0.17
Flow 6 USFWS	Woodland	8/24/2015	4.24	0	0	-0.55	Reach 3	0.00	0.17
Flow 9 US College (includes Beatty Springs)	Woodland	8/24/2015	3.44	5.41	5.41	4.86	Reach 4	3.51	3.68
Flow 8 Woodland Creek (DSC)	Woodland	8/24/2015	3.43	7.29	-0.06	4.8			
Flow 11 Woodland Creek Upper	Woodland	8/24/2015	3.36	4.26	-3.02	1.78	Reach 26	0.05	3.73
Flow 10 Woodland Creek I-5	Woodland	8/24/2015	3.25	10.39	6.12	7.9	Reach 5	0.27	4.00
Woodland @ 50' DS Draham RD	Woodland	8/24/2015	2.92	8.43	-1.95	5.94	Reach 6	0.01	4.00
Woodland @ 500' DS Draham RD	Woodland	8/24/2015	2.85	7.58	-0.85	5.09	Reach 7	0.00	4.00
Woodland @ 3000' DS of Draham RD	Woodland	8/24/2015	2.64	8.9	1.32	6.41	Reach 8	0.35	4.36
Woodland @ 50 US Eagle	Woodland	8/24/2015	2.25	9.78	0.87	7.29	Reach 9	0.42	4.78
Woodland @ 300' DS Eagle	Woodland	8/24/2015	2.2	9.45	-0.56	6.72			
Woodland @ 100' US Palm	Woodland	8/24/2015	1.96	9.88	0.43	7.16	Reach 10	0.60	5.38
Woodland @ 100' US Fox	Woodland	8/24/2015	1.81	9.47	-0.63	6.53	Reach 11	0.01	5.39
Woodland @ Pleasant Glade RD	Woodland	8/24/2015	1.62	11.43	1.44	7.97	Reach 24	0.96	6.35
Woodland @ 100' US Jorgensen	Woodland	8/25/2015	1.19	13.41	1.99	9.95	Reach 12	1.93	8.28
Woodland Creek to Henderson Inlet	Woodland		0				Reach 13	3.17	11.45
Jorgensen Creek Flow	Jorgensen	8/25/2015	1.19	0.7			Reach 22	0.53	0.53
DOBBS CREEK AT JOHNSON POINT ROAD (DB0.1)	Dobbs	6/23/2014		1.3			Reach 23	0.92	0.92
College Springs Flow	College springs	8/24/2015	3.43	1.94			Reach 26	0.05	0.05
College Creek	College						Reach 21	0.05	0.05
Palm Creek	Palm						Reach 25	0.89	0.89
North Spring Flow	North Spring	8/25/2015	0.46	0.14			Reach 0	0.05	0.05
Little McAllister	Little McAllister							3.29	3.29
Springs on east scarp discharging to Nisqually Valley	Scarp Springs							0.03	0.03

Table 26. Comparison of Observed and Simulated Travel Times

Well ID		Aquifer	Observed Time of First Arrival (days)		Observed Time of Peak Concentration (days)		Target Travel Time (days)	Simulated Travel Time (days)
			Bromide	SF_6	Bromide	SF_6		
MW-1		Shallow Aquifer (Qva)	15	ND	36	ND	15 - 36	2.6
MW-3a		Shallow Aquifer (Qva)	7	36	27	112	7 - 27	11.9
MW-5	Peak 1	Shallow Aquifer (Qva)	2	6	8	21	8	4.9
	Peak 2				19	30		
MW-8		Shallow Aquifer (Qva)	9	21	30	36	30	25.7
MW-9		Shallow Aquifer (Qva)	6	10	27	36	27	26.8
MW-11		Shallow Aquifer (Qva)	113	ND	260	ND	177 - 260	129.6
MW-13		Shallow Aquifer (Qva)	22	16	62.5	70	55 - 62.5	46.6
MW-15		Shallow Aquifer (Qva)	69	41	69	55	41 - 69	1.4
MW-16		Shallow Aquifer (Qva)	10	17	37	55	10 - 37	1.6
MW-25	Peak 1	Shallow Aquifer (Qva)	28	29	37	29	37 - 111	58.0
	Peak 2				111	83		
MW-27		Shallow Aquifer (Qva)	14	20	32	39	28 - 36	34.8
MW-12		Sea Level Aquifer (Qc)	55	29	62.5	113	55 - 70	67.9
MW-14		Sea Level Aquifer (Qc)	36	28	36	36	28 - 36	29.0

Notes:

1. The target time range refers to a period between the peak bromide sample and the first collected sample classified as a tracer detection.
2. Residuals reported in the text refer to the difference between simulated travel time and observed time to peak concentration (peak 1 where applicable).

This page intentionally left blank.

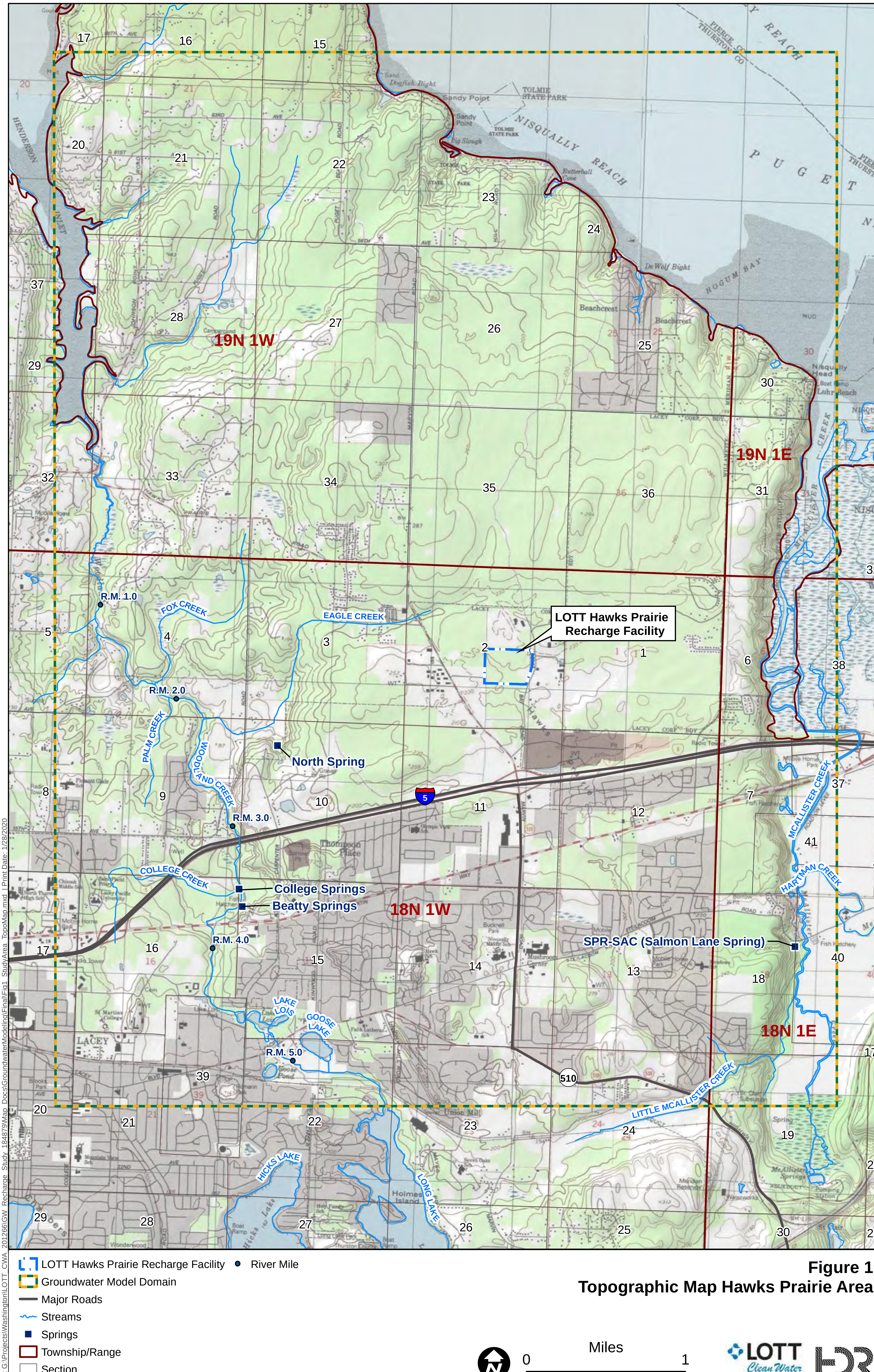


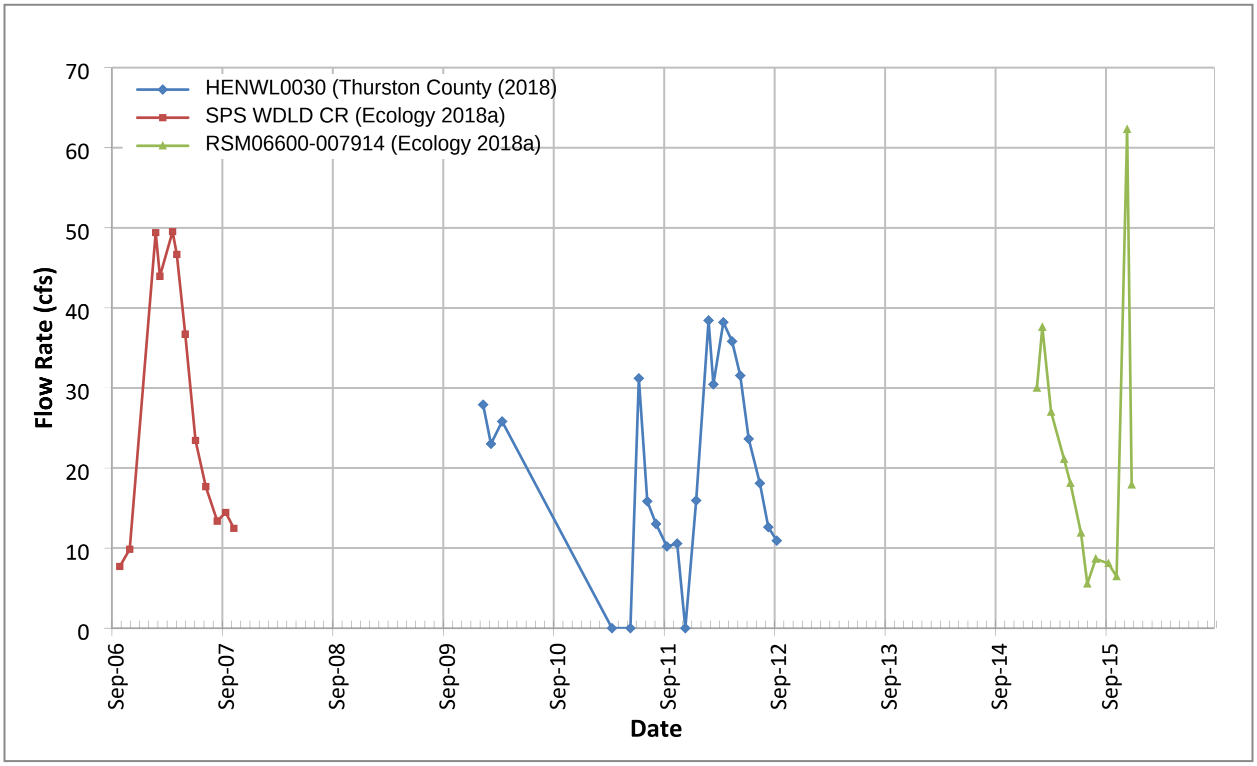
Figure 1
Topographic Map Hawks Prairie Area

Source: Bing Maps (2011), City of Bellevue (2013), WSDOT (2013)

Path: G:\Projects\Washington\LOTT_CWA_201266\GW_Recharge_Study_184879\Map_Docs\GroundwaterModeling\Final\Fig1_StudyArea_TopoMap.mxd | Print Date: 1/28/2020

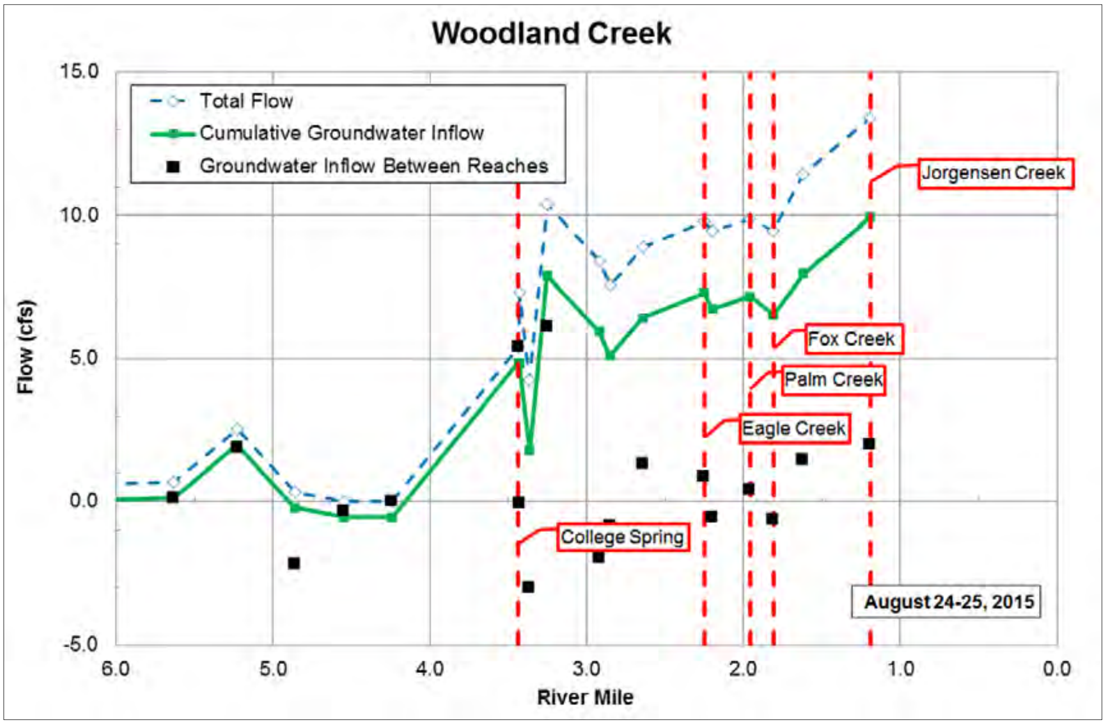
This page intentionally left blank.

Figure 2. Woodland Creek Stream Flow 2006–2016



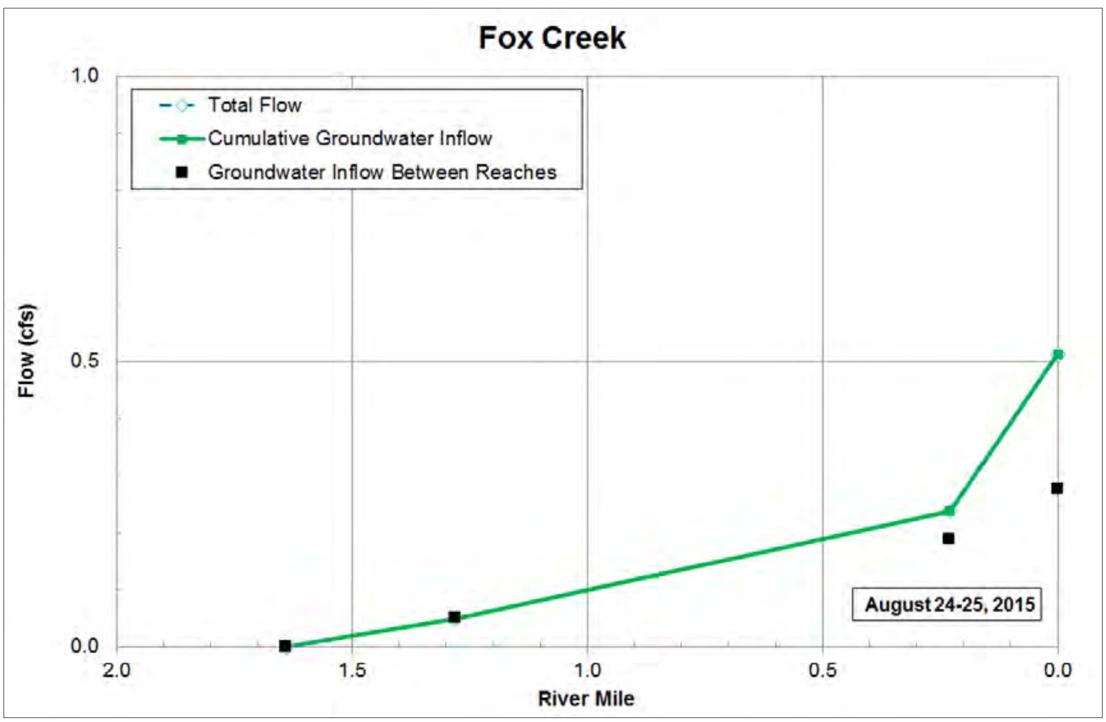
Notes:
1. Data sources are Thurston County (2018) and Ecology (2018a).
2. Record HENWL0030 location: Latitude: 47.06089, Longitude: -122.80429, near River Mile 3.
3. Record SPS WDLD CK location: Latitude: 47.071745, Longitude: -122.817047, between River Miles 1.5 and 2.
4. Record RSM06600-007914 location: Latitude: 47.061007, Longitude: -122.804292, near River Mile 3.

Figure 3a. Woodland Creek Flow Rate and Groundwater Inflow



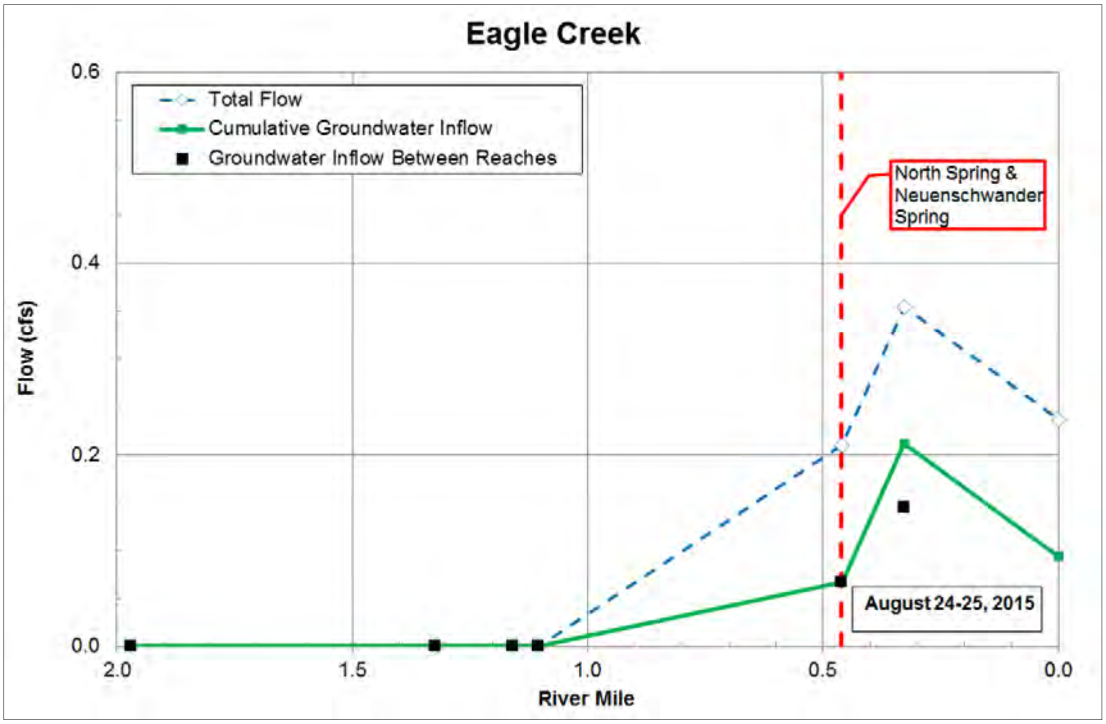
Note: Image reproduced from HDR (2015).

Figure 3b. Fox Creek Flow Rate and Groundwater Inflow



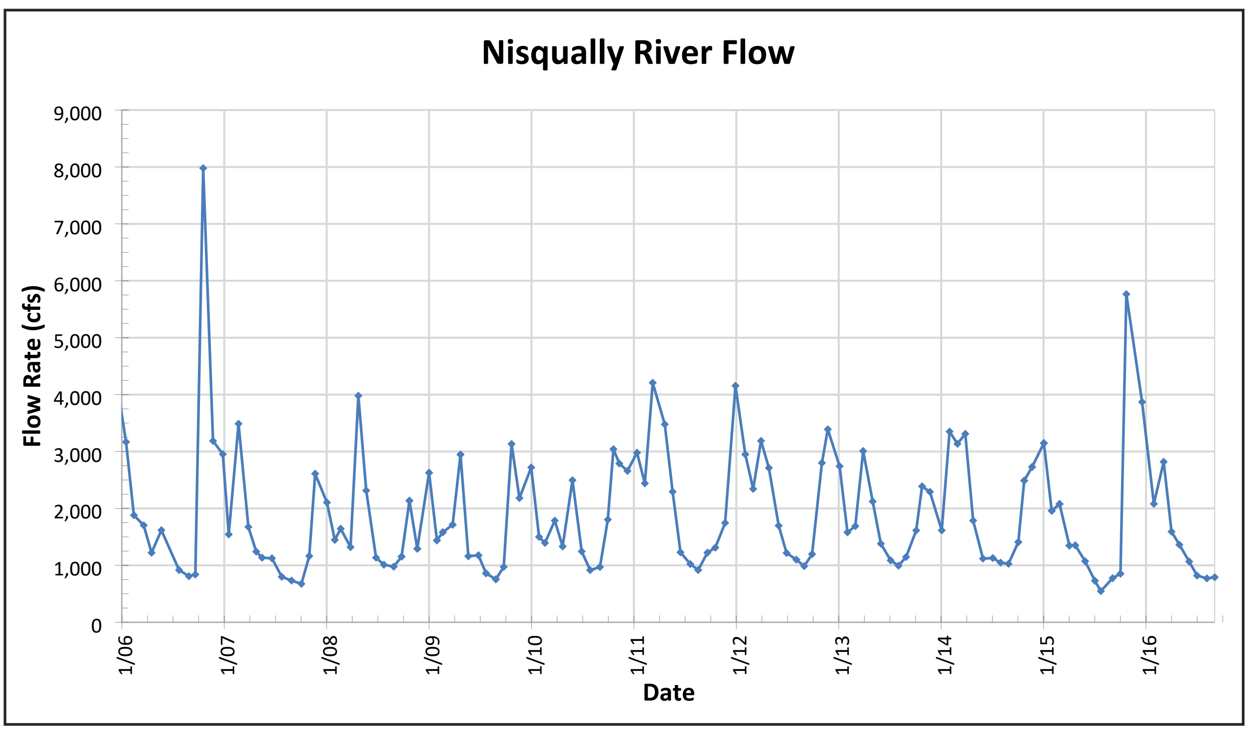
Note: Image reproduced from HDR (2015).

Figure 3c. Eagle Creek Flow Rate and Groundwater Inflow



Note: Image reproduced from HDR (2015).

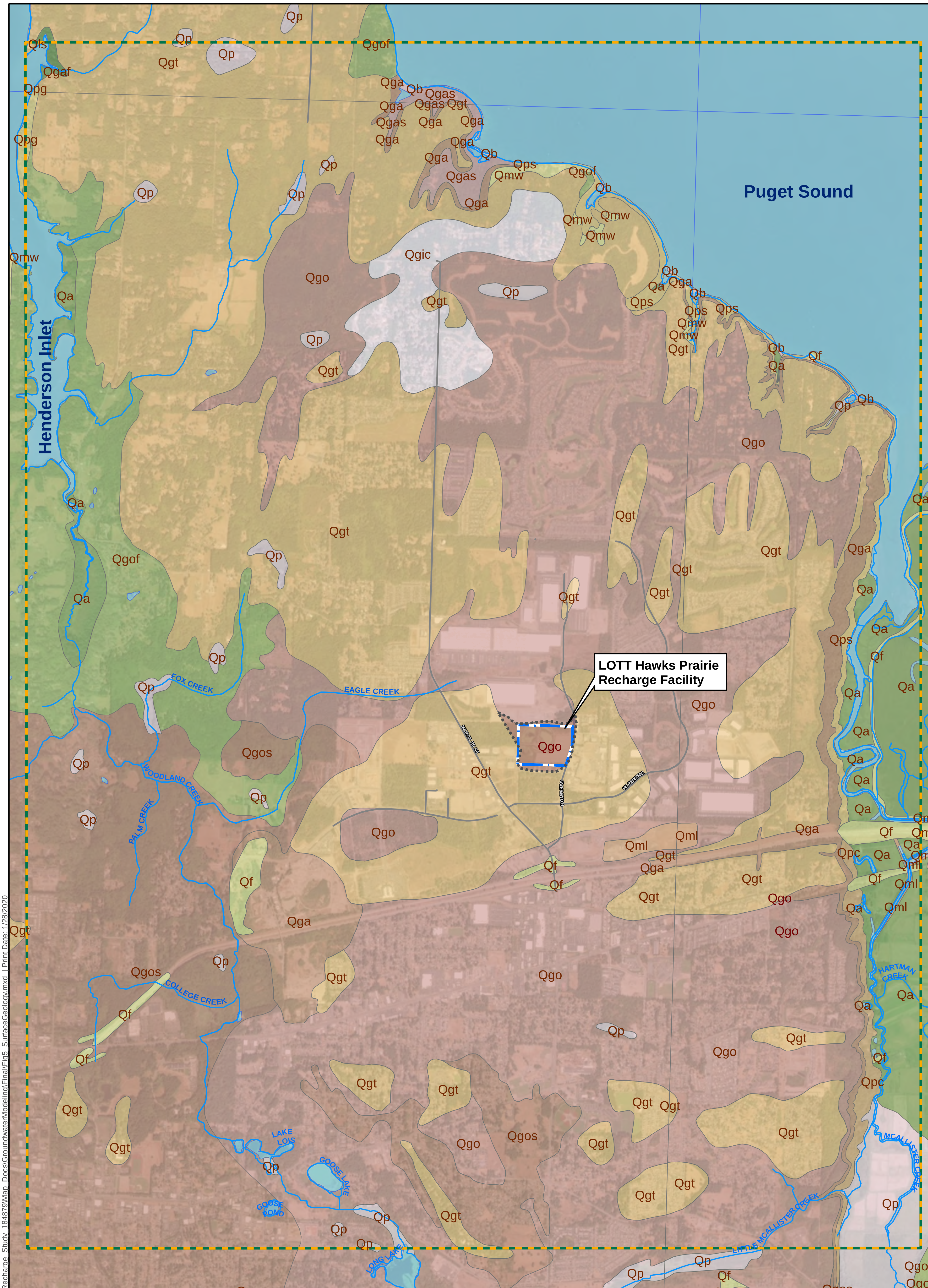
Figure 4. Nisqually River Flow, 2006–2016



Notes:

1. Data source is Ecology (2018c).
2. Flow rate measured at Latitude: 47.06176, Longitude: -122.69624, near River Mile 3.5.

This page intentionally left blank.



Geologic Units

- Qa - Alluvium
- Qb - Beach deposits
- Qf - Fill
- Qga - Vashon advance outwash
- Qgaf - Vahon advance outwash
- Qgas - Vashon advance outwash
- Qge - Eskers
- Qgic - Ice-contact deposits
- Qgo - Vashon recessional outwash
- Qgof - Latest Vashon fine-grained sediments
- Qgog - Vashon recessional outwash gravel
- Qgos - Latest Vashon recessional sand and minor silt
- Qgt - Vashon Till
- Qml - Modified land
- Qmw - Colluvium
- Qp - Peat
- Qpc - Pre-Vashon seiment of Cascade Range source, undifferentiated
- Qpg - Pre-Vashon gravel
- Qps - Pre-Vashon sand-size or finer deposits
- Water Body

- LOTT Hawks Prairie Recharge Facility
- Groundwater Model Domain
- Major Roads

NOTE:
Geologic unit symbols follow Logan et al. (2003)

Miles
0 1

Figure 5
Surface Geologic Units

LOTT Clean Water Alliance

HDR

Source: Bing Maps (2011), City of Lacey (2014), Washington Geological Survey (2017), WSDOT (2013)

Path: G:\Projects\Washington\LOTT_CWA_201266\GW_Recharge_Study_184879\Map_Docs\GroundwaterModeling\Final\Fig5_SurfaceGeology.mxd | Print Date: 1/28/2020

This page intentionally left blank.

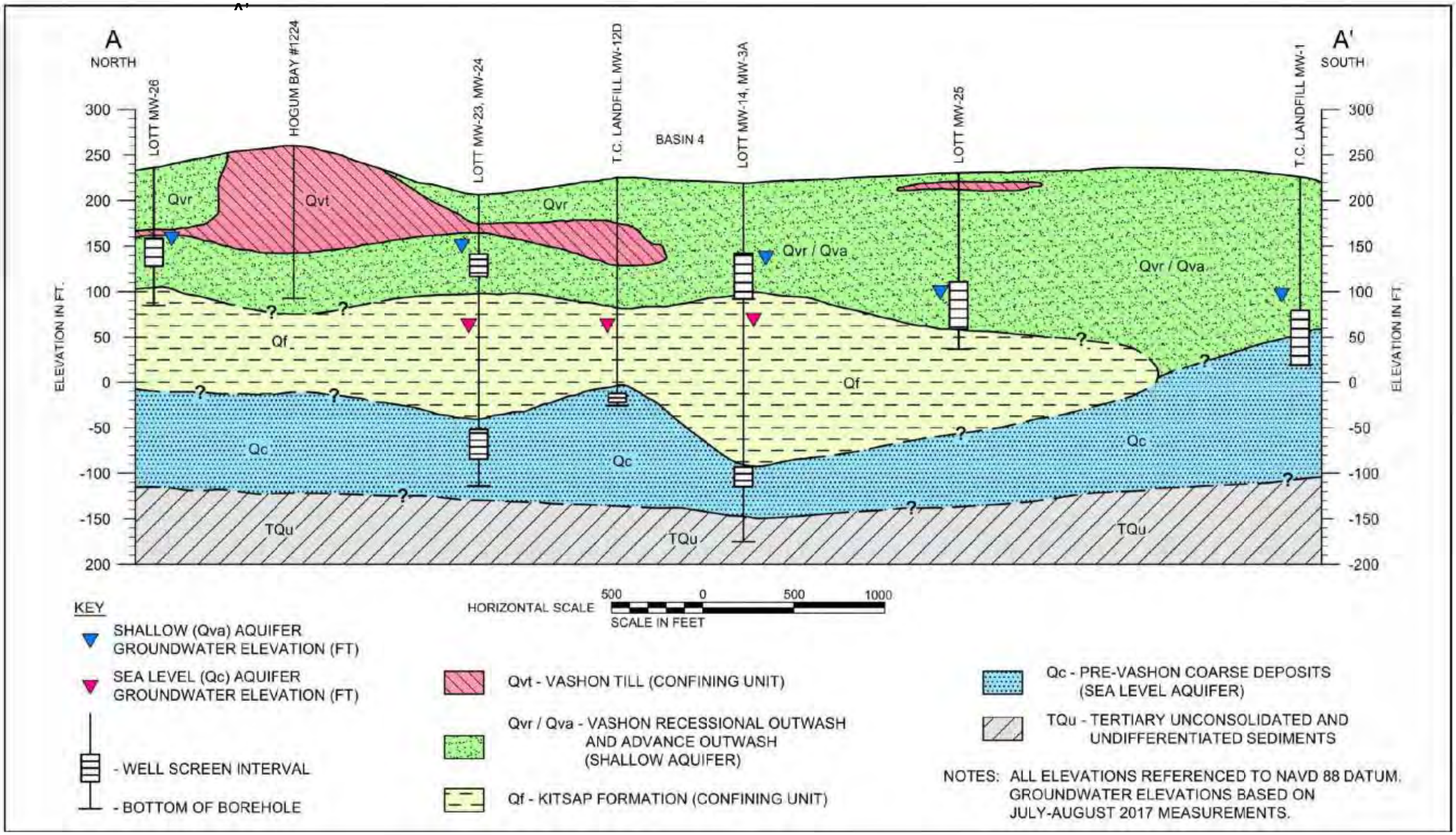


Figure 6a
Hydrogeologic Cross Section (HDR 2017b)

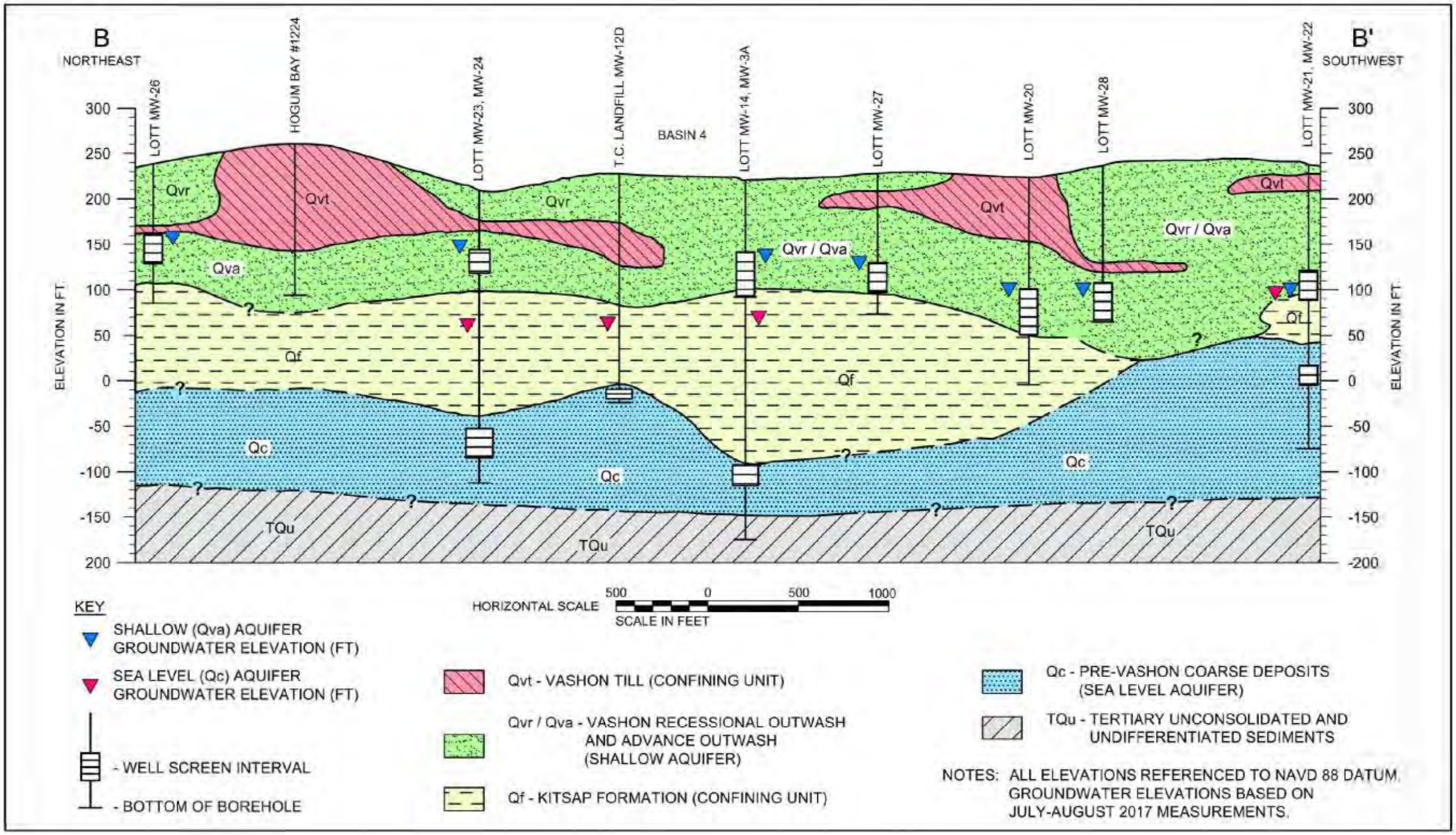


Figure 6b
Hydrogeologic Cross Section (HDR 2017b)

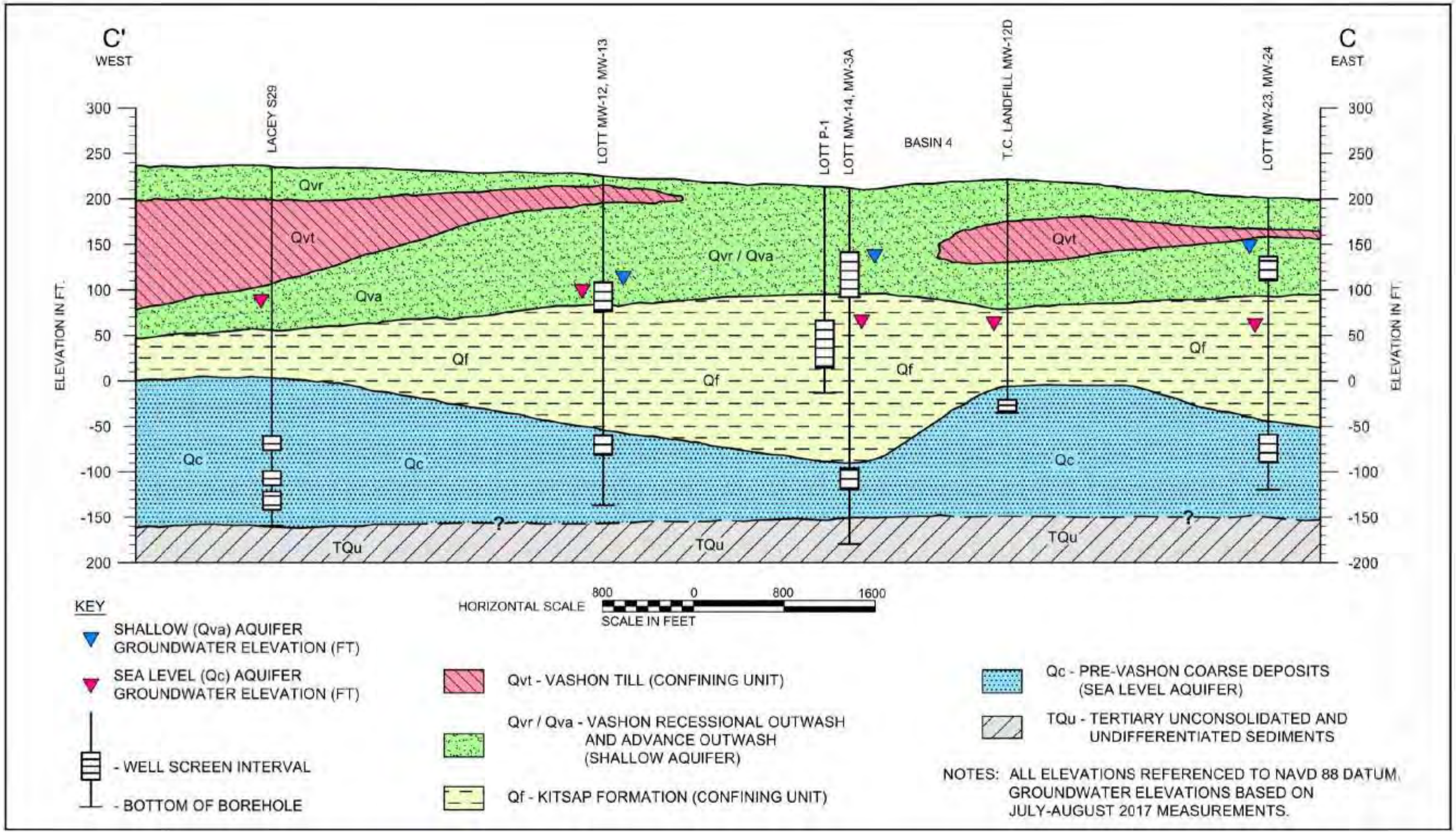
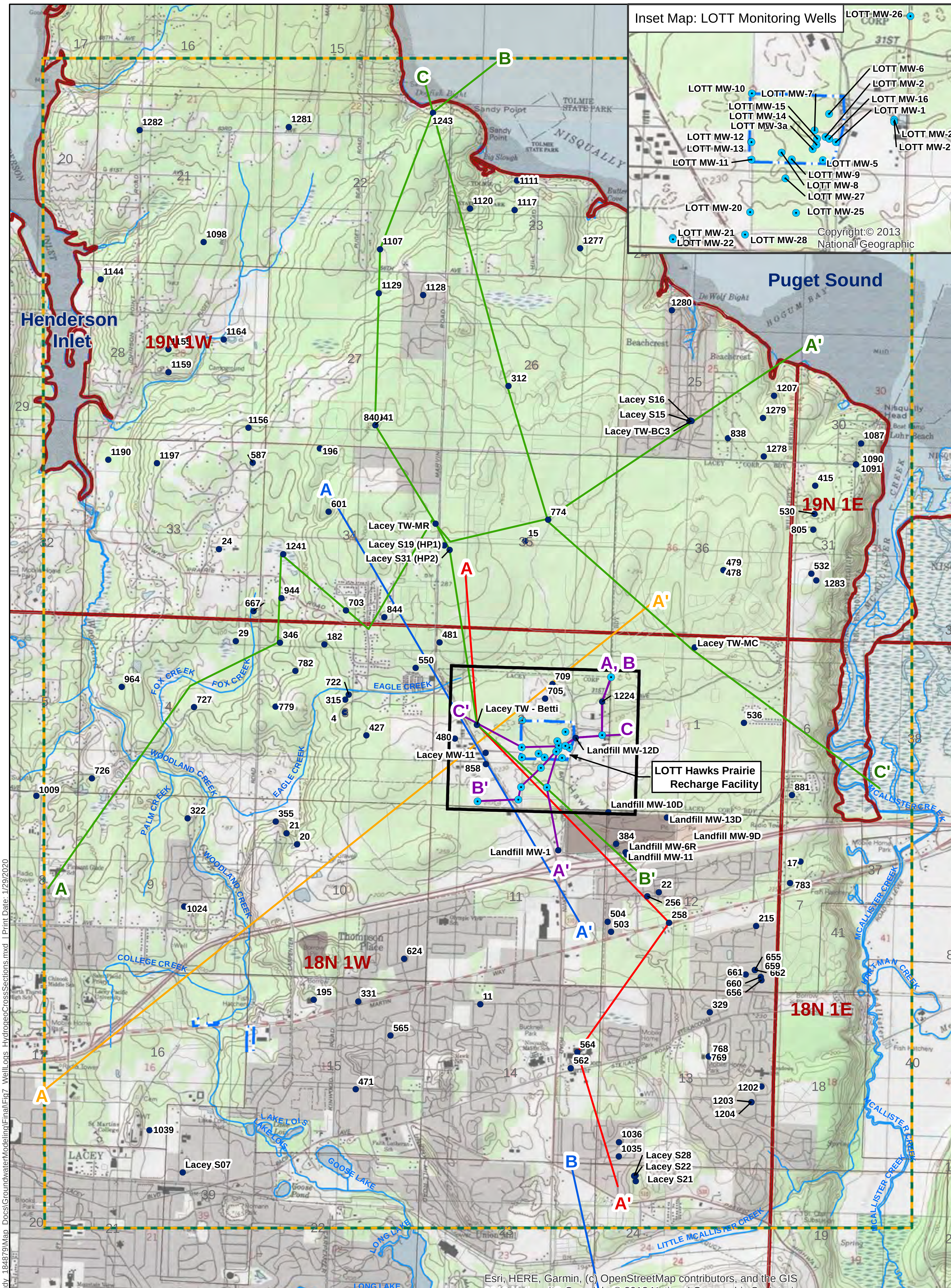


Figure 6c
Hydrogeologic Cross Section (HDR 2017b)

This page intentionally left blank.



Wells

- Study ID
- LOTT Monitoring Wells

Cross Sections

- HDR 2017
- NWLW 2008
- PGG 2004
- Landau 2016
- Brown and Caldwell 2004

- LOTT Hawks Prairie Recharge Facility
- Groundwater Model Domain
- Roads
- Section
- Township/Range
- Streams

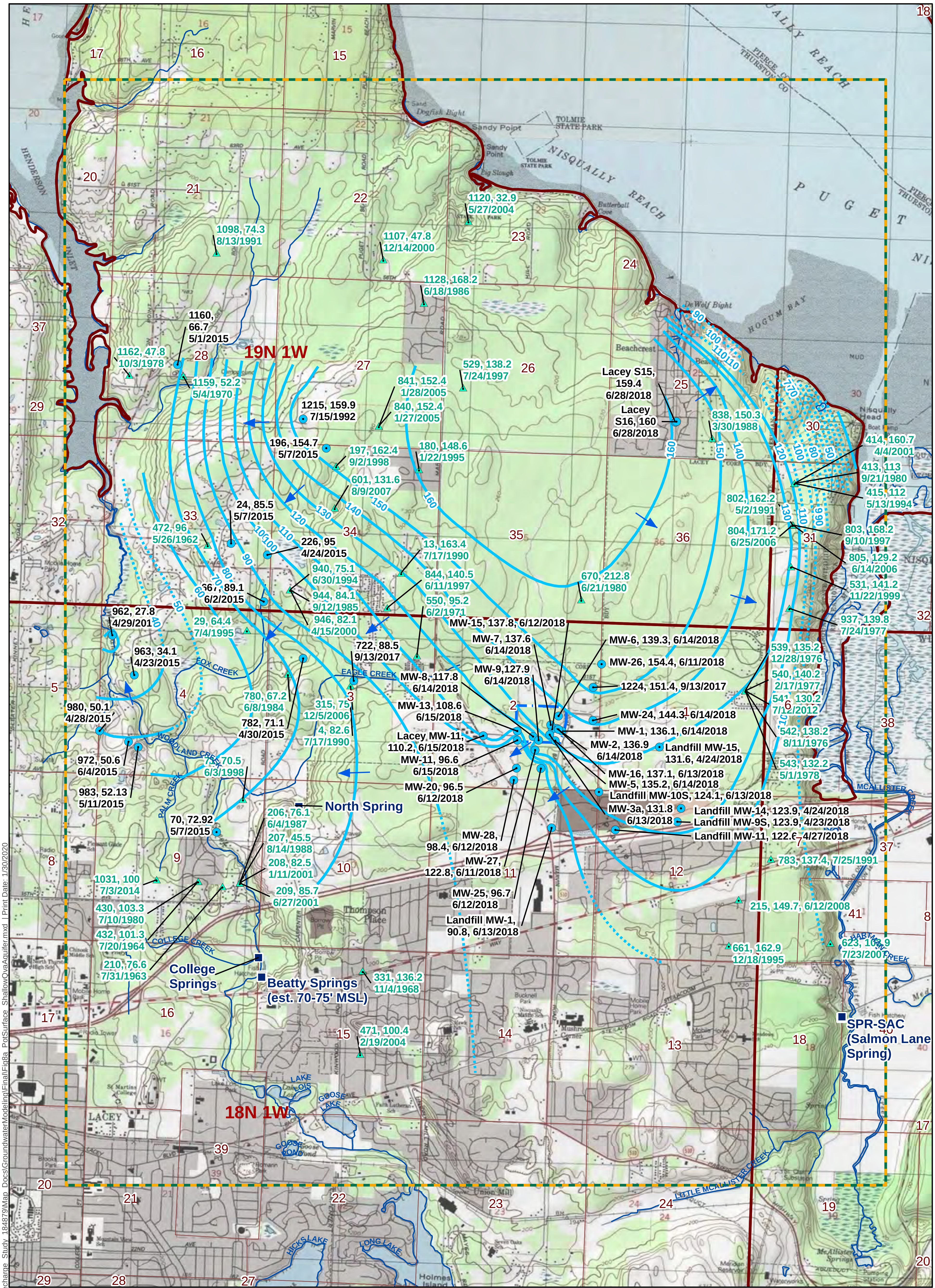
Figure 7
Well Logs used in Hydrostratigraphy Model and Hydrogeologic Cross Sections

Note:
Wells located from WA Dept. of Ecology, City of Lacey, Thurston County, and LOTT Clean Water Alliance. Wells are located to the centroid of the quarter-quarter section; where available well locations were corrected to address given on well log.

Miles
0 1

Path: G:\Projects\Washington\LOTT_CWA_201266\GW_Recharge_Study_184879\Map_Docs\GroundwaterModeling\Final\Fig7_WellLogs_HydrogeoCrossSections.mxd | Print Date: 1/29/2020

Source: WA Dept. of Ecology (2015), City of Lacey (2014), WSDOT (2013)



Groundwater Model Domain	
LOTT Hawks Prairie Recharge Facility	
Springs	
Streams	
Groundwater Elevation Contours (ft)	
* Dashed where data is limited and contours are inferred	
General Groundwater Flow Direction	

Measured Groundwater Levels
Well Name
Groundwater Elevation (ft)
Groundwater Elevation Date

Groundwater Levels Estimated from Well Logs
Study ID
Groundwater Elevation (ft)
Groundwater Elevation Date

Figure 8a
Groundwater Potentiometeric Surface Shallow (Qva) Aquifer

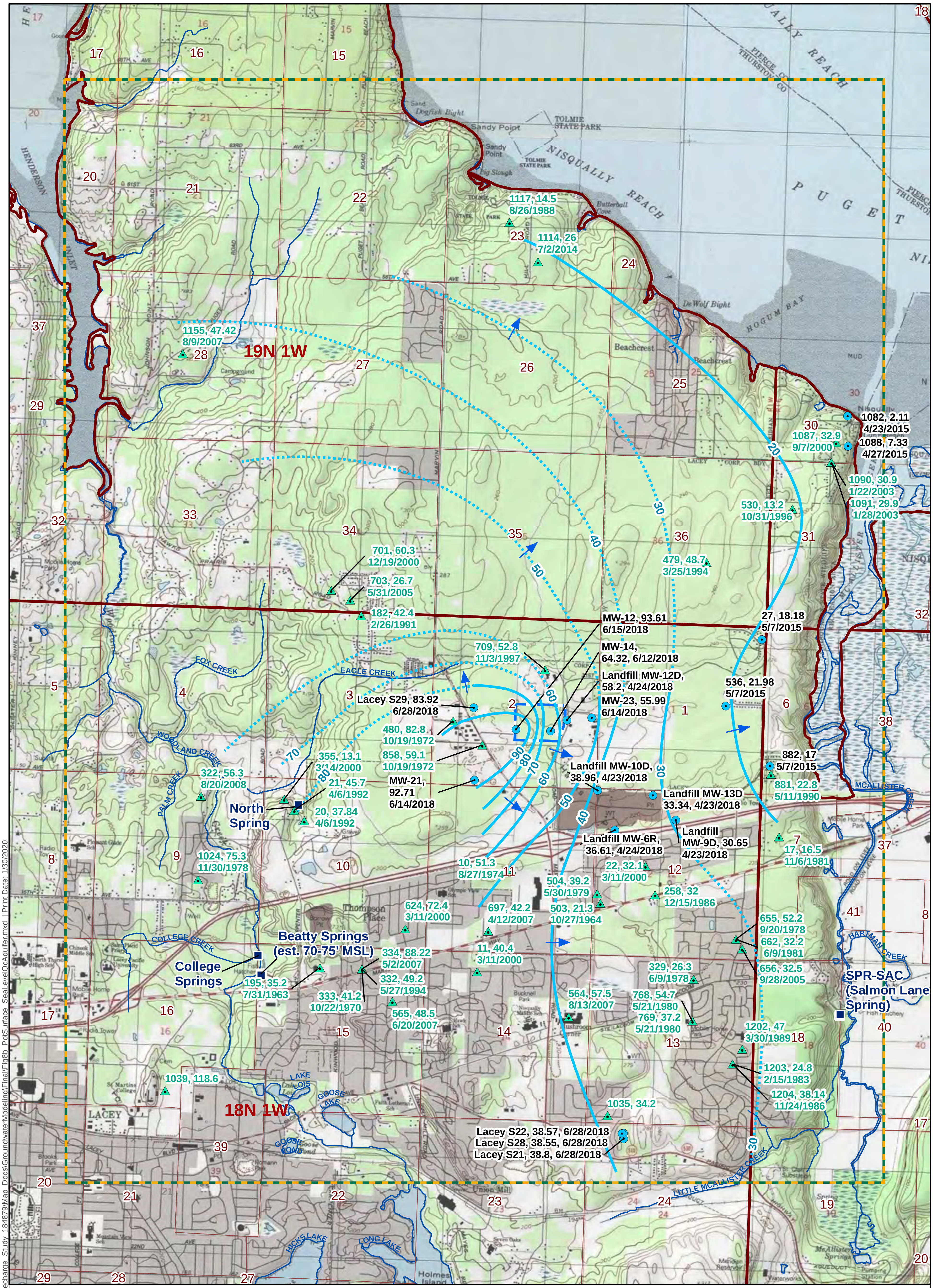
NOTE:
1. Vertical datum for groundwater elevations is NAVD 88.
2. Groundwater elevations for well log data were estimated using topographic data from a DEM (PSLC 2018) as the ground surface elevation and the depth to groundwater reported on the well log.

Miles
0 1

LOTT Clean Water Alliance

Source: City of Lacey (2018), Ecology (2015), Esri (2018), Thurston Co Landfill (2018), WSDOT (2018)

Path: G:\Projects\Washington\LOTT_CWA_201266\GW_Recharge_Study_184879\Map_Docs\GroundwaterModeling\Final\Fig8a_PotSurface_ShallowQvaAquifer.mxd | Print Date: 1/30/2020



Groundwater Model Domain

LOTT Hawks Prairie Recharge Facility

Springs

Streams

Groundwater Elevation Contours (ft)

* Dashed where data is limited and contours are inferred

General Groundwater Flow Direction

Measured Groundwater Levels
Well Name
Groundwater Elevation (ft)
Groundwater Elevation Date

Groundwater Levels Estimated from Well Logs
Study ID
Groundwater Elevation (ft)
Groundwater Elevation Date

Figure 8b
Groundwater Potentiometeric Surface Sea Level (Qc) Aquifer

NOTE:
1. Vertical datum for groundwater elevations is NAVD 88.
2. Groundwater elevations for well log data were estimated using topographic data from a DEM (PSLC 2018) as the ground surface elevation and the depth to groundwater reported on the well log.

Miles
0 1

Source: City of Lacey (2018), Ecology (2015), Esri (2018), Thurston Co Landfill (2018), WSDOT (2018)

Path: G:\Projects\Washington\LOTT_CWA_201266\GW_Recharge_Study_184879\Map_Docs\GroundwaterModeling\Final\Fig8b_PotSurface_SeaLevelQcAquifer.mxd | Print Date: 1/30/2020

Groundwater Model Domain

LOTT Hawks Prairie Recharge Facility

Springs

Streams

Groundwater Elevation Contours (ft)

* Dashed where data is limited and contours are inferred

General Groundwater Flow Direction

Measured Groundwater Levels
Well Name
Groundwater Elevation (ft)
Groundwater Elevation Date

Groundwater Levels Esimated from Well Logs:
Study ID
Groundwater Elevation (ft)
Groundwater Elevation Date

Figure 8c
Groundwater Potentiometeric Surface
Deep (TQu) Aquifer

NOTE:
1. Vertical datum for groundwater elevations is NAVD 88.
2. Groundwater elevations for well log data were estimated using topographic data from a DEM (PSLC 2018) as the ground surface elevation and the depth to groundwater reported on the well log.

Miles
0 1

LOTT Clean Water Alliance

HDR

Path: G:\Projects\Washington\LOTT_CWA_201266\GW_Recharge_Study_184879\Map_Docs\GroundwaterModeling\Final\Fig8c_PotSurface_DeepTQuAquifer.mxd | Print Date: 1/30/2020

Source: City of Lacey (2018), Ecology (2015), Esri (2018), Thurston Co Landfill (2018), WSDOT (2018)

Figure 9a. Groundwater Elevations in Nested Monitoring Wells MW-3a (Qva) and MW-14 (Qc)

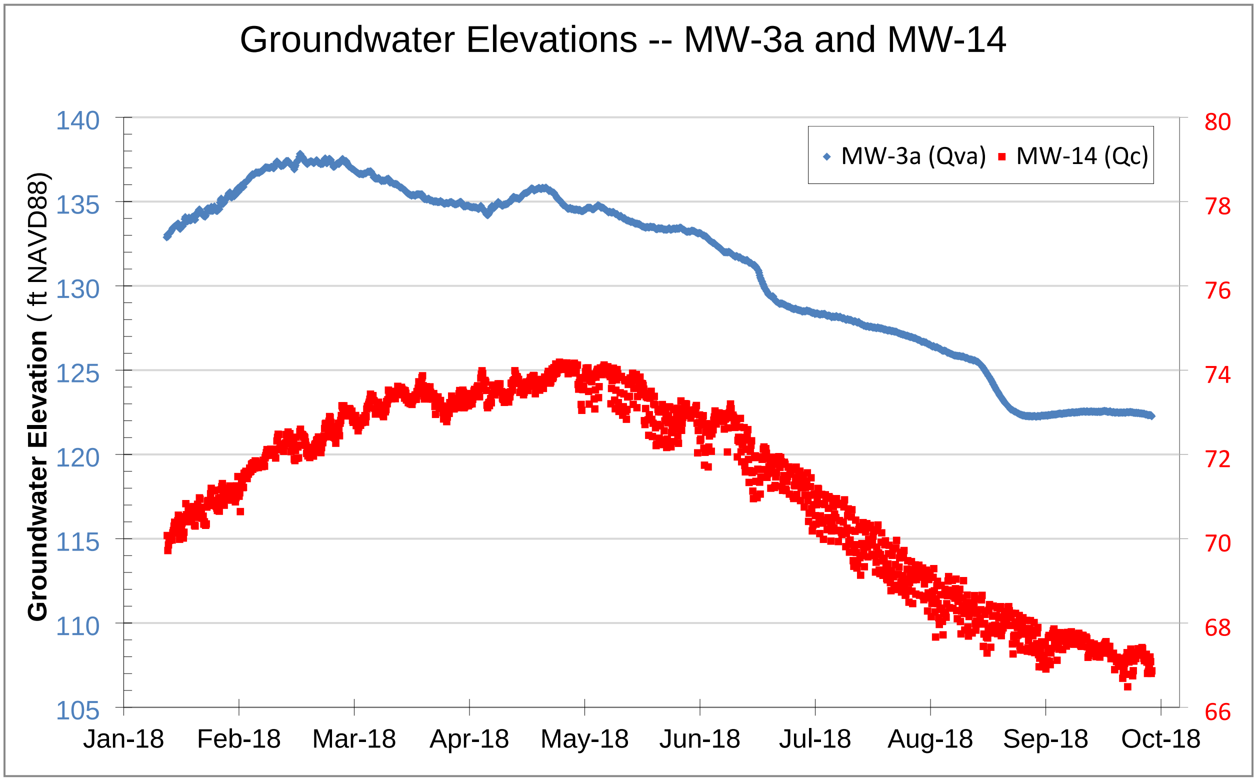


Figure 9b. Groundwater Elevations in Nested Monitoring Wells MW-13 (Qva) and MW-12 (Qc)

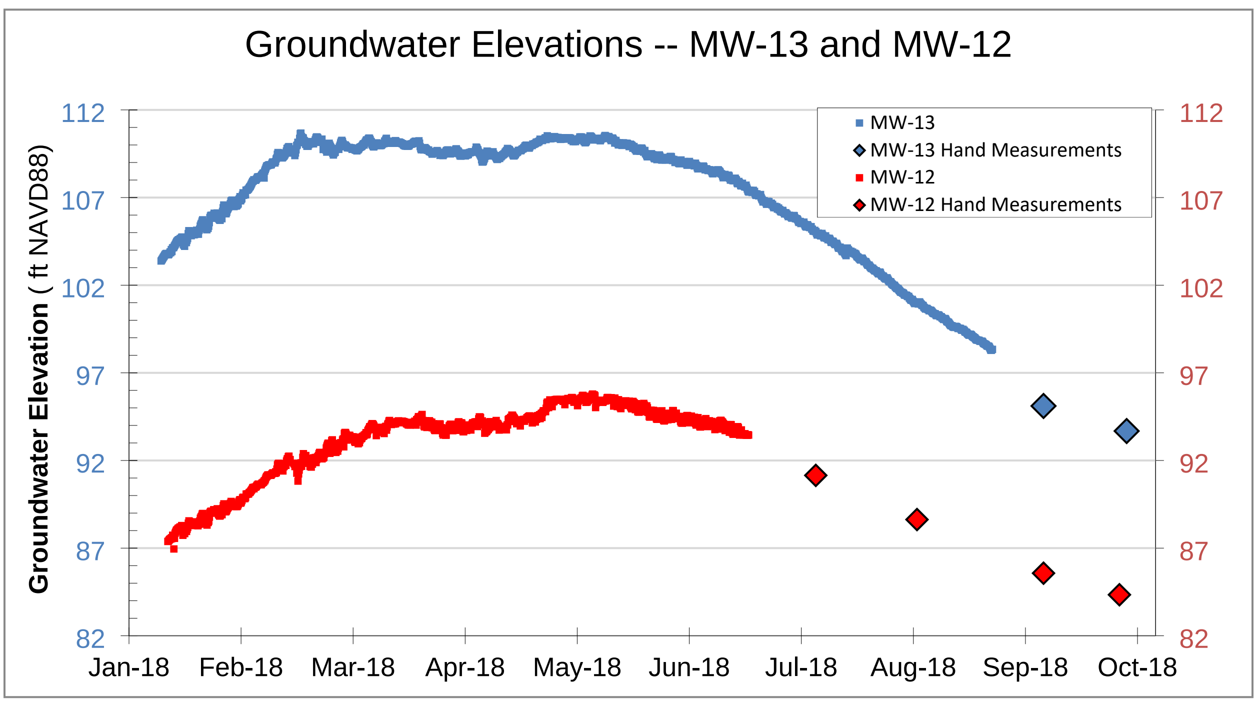


Figure 9c. Groundwater Elevations in Nested Monitoring Wells MW-22 (Qva) and MW-21 (Qc)

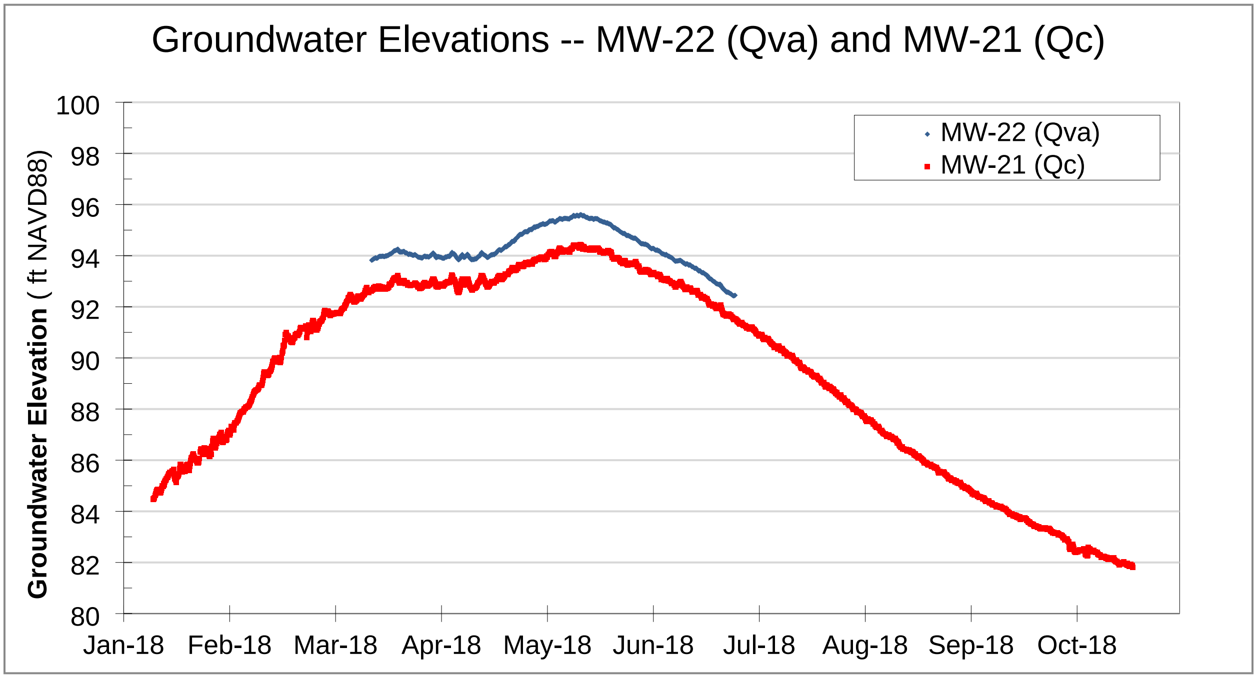


Figure 9d. Groundwater Elevations in Nested Monitoring Wells MW-24 (Qva) and MW-23 (Qc)

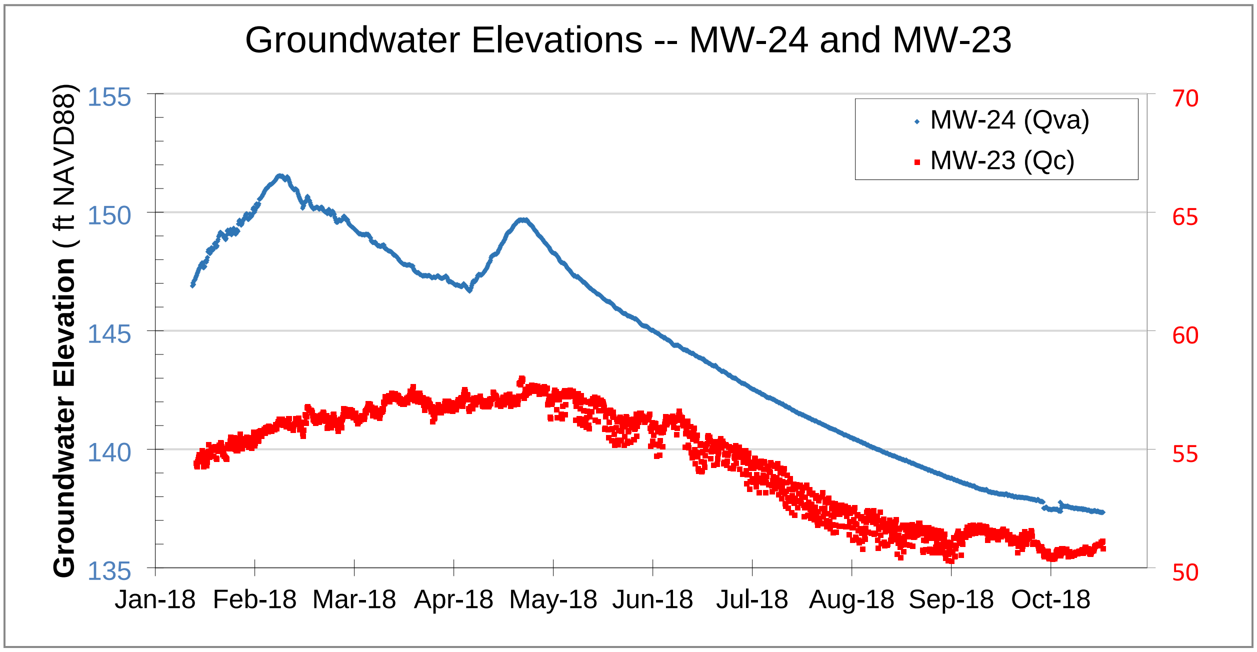


Figure 9e. Groundwater Elevations in Monitoring Wells MW-15 (Qva)

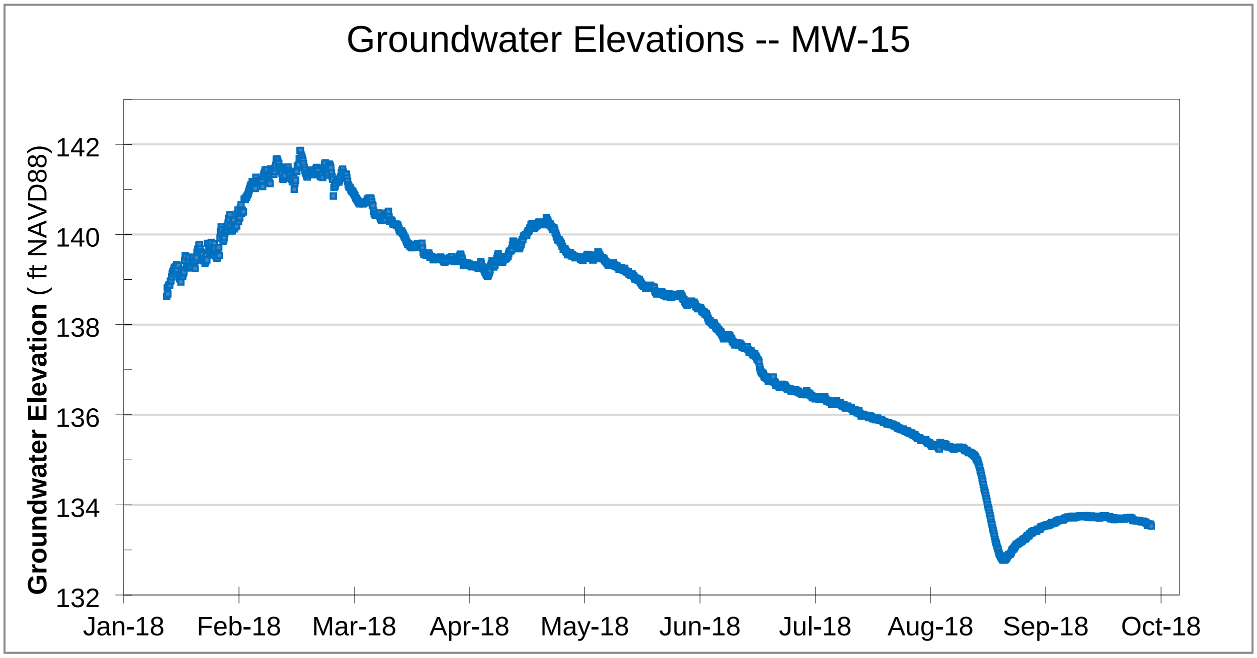


Figure 9f. Groundwater Elevations in Lacey S-16 (Qva)

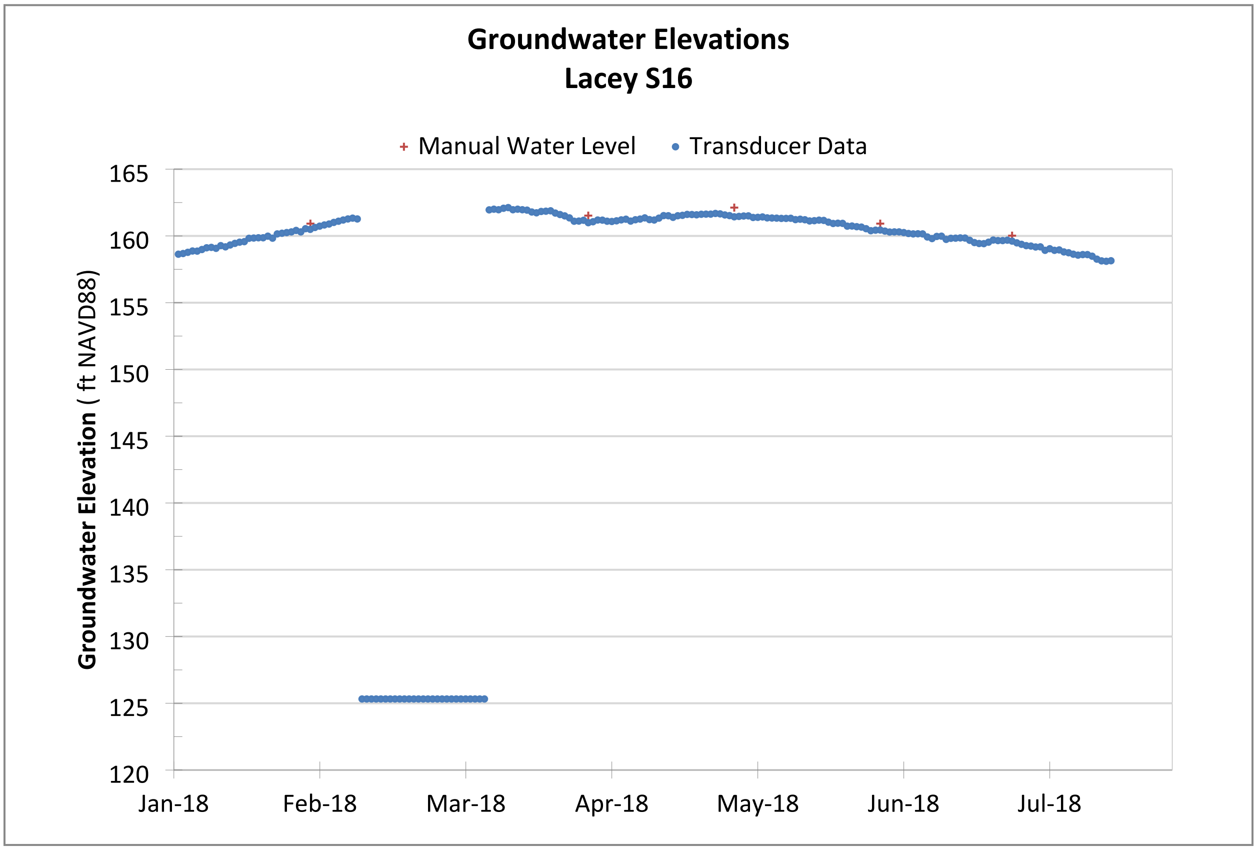


Figure 9g. Groundwater Elevations in Lacey S29 (Qc)

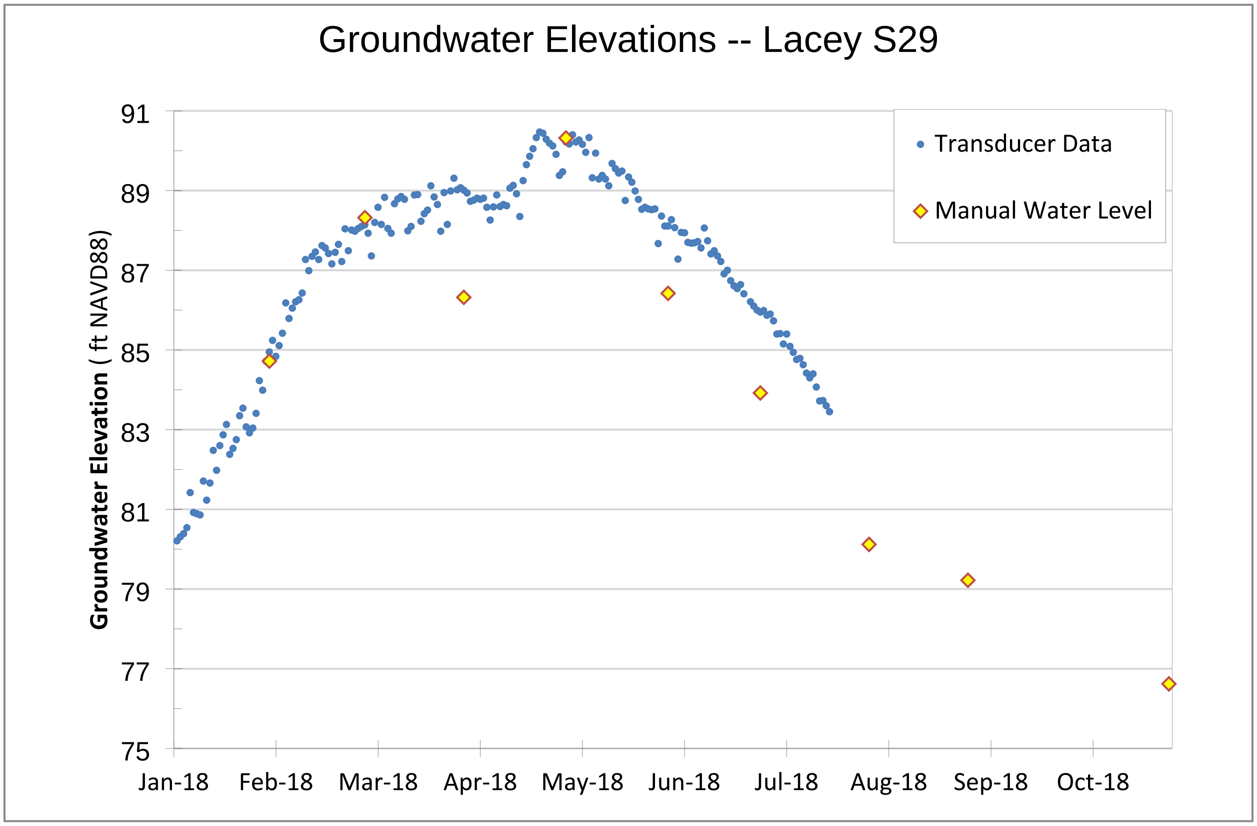


Figure 9h. Groundwater Elevations in Lacey TW-BC3 (TQu)

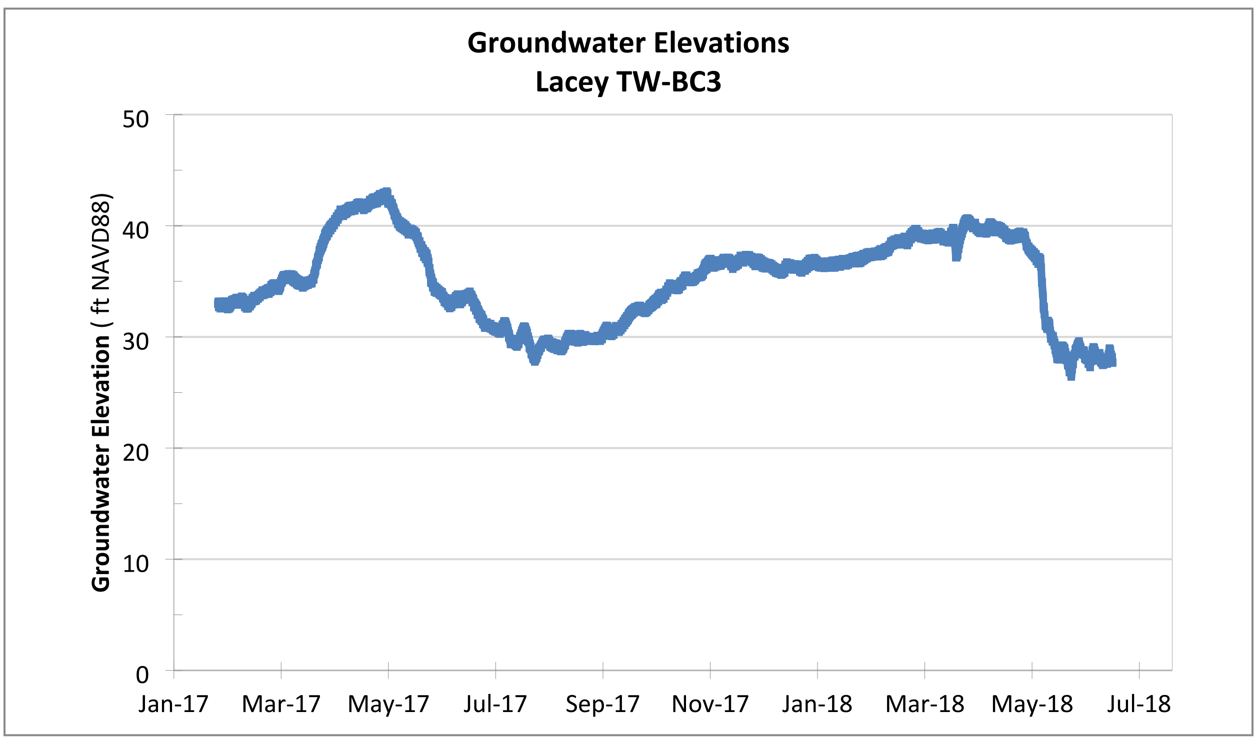


Figure 9i. Groundwater Elevations in Lacey TW-MC (TQu)

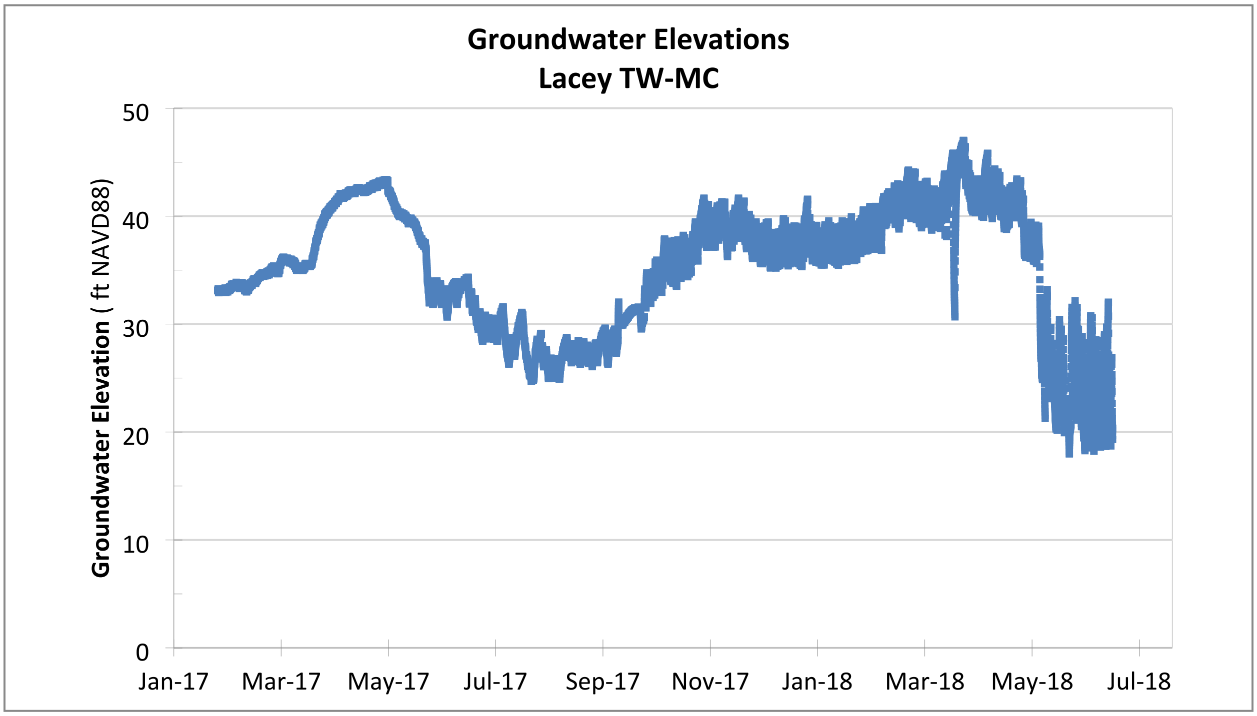


Figure 9j. Groundwater Elevations in Lacey TW-MR (TQu)

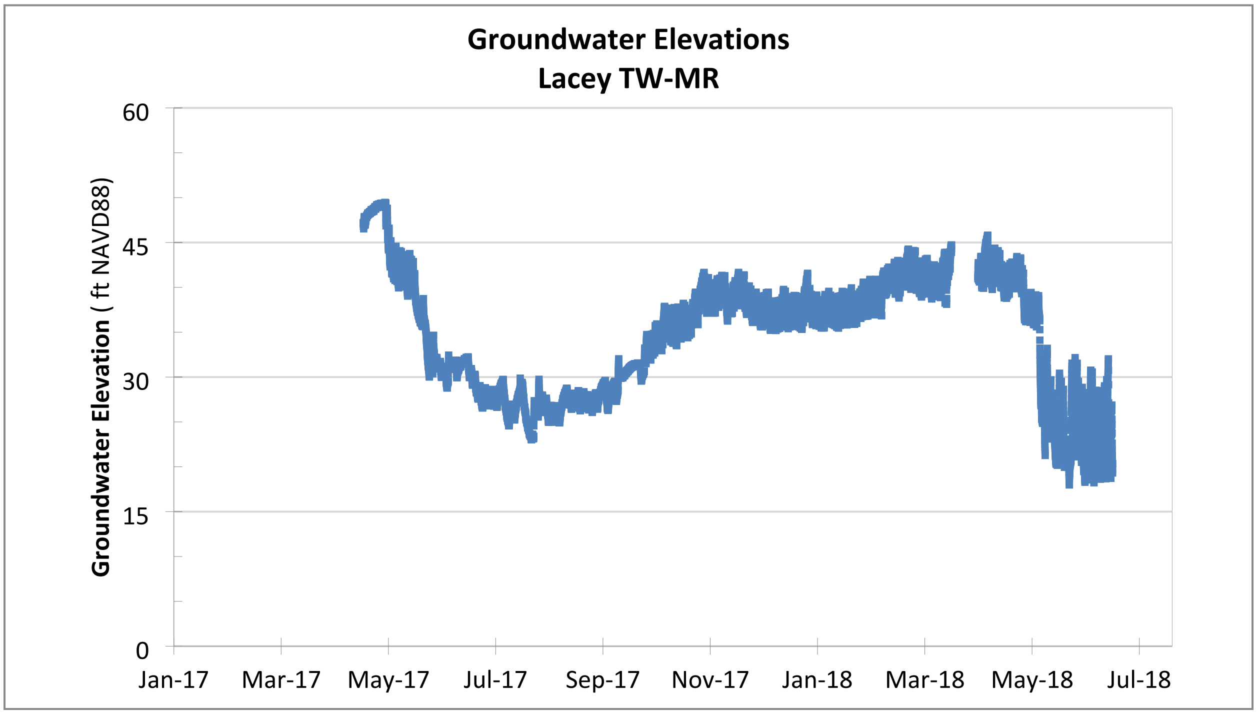
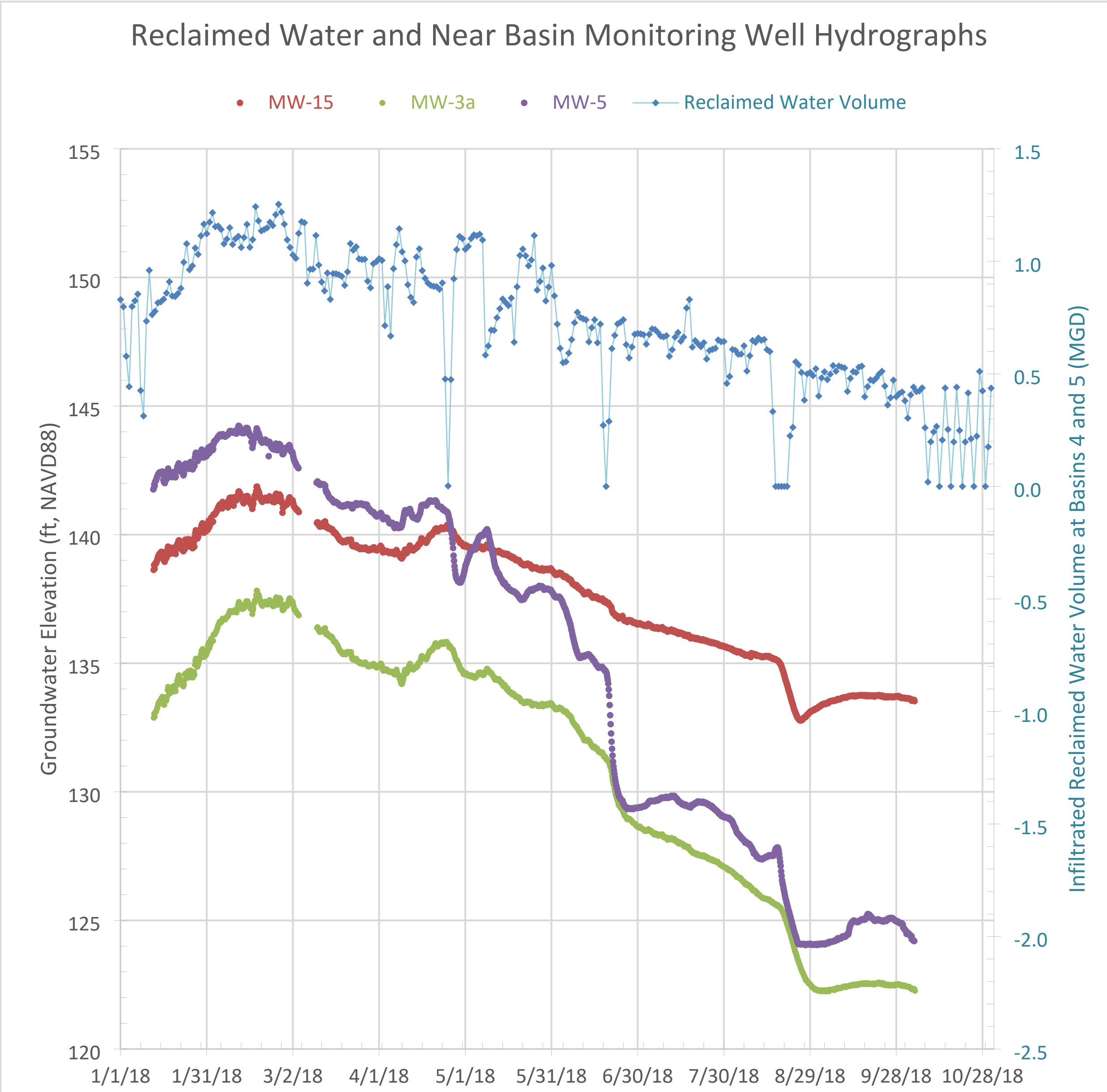
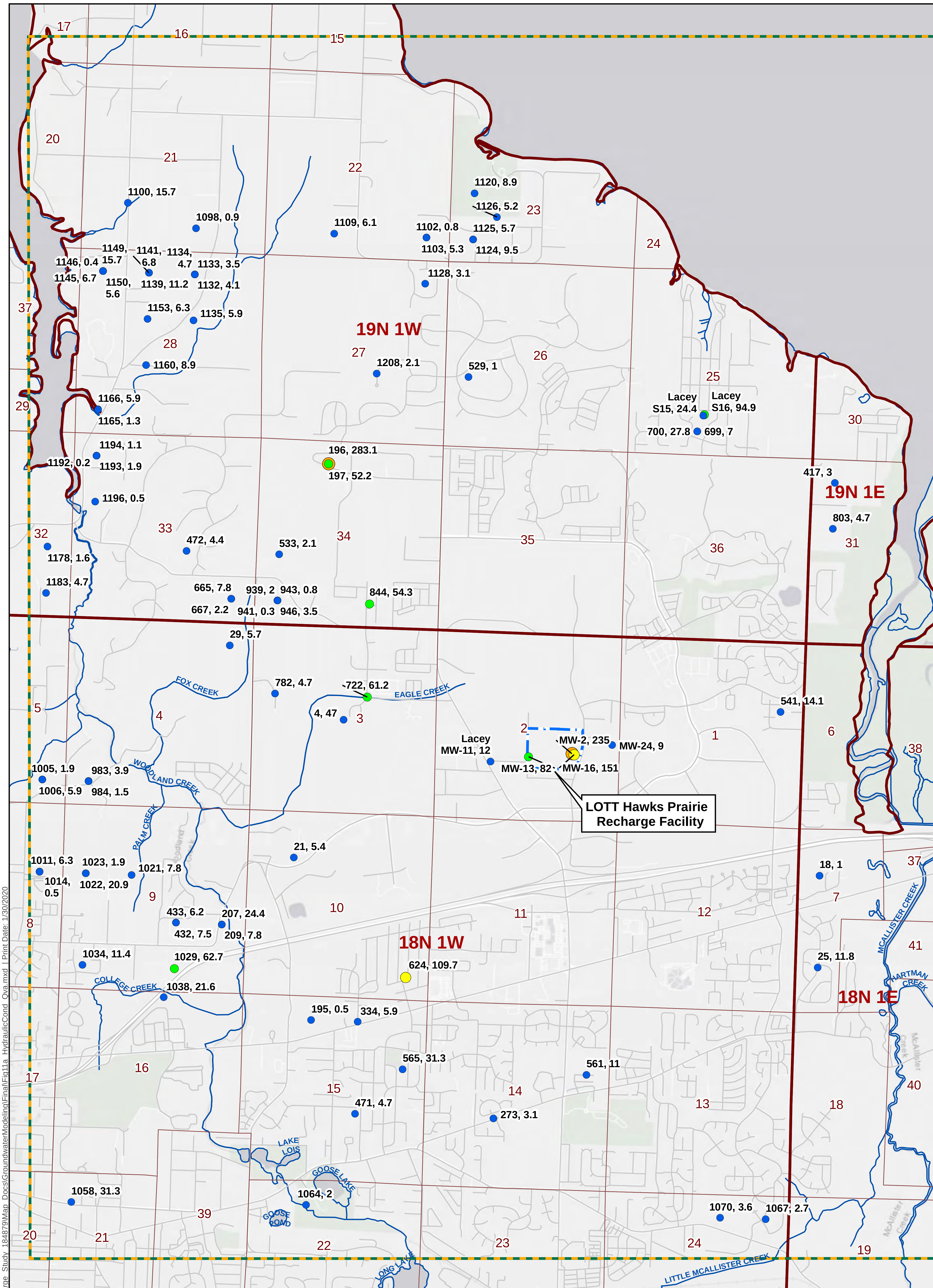


Figure 10. Reclaimed Water and Near Basin Monitoring Well Hydrographs



Notes:
MW-15 is screened under Basin 4, MW-3a is screened under Basin 5, and MW-5 is located south about 270 ft from the midpoint between Basins 4 and 5 to the south (downgradient), approximately 20 ft south of Basin 6 (see Figure 4-1 in HDR (2019a)).



Explanation of Well Information
273, 3.1 = Well ID, Hydraulic Conductivty (ft/d)

Hydraulic Conductivity (ft/d)
- 0 - 50
- 51 - 100
- 101 - 200
- 201 - 400
- 401 - 1,000

Groundwater Model Domain
LOTT Hawks Prairie Recharge Facility
Streams

Figure 11a
Hydraulic Conductivity
Shallow (Qva) Aquifer

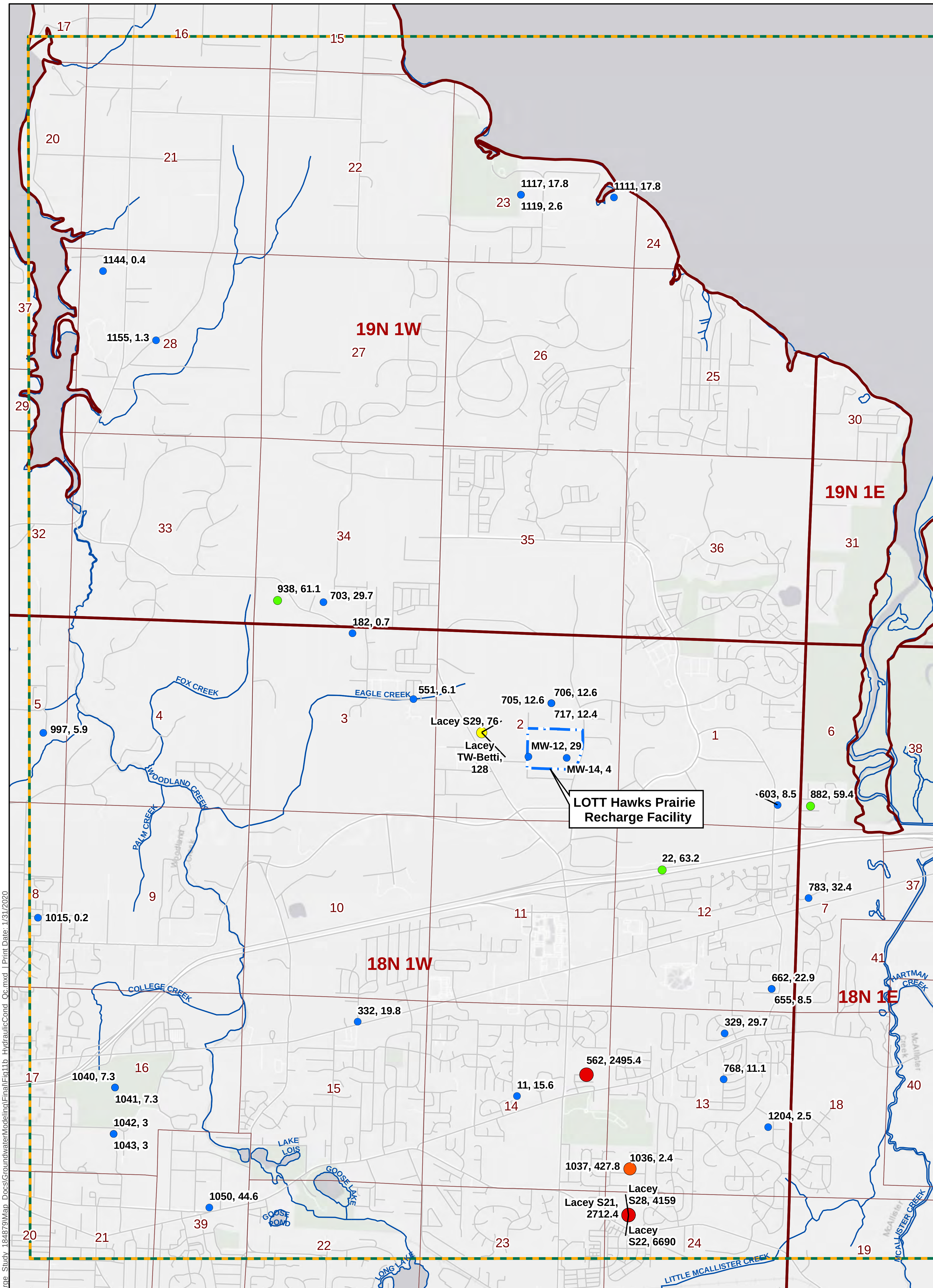
NOTE: Hydraulic conductivity was calculated from pumping tests as reported on well logs using the specific capacity equation from Driscoll (1986) and the layer thickness as estimated from well logs used for the hydrostratigraphy model, for the Qva this was 64 feet.

Miles
0 1

LOTT Clean Water Alliance
HDR

Path: G:\Projects\Washington\LOTT_CWA_201266\GW_Recharge_Study_184879\Map_Docs\GroundwaterModeling\Final\Fig11a_HydraulicCond_Qva.mxd | Print Date: 1/30/2020

Source: City of Lacey (2018), Ecology (2015), Esri (2018), NLW (2008), Thurston Co Landfill (2018), WSDOT (2018)



Explanation of Well Information
273, 3.1 = Well ID, Hydraulic Conductivty (ft/d)

Hydraulic Conductivity (ft/d)
- 0 - 50
- 50 - 100
- 100 - 200
- 200 - 400
- 400 - 1,000
- > 1,000

- Groundwater Model Domain
- LOTT Hawks Prairie Recharge Facility
- Streams

Figure 11b
Hydraulic Conductivity
Sea-Level (Qc) Aquifer

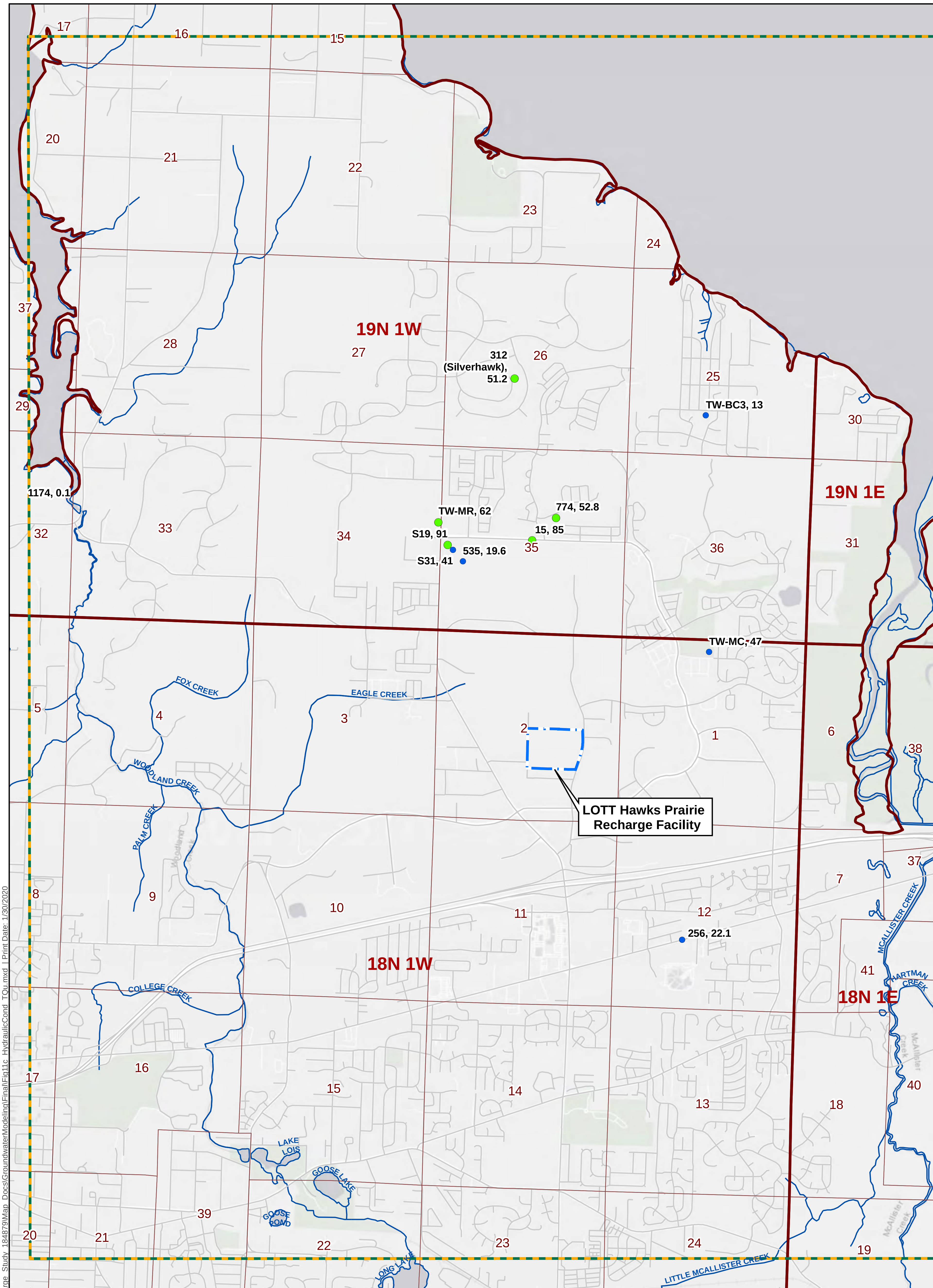
NOTE: Hydraulic conductivity was calculated from pumping tests as reported on well logs using the specific capacity equation from Driscoll (1986) and the layer thickness estimated from wells logs used for the hydrostatigraphy model, for the Qc this was 45 feet.

Miles
0 1

LOTT Clean Water Alliance
HDR

Path: G:\Projects\Washington\LOTT_CWA_201266\GW_Recharge_Study_184879\Map_Docs\GroundwaterModeling\Final\Fig11b_HydraulicCond_Qc.mxd | Print Date: 1/31/2020

Source: City of Lacey (2018), Ecology (2015), Esri (2018), PGG (1997), Robinson and Noble (2005), Thurston Co Landfill (2018), WSDOT (2018)



Explanation of Well Information
273, 3.1 = Well ID, Hydraulic Conductivty (ft/d)

Hydraulic Conductivity (ft/d)
- 1 - 50
- 50 - 500
- 100 -200

- Groundwater Model Domain
- LOTT Hawks Prairie Recharge Facility
- Streams

Figure 11c
Hydraulic Conductivity
Deep (TQu) Aquifer

NOTE: Hydraulic conductivity was calculated from pumping tests as reported on well logs using the specific capacity equation from Driscoll (1986) and the layer thickness as estimated from well logs used for the hydrostratigraphy model, for the TQu this was 81 feet.

Miles
0 1

Path: G:\Projects\Washington\LOTT_CWA_201266\GW_Recharge_Study_184879\Map_Docs\GroundwaterModeling\Final\Fig11c_HydraulicCond_TQu.mxd | Print Date: 1/30/2020

Source: City of Lacey (2018), Ecology (2015), Esri (2018), NLW (2008), Thurston Co Landfill (2018), WSDOT (2018)

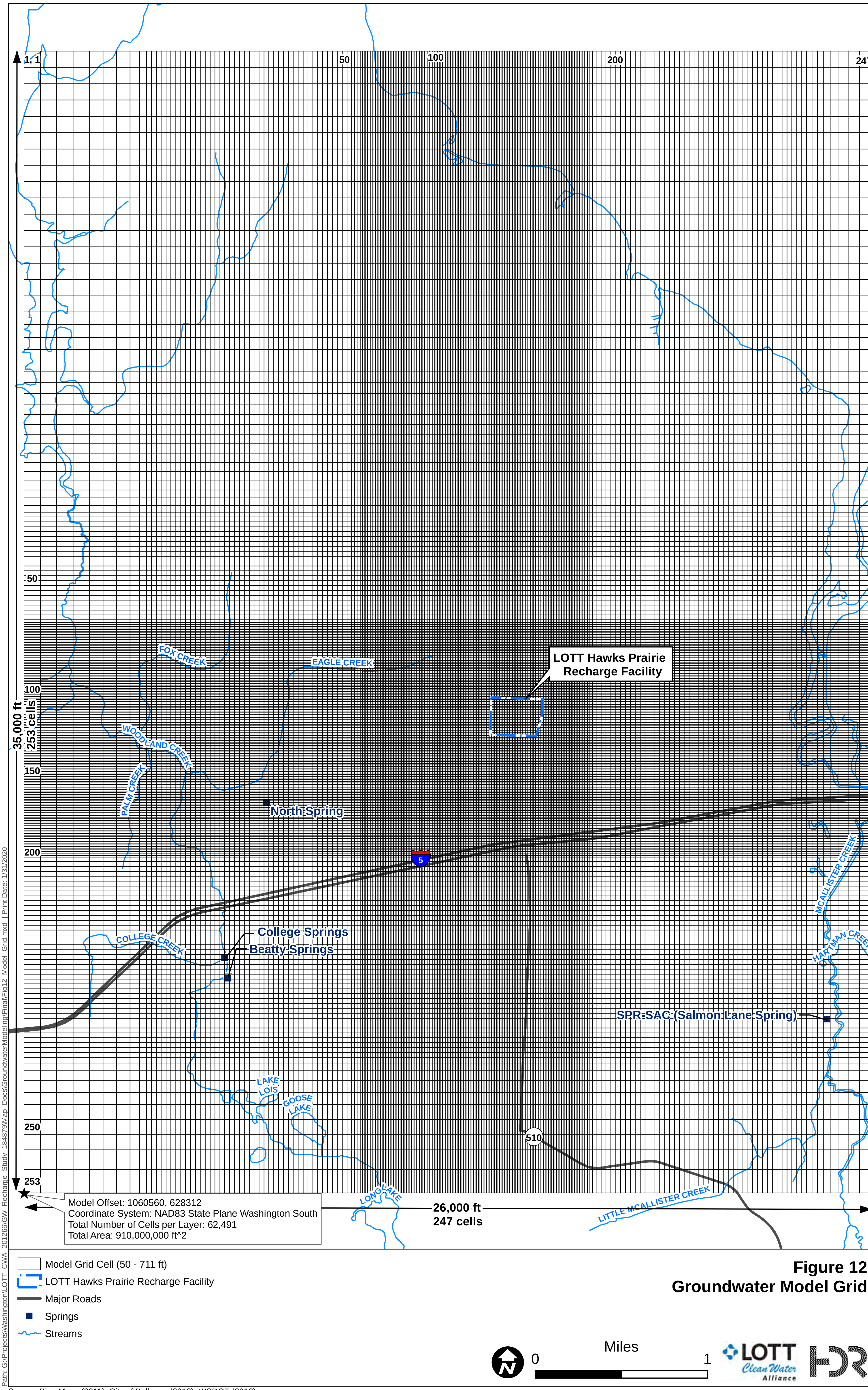


Figure 12
Groundwater Model Grid

Source: Bing Maps (2011), City of Bellevue (2013), WSDOT (2013)

Path: G:\Projects\Washington\LOTT_CWA_201266\GW_Recharge_Study_184879\Map_Docs\GroundwaterModeling\Final\Fig12_Model_Grid.mxd | Print Date: 1/31/2020

High Density Development
Low Density Development
New Development
LOTT Hawks Prairie Recharge Facility
Groundwater Model Domain
Streams

Figure 13
Developed Areas in Model Domain

Note:
Development data from Thurston GeoData Center (2016) zoning data with modifications based on aerial imagery.

Miles
0 1

Path: G:\Projects\Washington\LOTT_CWA_201266\GW_Recharge_Study_184879\Map_Docs\GroundwaterModeling\Final\Fig13_Developed_Areas.mxd | Print Date: 1/31/2020

Source: Bing Maps (2011), City of Bellevue (2013), WSDOT (2013)

Recharge Rate (in/yr)

Basin 4	24	15	0
Basin 5	23	14	New Development
31	22	13	Groundwater Model Domain
30	21	12	LOTT Hawks Prairie Recharge Facility
29	20	11	
28	19	10	
27	18	9	
26	17	8	
25	16	7	

Figure 14
Recharge Applied in Groundwater Model

NOTES:
1. Recharge values provided by Thurston County, April 2019. Values were modified in developed areas. A value of 7 in/yr was applied in areas of high density development, a value of 12 in/yr was applied in areas of low density development.
2. Values for recharge Basins 4 and 5 are from the average flow rate for May - June 2018. Basin 4 - 0.58 MGD (15209 in/yr per cell), Basin 5 - 0.19 MGD (5546 in/yr per cell).

Miles
0 0.95

Path: G:\Projects\Washington\LOTT_CWA_201266\GW_Recharge_Study_184879\Map_Docs\GroundwaterModeling\Final\Fig14_Recharge_Rates.mxd | Print Date: 1/31/2020

Source: Bing Maps (2011), City of Bellevue (2013), WSDOT (2013)

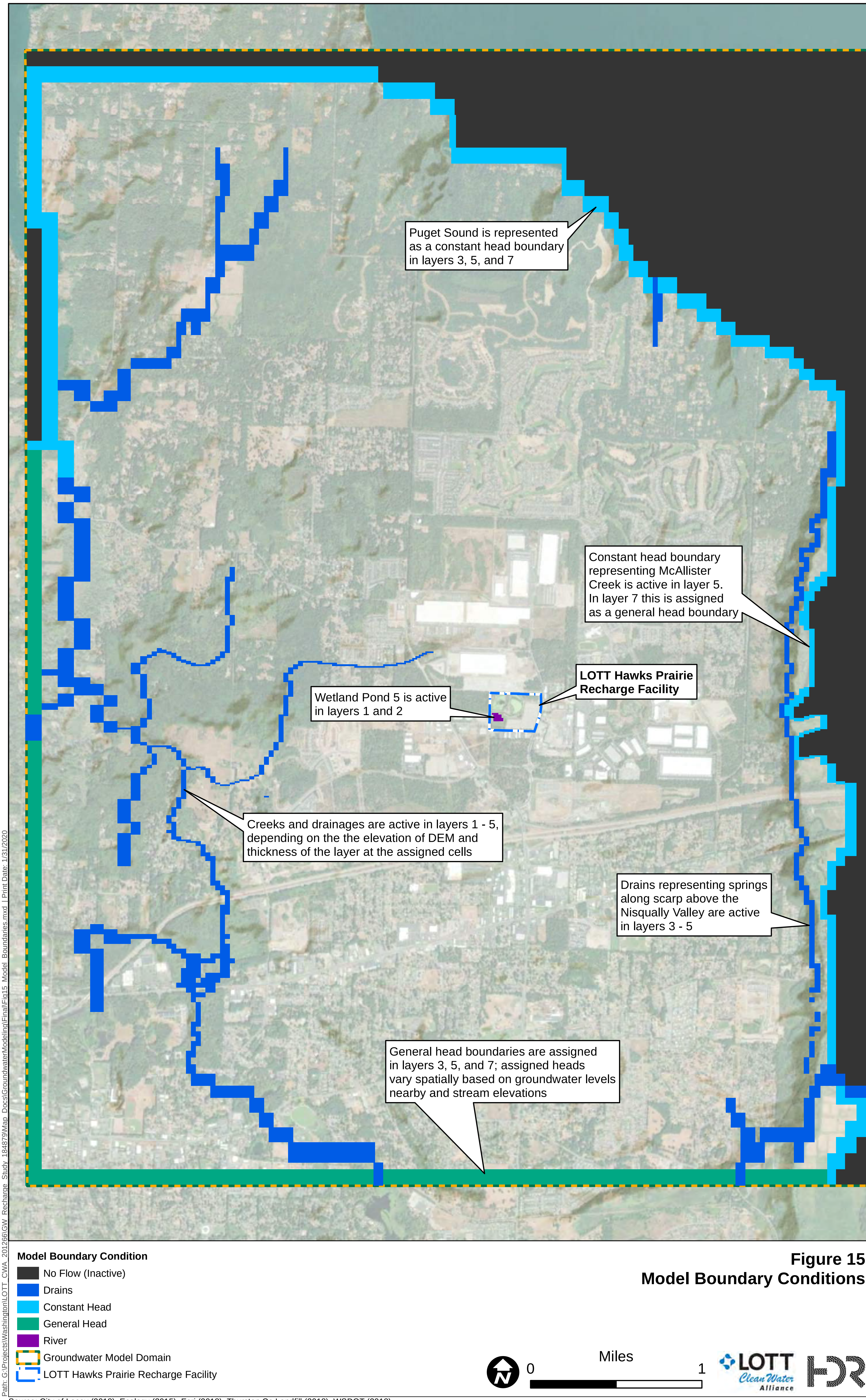
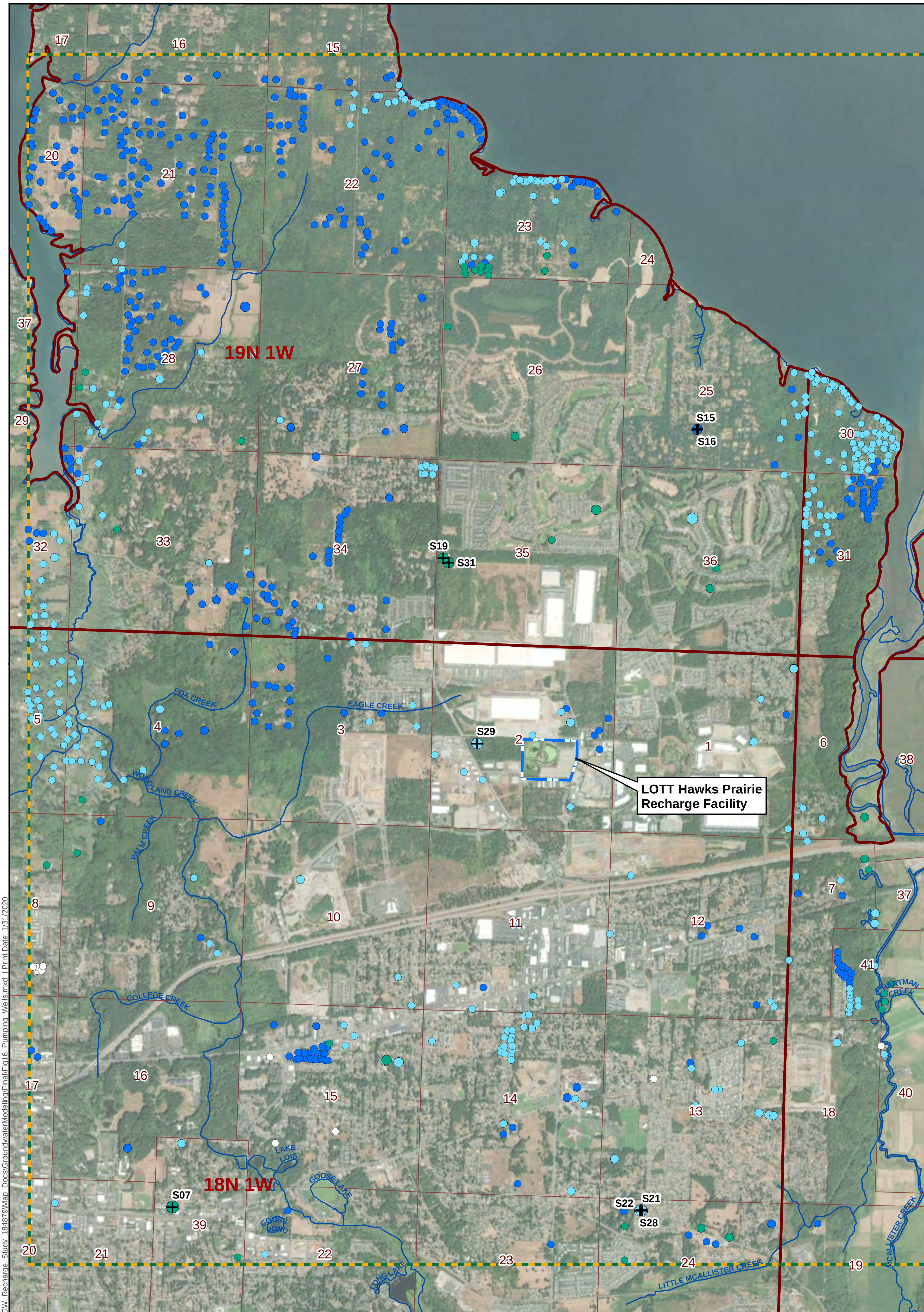


Figure 15
Model Boundary Conditions

Source: City of Lacey (2018), Ecology (2015), Esri (2018), Thurston Co Landfill (2018), WSDOT (2018)



+ City of Lacey Production Wells

Pumping Rate (gpm)

- 0 - 10
- 10 - 50
- 50 - 100
- 100 - 500
- > 500

Associated Layer

- 1 - Qvr
- 3 - Qva
- 5 - Qc
- 7 - TQu
- Groundwater Model Domain
- LOTT Hawks Prairie Recharge Facility

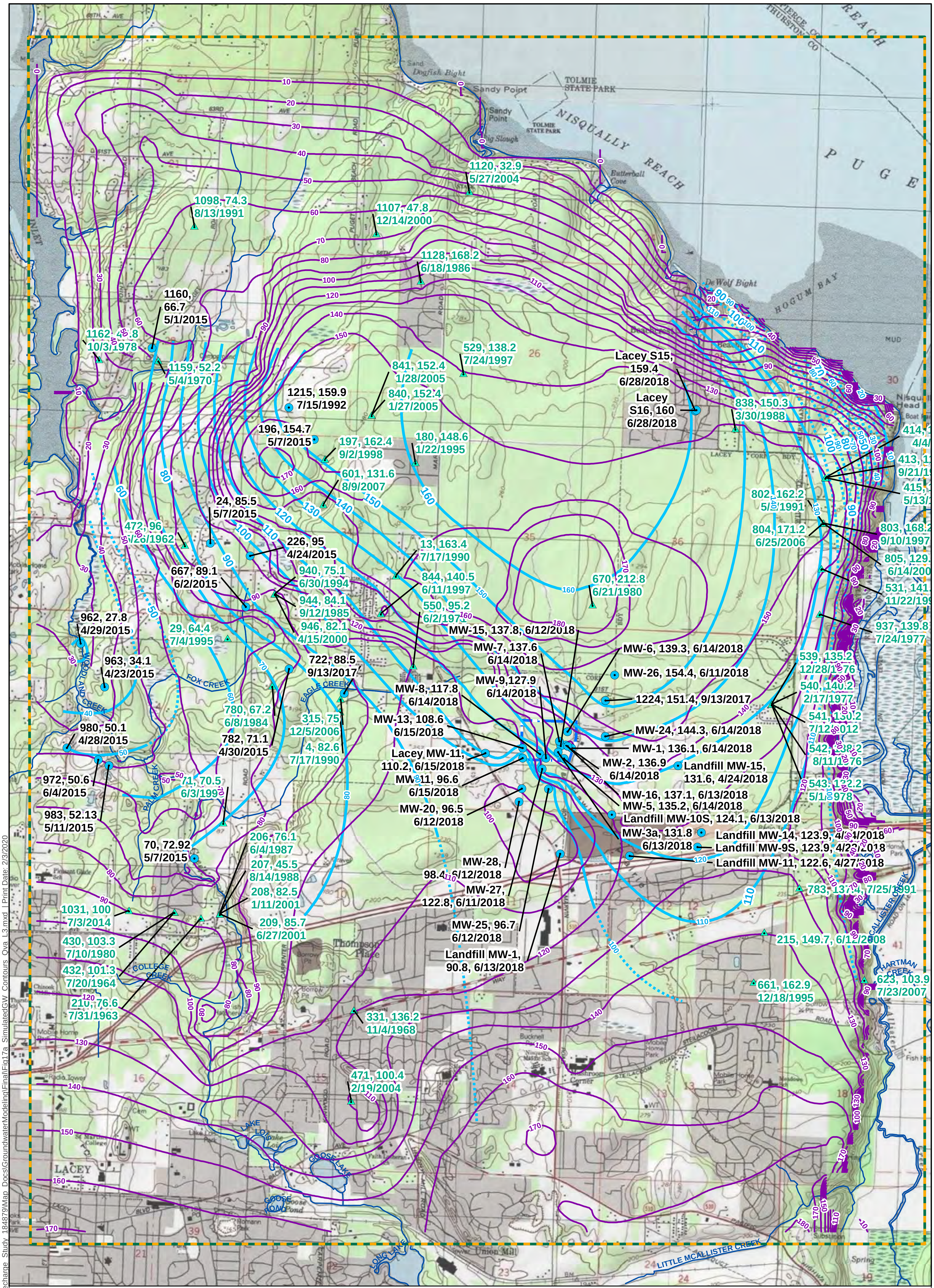
NOTE:
Pumping data from City of Lacey (Rector 2018) and Thurston County (Hansen 2019).

Miles
0 1

Figure 16
Simulated Pumping Wells

Path: G:\Projects\Washington\LOTT_CWA_201266\GW_Recharge_Study_184879\Map_Docs\GroundwaterModeling\Final\Fig16_Pumping_Wells.mxd | Print Date: 1/31/2020

Source: City of Lacey (2018), Ecology (2015), Esri (2018), Thurston Co Landfill (2018), WSDOT (2018)



- Modeled Groundwater Elevation Contours (ft)
- Observed Groundwater Elevation Contours (ft)
- Dashed where data is limited and contours are inferred
- Groundwater Model Domain
- LOTT Hawks Prairie Recharge Facility
- Streams

Measured Groundwater Levels
Well Name
Groundwater Elevation (ft)
Groundwater Elevation Date

Groundwater Levels Estimated from Well Logs
Study ID
Groundwater Elevation (ft)
Groundwater Elevation Date

Figure 17a
Observed and Modeled Groundwater Contours Shallow (Qva) Aquifer

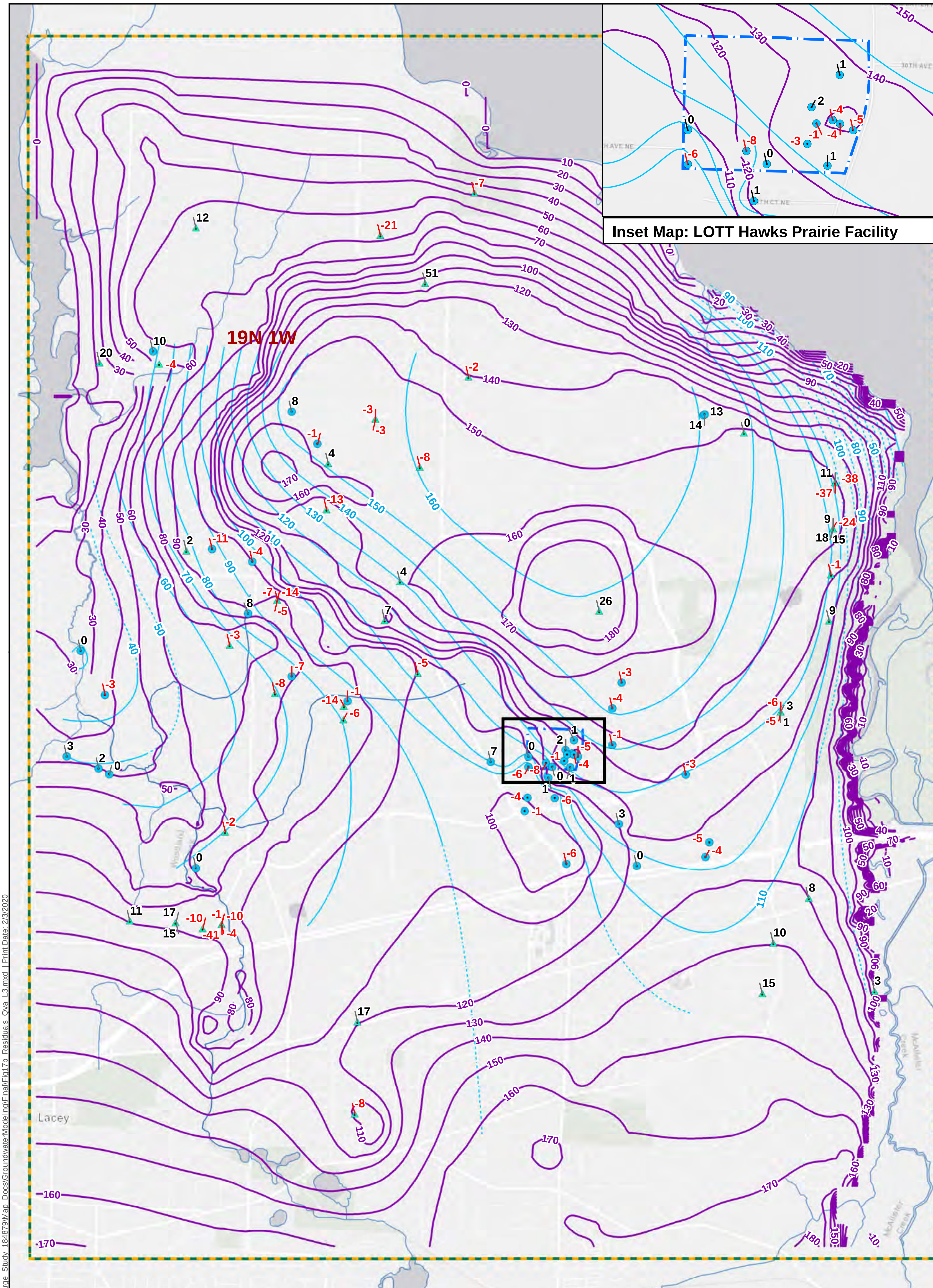
NOTE:
1. Vertical datum for groundwater elevations is NAVD 88.
2. Groundwater elevations for well log data were estimated using topographic data from a DEM (PSLC 2018) as the ground surface elevation and the depth to groundwater reported on the well log.

Miles
0 1

LOTT Clean Water Alliance
HDR

Path: G:\Projects\Washington\LOTT_CWA_201266\GW_Recharge_Study_184879\Map_Docs\GroundwaterModeling\Final\Fig17a_SimulatedGW_Contours_Qva_L3.mxd | Print Date: 2/3/2020

Source: City of Lacey (2018), Ecology (2015), Esri (2018), Thurston Co Landfill (2018), WSDOT (2018)



Residual = Observed - Modeled Groundwater Level (ft)
Observed > Modeled
Observed < Modeled

- Measured Water Level
- Water Level Estimated from Well Log
- Modeled Groundwater Elevation Contours (ft)
- Observed Groundwater Elevation Contours (ft)
- Dashed where data is limited and controus are inferred
- Groundwater Model Domain
- LOTT Hawks Prairie Recharge Facility

Figure 17b
Simulated Groundwater Potentiometric Surface and Residuals Shallow (Qva) Aquifer

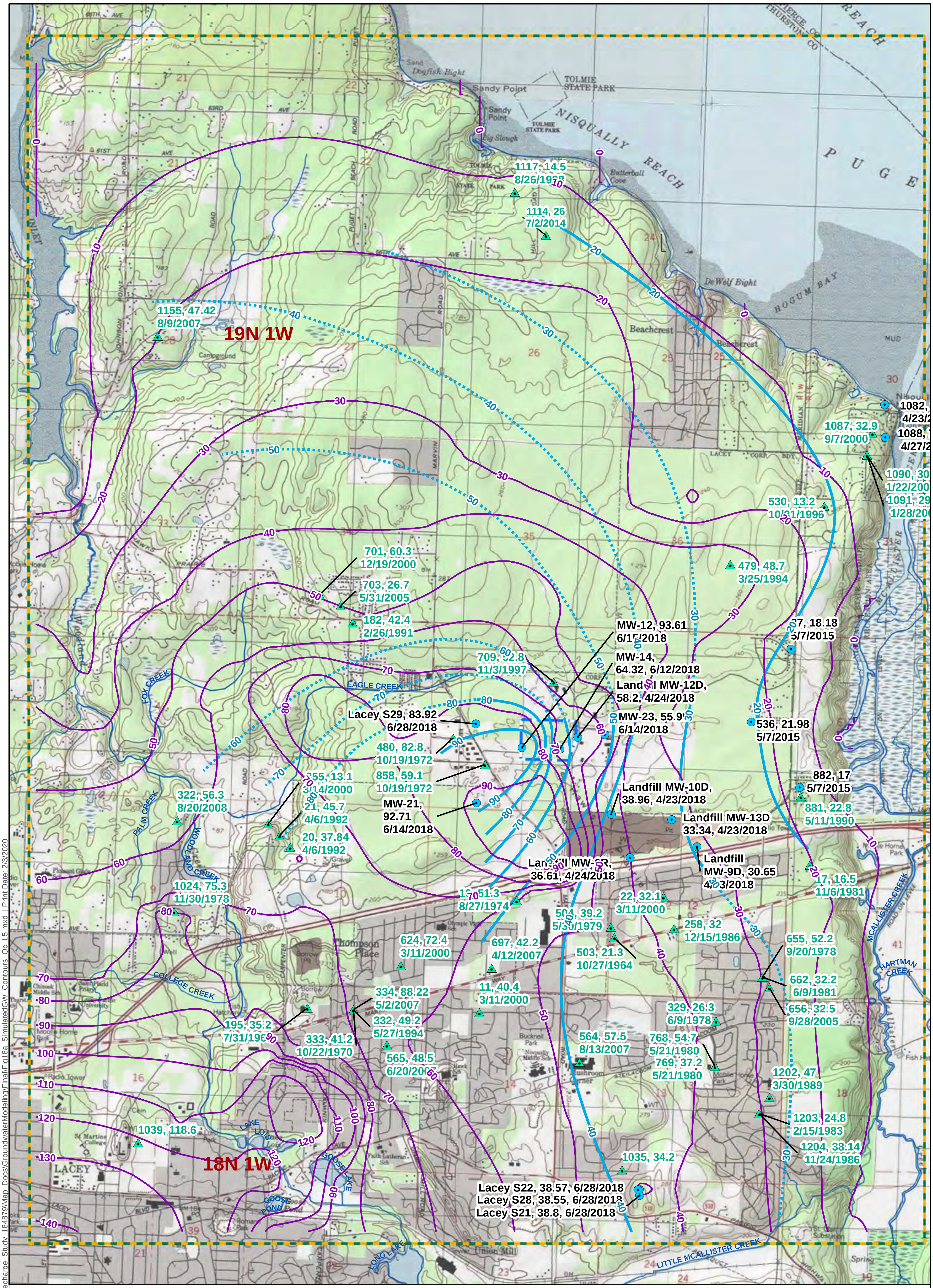
NOTE:
1. Vertical datum for groundwater elevations is NAVD 88.

Miles
0 1

LOTT Clean Water Alliance
HDR

Source: City of Lacey (2018), Ecology (2015), Esri (2018), Thurston Co Landfill (2018), WSDOT (2018)

Path: G:\Projects\Washington\LOTT_CWA_201266\GW_Recharge_Study_184879\Map_Docs\GroundwaterModeling\Final\Fig17b_Residuals_Qva_L3.mxd | Print Date: 2/3/2020



- Modeled Groundwater Elevation Contours (ft)
- Observed Groundwater Elevation Contours (ft)
- Dashed where data is limited and contours are inferred
- Groundwater Model Domain
- LOTT Hawks Prairie Recharge Facility
- Streams

Measured Groundwater Levels
Well Name
Groundwater Elevation (ft)
Groundwater Elevation Date

Groundwater Levels Esimated from Well Logs:
Study ID
Groundwater Elevation (ft)
Groundwater Elevation Date

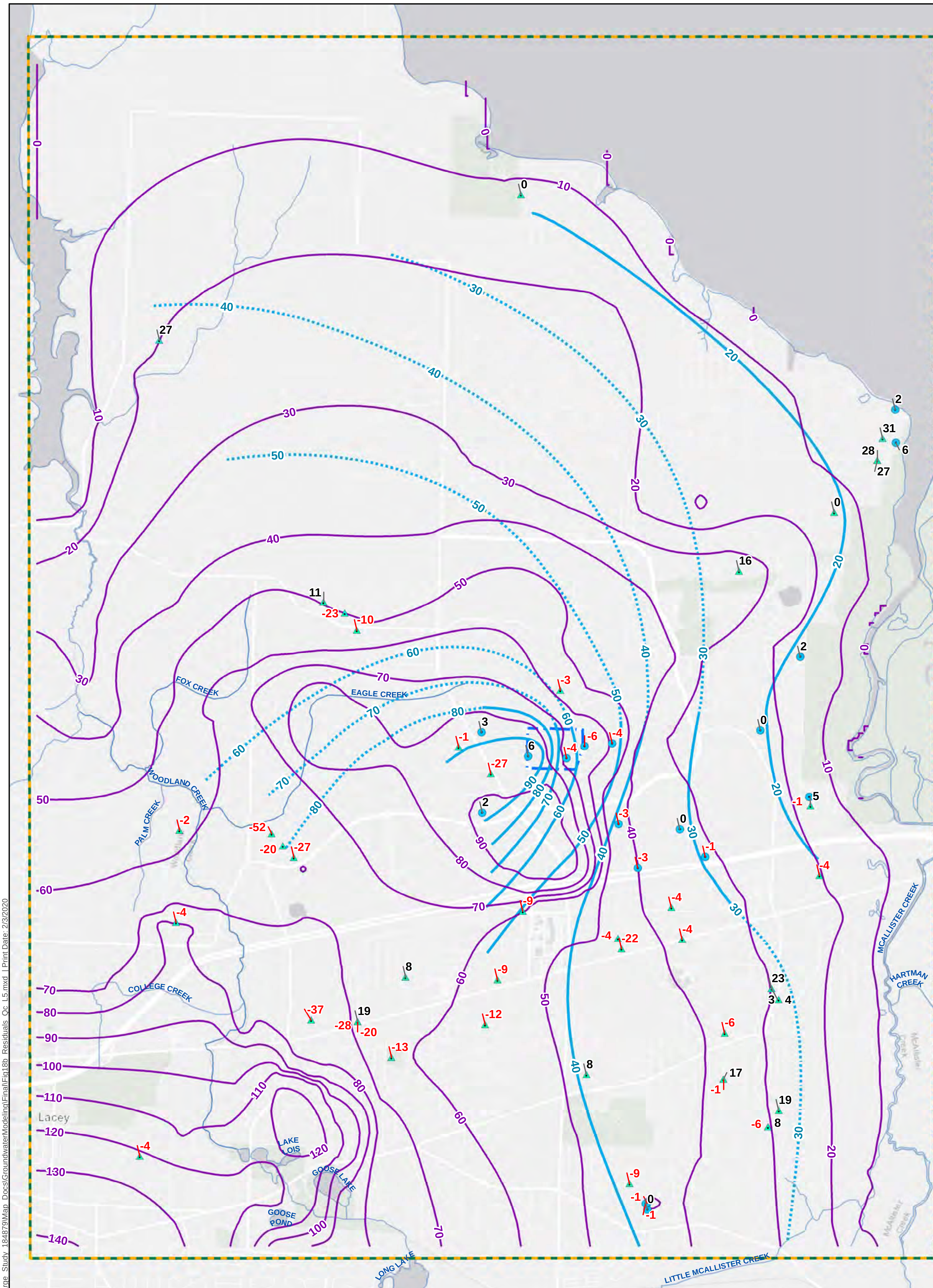
Figure 18a
Observed and Modeled Groundwater Elevation Sea-Level (Qc) Aquifer

NOTE:
1. Vertical datum for groundwater elevations is NAVD 88.
2. Groundwater elevations for well log data were estimated using topographic data from a DEM (PSLC 2018) as the ground surface elevation and the depth to groundwater reported on the well log.

Miles
0 1

LOTT Clean Water Alliance
HDR

Source: City of Lacey (2018), Ecology (2015), Esri (2018), Thurston Co Landfill (2018), WSDOT (2018)



Residual = Observed - Modeled Groundwater Level (ft)
Observed > Modeled
Observed < Modeled

- Measured Water Level
- Water Level Estimated from Well Log
- Modeled Groundwater Elevation Contours (ft)
- Observed Groundwater Elevation Contours (ft)
- Dashed where data is limited and contours are inferred
- Groundwater Model Domain
- LOTT Hawks Prairie Recharge Facility

Figure 18b
Simulated Groundwater Potentiometric Surface and Residuals
Sea-Level (Qc) Aquifer

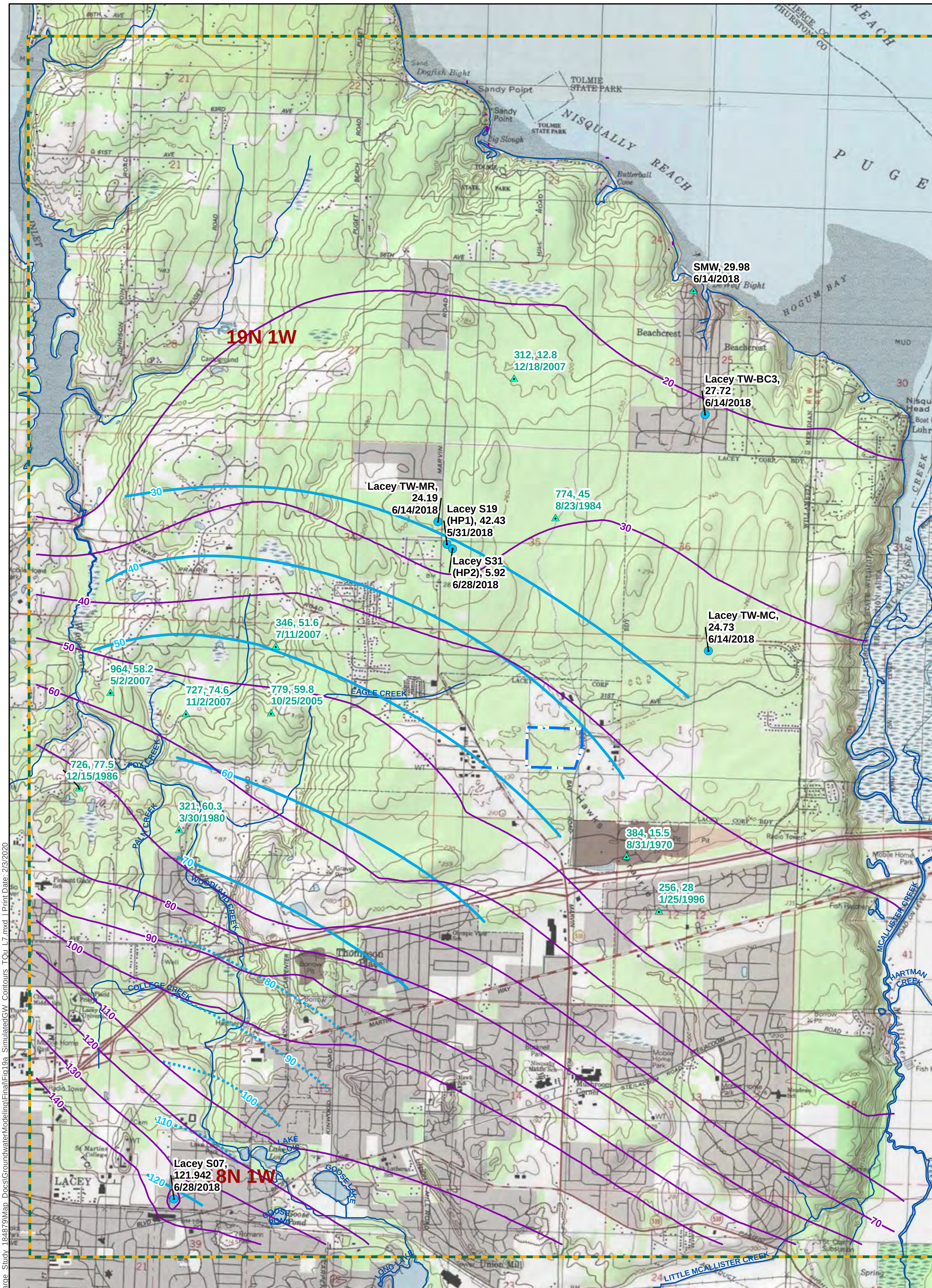
NOTE:
1. Vertical datum for groundwater elevations is NAVD 88.
2. Displayed residuals are rounded to the nearest foot.

Miles
0 1

LOTT Clean Water Alliance
HDR

Path: G:\Projects\Washington\LOTT_CWA_201266\GW_Recharge_Study_184879\Map_Docs\GroundwaterModeling\Final\Fig18b_Residuals_Qc_L5.mxd | Print Date: 2/3/2020

Source: City of Lacey (2018), Ecology (2015), Esri (2018), Thurston Co Landfill (2018), WSDOT (2018)



Path: G:\Projects\Washington\LOTT_CWA_201266\GW_Recharge_Study_184879\Map_Docs\GroundwaterModeling\Final\Fig19a_SimulatedGW_Contours_TQu_L7.mxd | Print Date: 2/3/2020

- Modeled Groundwater Elevation Contours (ft)
- Observed Groundwater Elevation Contours (ft)
- Dashed where data is limited and contours are inferred
- Groundwater Model Domain
- LOTT Hawks Prairie Recharge Facility
- Streams

Measured Groundwater Levels
Well Name
Groundwater Elevation (ft)
Groundwater Elevation Date

Groundwater Levels Esimated from Well Logs:
Study ID
Groundwater Elevation (ft)
Groundwater Elevation Date

Figure 19a
Observed and Modeled Groundwater Elevation
Deep (TQu) Aquifer

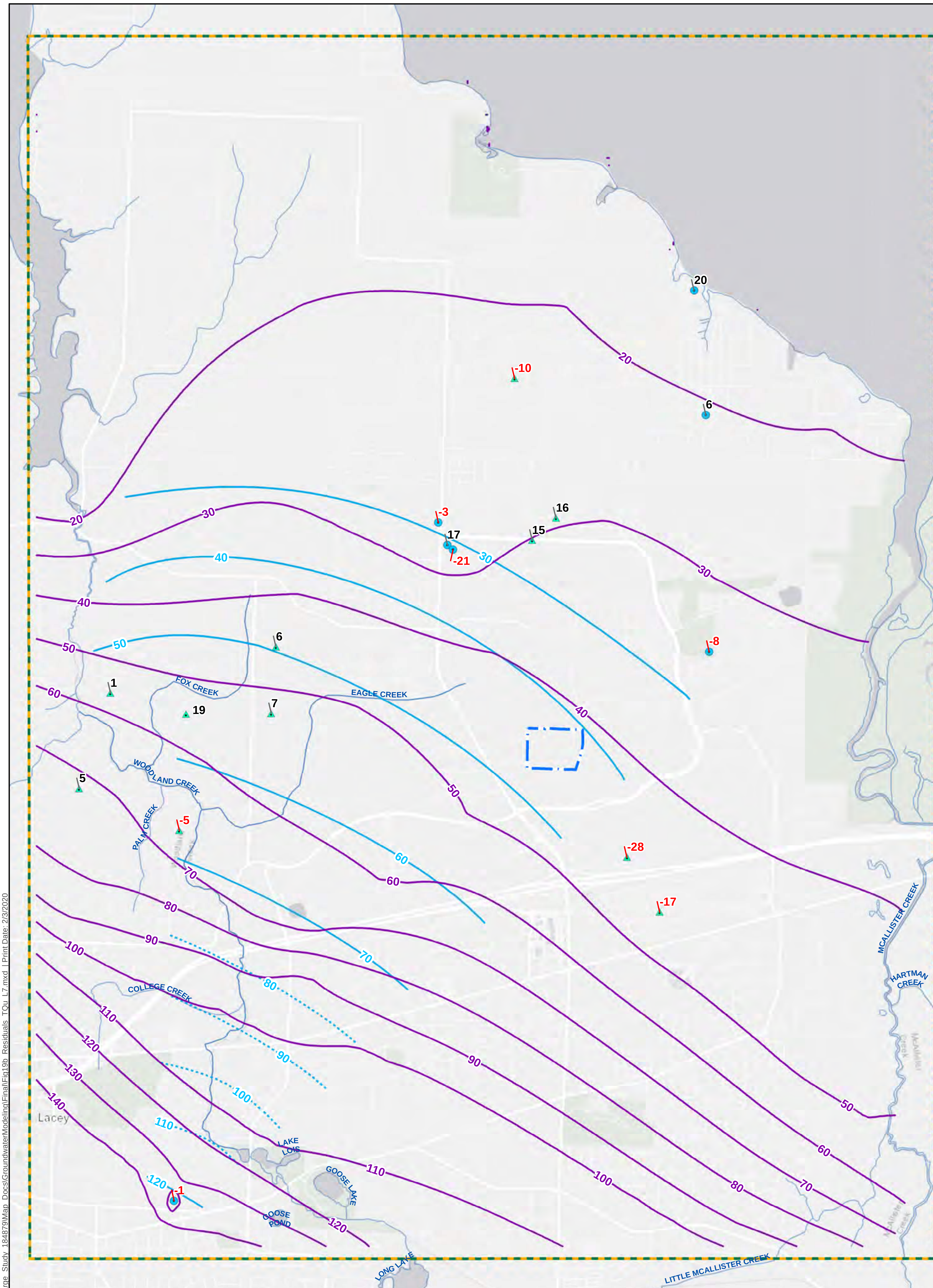
NOTE:
1. Vertical datum for groundwater elevations is NAVD 88.
2. Groundwater elevations for well log data were estimated using topographic data from a DEM (PSLC 2018) as the ground surface elevation and the depth to groundwater reported on the well log.

N

Miles
0 1

LOTT Clean Water Alliance
HDR

Source: City of Lacey (2018), Ecology (2015), Esri (2018), Thurston Co Landfill (2018), WSDOT (2018)



Residual = Observed - Modeled Groundwater Elevation (ft)
Observed > Modeled
Observed < Modeled

- Measured Water Level
- Water Level Estimated from Well Log
- Modeled Groundwater Elevation Contours (ft)
- Observed Groundwater Elevation Contours (ft)
- Dashed where data is limited and contours are inferred
- Groundwater Model Domain
- LOTT Hawks Prairie Recharge Facility

Figure 19b
Simulated Groundwater Potentiometric Surface and Residuals Deep (TQu) Aquifer

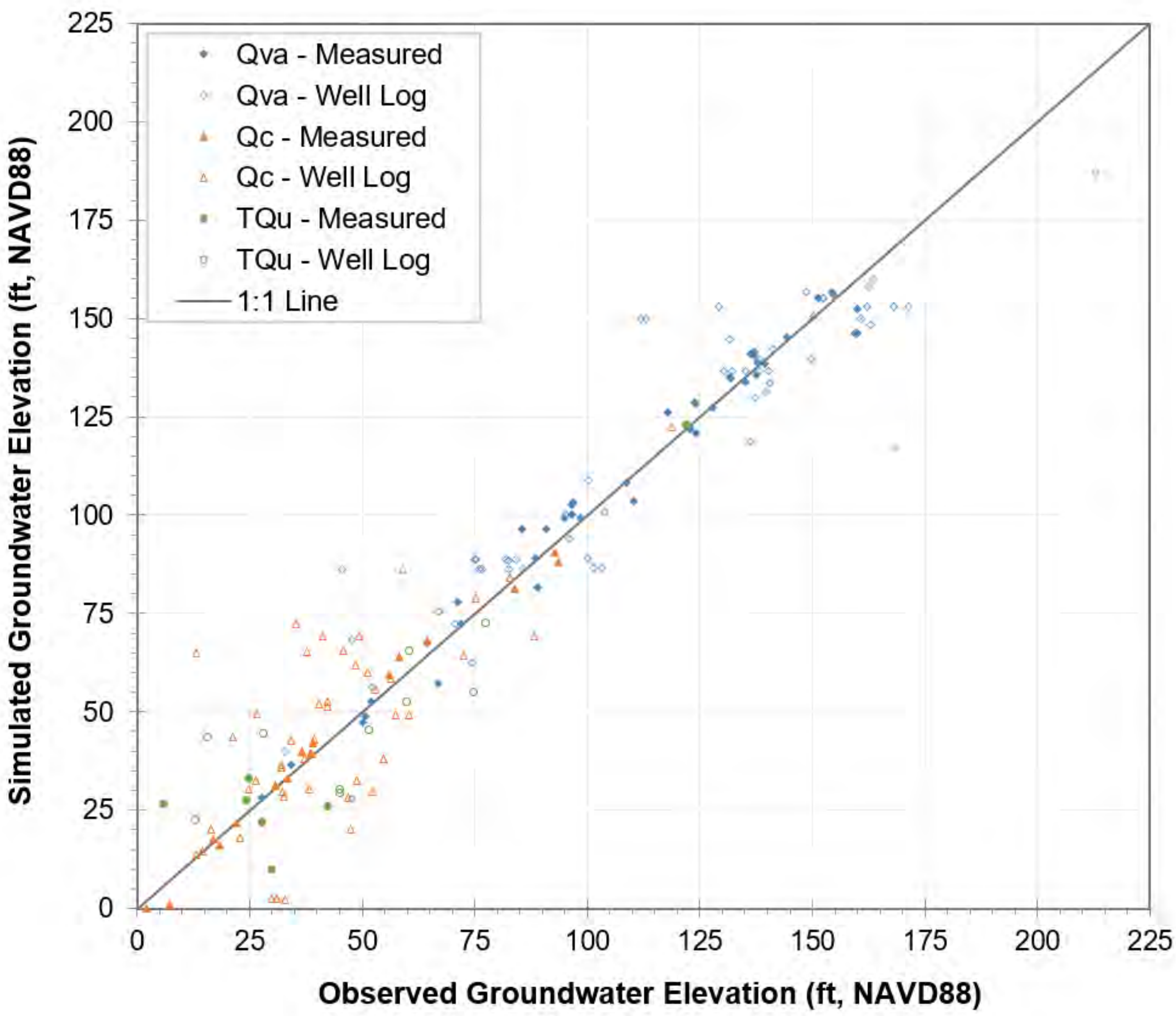
NOTE:
1. Vertical datum for groundwater elevations is NAVD 88.
2. Displayed residuals are rounded to the nearest foot.

Miles
0 1

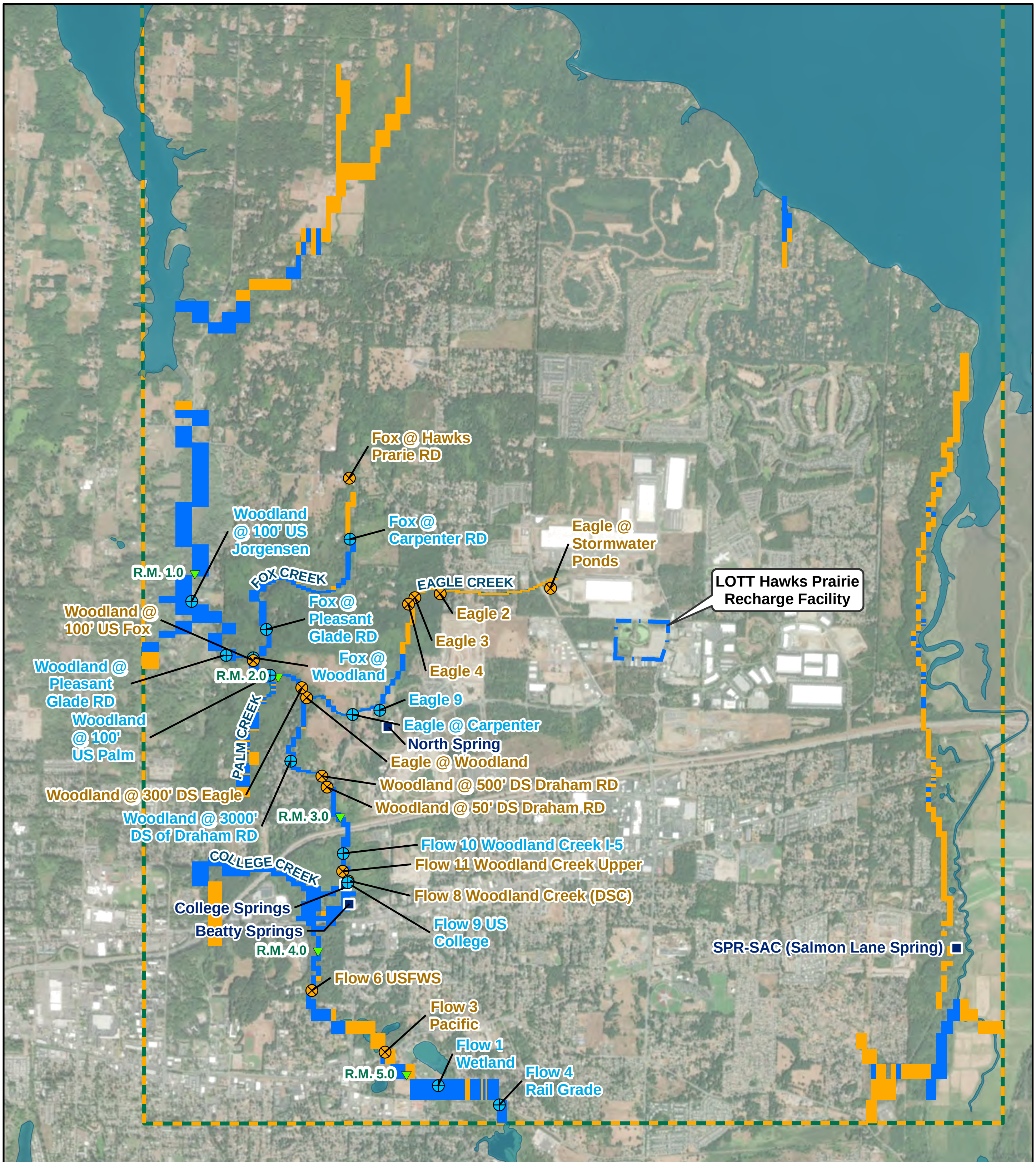
Source: City of Lacey (2018), Ecology (2015), Esri (2018), Thurston Co Landfill (2018), WSDOT (2018)

Path: G:\Projects\Washington\LOTT_CWA_201266\GW_Recharge_Study_184879\Map_Docs\GroundwaterModeling\Final\Fig19b_Residuals_TQu_L7.mxd | Print Date: 2/3/2020

Figure 20. Observed Groundwater Elevations Compared to Simulated Groundwater Elevations



This page intentionally left blank.



Source: Bing Maps (2011), Thurston County (2013), WSDOT (2013), City of Lacey (2002), River Miles approximated from WA DOE TMDL Study figures

No Groundwater Inflow Observed Between Reaches

Groundwater Inflow Observed Between Reaches

Groundwater Inflow Simulated to Drain Cell

No Groundwater Inflow Simulated to Drain Cell

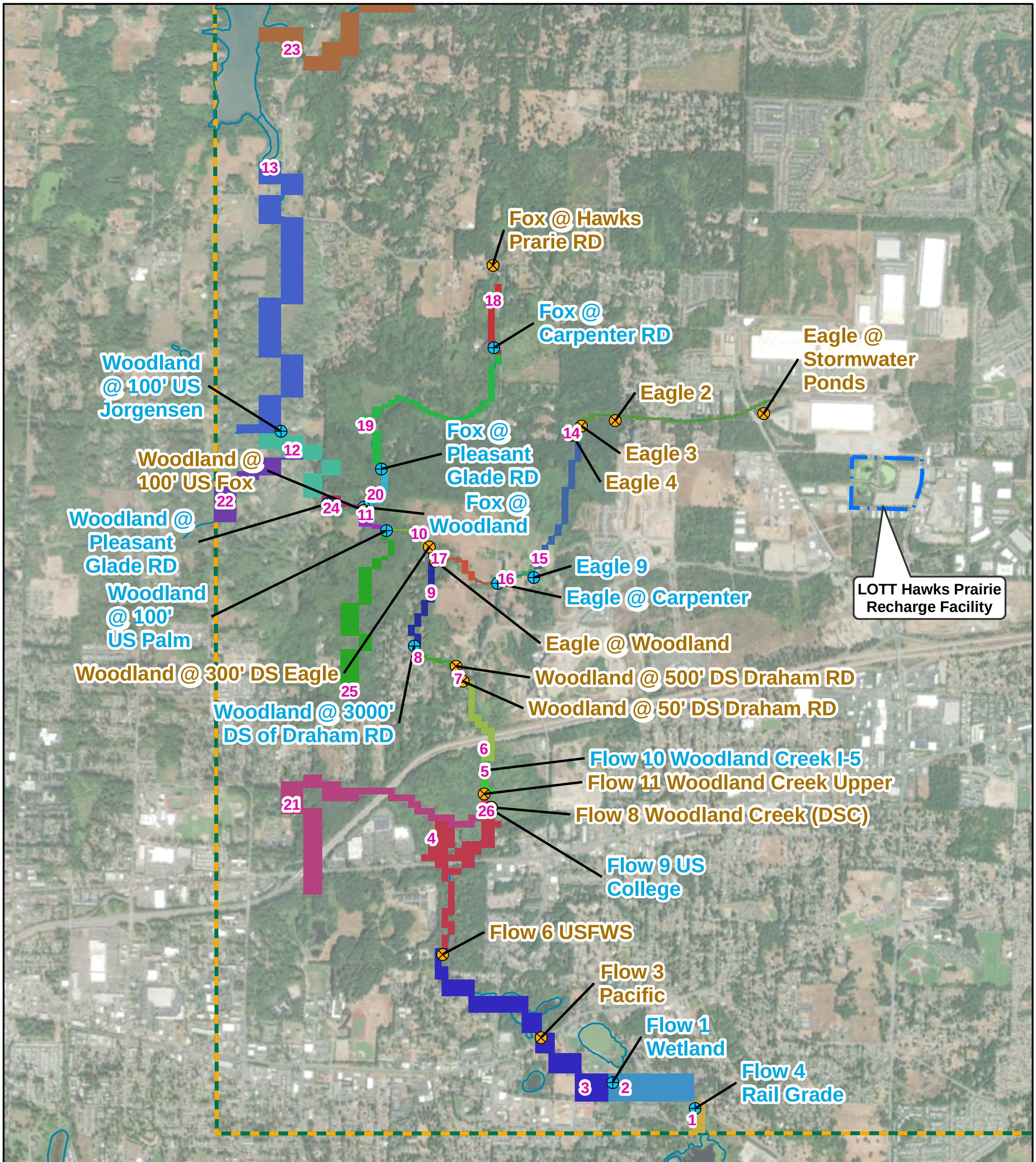
Miles

0 1

LOTT Clean Water Alliance

Figure 21
Simulated and Observed Stream Reaches Receiving Groundwater Inflow

Document Path: G:\Projects\Washington\LOTT_CWA_201266\GW_Recharge_Study_184879\Map_Docs\GroundwaterModeling\Final\Fig21_DrainsReceivingGW.mxd



Document Path: G:\Projects\Washington\LOTT_CWA_201266\GW_Recharge_Study_184879\Map_Docs\GroundwaterModeling\Final\Fig22_StreamReaches.mxd

Source: Bing Maps (2011), Thurston County (2013), WSDOT (2013), City of Lacey (2002), River Miles approximated from WA DOE TMDL Study figures

No Groundwater Inflow Observed Between Reaches

Groundwater Inflow Observed Between Reaches

Reach

1	8	17
2	9	18
3	10	19
4	11	20
5	12	21
6	13	22
7	14	23
	15	24
	16	25

0 0.5 Miles

Figure 22

Stream Reaches for Water Budget

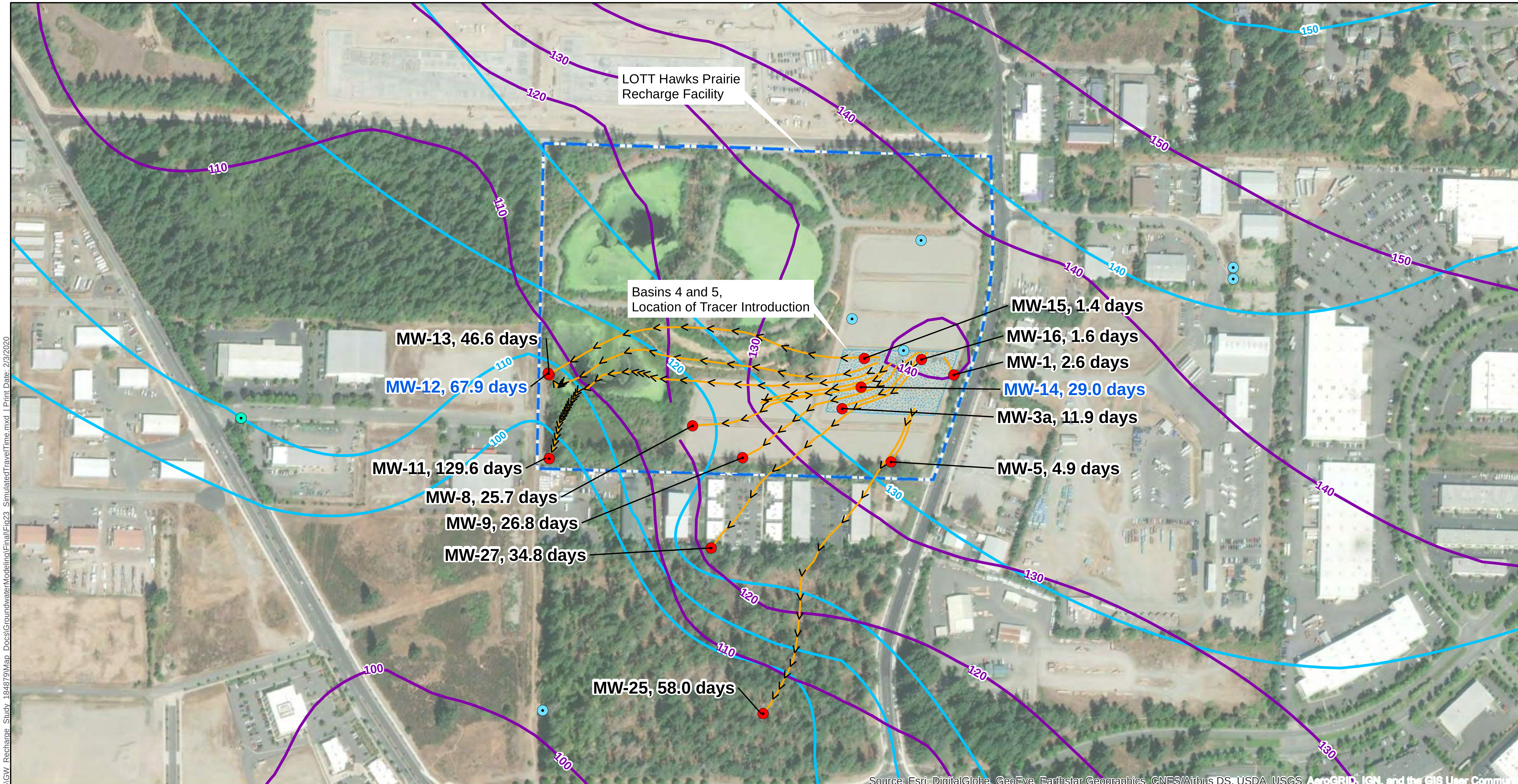


Figure 23
Simulated Travel Time

- Shallow Monitoring Well with Tracer Detection, Simulated Travel Time
- Sea-Level Monitoring Well with Tracer Detection, Simulated Travel Time
- Monitoring Well Without Tracer Detection
- Monitoring Well With Possible Tracer Detection
- Modeled Travel Time (arrows every 5 days)
- Modeled Flow Path
- Observed Groundwater Elevation Contours (ft)
- Modeled Groundwater Elevation Contours (ft)
- LOTT Hawks Prairie Recharge Facility
- Basins 4 and 5

NOTE:
1. Vertical datum for groundwater elevations is NAVD 88.
2. Observed groundwater potentiometric elevation contours are based on June, 2018 water elevations.

Miles

0 0.5

LOTT Clean Water Alliance

HDR

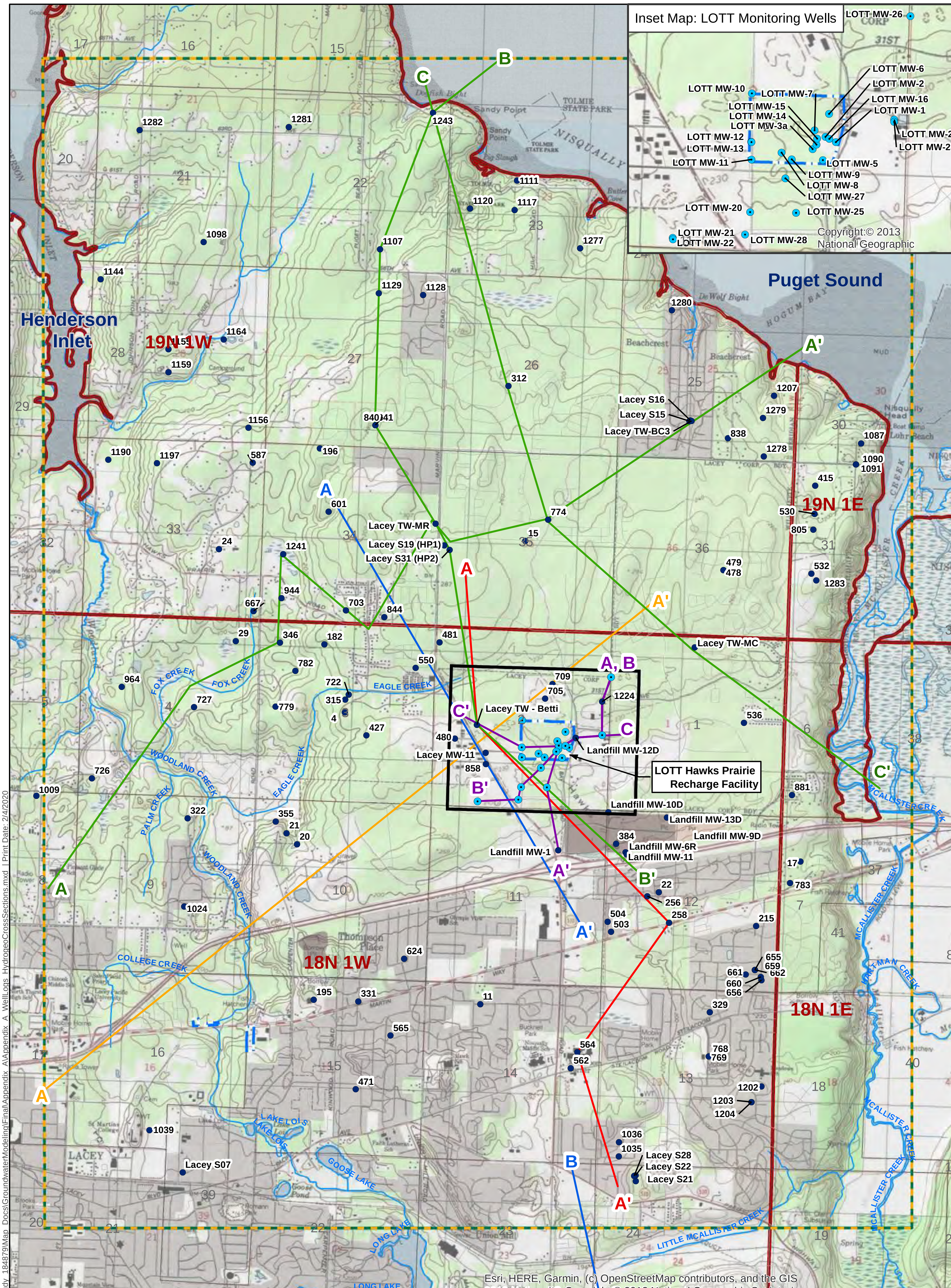
Path: G:\Projects\Washington\LOTT_CWA_201266\GW_Recharge_Study_184879\Map_Docs\GroundwaterModeling\Final\Fig23_SimulatedTravelTime.mxd | Print Date: 2/3/2020

Source: City of Lacey (2018), Ecology (2015), Esri (2018), Thurston Co Landfill (2018), WSDOT (2018)

This page intentionally left blank.

Appendix A – Cross Sections from Prior Groundwater Supply Investigation Reports and Corresponding Hydrostratigraphic Model Cross Sections

This page intentionally left blank.



Path: G:\Projects\Washington\LOTT_CWA_201266\GW_Recharge_Study_184879\Map_Docs\GroundwaterModeling\Final\Appendix_A\Appendix_A_WellLogs_HydrogeoCrossSections.mxd | Print Date: 2/4/2020

Well Logs used in Hydrostratigraphy Model and Hydrogeologic Cross Sections

Wells

- Study ID
- LOTT Monitoring Wells

Cross Sections

- HDR 2017
- NWLW 2008
- PGG 2004
- Landau 2016
- Brown and Caldwell 2004

- LOTT Hawks Prairie Recharge Facility
- Groundwater Model Domain
- Roads
- Section
- Township/Range
- Streams

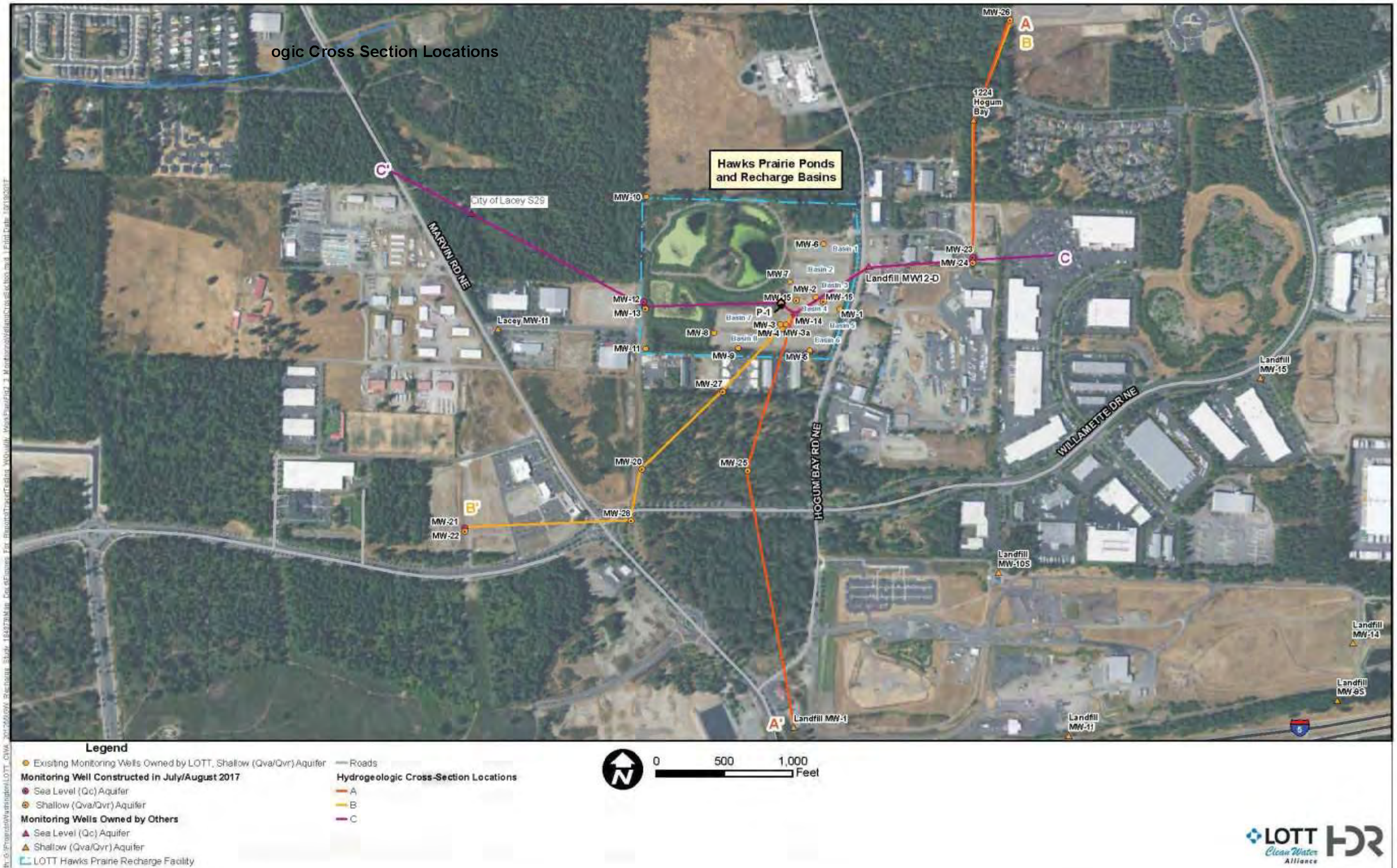
Note:
Wells located from WA Dept. of Ecology, City of Lacey, Thurston County, and LOTT Clean Water Alliance. Wells are located to the centroid of the quarter-quarter section; where available well locations were corrected to address given on well log.

Miles
0 1

LOTT Clean Water Alliance

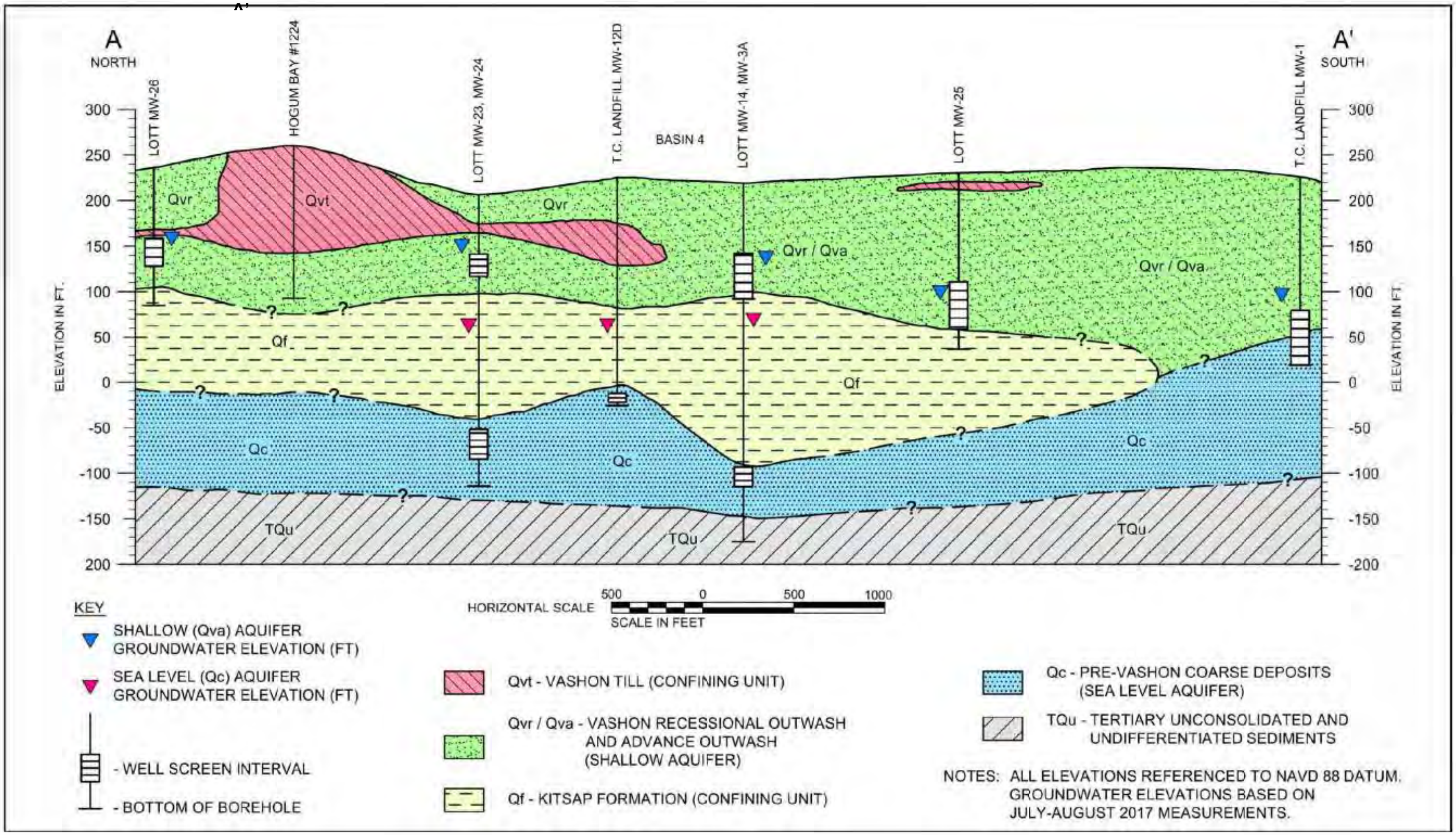
HDR

Source: WA Dept. of Ecology (2015), City of Lacey (2014), WSDOT (2013)



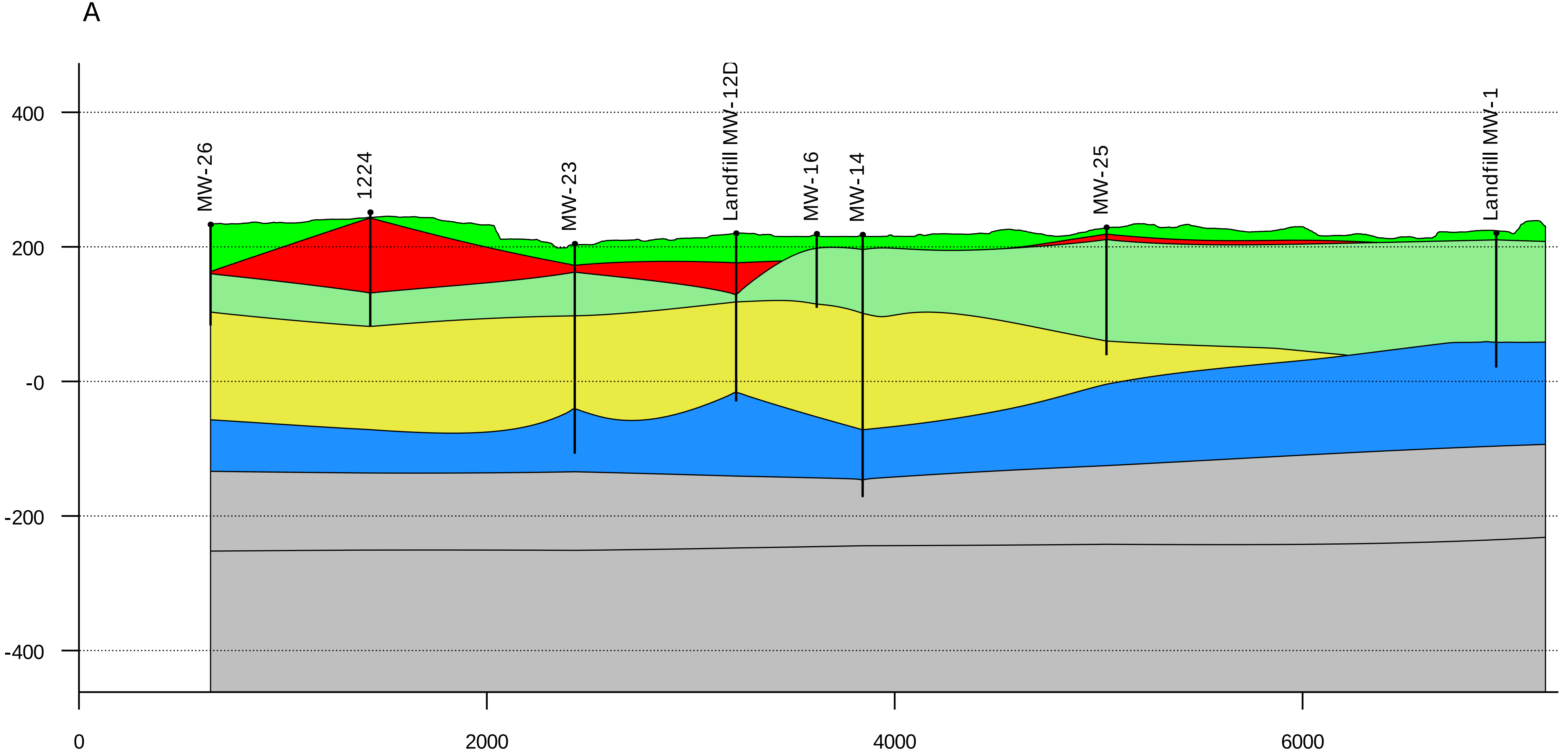
Source: Bing Maps (2011), City of Lacey (2014), WSDOT (2013)

Hydrogeologic Cross Sections, HDR 2017



Hydrogeologic Cross Sections, HDR 2017

HDR 2017 A - A'



Final Geo Model 0319

LCU | Qva | TQu
Qc | Qvr
Qf | Qvt

Scale: 1:8,700

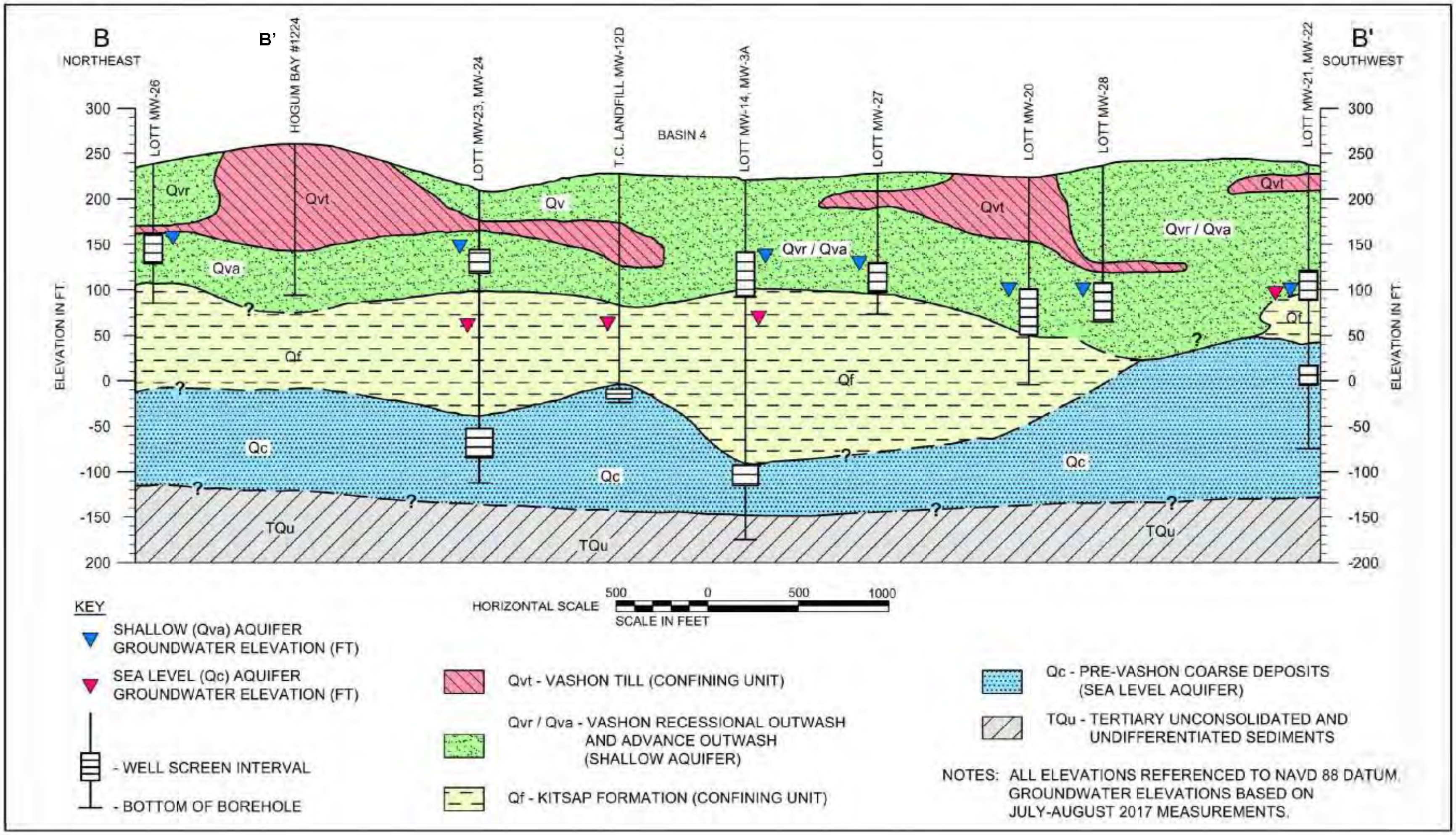
Vertical exaggeration: 3.3x

0ft 1000ft

Location

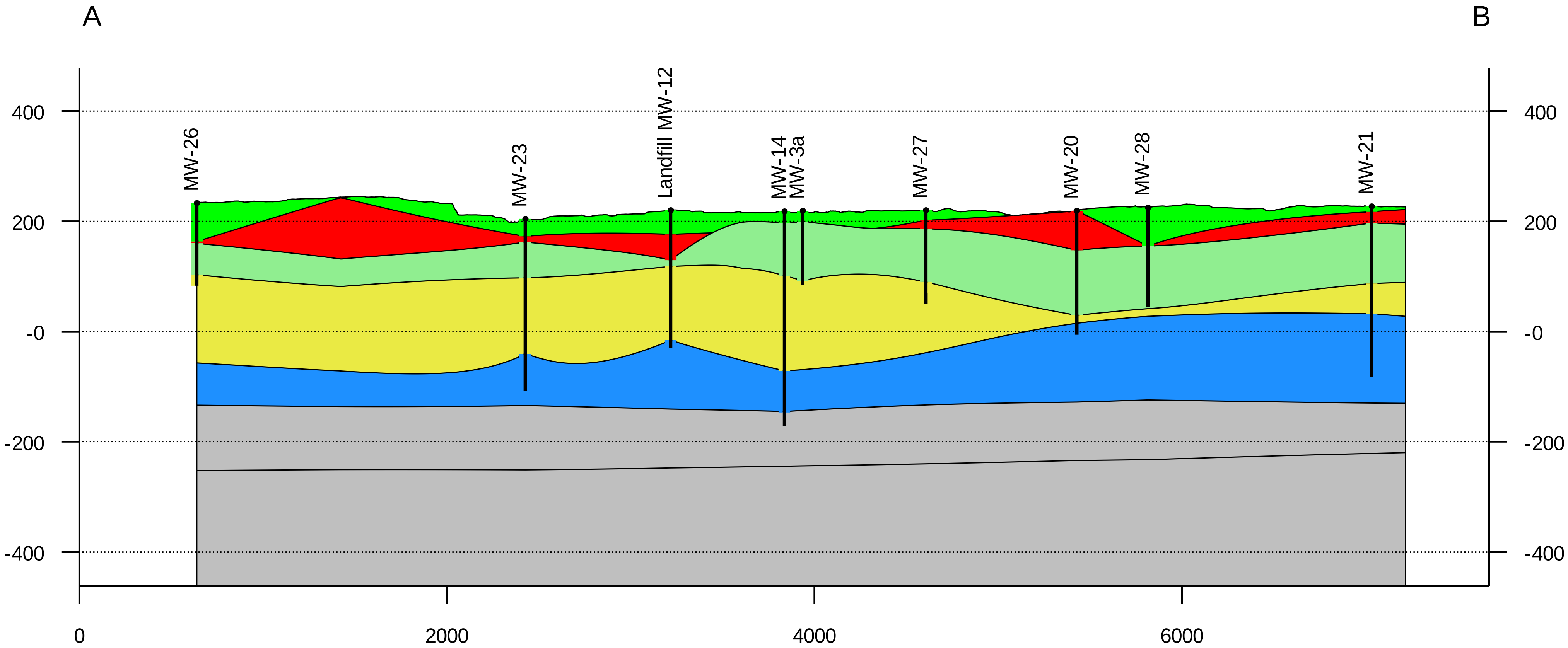
A: 1077794, 645403

B: 1076129, 638836



Hydrogeologic Cross Sections, HDR 2017

HDR 2017 B - B'



Hydrostratigraphic Unit

LCU Qva TQu
Qc Qvr
Qf Qvt

Scale: 1:9,700

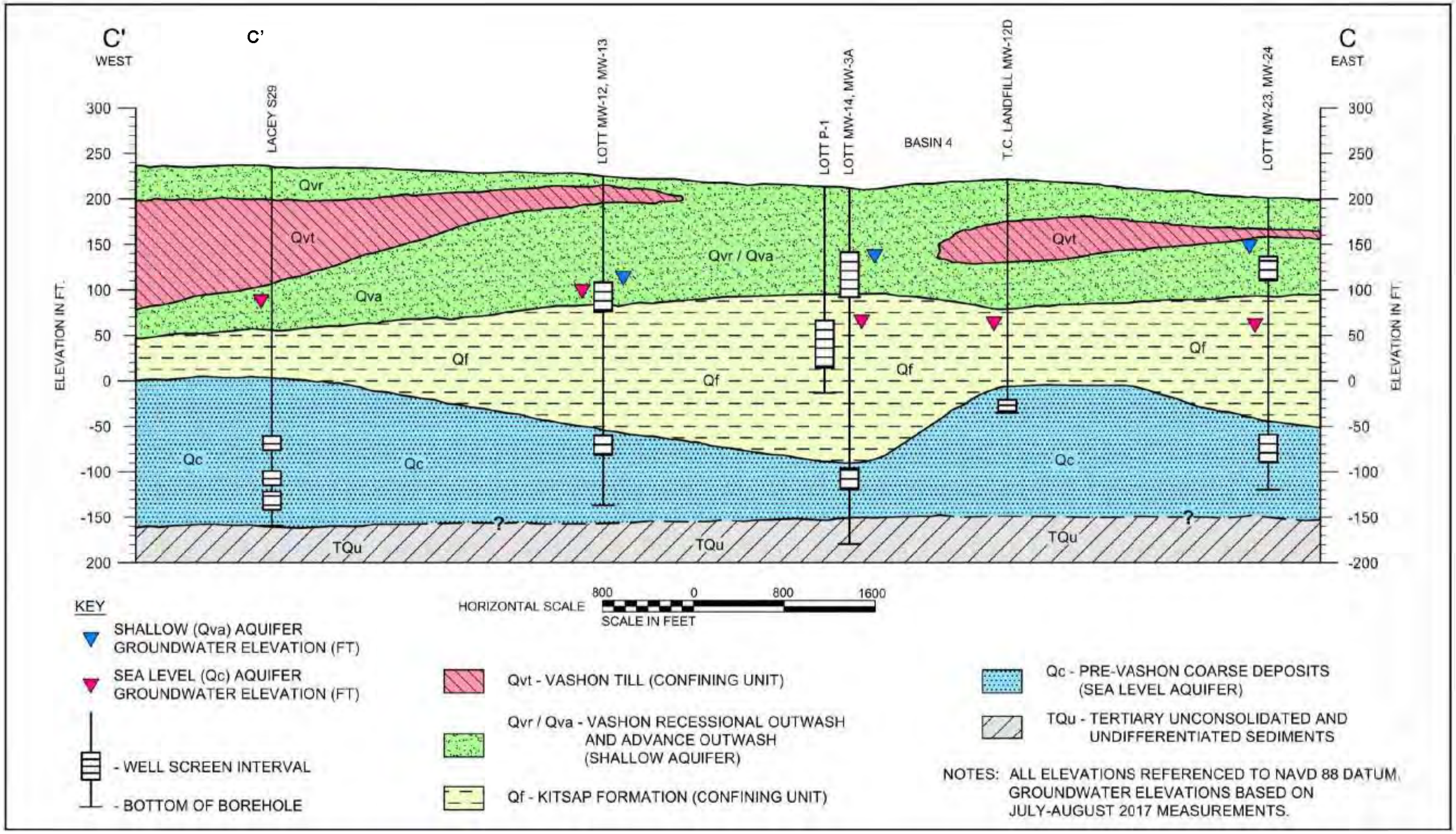
Vertical exaggeration: 3x

0ft 1000ft

Location

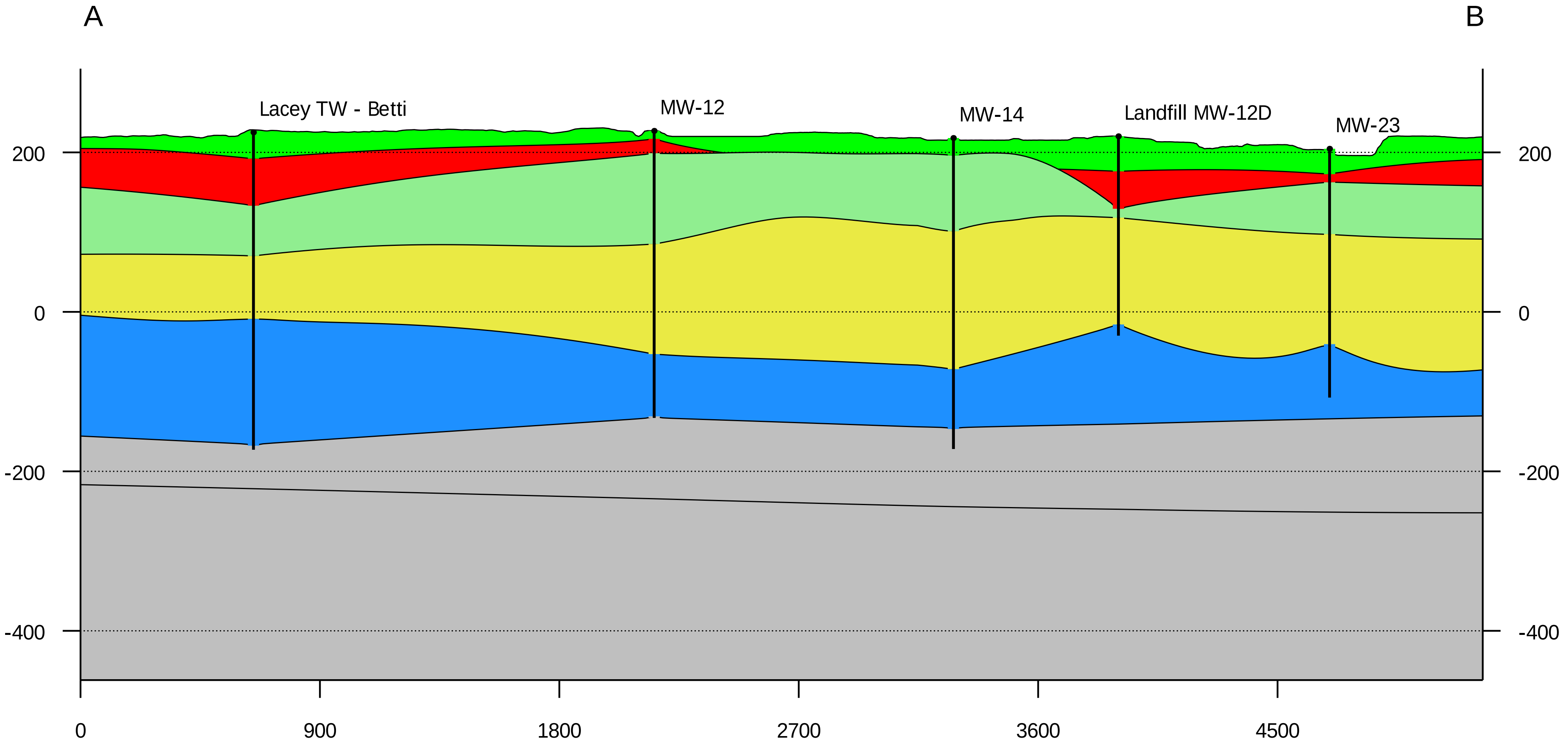
A: 1077792, 645398

B: 1072935, 641049



Hydrogeologic Cross Sections, HDR 2017

HDR 2017 C - C'



Hydrostratigraphic Unit

LCU
Qva
TQu
Qc
Qvr
Qf
Qvt

Scale: 1:6,800

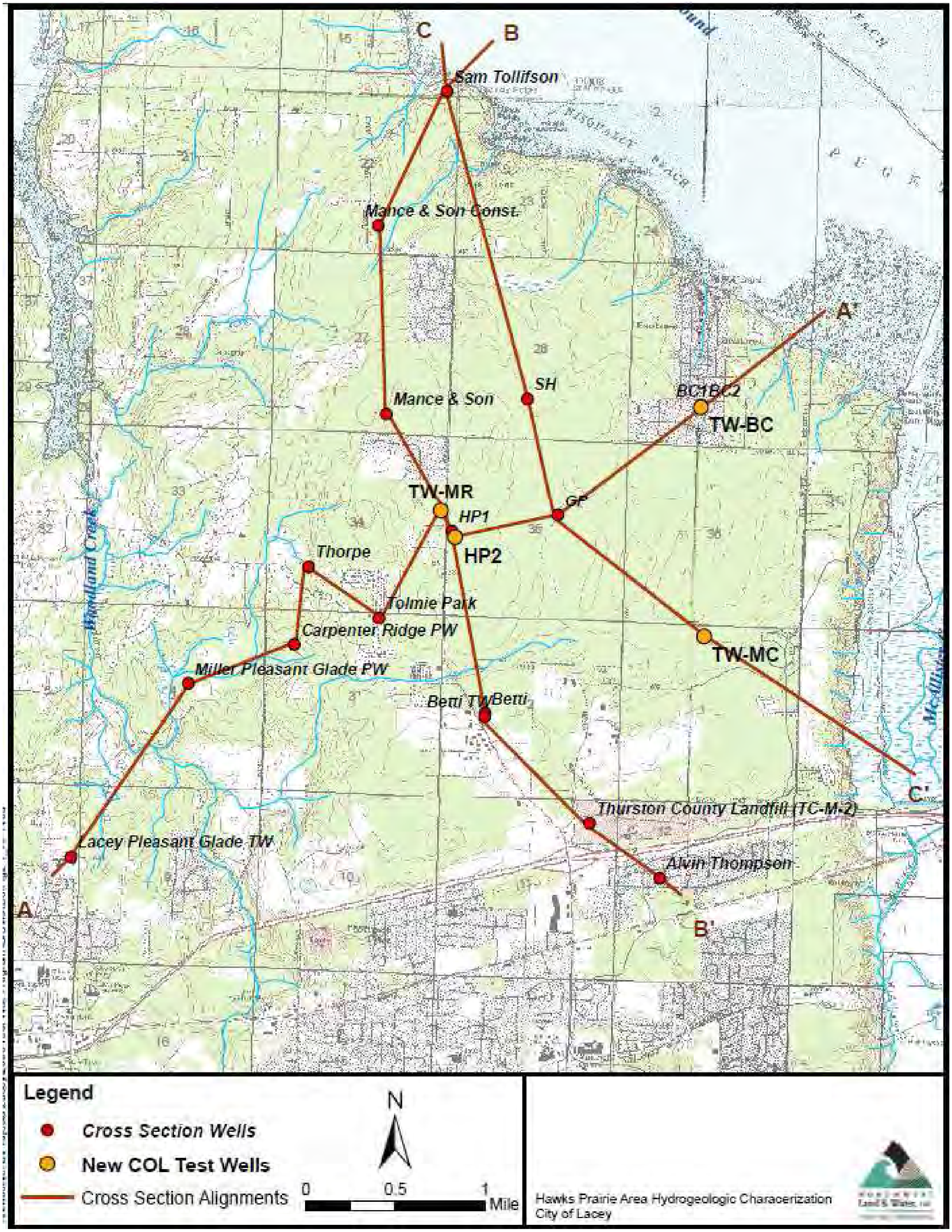
Vertical exaggeration: 3x

0ft 1000ft

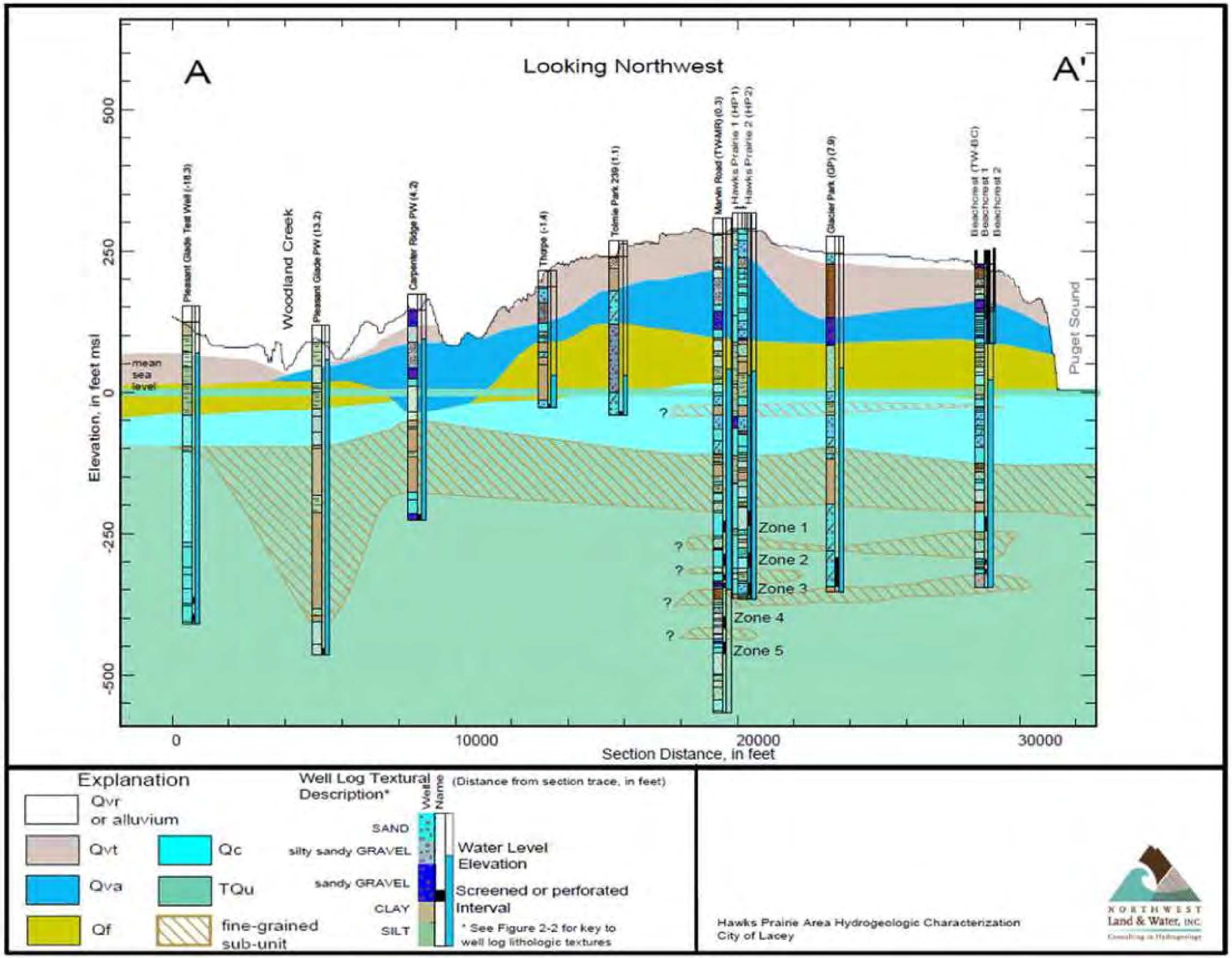
Location

A: 1072975, 643676

B: 1077875, 643075

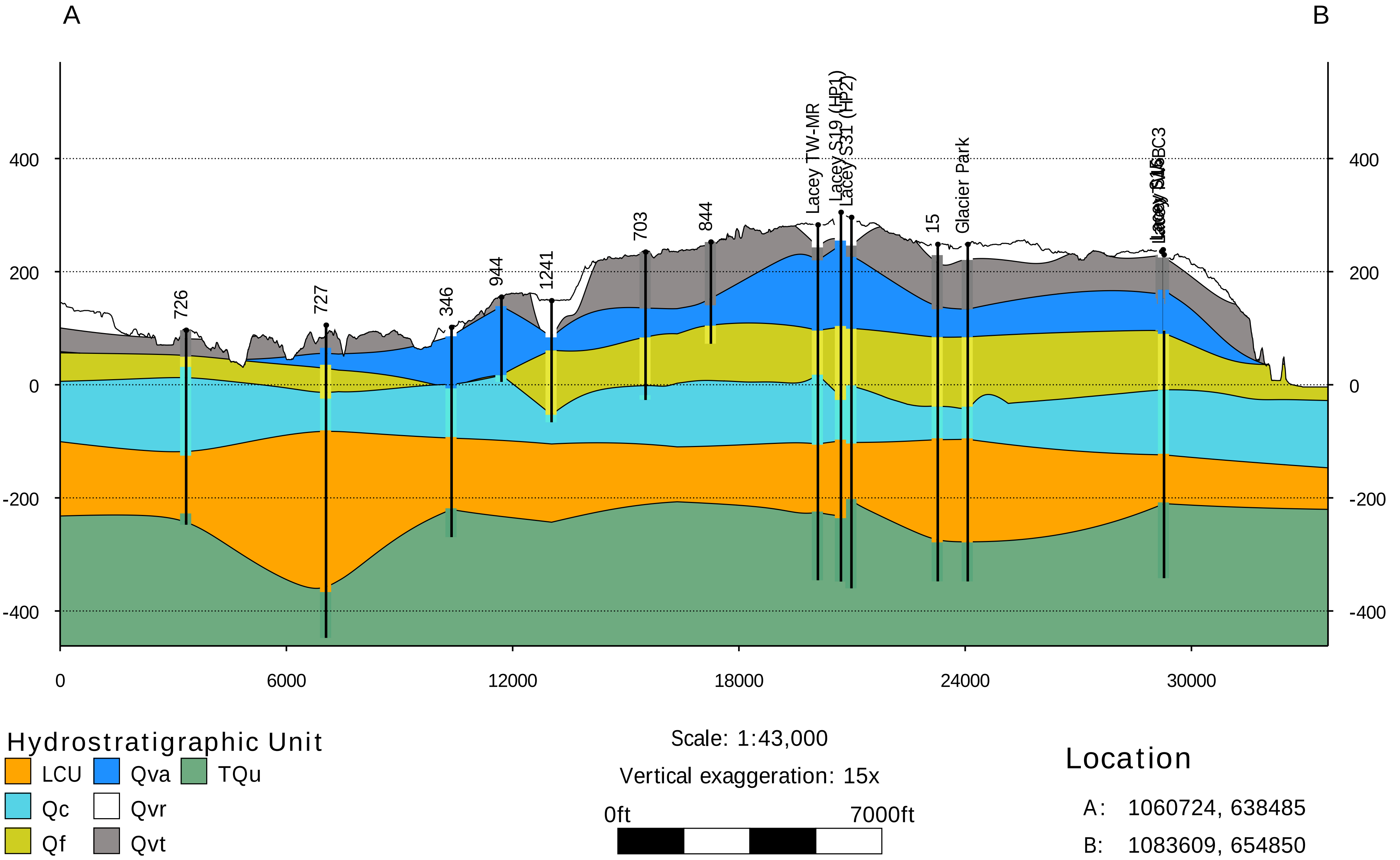


Hydrogeologic Cross Sections, NWLW 2008

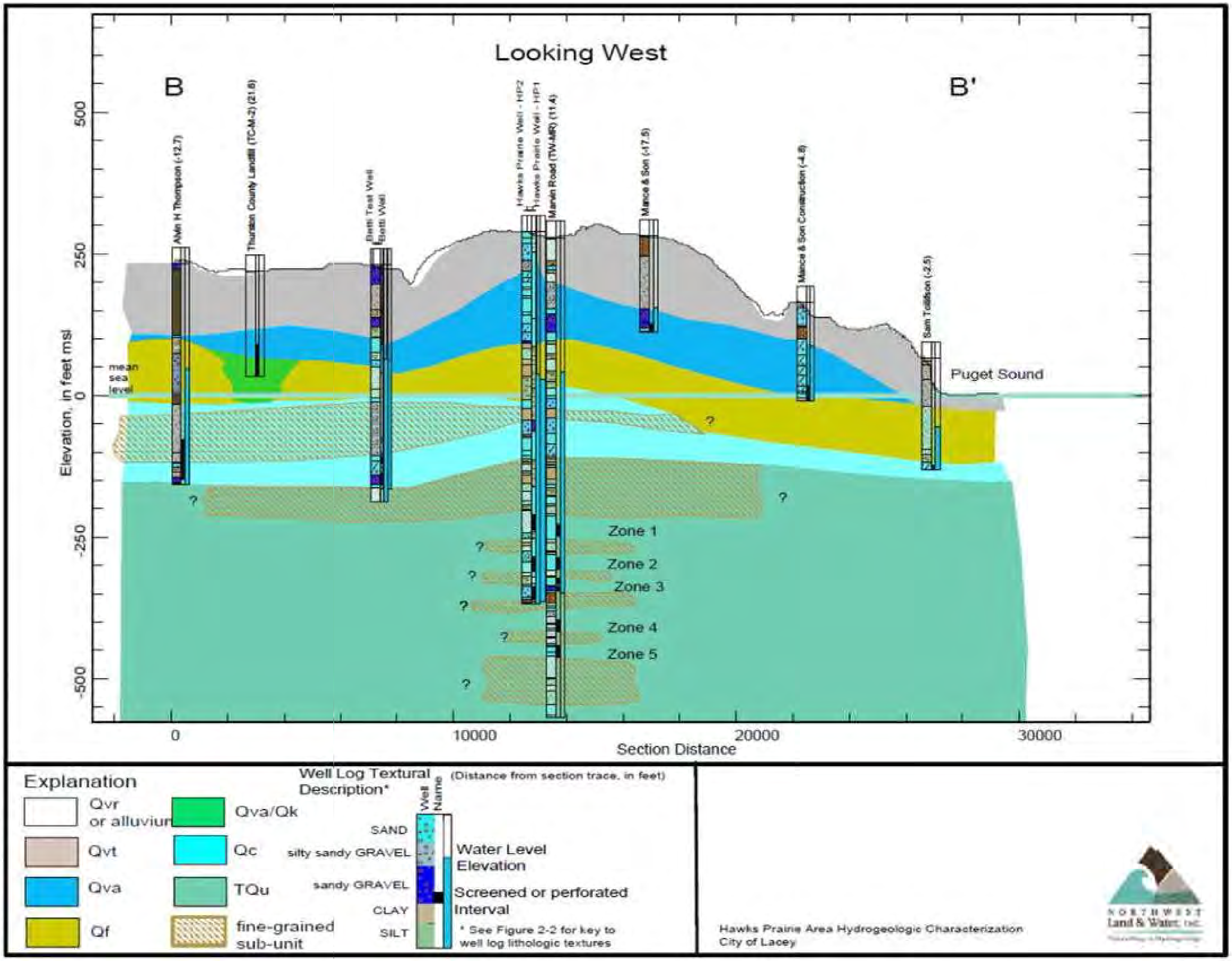


Hydrogeologic Cross Sections, NWLW 2008

NWLW 2008 A - A'

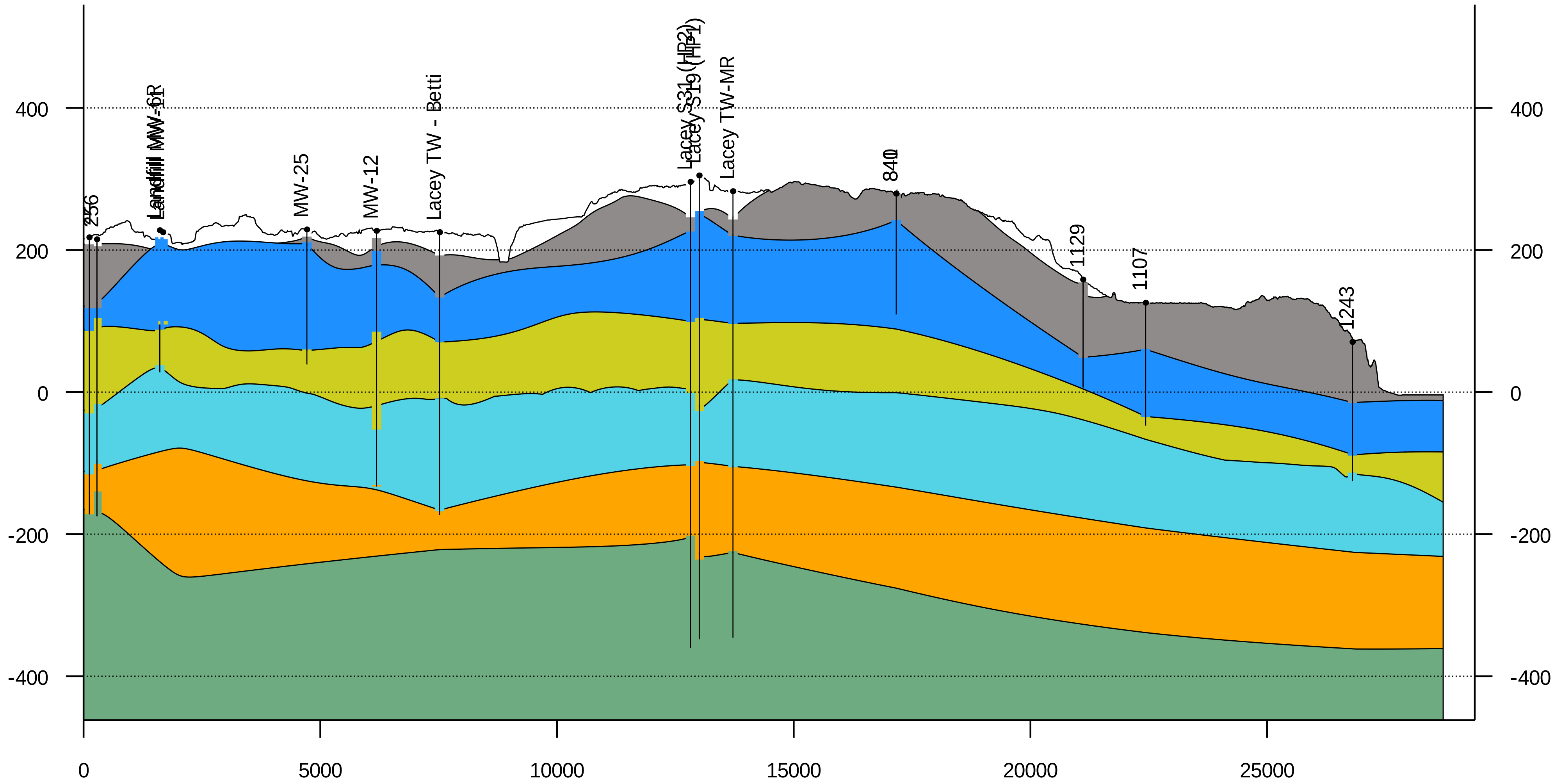


A
B
400
200
0
-200
-400
726
727
346
944
1241
703
844
Lacey TW-MR
Lacey S19 (HP1)
Lacey S31 (HP2)
15
Glacier Park
0
6000
12000
18000
24000
30000
Hydrostratigraphic Unit
LCU
Qva
TQu
Qc
Qvr
Qf
Qvt
Scale: 1:43,000
Vertical exaggeration: 15x
0ft
7000ft
Location
A: 1060724, 638485
B: 1083609, 654850



Hydrogeologic Cross Sections, NWLW 2008

NWLW 2008 B - B'



Hydrostratigraphic Unit

LCU
Qva
TQu
Qc
Qvr
Qf
Qvt

Scale: 1:38,000

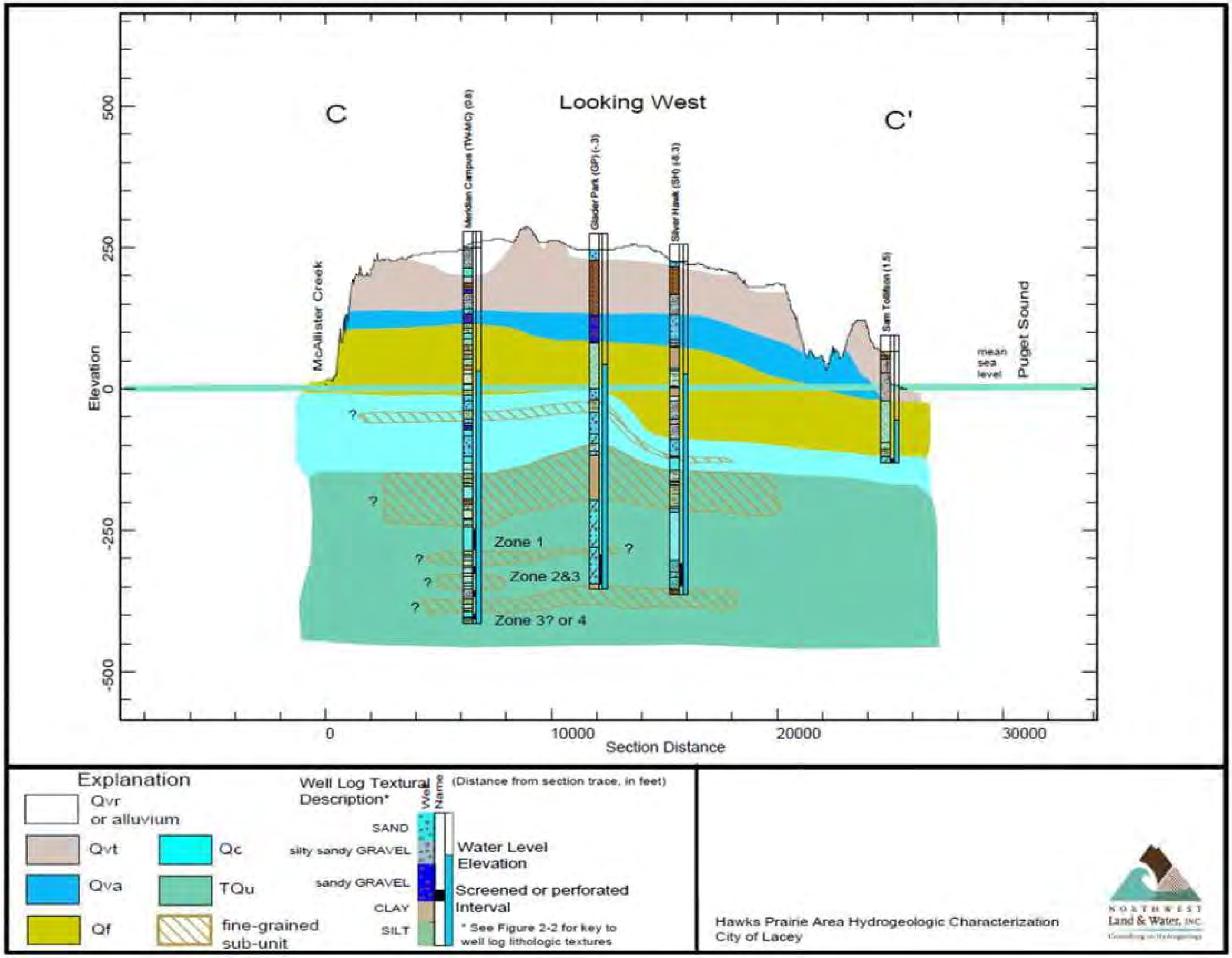
Vertical exaggeration: 15x

0ft 6000ft

Location

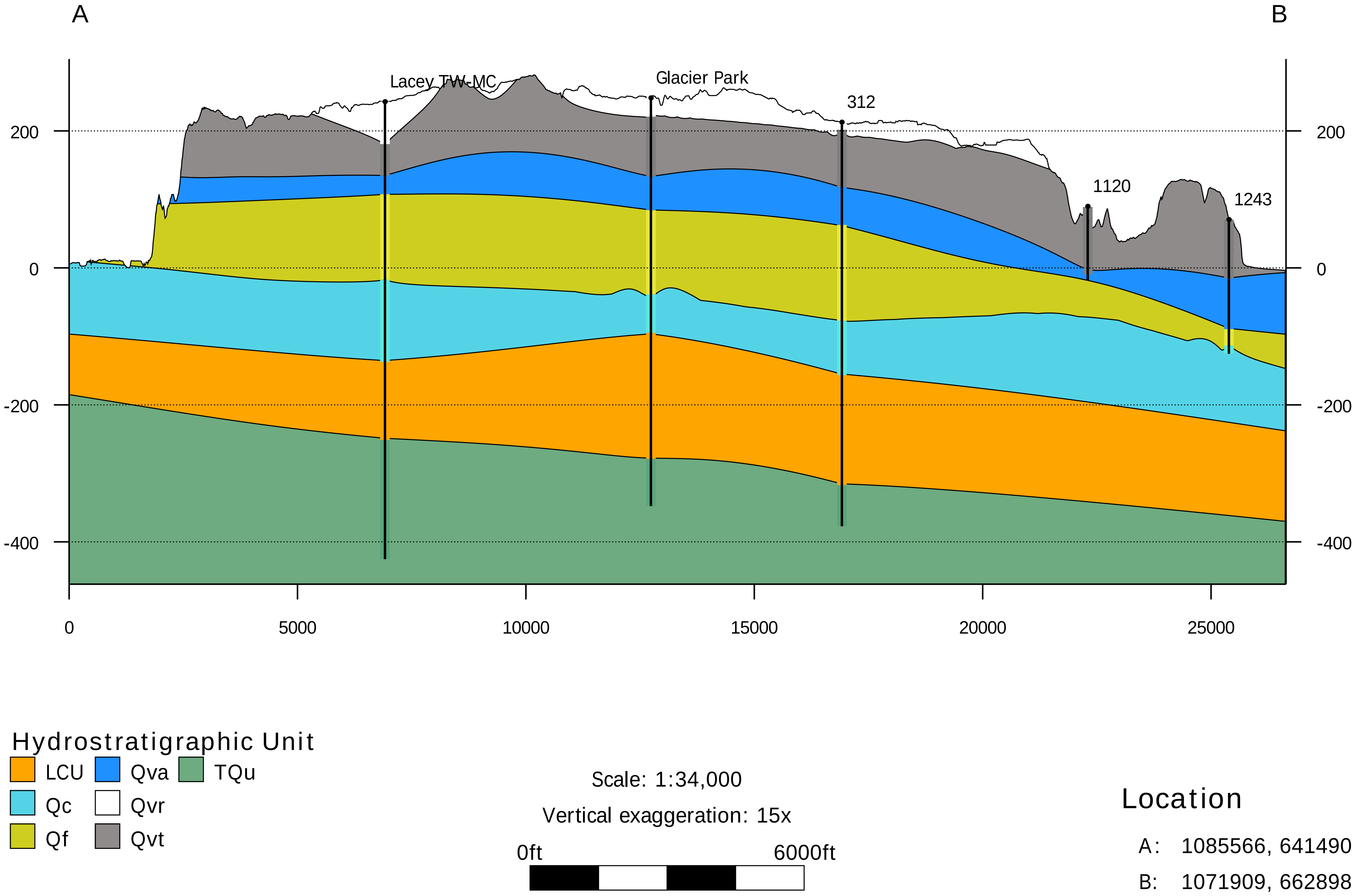
A: 1079081, 638275

B: 1074256, 663294

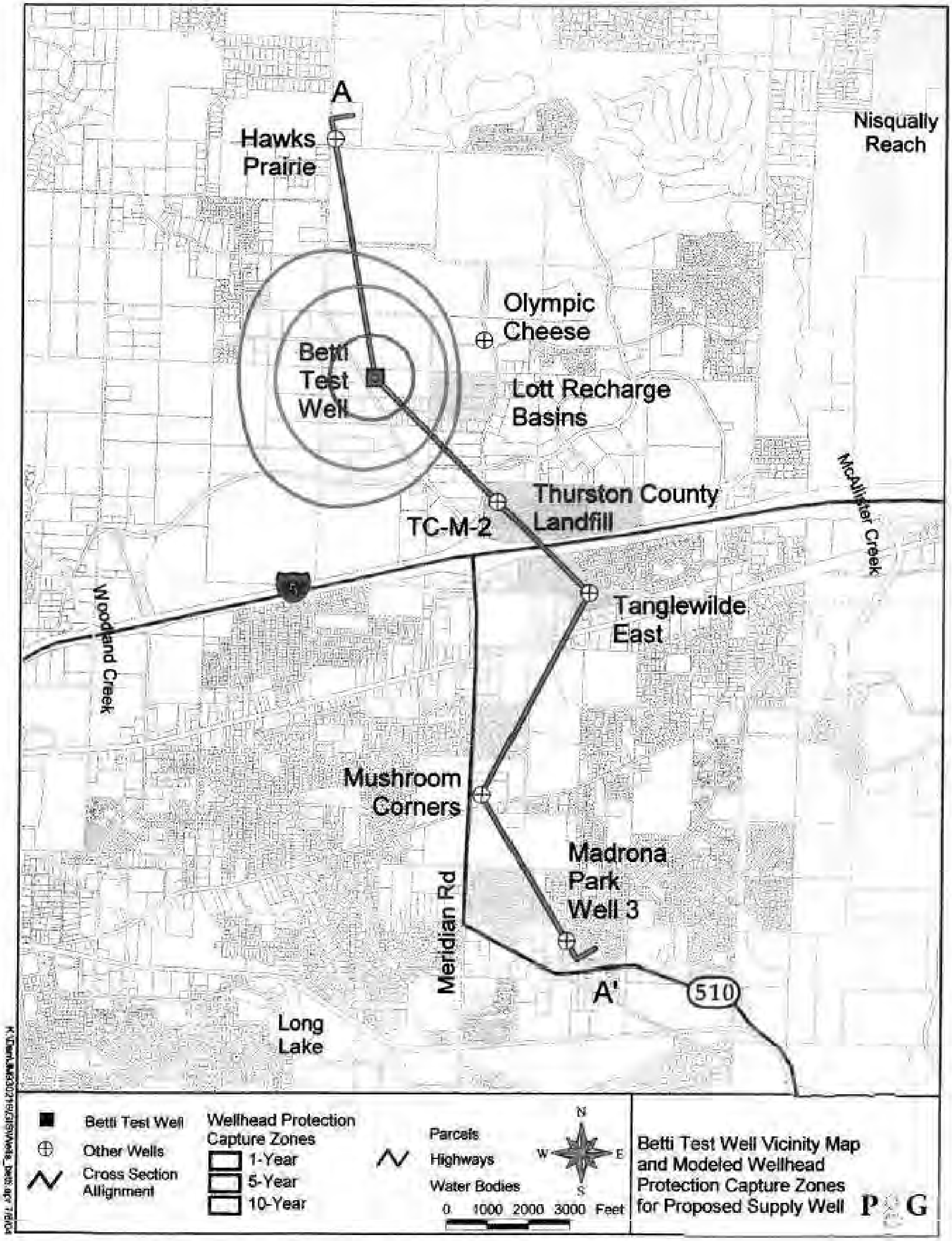


Hydrogeologic Cross Sections, NWLW 2008

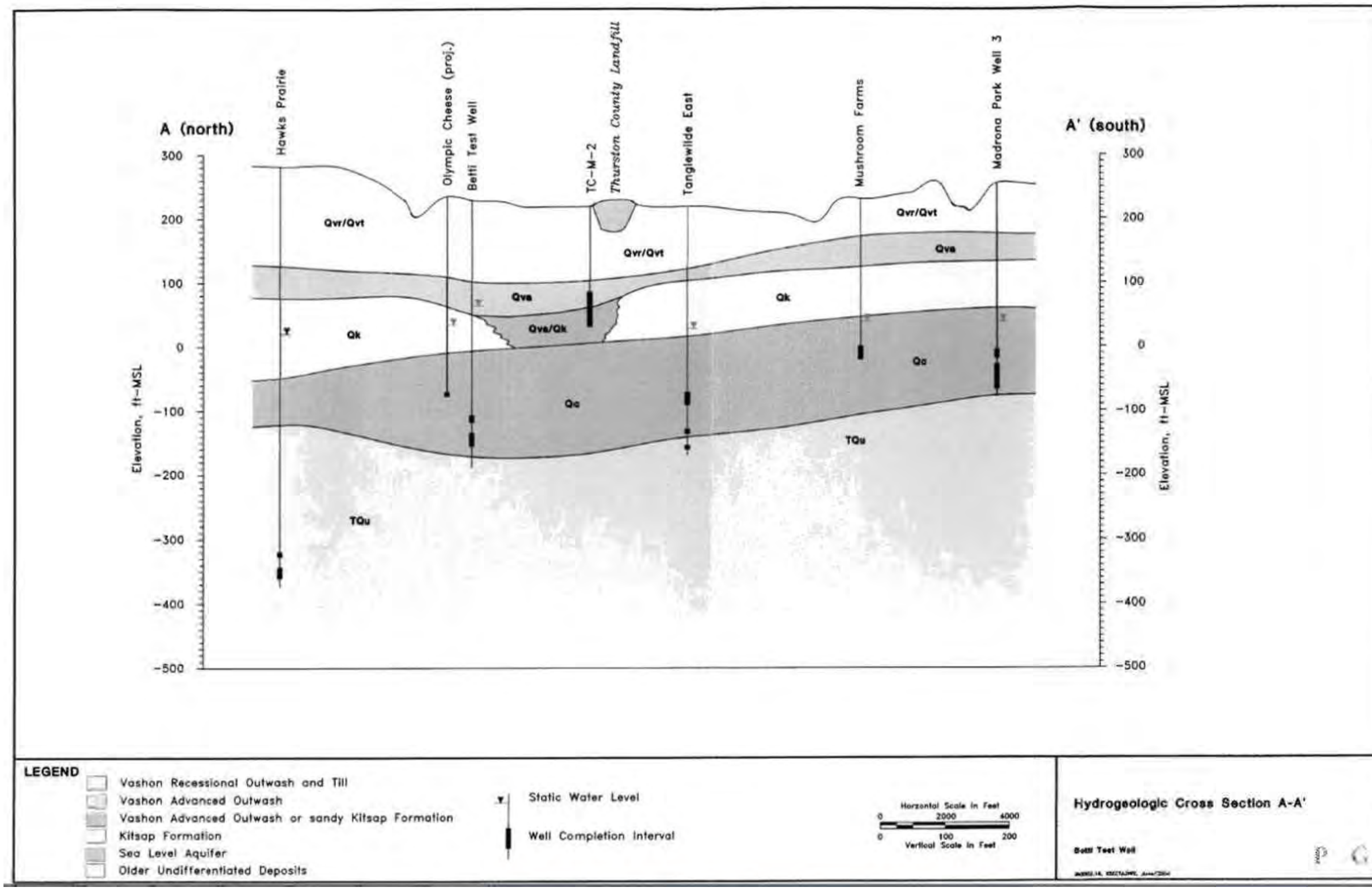
NWLW 2008 C - C'



A
B
Lacey TW-MC
Glacier Park
312
1120
1243
200
0
-200
-400
0
5000
10000
15000
20000
25000
Hydrostratigraphic Unit
LCU
Qva
TQu
Qc
Qvr
Qf
Qvt
Scale: 1:34,000
Vertical exaggeration: 15x
0ft
6000ft
Location
A: 1085566, 641490
B: 1071909, 662898

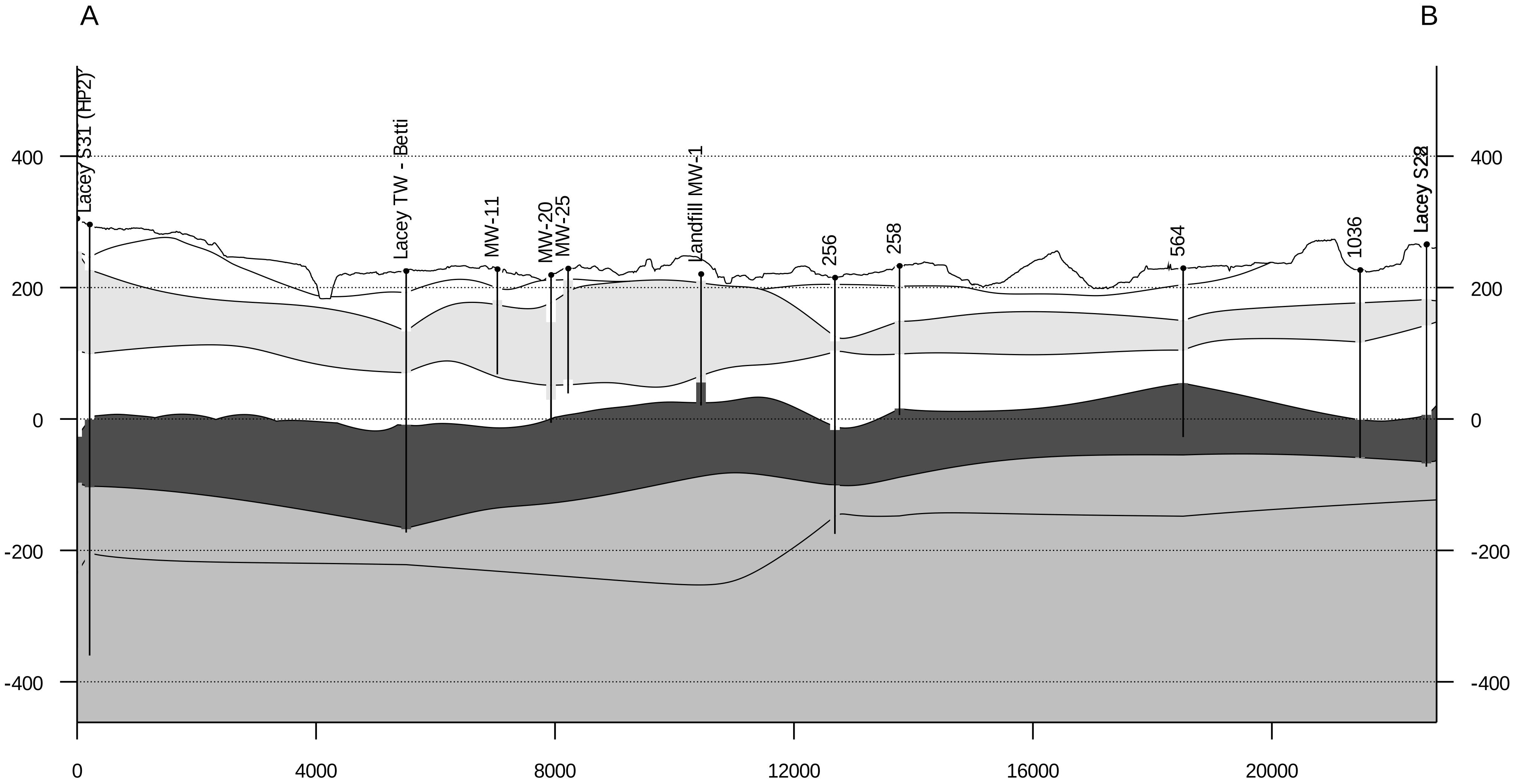


Hydrogeologic Cross Sections, PGG 2004



Hydrogeologic Cross Sections, PGG 2004

PGG 2004 A - A'



Hydrostratigraphic Unit

LCU
Qva
TQu
Qc
Qvr
Qf
Qvt

Scale: 1:29,000

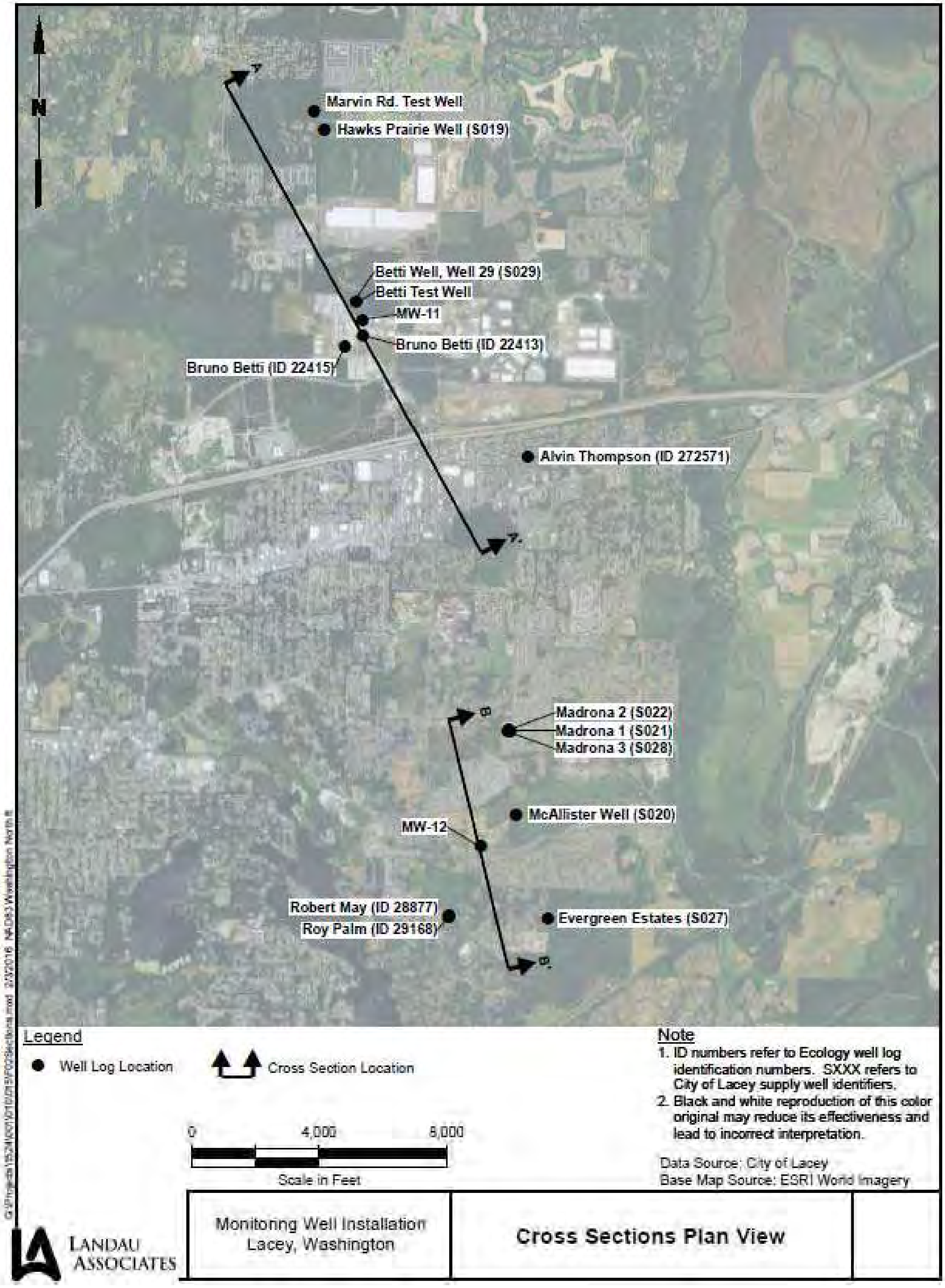
Vertical exaggeration: 11x

0ft 5000ft

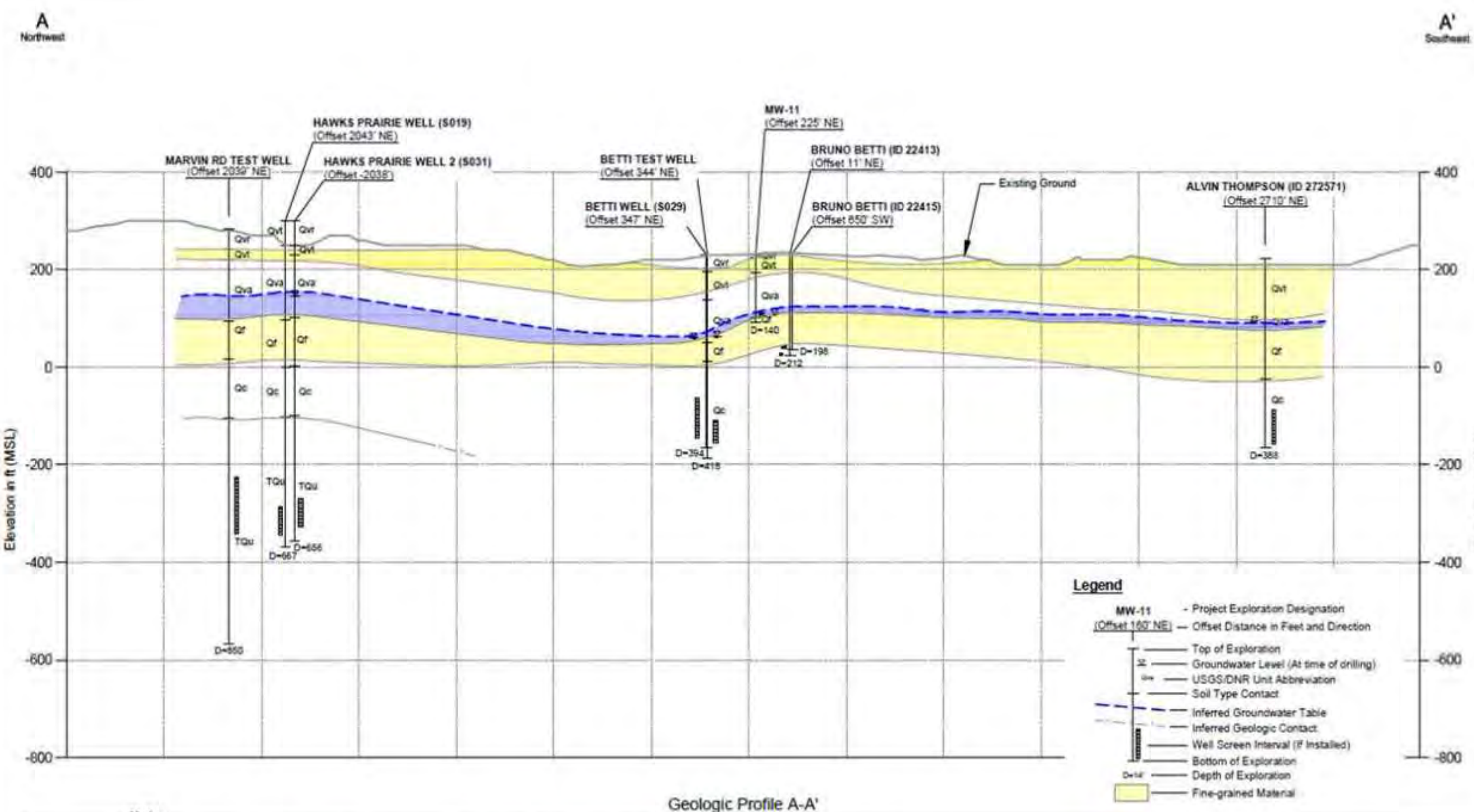
Location

A: 1072576, 648745

B: 1078305, 629705



Hydrogeologic Cross Sections, Landau 2016



Notes

1. Soil descriptions are generalized, based on interpretation of field and laboratory data. Stratigraphic contacts are interpolated between borings and based on topographic features; actual conditions may vary.
2. See report text for descriptions of geologic units.
3. For Cross Section location, see the Site and Exploration Plan, Figure 2.
4. Black and white reproduction of this color original may reduce its effectiveness and lead to incorrect interpretation.

0 1200 2400
Scale in Feet
6x Vertical Exaggeration

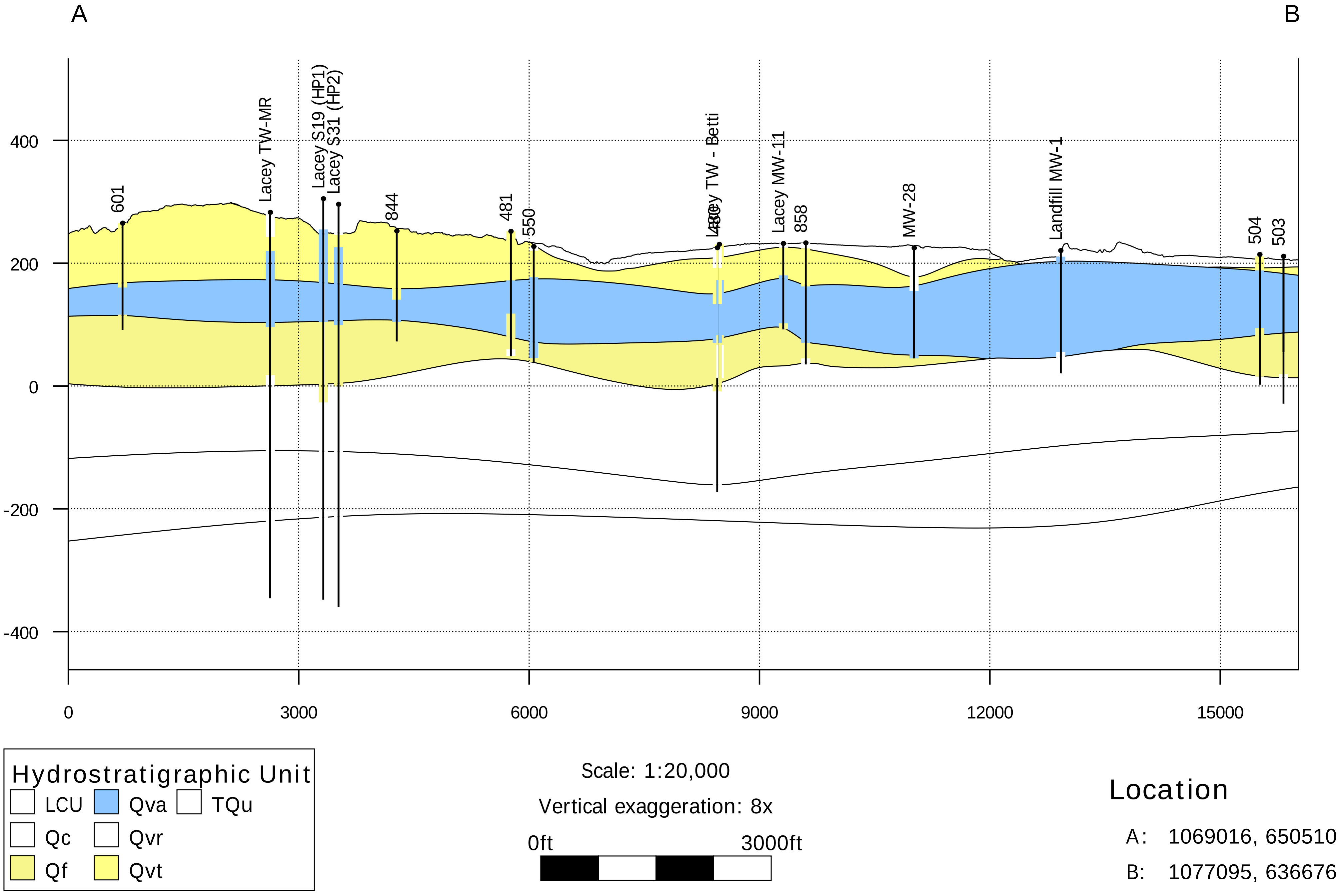
Source: PSLC Lidar Data

LANDAU ASSOCIATES

Monitoring Well Installation Lacey, Washington	Cross Section A-A'

Hydrogeologic Cross Sections, Landau 2016

Landau 2016 A - A'



Appendix B – Well Logs

(Provided electronically)

This page intentionally left blank.

Appendix C – Hydraulic Conductivity Calculated from Grain Size Analysis

This page intentionally left blank.

Hydraulic Conductivity Calculated from Grain Size Analysis of Soil Samples Collected from LOTT Hawks Prairie Property Area (HDR 2017b)

Well ID	Depth Interval	Formation	Size Fractions [1]			Effective Grain Size [2]			Hydraulic Conductivity Hazen Formula [3]	
			Gravel	Sand	Silt/Clay	d_{10}	d_{50}	d_{90}		
	(feet)		(%)	(%)	(%)	(mm)	(mm)	(mm)	(cm/sec)	ft/day
MW-16 (B2)	18-20	Qva	49.4	43.7	6.9	0.16	4.10	31.00	2.0E-02	58
MW-15 (B1)	28-30	Qva	39.5	56.1	4.4	0.40	2.70	19.00	1.3E-01	363
MW-15 (B1)	38-40	Qva	40.3	56.9	2.8	0.34	3.00	41.00	9.2E-02	262
MW-16 (B2)	38-40	Qva	56.9	36.5	6.6	0.21	7.50	28.00	3.5E-02	100
MW-14 (R)	48-50	Qva	27.3	67.7	5.0	0.23	0.70	23.00	4.2E-02	120
MW-15 (B1)	48-50	Qva	33.3	60.6	6.1	0.21	0.83	24.00	3.5E-02	100
MW-16 (B2)	48-50	Qva	47.0	49.4	3.6	0.48	4.00	21.00	1.8E-01	523
MW-21 (P)	54-56	Qva	53.1	38.8	8.1	0.42	7.90	21.00	1.4E-01	400
MW-12 (O)	56-58	Qva	45.0	52.5	2.5	0.47	3.30	17.00	1.8E-01	501
MW-15 (B1)	58-60	Qva	75.8	17.0	7.2	0.23	18.00	40.00	4.2E-02	120
MW-16 (B2)	58-60	Qva	69.3	24.7	6.0	0.31	11.00	40.00	7.7E-02	218
MW-15 (B1)	68-70	Qva	62.1	30.6	7.3	0.17	8.80	29.00	2.3E-02	66
MW-15 (B1)	18-20	Qva	0.2	45.7	54.1	0.01	0.07	0.30	*4.0E-05*	*0.1*
MW-16 (B2)	68-70	Qva	67.2	27.4	5.4	0.41	10.00	35.00	1.3E-01	381
MW-27 (E)	70-72	Qva	47.2	50.1	2.7	0.36	4.10	14.00	1.0E-01	294
MW-23 (Q)	72-74	Qva	5.1	91.3	3.6	0.22	0.51	1.10	3.9E-02	110
MW-16 (B2)	78-80	Qva	53.1	40.1	6.8	0.17	5.90	24.00	2.3E-02	66
MW-14 (R)	86-88	Qva	51.9	44.8	3.3	0.40	5.10	21.00	1.3E-01	363
MW-12 (O)	88-90	Qva	57.4	38.2	4.4	0.36	7.20	31.00	1.0E-01	294
MW-23 (Q)	95-97	Qva	19.8	74.4	5.8	0.20	0.60	8.40	4.0E-02	113
MW-27 (E)	106-108	Qva	50.6	45.8	3.6	0.43	4.90	29.00	1.5E-01	419
MW-25 (K)	148-150	Qva	52.5	44.6	2.9	0.41	5.20	31.00	1.3E-01	381
MW-25 (K)	166-168	Qva	23.5	72.0	4.5	0.21	1.70	9.50	4.4E-02	125
MW-28 (G)	168-170	Qva	57.6	35.5	6.9	0.20	8.00	30.00	3.2E-02	91
MW-23 (Q)	107-109	Qf	0.0	20.7	79.3	0.00	0.02	0.30	*6.0E-07*	*0.002*
MW-14 (R)	130-132	Qf	0.0	3.6	96.4	0.01	0.02	0.06	*2.2E-05*	*0.06*
MW-26 (J)	138-140	Qf	0.0	9.8	91.2	0.00	0.03	0.08	*3.6E-06*	*0.01*
MW-27 (E)	138-140	Qf	0.0	93.1	6.9	0.10	0.21	0.33	*5.8E-03*	*16*
MW-26 (J)	143-145	Qf	0.0	17.2	82.8	0.00	0.04	0.10	*1.6E-06*	*0.005*
MW-27 (E)	143-145	Qf	0.2	87.5	12.3	0.04	0.28	0.51	*1.1E-03*	*3*
MW-12 (O)	148-150	Qf	0.0	56.6	43.4	0.01	0.09	0.24	*2.9E-05*	*0.08*
MW-21 (P)	148-150	Qf	0.0	48.6	51.4	0.01	0.07	0.19	*4.9E-05*	*0.1*
MW-23 (Q)	160-162	Qf	0.0	10.8	89.2	0.00	0.03	0.08	*1.0E-05*	*0.03*
MW-25 (K)	171-172	Qf	0.0	92.4	7.6	0.09	0.23	0.41	*5.2E-03*	*15*
MW-25 (K)	179-180	Qf	47.5	34.8	17.7	0.02	3.90	19.00	*1.4E-04*	*0.4*
MW-12 (O)	185-187	Qf	0.0	89.8	10.2	0.08	0.21	0.36	*3.4E-03*	*10*
MW-21 (P)	186-188	Qf	1.2	88.8	10.0	0.08	0.22	0.60	*3.4E-03*	*10*
MW-12 (O)	234-236	Qf	0.0	25.9	74.1	0.00	0.03	0.18	*2.4E-06*	*0.007*
MW-21 (P)	228-230	Qc	41.1	56.4	2.5	0.42	3.10	25.00	1.4E-01	400
MW-23 (Q)	273-275	Qc	43.8	50.6	5.6	0.22	2.30	30.00	4.8E-02	137
MW-12 (O)	295-297	Qc	60.1	34.7	4.6	0.71	6.90	21.00	5.0E-01	1,429
MW-23 (Q)	305-307	Qc	6.8	84.1	9.1	0.10	0.81	2.80	*5.4E-03*	*15*
MW-14 (R)	308-310	Qc	7.1	84.7	8.2	0.11	0.92	3.10	1.2E-02	34

Hydraulic Conductivity Calculated from Grain Size Analysis of Soil Samples Collected from LOTT Hawks Prairie Property Area (HDR 2017b)

Well ID	Depth Interval	Formation	Size Fractions [1]			Effective Grain Size [2]			Hydraulic Conductivity Hazen Formula [3]	
			Gravel	Sand	Silt/Clay	d_{10}	d_{50}	d_{90}		
	(feet)		(%)	(%)	(%)	(mm)	(mm)	(mm)	(cm/sec)	ft/day
MW-23 (Q)	314-316	Qc	0.0	33.1	66.9	0.01	0.05	0.12	*7.3E-05*	*0.2*
MW-14 (R)	338-340	Qc	0.0	84.3	15.7	0.02	0.31	0.58	*2.6E-04*	*1*
MW-14 (R)	378-380	TQu	0.0	7.6	92.4	0.00	0.02	0.07	*6.0E-07*	*0.002*

Notes

1) Size Fractions based on the following:

Gravel = material between 4.75 mm and 3 inch

Sand = material between 0.75 mm and 4.75 mm

Silt and or Clay = material less than 0.75 mm

2) Effective Grain Sizes:

d_{10} = 10% passing grain size

d_{50} = 50% passing grain size

d_{90} = 90% passing grain size

3) Hazen formula guidance is D_{10} grain size >0.1mm and < 3mm. Results outside of this range of grain-size values are shown in italics.

Summary Table of Hydraulic Conductivity Calculated from Grain Size Analysis of Soil Samples Collected from LOTT Hawks Prairie Property Area (HDR 2017b)

Hydraulic Conductivity (ft/day)			
Formation Name	Minimum	Geometric Mean	Maximum
Qva	0.1	138	523
Qf	0.002	0.2	16.3
Qc	0.2	25	1429
TQu (Lower Confining Unit)	0.002		

Appendix D – Aquifer Properties Estimated from Pumping Tests Reported on Well Logs

This page intentionally left blank.

Aquifer Properties as Estimated from Pumping Tests as Reported on Well Logs

Summary Table

Aquifer	Maximum Pumping Rate (gpm)	Hydraulic Conductivity (ft/day)			
		Minimum	Maximum	Geometric Mean	Average
Qva	810	0.1	373	5	18
Qc	1680	0.2	4159	20	341
TQu	860	0.1	85	14	43

Study ID	DOE ID	Type	Date Drilled	Well Diameter (in)	Well Depth (ft)	Top of Screen (ft bgs)	Bottom of Screen (ft bgs)	Pumping Rate (gpm)	Drawdown (ft)	Time (hrs)	Aquifer	Specific Capacity (gpm/ft)	Transmissivity (ft^2/d)	Hydraulic Conductivity (ft/d)
4	25532	D	7/17/90	6	151	145.75	151	30	2	3	Qva	15.0	3,007.8	47
18	26115	D,Ir,O	9/8/72	8	87	77	87	25	80	1	Qva	0.3	62.7	< 1
21	273373	W	4/6/92	8	195	155	195	150	87	4	Qva	1.7	345.7	5
25	24407	D	5/15/77	12	100	8	10	300	80	25	Qva	3.8	752.0	12
29	30794	D	7/4/95	6	77	73	77.57	30	16.5	1	Qva	1.8	364.6	6
195	30684	D	7/31/63	6	179	172	179	25	160	2	Qva	0.2	31.3	< 1
196	43614	D	3/28/98	10	158	145	158	150	1.66	24	Qva	90.4	18,119.4	283
197	42680	D	9/2/98	6	133	129	133	50	3	2	Qva	16.7	3,342.0	52
207	26202	D	8/14/88	6		70	80	70	9		Qva	7.8	1,559.6	24
209	381426	D	6/27/01	6	60	56	60	20	8	2	Qva	2.5	501.3	8
273	22937	D	10/18/10	6	51			40	40	1	Qva	1.0	200.5	3
334	272576	W	5/2/07	6	149	139	149	30	16	2	Qva	1.9	376.0	6
414	311820	D	4/4/01	6	47	43	47	20	0	2	Qva			
417	443509	D	5/27/06	6	74	70	74	20	21	3	Qva	1.0	191.0	3
432	23376	D	7/20/64	10	23	23.25	32.83333	60	25	4	Qva	2.4	481.3	8
433	28292	D	11/9/90	8	88	79	88	71	36	4	Qva	2.0	395.5	6
471	386846	D	2/19/04	6	109	105	109	15	10	2	Qva	1.5	300.8	5
472	38147	D	5/26/62	6	122	117	122	14	10		Qva	1.4	280.7	4
529	39879	D	7/24/97	6	136	132.33	136	10	31	2	Qva	0.3	64.7	1
533	380497	D	3/23/04	6	145.8	141	145.75	15	21.8333333	2	Qva	0.7	137.8	2
541	21673	D	7/12/12	6	114			25	5.5625	4	Qva	4.5	901.2	14
561	27964	W	7/1/46	8	64			35	10		Qva	3.5	701.8	11
565	273380	W	6/20/07	12	186			100	10		Qva	10.0	2,005.2	31
624	21759	W	3/11/00	8	171	161	171	140	4		Qva	35.0	7,018.2	110
665	537780	D	6/6/08	6	106	101	106	15	6	1	Qva	2.5	501.3	8
667	737252	D	4/15/11	6	80	75	80	14	20	1	Qva	0.7	140.4	2
699	36278	M	5/29/12	12	140	115	140	250	112	4	Qva	2.2	447.6	7
700	37941	D	4/23/79	10	138	113	138	275	31	4	Qva	8.9	1,778.8	28
722	24137	O	7/9/85	8	153	141.75	153.75	122	6.25		Qva	19.5	3,914.2	61
782	386847	D	3/8/04	6	72.5	68.75	72.5	15	10	1	Qva	1.5	300.8	5
803	39286	D	9/10/97	6	96	91	96	14	9.33	2	Qva	1.5	300.9	5
844	275062	D	6/11/97	6	114	120	149	104	6	4	Qva	17.3	3,475.7	54
939	36952	D	10/17/01	6	111	106	111	15	23	2	Qva	0.7	130.8	2
941	37654	D	4/13/84	6	112	106	118	10	106	3	Qva	0.1	18.9	< 1

Study ID	DOE ID	Type	Date Drilled	Well Diameter (in)	Well Depth (ft)	Top of Screen (ft bgs)	Bottom of Screen (ft bgs)	Pumping Rate (gpm)	Drawdown (ft)	Time (hrs)	Aquifer	Specific Capacity (gpm/ft)	Transmissivity (ft^2/d)	Hydraulic Conductivity (ft/d)
942	37661	D	5/26/81	6	127	122	127	15	0	2	Qva			
943	37662	D	5/26/81	6	110	103	109	25	95.83	1.5	Qva	0.3	52.3	< 1
944	38461	D	9/12/85	6	148	144	148.75	4	77.75	1	Qva	0.0	9.0	< 1
946	256405	D	4/15/00	6	104	99	104	17	15	2	Qva	1.1	227.3	4
983	380547	D	7/5/2001	6	90	86	90	15	12.00	2.00	Qva	1.3	250.7	4
984	28042	D		6	92	87	92	12	25.00	2.00	Qva	0.5	96.3	2
1005	528471	D	5/30/2008	6	86.6	80.66	86.5	15	25.00		Qva	0.6	120.3	2
1006	537774	D	4/8/2008	6	65	60	65	15	8.00	1.00	Qva	1.9	376.0	6
1011	22867	T	9/20/1988			487; 516	497; 529	350	175.00	8.00	Qva	2.0	401.0	6
1012	31214	D	7/27/1994	6	96	91.5	95.5	20	0.00	2.00	Qva			
1014	754893	D	6/9/2011	6	174	164	174	20	120.00	4.00	Qva	0.2	33.4	< 1
1021	476799	D	3/29/2007	6	85	80.5	85	15	6.00	2.00	Qva	2.5	501.3	8
1022	31754	D	6/3/1998	6	76	71.25	76	20	3.00	2.00	Qva	6.7	1,336.8	21
1023	26215	D	5/2/1990	6	105	101	106	20	33.00	1.00	Qva	0.6	121.5	2
1029	251865	D	1/21/2000	6	42	37.75	42	20	1.00	2.00	Qva	20.0	4,010.4	63
1034	272570	D		6	104	84.5	104.5	120	33.00		Qva	3.6	729.2	11
1038	24904	T	10/27/1990	6	41	26	41	138	20.00	48.00	Qva	6.9	1,383.6	22
1058	273214	D				33	38	350	35.00		Qva	10.0	2,005.2	31
1064	25482	D		6	99	95	99	38	58.00		Qva	0.7	131.4	2
1070	24468	O	5/31/1985	6	103	98	103	25	22.00	1.15	Qva	1.1	227.9	4
1093	38619	D, O	8/10/1960	6	56			125	8.00	4.00	Qva	15.6	3,133.1	49
1095	39743	D	6/28/1971	6	64	59	64	35	4.00	1.00	Qva	8.8	1,754.6	27
1098	38677	D	8/13/1991	6	187	183	187.5	15	52.00	1.00	Qva	0.3	57.8	< 1
1100	35076	D		6	67	47	62	15	3.00	3.00	Qva	5.0	1,002.6	16
1102	42681	D	11/11/1998	6	113.5	109.1	113.5	20	80.00	2.00	Qva	0.3	50.1	< 1
1103	410060	D	3/23/2005	6	108	103	108	17	10.00	1.00	Qva	1.7	340.9	5
1109	59616	D	5/12/1999	6	125	121	125.6	20	10.25	3.00	Qva	2.0	391.3	6
1120	387450	D	5/27/2004	6	104	103	107.5	20	7.00	2.00	Qva	2.9	572.9	9
1124	37969	D	1/27/1984	6	101			32	10.60	4.00	Qva	3.0	605.3	9
1125	37972	D	10/24/1984	6	96	91	96	33	18.00	4.00	Qva	1.8	367.6	6
1126	37971	M	9/27/1985	6	111	101	103	28	17.00	3.00	Qva	1.6	330.3	5
1128	274779	D	6/18/1986	8	118	107	117	16	16.00	3.00	Qva	1.0	200.5	3
1132	353894	D	10/7/2002	6	101	96.5	101	17	13.00	1.00	Qva	1.3	262.2	4
1133	360217	D	2/24/2003	6	137	132.75	137	17	15.00	2.00	Qva	1.1	227.3	4
1134	609548	D	9/4/2009	6	87	83	87.33	15	10.00	1.00	Qva	1.5	300.8	5
1135	35765	D	1/26/1990	6	86	81	86	15	8.00	1.00	Qva	1.9	376.0	6
1138	381412	D	5/12/2003	6	124	116	124	20	0.00	2.00	Qva			
1139	34648	D	10/20/1990		140	135	140	25	7.00	4.00	Qva	3.6	716.1	11
1141	739027	D	10/18/2010	6	129	124	129	13	6.00	1.00	Qva	2.2	434.5	7
1143	381398	D	3/17/2003	6	134	124	134	7	28.00	2.00	Qva	0.3	50.1	< 1
1145	274324	D		6	134	130	134	15	7.00	1.00	Qva	2.1	429.7	7
1146	35088	D	7/6/1978	6		217.5	227.5	10	80.00	48.00	Qva	0.1	25.1	< 1
1149	38696	D		6	119	113.1	119.25	30	6.00	2.00	Qva	5.0	1,002.6	16
1150	41565	D	4/7/1994			366.66	375	25	14.00	1.00	Qva	1.8	358.1	6
1153	337504	D	11/16/2001	6	76.75	72.25	76.75	20	10.00	2.00	Qva	2.0	401.0	6
1160	392707	D	11/5/2004	6	76	66	76	20	7.00	2.00	Qva	2.9	572.9	9

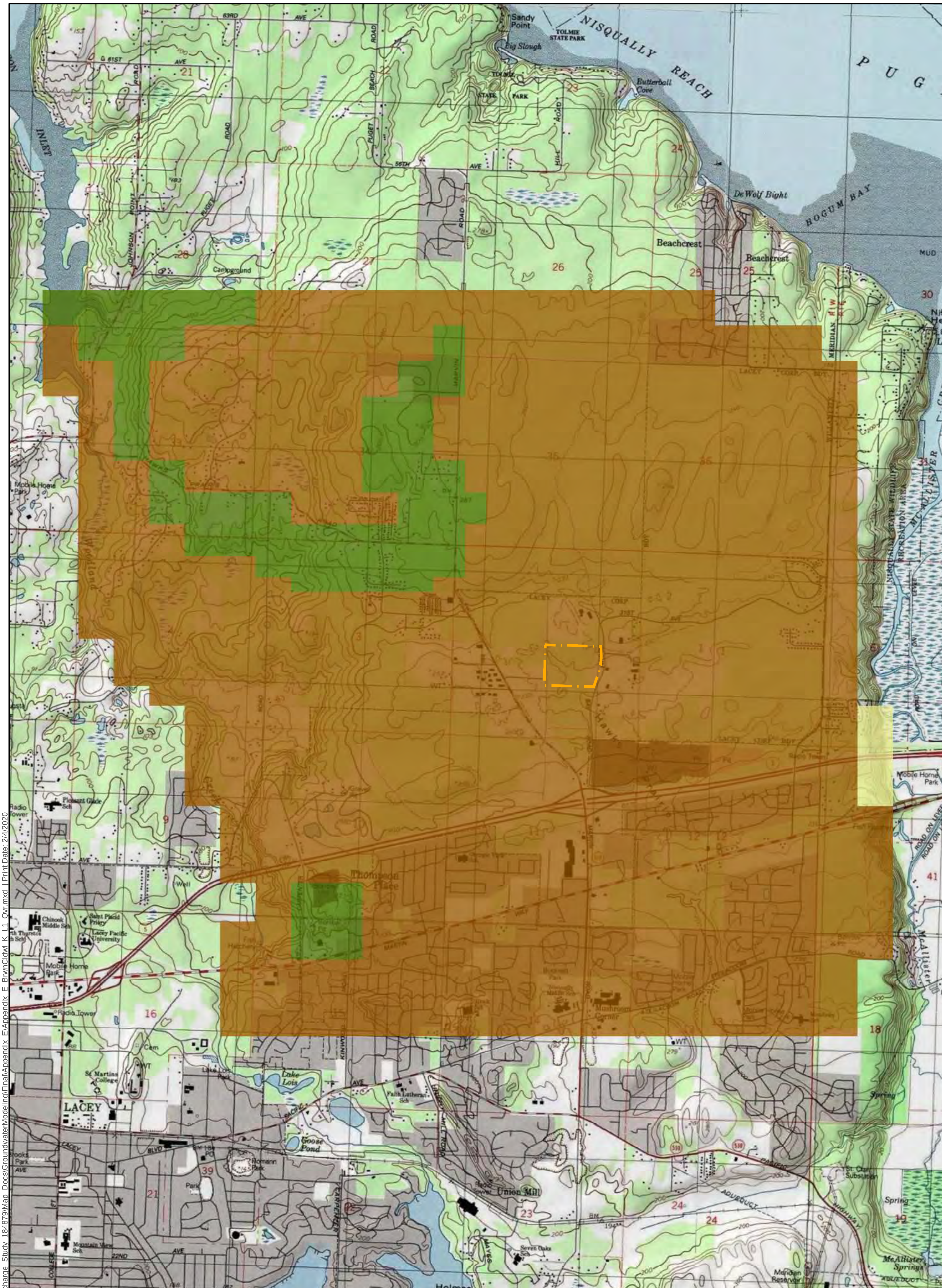
Study ID	DOE ID	Type	Date Drilled	Well Diameter (in)	Well Depth (ft)	Top of Screen (ft bgs)	Bottom of Screen (ft bgs)	Pumping Rate (gpm)	Drawdown (ft)	Time (hrs)	Aquifer	Specific Capacity (gpm/ft)	Transmissivity (ft^2/d)	Hydraulic Conductivity (ft/d)
1165	33372	D	3/24/1988	6	68	64	68.75	10	24.00	1.00	Qva	0.4	83.6	1
1166	39298	O		6	83	68.66	83.75	35	18.50	5.50	Qva	1.9	379.4	6
1170	36698	D	7/31/1978	6	107	103.5	107.66	15	85.00		Qva	0.2	35.4	< 1
1173	381399	D	4/4/2003	6	96	94	96	20	6.00	2.00	Qva	3.3	668.4	10
1178	440716	D	5/12/2006	6	47.6	42	47.5	10	20.00	1.00	Qva	0.5	100.3	2
1183	386857	D	5/27/2004	6	65	60.25	65	15	10.00	1.00	Qva	1.5	300.8	5
1192	377410	D	6/12/2003	6	142.5	138	142.5	8	115.00	2.00	Qva	0.1	13.1	< 1
1193	537782	D, Ir	6/24/2008	6	53	49.75	53	12	20.00	1.00	Qva	0.6	120.3	2
1194	419172	D, Ir	6/6/2005	6	84.2	74	84	17	50.00	1.00	Qva	0.3	68.2	1
1196	123011	D	3/12/1999	6	56	52	56	6	42.00	2.00	Qva	0.1	28.6	< 1
1208	626948	D	5/11/1990	8	149			60	88	7	Qva	0.7	136.7	2
1210		D	4/11/1992	8	149			60	83	7	Qva	0.7	145.0	2
1215		O	7/15/1992	8	133	133	143	100	19	3	Qva	5.3	1,055.4	16
1217		M	6/28/1976	12	140	115	140	250	112	4	Qva	2.2	447.6	7
1220		D	5/26/1981	8	94	93	103	20	20		Qva	1.0	200.5	3
1227		M	9/29/1950	8	112			810	6.8	0.75	Qva	119.1	23,885.6	373
1228		M	11/1/1976	6	87	77	82	30	12	4	Qva	2.5	501.3	8
1229 Lacey S15		M	6/28/1976	12	140	115.5	140	250	112.00	4.00	Qva	2.2	596.8	9
1230 Lacey S16		M	4/23/1979	10	138	113	138	275	31.00	4.00	Qva	8.9	2,371.8	37
11	272572	W	3/11/00	12	226	211	223	118	45		Qc	2.6	701.1	16
22	272571	D	3/11/00	12	390	311	380	500	47	6.5	Qc	10.6	2,844.3	63
182	30510	D	2/26/91	6	203	199.5	203.5	20	174.66	5.5	Qc	0.1	30.6	< 1
237	405357	M	3/22/05	20	392	293.6	394	400	70	0.5	Qc	5.7	1,527.8	34
256	22851	M	1/25/96	12	383	291	354	375	56.1	0.05	Qc	6.7	1,787.2	40
329	28847	O	6/9/78	6	257			35	7	4	Qc	5.0	1,336.8	30
332	825295	D	5/27/94	8	242			50	15		Qc	3.3	891.2	20
551	273685	D, M	5/1/98	12	233	223.33	233.25	200	195	5	Qc	1.0	274.2	6
562	273371	W	1/19/56	8	260	240	260	210	0.5		Qc	420.0	112,292.0	2,495
603	29118	D	6/30/73	6	238	231	236	10	7	2	Qc	1.4	381.9	8
655	23853	D	9/20/78	6	222			20	14	4	Qc	1.4	381.9	8
662	27165	O	6/9/81	8	292	272	292	220	57	5	Qc	3.9	1,031.9	23
703	410233	D	5/31/05	6	261.6	258.5	261.5	20	4	2	Qc	5.0	1,336.8	30
705	23737	In	5/2/91	8	319	309.5	319.25	430	203.25	4	Qc	2.1	565.6	13
706	23738	In	5/2/91	8	314	309.5	319.25	430	203.25	4	Qc	2.1	565.6	13
717	30392	In	10/5/74	8	241	231	241	100	48	4	Qc	2.1	557.0	12
768	30380	D	5/21/80	8	259	248	259	126	67.5	0.75	Qc	1.9	499.1	11
783	23418	Ir	7/25/91	0		190.5	195.5	100	13.74	6	Qc	7.3	1,459.4	32
882	26320	D	12/2/74	6	258	253	258	30	3	4	Qc	10.0	2,673.6	59
938	398095	D	5/4/92	6	239	234	239	36	3.5	4	Qc	10.3	2,750.0	61
997	511293	D	10/26/2007	6	229			15	15.00	0.50	Qc	1.0	267.4	6
1015	30419	T	12/5/1997	6	272	267	272	7	250.00	4.00	Qc	0.0	7.5	< 1
1036	29432	M		8	286	274.33	284.5	72	177.00	4.00	Qc	0.4	108.8	2
1037	273604	M		8	274	274	294.5	72	1.00	4.00	Qc	72.0	19,250.1	428
1040	270672		8/24/1990	12	187	168	182	83	51.00	1.00	Qc	1.6	326.3	7
1041	29455		8/24/1990	12	187	168	182	83	51.00	1.00	Qc	1.6	326.3	7
1042	270671		5/21/1991	12		175	190	70	105.00	4.00	Qc	0.7	133.7	3

Study ID	DOE ID	Type	Date Drilled	Well Diameter (in)	Well Depth (ft)	Top of Screen (ft bgs)	Bottom of Screen (ft bgs)	Pumping Rate (gpm)	Drawdown (ft)	Time (hrs)	Aquifer	Specific Capacity (gpm/ft)	Transmissivity (ft^2/d)	Hydraulic Conductivity (ft/d)
1043	29456			12		175	190	70	105.00	4.00	Qc	0.7	133.7	3
1050	23341	D		8	339	324.33	339.66	300	40.00	4.00	Qc	7.5	2,005.2	45
1074	31684	M		16	329	3 ;279.5; 3	1; 292.5; 3	1050	2.30	9.00	Qc	456.5	122,056.5	2,712
1075	32323	M	6/11/1997	16	333	65; 294; 31	82; 306; 32	1025	2.01	1.00	Qc	510.0	136,341.2	3,030
1076	251552	M	6/9/2000	20	330			1680	2.40	4.00	Qc	700.0	187,153.3	4,159
1111	43074	D	8/3/1997	6	224	221.5	227.25	30	10.00	3.50	Qc	3.0	802.1	18
1117	274345	D		8	191	186	191	60	15.00	4.00	Qc	4.0	802.1	18
1119	41069	D		5	383	379	384	20	46.00	5.00	Qc	0.4	116.2	3
1144	491867	D	6/28/2007	6	286			10	148.00	4.00	Qc	0.1	18.1	< 1
1155	494376	D	8/9/2007	6	206	200	204	15	67.60	2.00	Qc	0.2	59.3	1
1204	398090		11/24/1986	6	336	327	336	17	41	7	Qc	0.4	110.9	2
1211		M	6/2/2010	16	270	194	255	700	40.5	4	Qc	17.3	4,621.1	103
1212			4/17/1979	8	280	275	280	80	35	4	Qc	2.3	611.1	14
1220		M	10/12/1977	8	274	274	284.5	72	1	4	Qc	72.0	19,250.1	428
15	825289	M	9/4/84	16	596	539	590	755	29.3	24	TQu	25.8	6,889.4	85
236	387395	T	6/5/04	7	398			500	42.21	24	TQu	11.8	3,167.0	39
312	517569	M	12/18/07	16	590	535	575	750	35.6	1	TQu	21.1	5,632.6	70
535	34019	M	12/13/88	16	646	585	643	860	145	24	TQu	5.9	1,585.7	20
774	35933	M	9/4/84	16	596	539	590	755	29.3	24	TQu	25.8	6,889.4	85
1067	27780	D		8	796	781.25	796.33	200	230.50	5.00	TQu	0.9	232.0	3
1174	387281	D	4/27/2004	6	501.5	492.75	501.5	9	286.00	8.00	TQu	0.0	8.4	< 1

Notes
1. Type
D = Domestic
In = Industry
Ir = Irrigation
M = Muncipal
O = Other
T = Test
W= Water Supply, Other
2. Transmissivity calculated using specific capacity equation from Driscoll (1986)
3. Wells in Qva were assumed to be unconfined, wells screened in the Qc and Tqu were assumed to be confined
4. Hydraulic conductivity was calculated from transmissivity using the average hydrostratigraphic unit thickness from well logs used to construct the geology model. This thickness was 64 feet for the Qva, 45 feet for the Qc, and 81 for the TQu.

Appendix E – Implemented Recharge and Hydraulic Conductivity in Previous Models

This page intentionally left blank.



Hydraulic Conductivity - Brown and Caldwell Layer 1 - Qvr (ft/d)

- 1
- 40
- 150
- LOTT Hawks Prairie Recharge Facility

Hydraulic Conductivity - Qvr
Brown and Caldwell (2009)

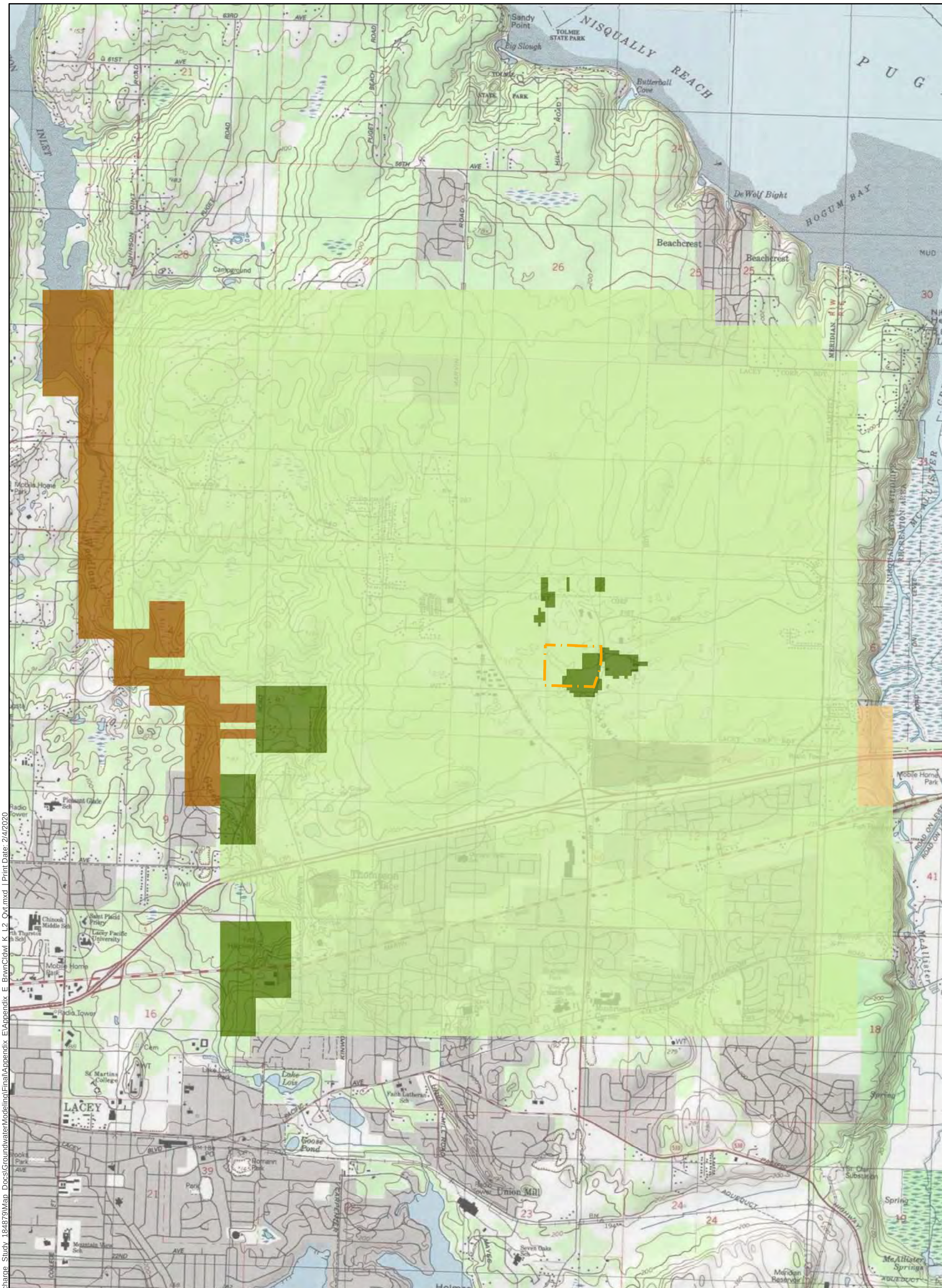
Miles: 0 — 1

LOTT Clean Water Alliance

HDR

Source: Bing Maps (2011), City of Bellevue (2013), WSDOT (2013)

Path: G:\Projects\Washington\LOTT_CWA_201266\GW_Recharge_Study_184879\Map_Docs\GroundwaterModeling\Final\Appendix_E\Appendix_E_BrwnCldwl_K_L1_Qvr.mxd | Print Date: 2/4/2020



Hydraulic Conductivity - Brown and Caldwell Layer 2 - Qvt (ft/d)

- 1
- 40
- 150
- 320
- LOTT Hawks Prairie Recharge Facility

Hydraulic Conductivity - Qvt

Brown and Caldwell (2009)

Miles

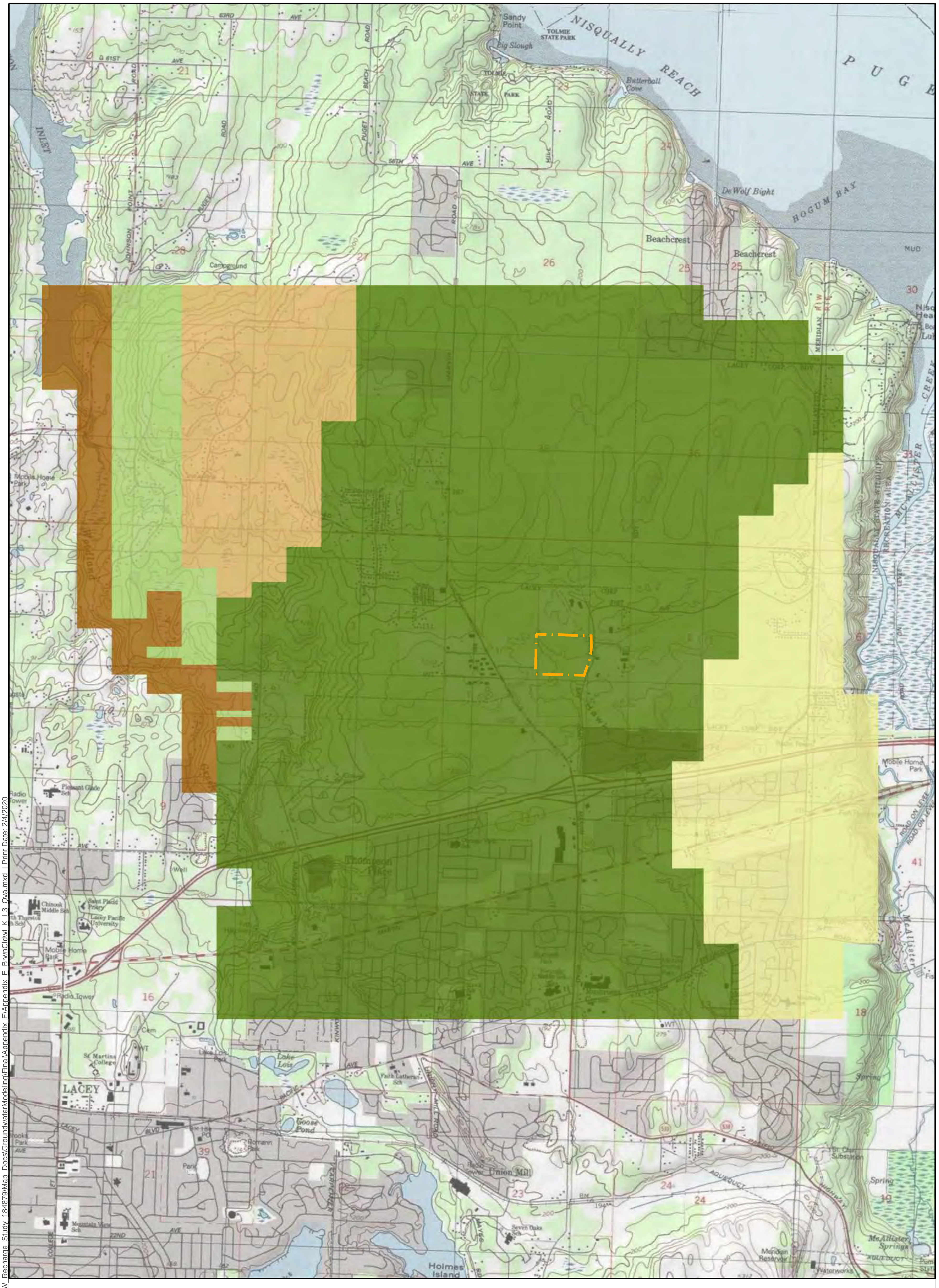
0 1

LOTT Clean Water Alliance

HDR

Source: Bing Maps (2011), City of Bellevue (2013), WSDOT (2013)

Path: G:\Projects\Washington\LOTT CWA 201266\GW Recharge Study 184879\Map Docs\GroundwaterModeling\Final\Appendix E\Appendix E BrwnCldwl K L2 Qvt.mxd | Print Date: 2/4/2020



Hydraulic Conducitvity - Brown and Caldwell Layer 3 - Qva (ft/d)

- 1
- 36
- 40
- 150
- 320
- LOTT Hawks Prairie Recharge Facility

Hydraulic Conductivity - Qva

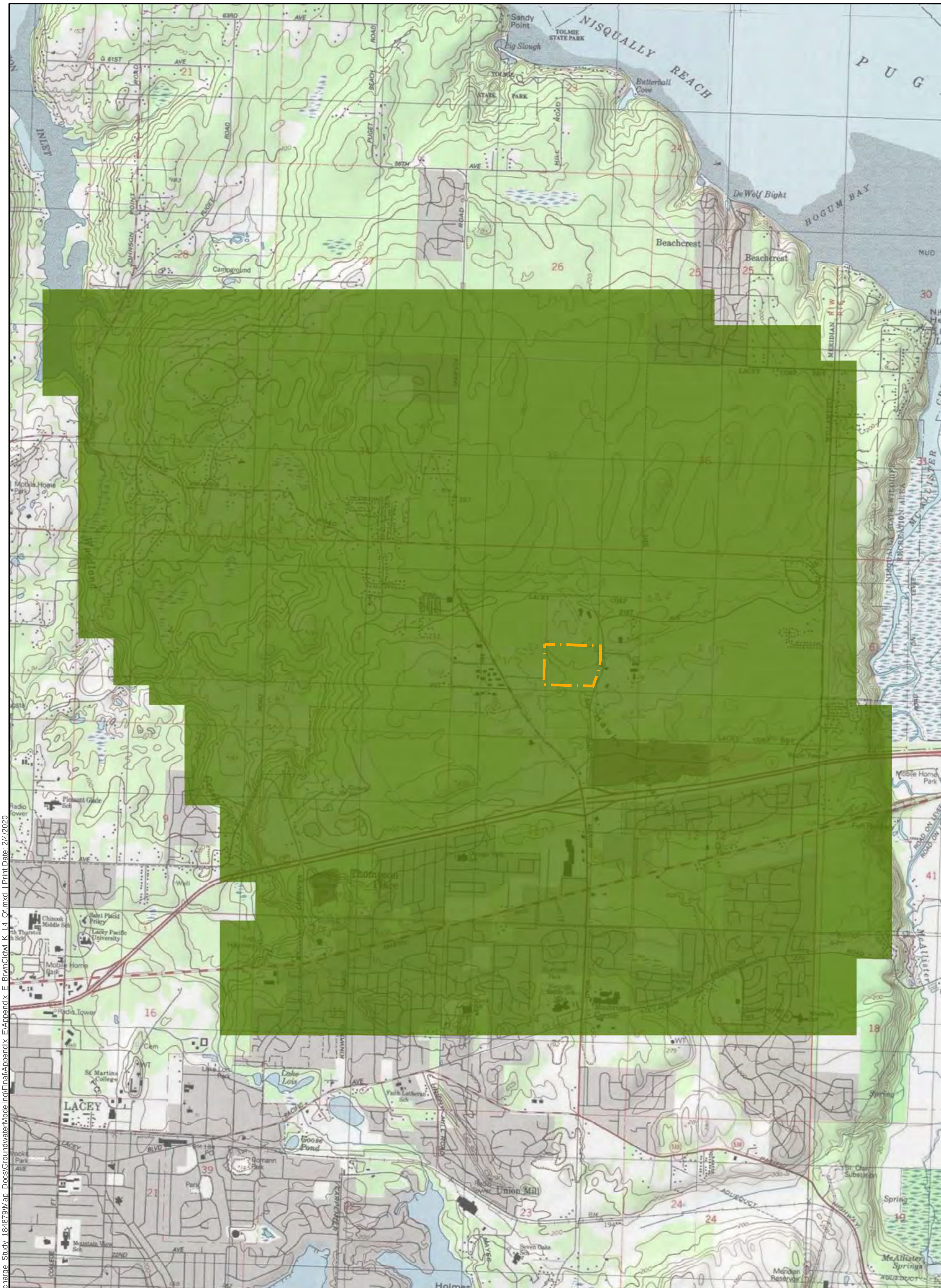
Brown and Caldwell (2009)

Miles

0 1

Path: G:\Projects\Washington\LOTT_CWA_201266\GW_Recharge_Study_184879\Map Docs\GroundwaterModeling\Final\Appendix E\Appendix_E_BrwnCldwl_K_L3_Qva.mxd | Print Date: 2/4/2020

Source: Bing Maps (2011), Brown and Caldwell (2009), City of Bellevue (2013), WSDOT (2013)



Hydraulic Conductivity - Brown and Caldwell Layer 4 - Qf (ft/d)

0.1

LOTT Hawks Prairie Recharge Facility

Hydraulic Conductivity - Qf

Brown and Caldwell (2009)

Miles

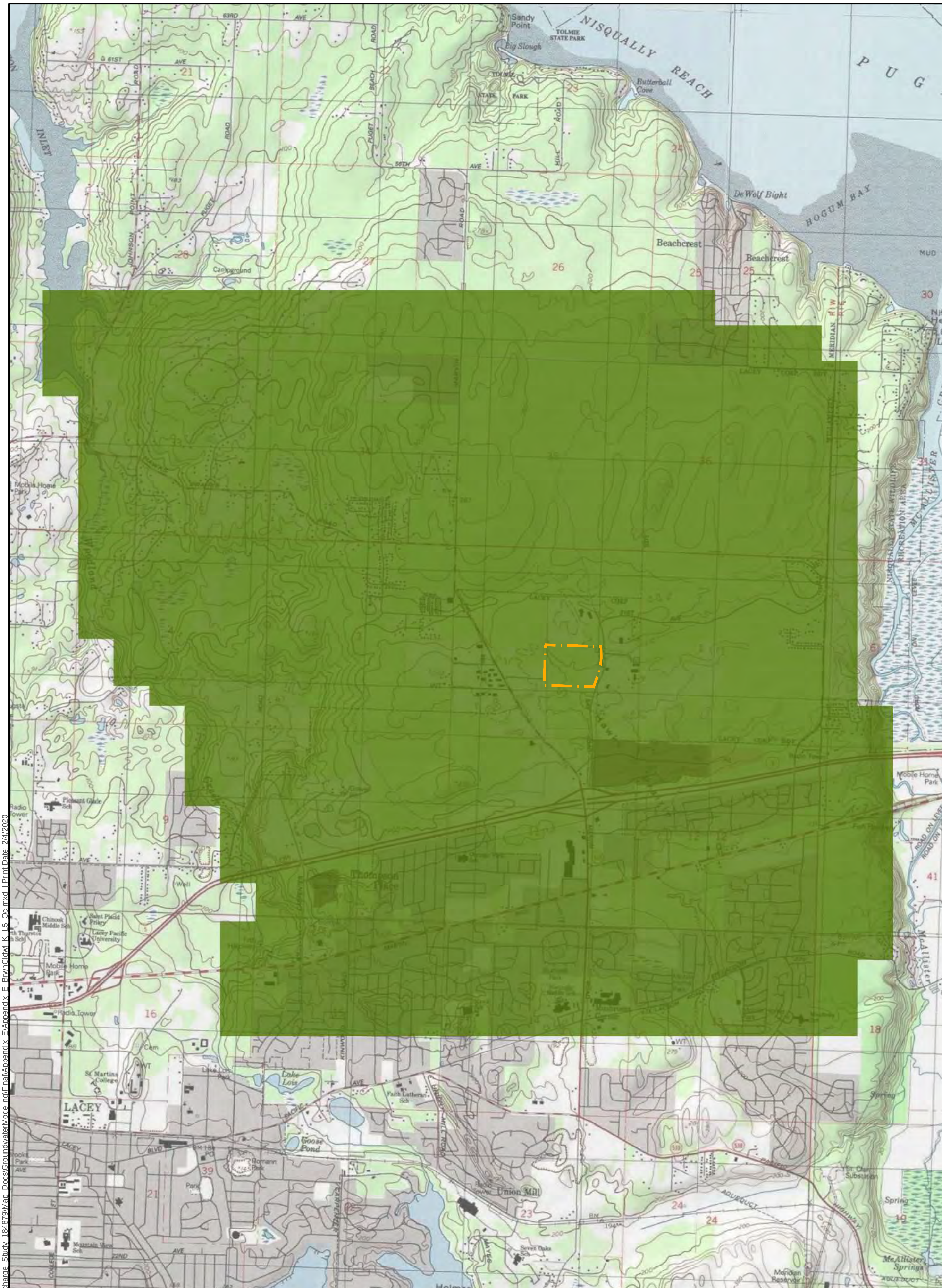
0 1

LOTT Clean Water Alliance

HDR

Path: G:\Projects\Washington\LOTT_CWA_201266\GW_Recharge_Study_184879\Map_Docs\GroundwaterModeling\Final\Appendix_E\Appendix_E_BrwnCldwl_K_L4_Qf.mxd | Print Date: 2/4/2020

Source: Bing Maps (2011), Brown and Caldwell (2009), City of Bellevue (2013), WSDOT (2013)



Hydraulic Conducitivity - Brown and Caldwell Model Layer 5 - Qc (ft/d)

59

LOTT Hawks Prairie Recharge Facility

Hydraulic Conductivity - Qc

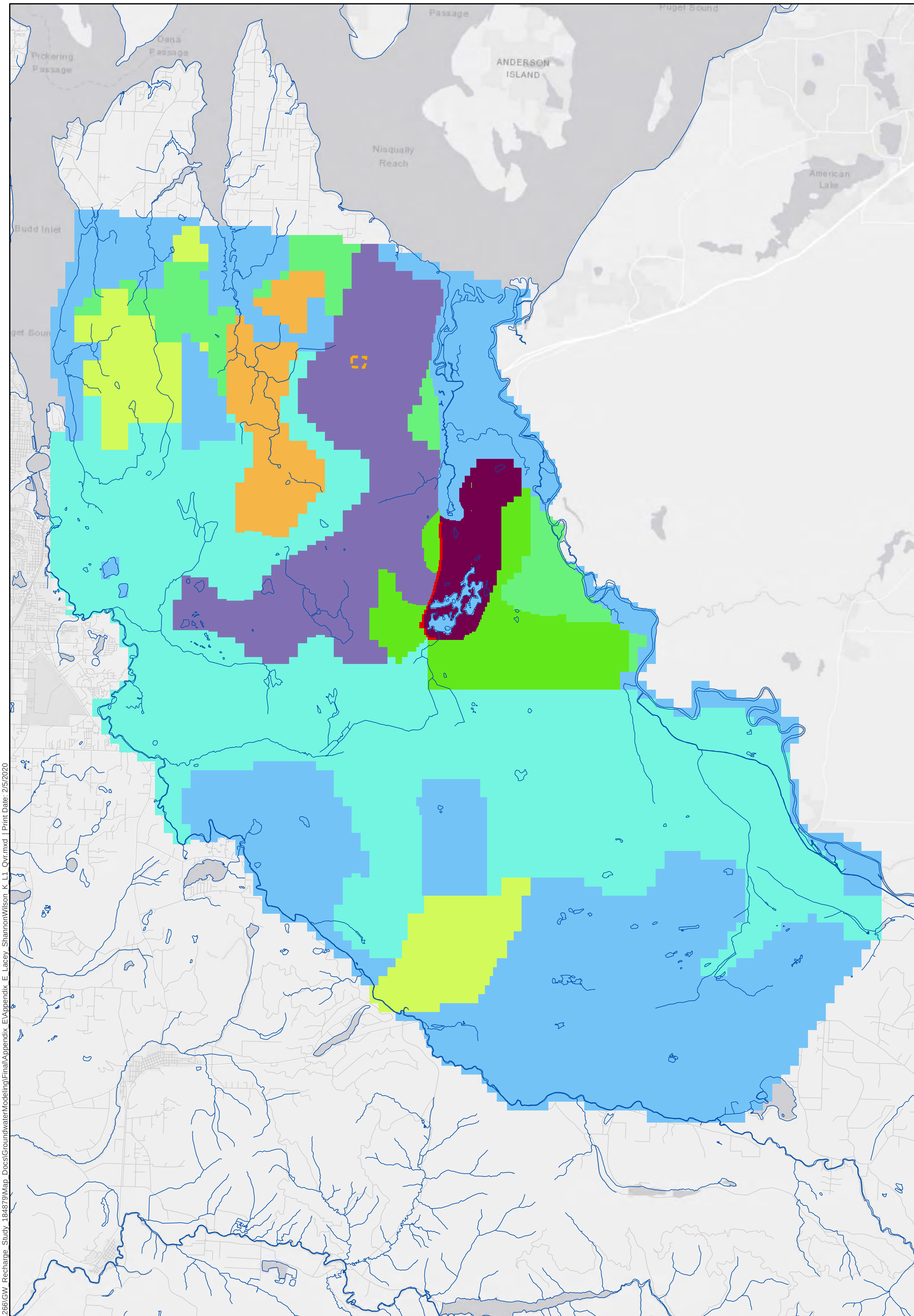
Brown and Caldwell (2009)

Miles

0 1

Source: Bing Maps (2011), Brown and Caldwell (2009), City of Bellevue (2013), WSDOT (2013)

Path: G:\Projects\Washington\LOTT_CWA_201266\GW_Recharge_Study_184879\Map_Docs\GroundwaterModeling\Final\Appendix_E\Appendix_E_BrwnCldwl_K_L5_Qc.mxd | Print Date: 2/4/2020



Hydraulic Conductivity (ft/day)

- 0
- 16
- 32
- 60
- 100
- 120
- 200
- 640
- 2000
- Roads
- Streams
- LOTT Hawks Prairie Recharge Facility

Horizontal Hydraulic Conductivity
Layer 1 - Vashon Recessional Outwash (Qvr)
Shannon and Wilson (2012) - McAllister Model

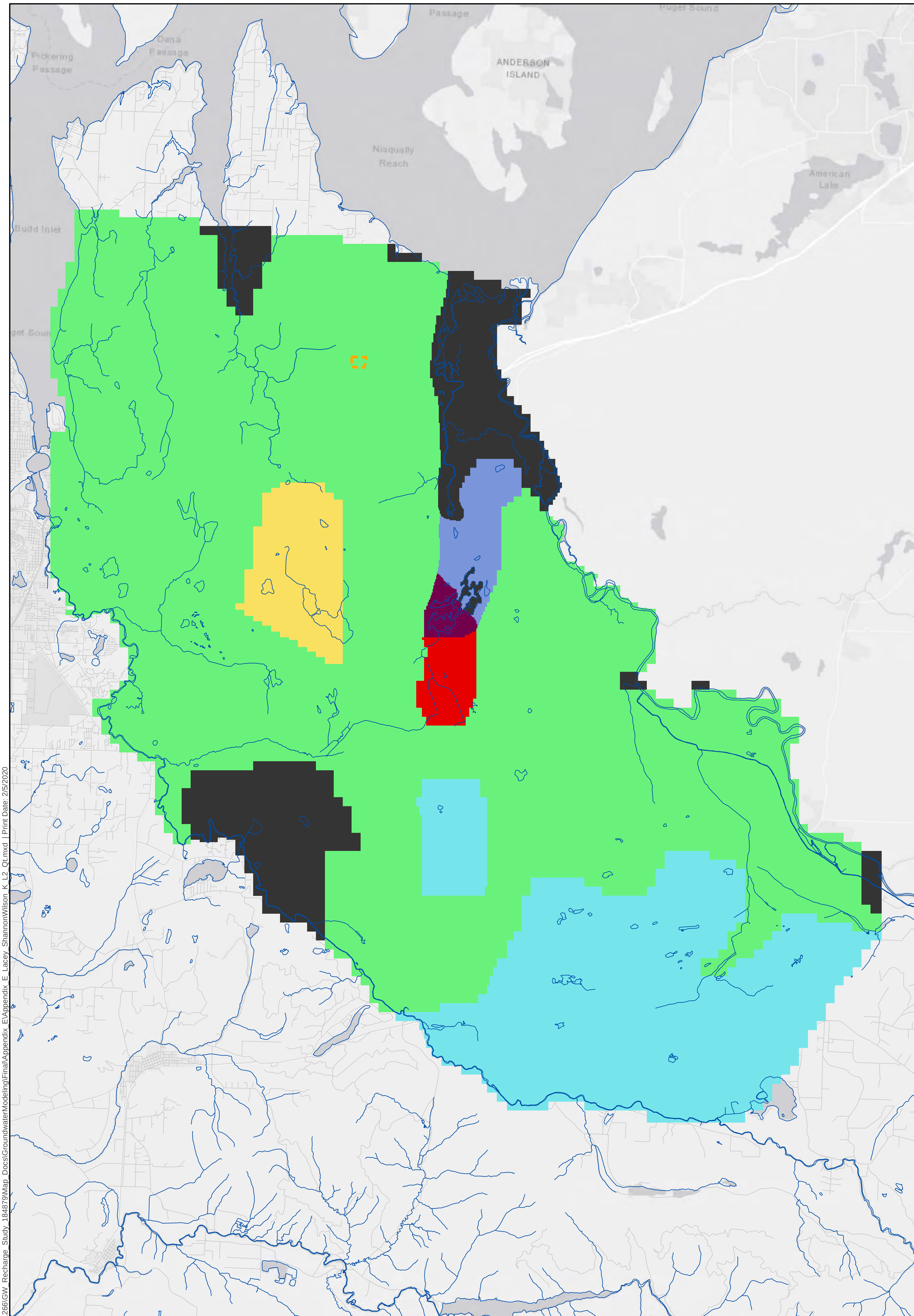
Miles
0 5

LOTT Clean Water Alliance

HDR

Source: City of Lacey (2018), Esri (2018), Thurston Co Landfill (2018), WSDOT (2018)

Path: G:\Projects\Washington\LOTT_CWA_201266\GW_Recharge_Study_184879\Map_Docs\GroundwaterModeling\Final\Appendix_E\Appendix_E_Lacey_ShannonWilson_K_L1_Qvr.mxd | Print Date: 2/5/2020



Hydraulic Conductivity (ft/day)

- 0
- 1
- 3
- 10
- 20
- 250
- 2000
- Roads
- Streams
- LOTT Hawks Prairie Recharge Facility

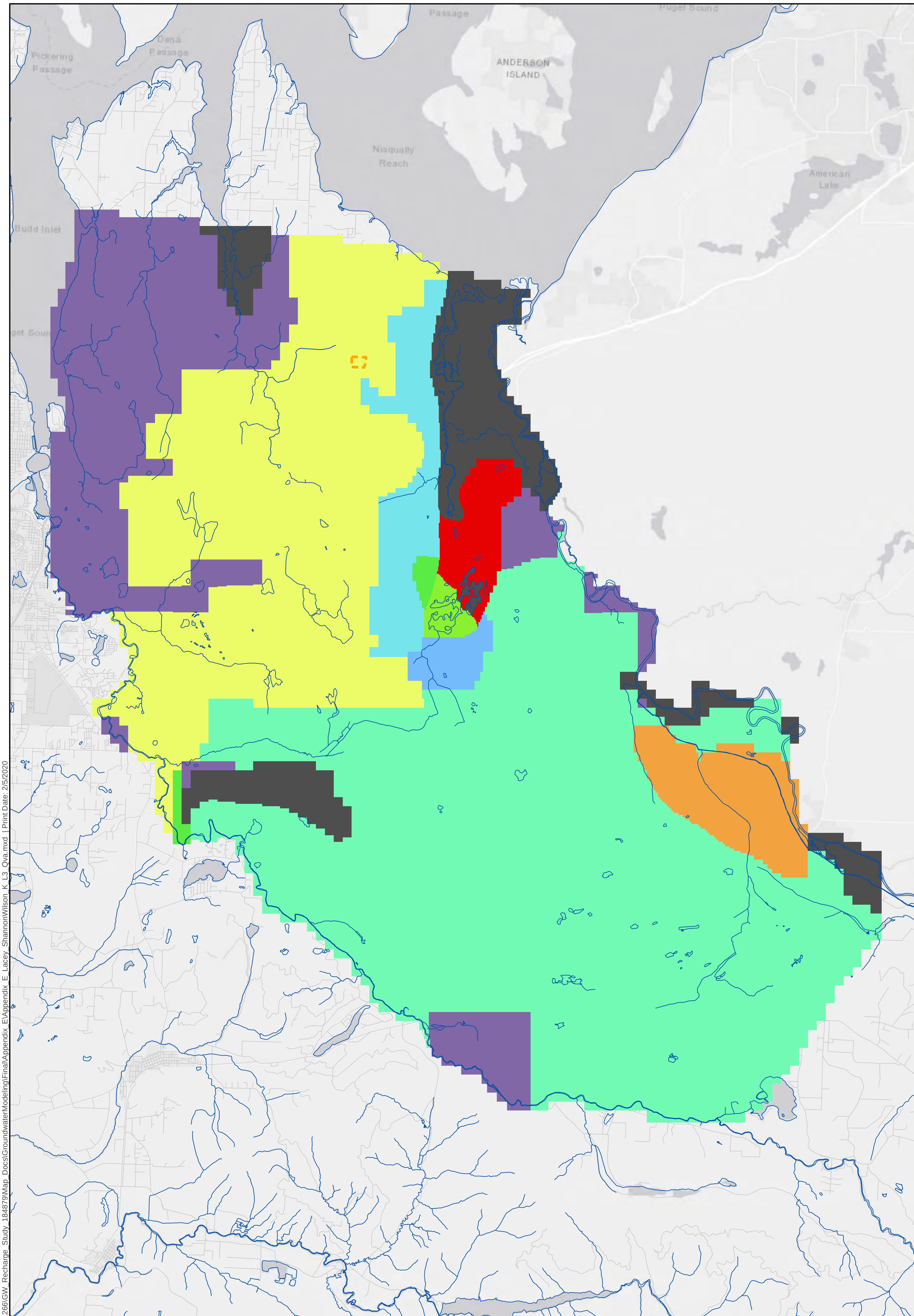
Horizontal Hydraulic Conductivity
Layer 2 - Vashon Till (Qt)
Shannon and Wilson (2012) - McAllister Model

Miles
0 5

LOTT Clean Water Alliance

Source: City of Lacey (2018), Esri (2018), Thurston Co Landfill (2018), WSDOT (2018)

Path: G:\Projects\Washington\LOTT CWA 201266\GW Recharge Study 184879\Map Docs\GroundwaterModeling\Final\Appendix E\Appendix E Lacey ShannonWilson K L2 Qt.mxd | Print Date: 2/5/2020



Hydraulic Conductivity (ft/day)

0	100	LOTT Hawks Prairie Recharge Facility	
35	252		
50	640		
60	2000		
70	Roads		
77	Streams		

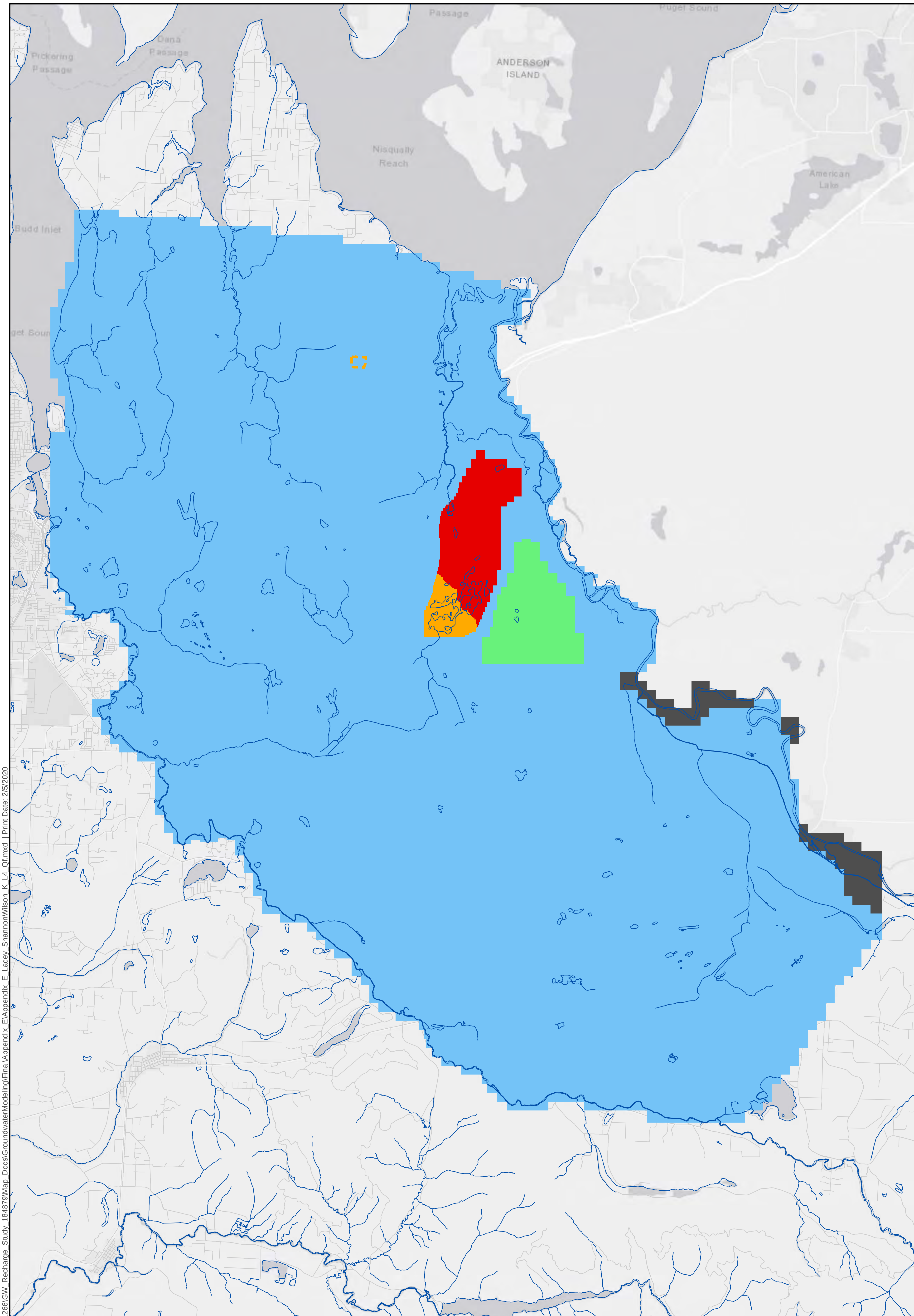
Horizontal Hydraulic Conductivity
Layer 3 - Vashon Advance Outwash (Qva)
Shannon and Wilson (2012) - McAllister Model

Miles
0 5

LOTT Clean Water Alliance
HDR

Path: G:\Projects\Washington\LOTT CWA 201266\GW Recharge Study 184879\Map Docs\GroundwaterModeling\Final\Appendix E\Appendix E Lacey ShannonWilson K L3 Qva.mxd | Print Date: 2/5/2020

Source: City of Lacey (2018), Esri (2018), Thurston Co Landfill (2018), WSDOT (2018)



Path: G:\Projects\Washington\LOTT_CWA_201266\GW_Recharge_Study_184879\Map_Docs\GroundwaterModeling\Final\Appendix_E\Appendix_E_Lacey_ShannonWilson_K_L4_Qf.mxd | Print Date: 2/5/2020

Hydraulic Conductivity (ft/day)

- 0
- 1
- 3
- 100
- 2000
- Roads
- Streams
- LOTT Hawks Prairie Recharge Facility

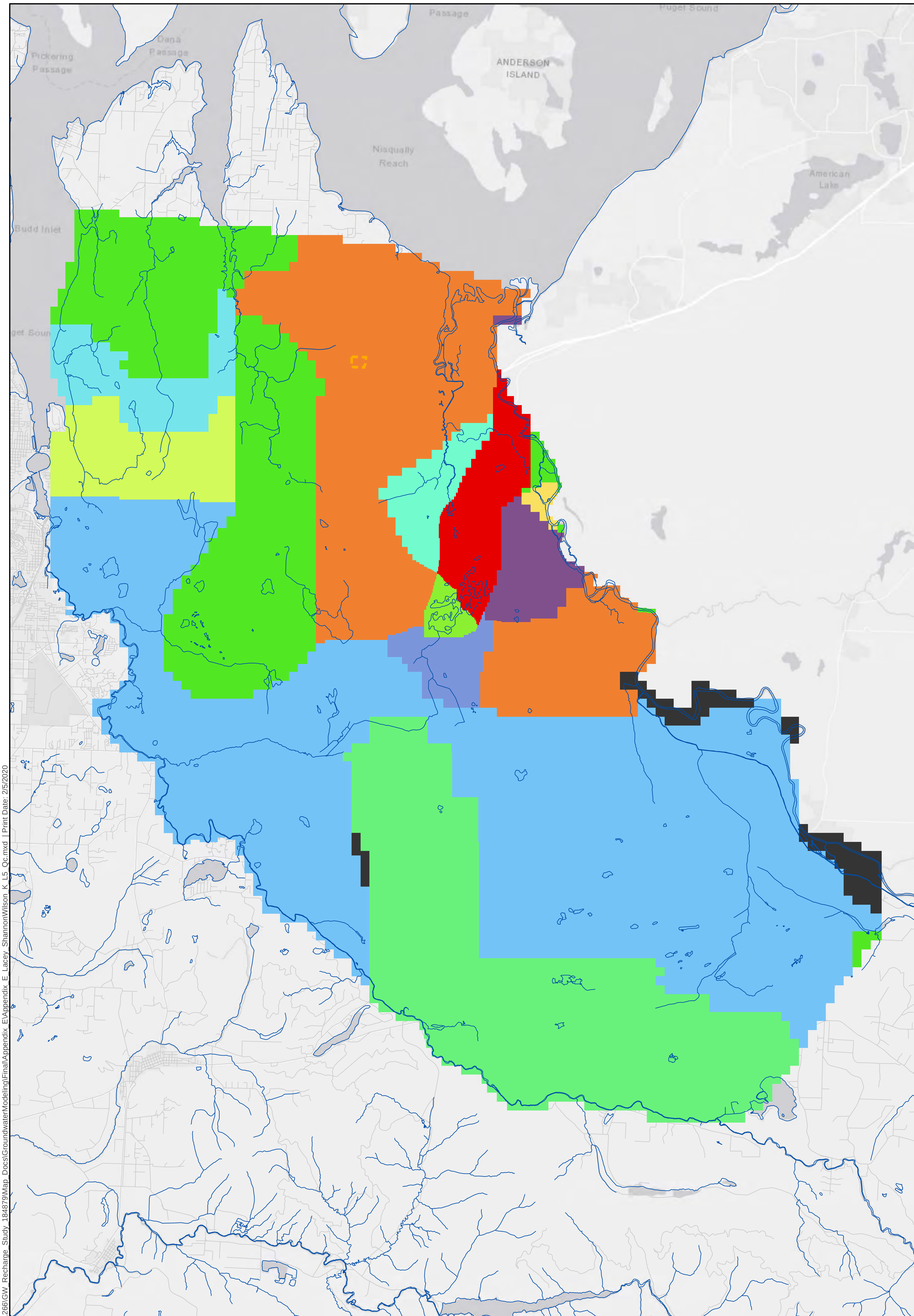
Horizontal Hydraulic Conductivity
Layer 4 - Kitsap Formation (Qf)

Shannon and Wilson (2012) - McAllister Model

Miles
0 5

LOTT Clean Water Alliance
HDR

Source: City of Lacey (2018), Esri (2018), Thurston Co Landfill (2018), WSDOT (2018)



Hydraulic Conductivity (ft/day)

0	180	2000
7.5	200	Roads
10	250	Streams
47	300	LOTT Hawks Prairie Recharge Facility
60	600	
100	640	

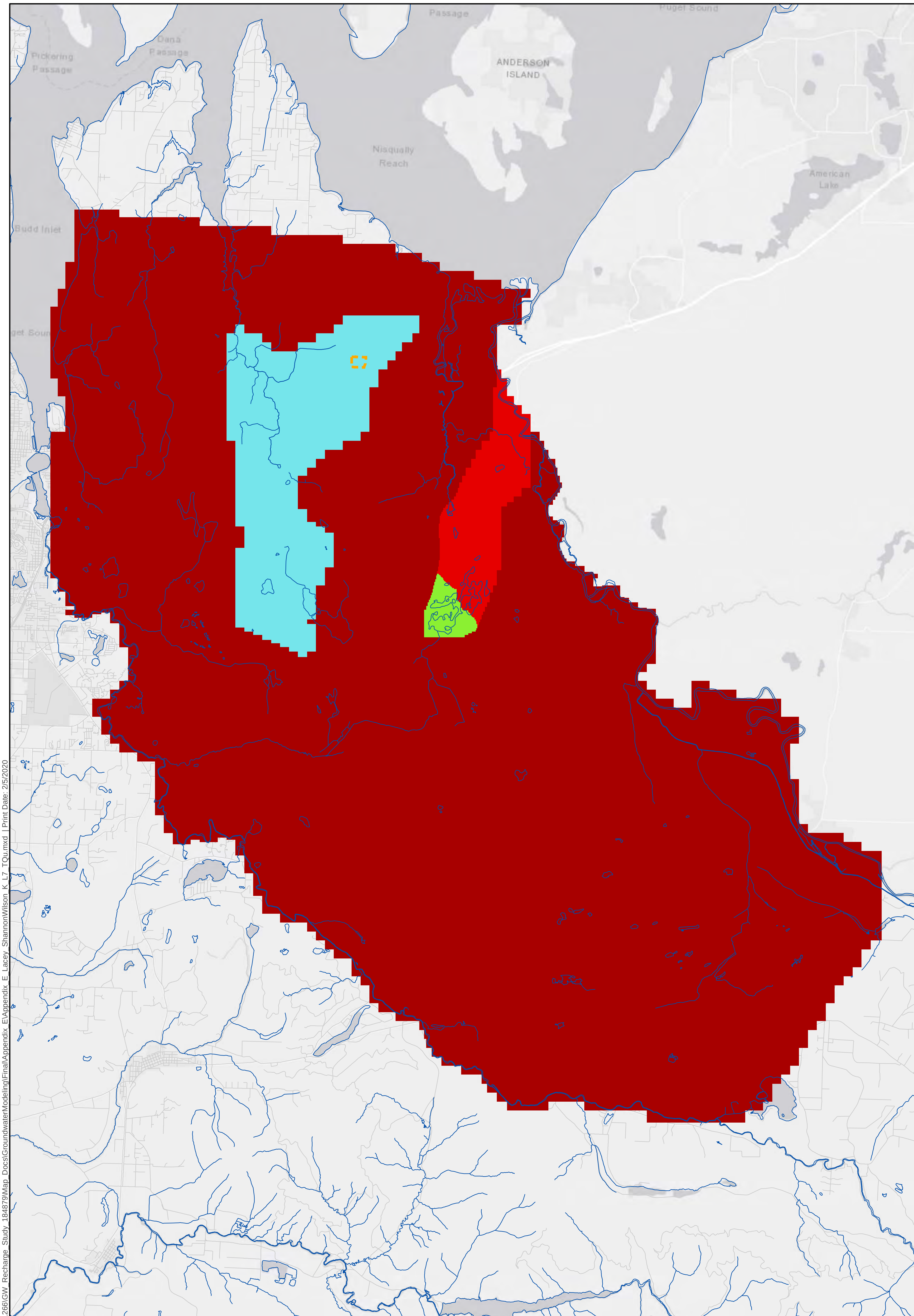
Horizontal Hydraulic Conductivity
Layers 5 & 6 - Sea-Level Aquifer (Qc)
Shannon and Wilson (2012) - McAllister Model

Miles
0 5

LOTT Clean Water Alliance
HDR

Path: G:\Projects\Washington\LOTT CWA 201266\GW Recharge Study 184879\Map Docs\GroundwaterModeling\Final\Appendix E\Appendix E Lacey ShannonWilson K L5 Qc.mxd | Print Date: 2/5/2020

Source: City of Lacey (2018), Esri (2018), Thurston Co Landfill (2018), WSDOT (2018)



Hydraulic Conductivity (ft/day)

- 1
- 40
- 250
- 2000

- Roads
- Streams
- LOTT Hawks Prairie Recharge Facility

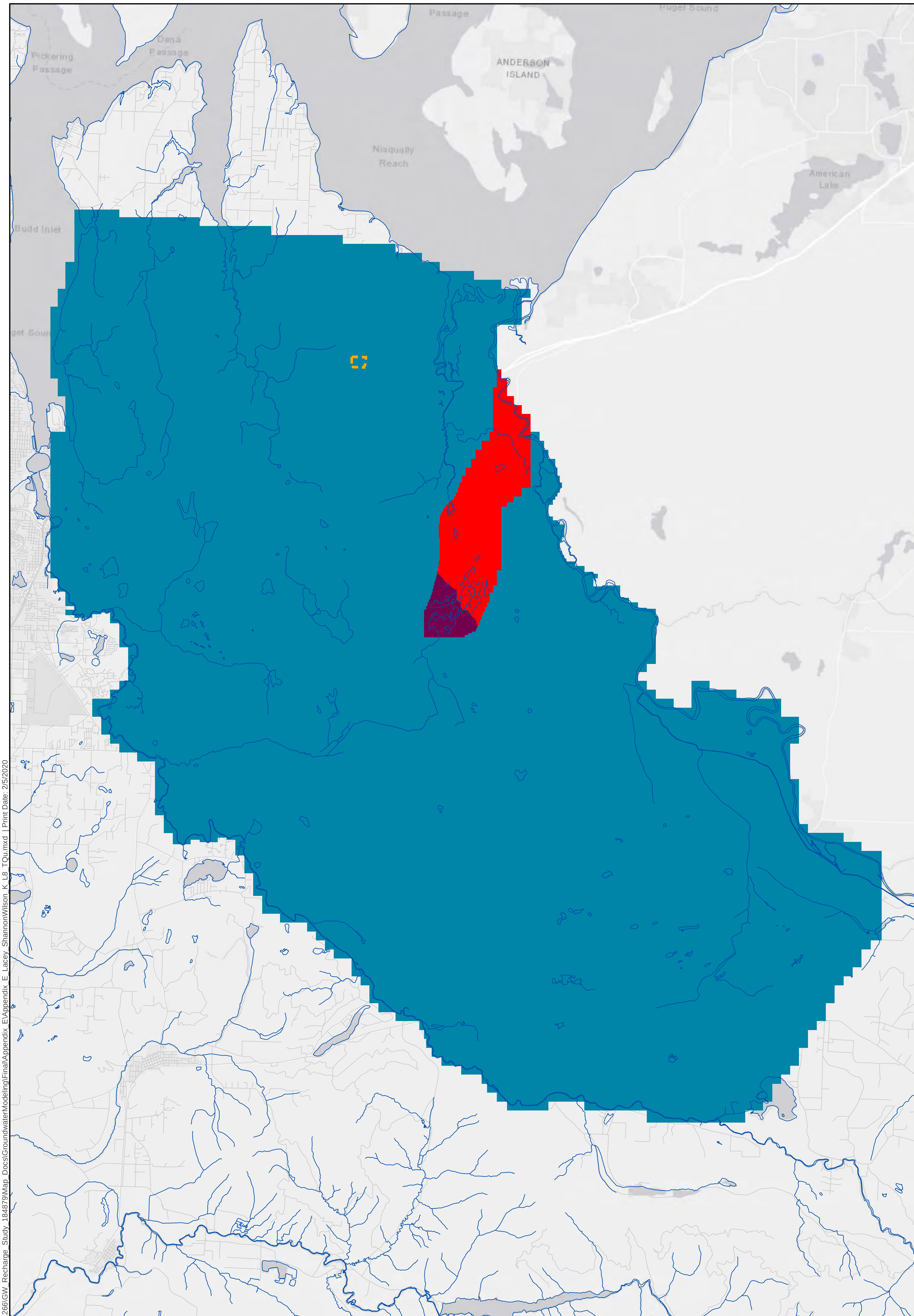
Horizontal Hydraulic Conductivity
Layer 7 - Lower Confining Unit (TQu)

Shannon and Wilson (2012) - McAllister Model

Miles
0 5

Source: City of Lacey (2018), Esri (2018), Thurston Co Landfill (2018), WSDOT (2018)

Path: G:\Projects\Washington\LOTT_CWA_201266\GW_Recharge_Study_184879\Map_Docs\GroundwaterModeling\Final\Appendix_E\Appendix_E_Lacey_ShannonWilson_K_L7_TQu.mxd | Print Date: 2/5/2020



Hydraulic Conductivity (ft/day)

- 75
- 250
- 2000
- Roads
- Streams
- LOTT Hawks Prairie Recharge Facility

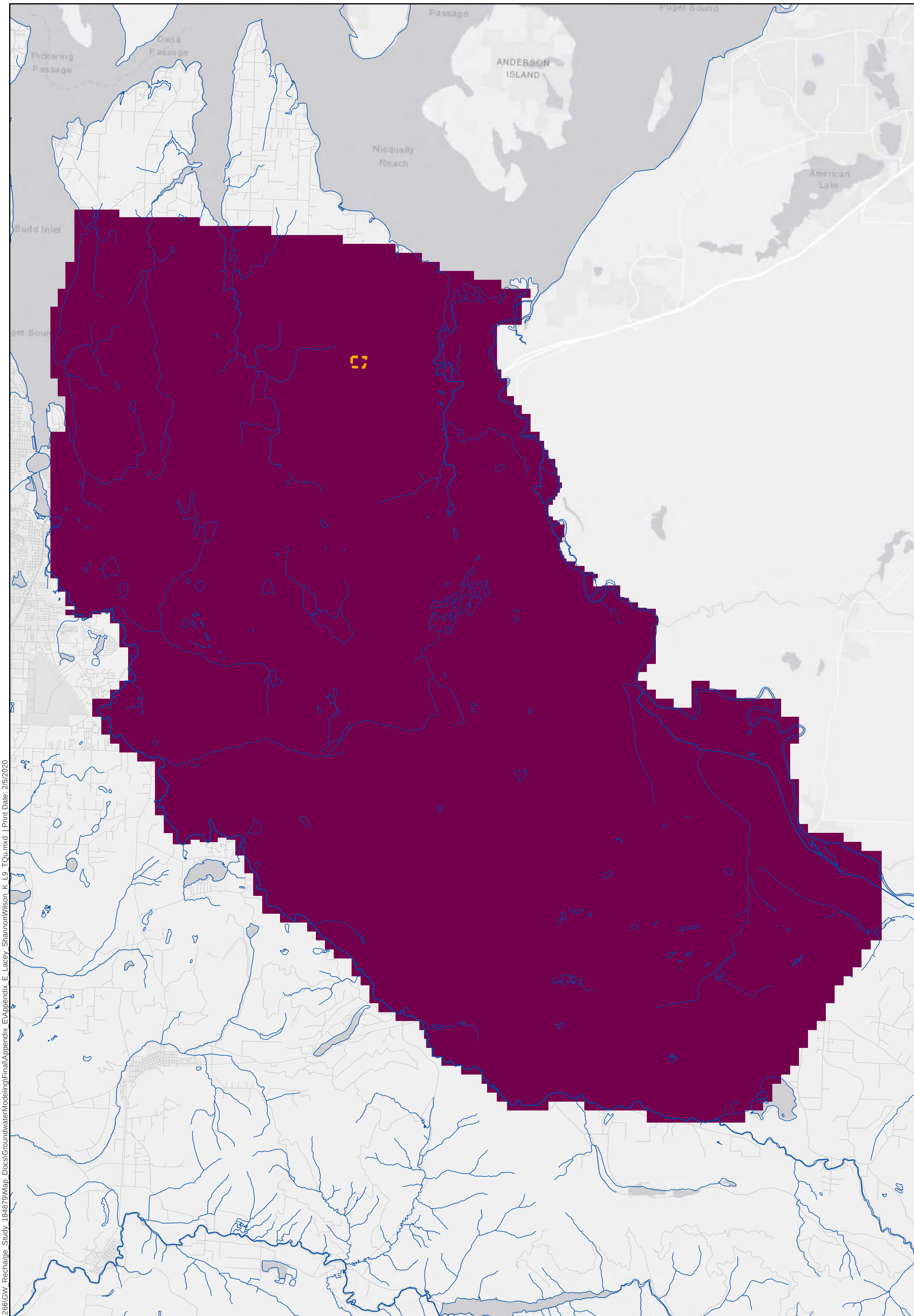
Horizontal Hydraulic Conductivity
Layer 8 - Deep Aquifer (TQu)

Shannon and Wilson (2012) - McAllister Model

Miles
0 5

Path: G:\Projects\Washington\LOTT CWA 201266\GW Recharge Study 184879\Map Docs\GroundwaterModeling\Final\Appendix E\Appendix E Lacey ShannonWilson K L8 TQu.mxd | Print Date: 2/5/2020

Source: City of Lacey (2018), Esri (2018), Thurston Co Landfill (2018), WSDOT (2018)



Hydraulic Conductivity (ft/day)

75

LOTT Hawks Prairie Recharge Facility

Roads

Streams

Horizontal Hydraulic Conductivity
Layer 9 - Deep Aquifer (Qc)

Shannon and Wilson (2012) - McAllister Model

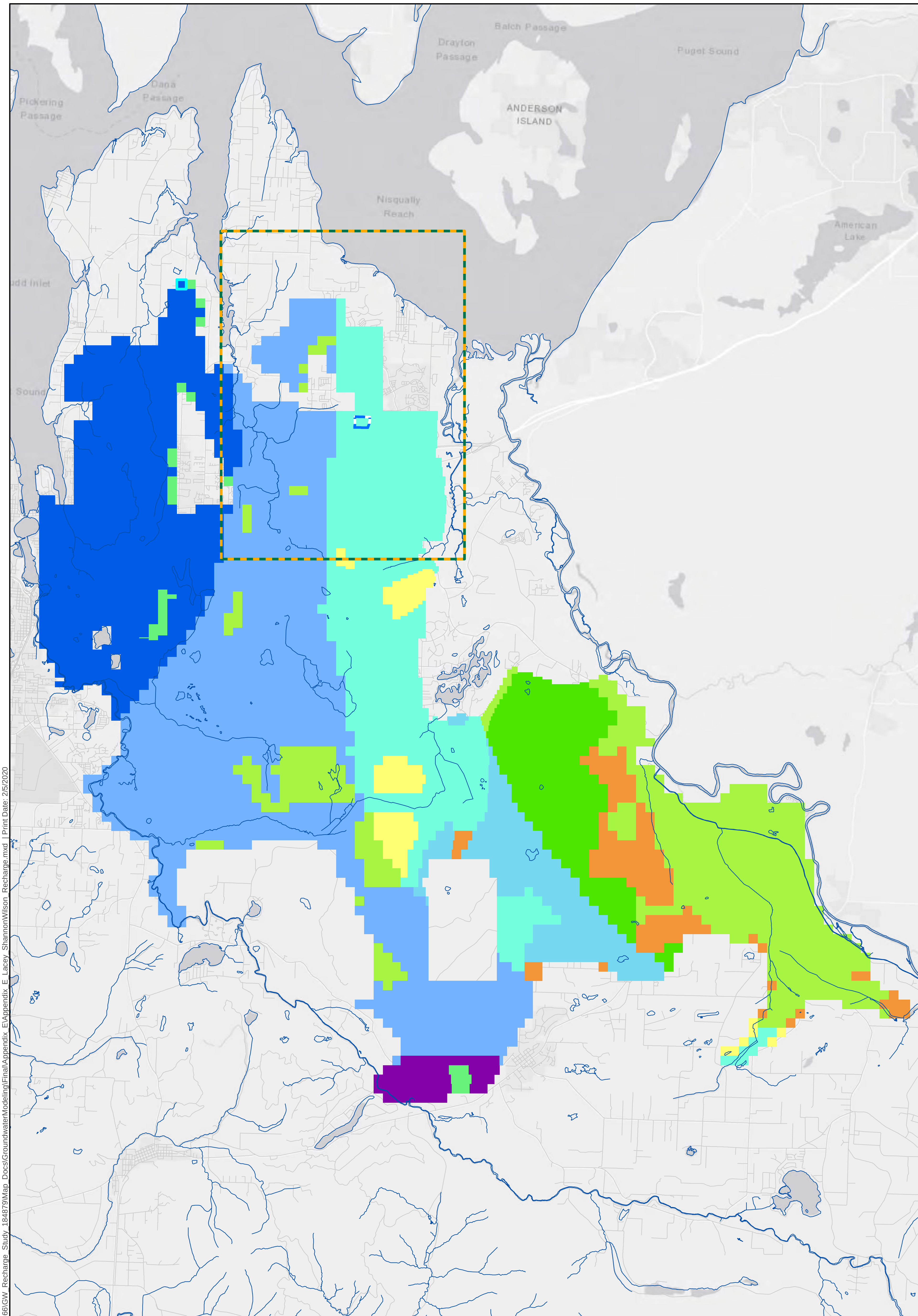
Miles
0 5

LOTT Clean Water Alliance

HDR

Path: G:\Projects\Washington\LOTT_CWA_201266\GW_Recharge_Study_184879\Map_Docs\GroundwaterModeling\Final\Appendix_E\Appendix_E_Lacey_ShannonWilson_K_L9_TQu.mxd | Print Date: 2/5/2020

Source: City of Lacey (2018), Esri (2018), Thurston Co Landfill (2018), WSDOT (2018)



Recharge Rate (in/yr)

- 33.29
- 28.91
- 27.16
- 25.40
- 22.34
- 21.46
- 18.83
- 17.96
- 14.45
- 12.70
- Roads
- Streams

- Groundwater Model Domain (HDR)
- LOTT Hawks Prairie Recharge Facility

Implemented Recharge

Shannon and Wilson (2012) - McAllister Model

Miles

0 5

LOTT Clean Water Alliance

HDR

Source: City of Lacey (2018), Esri (2018), Shannon & WIlson (2012), Thurston Co Landfill (2018), WSDOT (2018)

Path: G:\Projects\Washington\LOTT_CWA_201266\GW_Recharge_Study_184879\Map_Docs\GroundwaterModeling\Final\Appendix_E\Appendix_E_Lacey_ShannonWilson_Recharge.mxd | Print Date: 2/5/2020

Appendix F – Numerical Model Grid Cell Dimensions

This page intentionally left blank.

Model offset	x	1060560
(NAD83 State Plane WA South)	y	628312
Height	(ft)	35000
Width	(ft)	26000
Total Cells Per Layer	62491	
Index	Row Spacing (ft)	Column Spacing (ft)
1	500	500
2	500	500
3	500	500
4	500	500
5	500	418
6	500	417
7	500	411
8	500	294
9	500	210
10	500	150
11	500	150
12	500	150
13	500	150
14	500	150
15	500	150
16	468	150
17	409	150
18	400	150
19	371	150
20	348	150
21	334	150
22	334	150
23	327	150
24	327	150
25	324	150
26	306	150
27	300	150
28	292	150
29	286	150
30	286	150
31	281	150
32	281	150
33	280	150
34	239	150
35	239	150
36	200	150
37	150	150
38	150	150
39	150	150
40	150	150
41	150	150
42	150	150
43	150	150
44	150	150
45	150	150
46	150	150

Model offset	x	1060560
(NAD83 State Plane WA South)	y	628312
Height	(ft)	35000
Width	(ft)	26000
Total Cells Per Layer	62491	
Index	Row Spacing (ft)	Column Spacing (ft)
47	150	150
48	150	150
49	150	150
50	150	150
51	150	137
52	150	98
53	150	98
54	150	70
55	150	70
56	150	50
57	150	50
58	132	50
59	98	50
60	70	50
61	50	50
62	50	50
63	50	50
64	50	50
65	50	50
66	50	50
67	50	50
68	50	50
69	50	50
70	50	50
71	50	50
72	50	50
73	50	50
74	50	50
75	50	50
76	50	50
77	50	50
78	50	50
79	50	50
80	50	50
81	50	50
82	50	50
83	50	50
84	50	50
85	50	50
86	50	50
87	50	50
88	50	50
89	50	50
90	50	50
91	50	50
92	50	50

Model offset	x	1060560
(NAD83 State Plane WA South)	y	628312
Height	(ft)	35000
Width	(ft)	26000
Total Cells Per Layer	62491	
Index	Row Spacing (ft)	Column Spacing (ft)
93	50	50
94	50	50
95	50	50
96	50	50
97	50	50
98	50	50
99	50	50
100	50	50
101	50	50
102	50	50
103	50	50
104	50	50
105	50	50
106	50	50
107	50	50
108	50	50
109	50	50
110	50	50
111	50	50
112	50	50
113	50	50
114	50	50
115	50	50
116	50	50
117	50	50
118	50	50
119	50	50
120	50	50
121	50	50
122	50	50
123	50	50
124	50	50
125	50	50
126	50	50
127	50	50
128	50	50
129	50	50
130	50	50
131	50	50
132	50	50
133	50	50
134	50	50
135	50	50
136	50	50
137	50	50
138	50	50

Model offset	x	1060560
(NAD83 State Plane WA South)	y	628312
Height	(ft)	35000
Width	(ft)	26000
Total Cells Per Layer	62491	
Index	Row Spacing (ft)	Column Spacing (ft)
139	50	50
140	50	50
141	50	50
142	50	50
143	50	50
144	50	50
145	50	50
146	50	50
147	50	50
148	50	50
149	50	50
150	50	50
151	50	50
152	50	50
153	50	50
154	50	50
155	50	50
156	50	50
157	50	50
158	50	50
159	50	50
160	50	50
161	50	50
162	50	50
163	50	50
164	50	50
165	50	50
166	50	50
167	50	50
168	50	50
169	50	50
170	50	50
171	50	50
172	50	50
173	50	50
174	50	50
175	50	50
176	50	50
177	50	50
178	50	50
179	50	50
180	50	50
181	50	50
182	50	50
183	50	50
184	50	50

Model offset	x	1060560
(NAD83 State Plane WA South)	y	628312
Height	(ft)	35000
Width	(ft)	26000
Total Cells Per Layer	62491	
Index	Row Spacing (ft)	Column Spacing (ft)
185	50	50
186	50	50
187	50	50
188	50	50
189	50	50
190	50	50
191	50	50
192	50	50
193	50	50
194	50	70
195	50	80
196	50	112
197	50	150
198	50	150
199	50	150
200	50	150
201	70	150
202	80	150
203	112	150
204	150	150
205	150	150
206	150	150
207	150	150
208	150	150
209	150	150
210	150	150
211	150	150
212	150	150
213	150	150
214	150	150
215	150	150
216	150	150
217	150	150
218	150	150
219	150	150
220	150	150
221	150	150
222	150	150
223	150	150
224	150	150
225	150	150
226	150	150
227	150	150
228	150	150
229	150	150
230	150	150

Model offset	x	1060560
(NAD83 State Plane WA South)	y	628312
Height	(ft)	35000
Width	(ft)	26000
Total Cells Per Layer	62491	
Index	Row Spacing (ft)	Column Spacing (ft)
231	150	150
232	150	150
233	150	150
234	150	150
235	150	150
236	150	150
237	150	150
238	150	150
239	150	150
240	150	166
241	150	166
242	150	180
243	150	214
244	200	270
245	210	278
246	294	350
247	373	391
248	373	
249	455	
250	455	
251	455	
252	630	
253	711	

Appendix G - Hydrostratigraphic Model Input

This page intentionally left blank.

	B	C	D	E	F	G
1	**Well ID**	**X**	**Y**	**Elevation**	**Depth (ft)**	**Owner**
2	4	1069600	643746	205.6	151	JAMES CLARK
3	11	1073654	635006.7	202.9	226	ALVIN THOMPSON
4	15	1075004	648877	248.3	596	HAWKS PRAIRIE GOLF COURSE, LLC
5	17	1083238	639278	221.5	239	BOB SMITH
6	20	1068172	639794	134.84	142	OLYMPIA SAND & GRAVEL CO.
7	21	1067860	640127.3	113.7	195	OLYMPIA SAND & GRAVEL CO.
8	22	1078994	638358.7	217.9	390	ALVIN THOMPSON
9	24	1065837	648628.9	165.6	163	VIRCE
10	29	1066340	645878	92.866	82	JIM BAIN
11	182	1068986	645778	191.9	223	WILBUR LENARD
12	195	1068670	635138	165.2	179	YOUR HOME BUILDERS
13	196	1068854	651639.1	269.3	158	F. MORRIS
14	215	1081908	637349	248.7	232	PAUL & BEVERLY RICHARDSON
15	256	1078653	638234.2	215.1	390	Lacey
16	258	1079301	637446	232.995	227	JOHN KEYES
17	312	1074499	653513	212.8	590	MANKE LUMBER CO INC
18	315	1069614	644125	198.3	161.9	WASHINGTON WATER
19	322	1064895	640570	80.3	210	DAVID SIMONSEN
20	329	1080520	634763	235.3	260	ROBERT HALL
21	331	1070001	635091	196.2	136	JEWELL PAIGE
22	346	1067664	645831	101.6	371	MILLER LAND AND TIMBER
23	355	1067534	640479	103.1	157	OLYMPIA SAND & GRAVEL
24	384	1077718	639804.6	205.5	510	J. D. SHOTWELL COMPANY
25	415	1083675	650529	173.034	96	PAUL & TONYA WOLFE
26	427	1070249	643053	222.169	122	Capital Development Co (22517)
27	471	1069924	632457	170.36	109	PAT HEITZMANN
28	478	1080932	647998	277.7	309	BRADLEY - NOBLE
29	479	1080932	647998	277.7	293	BRADLEY-NOBLE
30	480	1072894	642960	230.8	218	BRUNO BETTI
31	481	1072436	645835	251.9	203.5	H. D. FOWLER INC.
32	503	1077565	637178.3	211.3	240	RICHARD BERGT
33	504	1077465	637478.3	214.2	212	RICHARD NOBEL CORROLL
34	530	1083659	649678.7	203.2	239	BRUCE MORRISON
35	532	1083562	647894	265.217	71	BELENSKI WILLIAM
36	536	1081546	643432.5	224.9	255	CONSOLIDATED CONST.
37	550	1071723	645074.1	227.2	188	JAMES CLARK
38	562	1076363	633091.8	233.4	260	OLYMPIA MUSHROOM FARMS, INC.
39	564	1076557	633571	229.5	257	OSTROMS MUSHROOM FARM
40	565	1070970	634065.5	183.6	186	P. U. D. #1 OF THURSTON COUNTY
41	587	1066844	651217.7	212.7	183	CLIFF CASEBOLT
42	601	1069116	649752	265.2	174	ROBERT DROHMAN
43	624	1071375	636365	208.403	171	ALVIN THOMPSON
44	655	1081867	636034	234.2	222	DONAHUE CONST. CO.
45	656	1082068	635725	230.5	230	DORIS BURTON
46	659	1081867	636034	234.2	231	JAMES DUTTEROW
47	660	1082048	635820.1	232	228	JEFF BONTEMPS
48	661	1081595	635897.9	231.9	108	JESS CROFT
49	662	1081867	636034	234.2	292	M & R CONSTRUCTION
50	667	1066868	646779	132.75	82	Whittaker
51	703	1069632	646795.1	234.7	261.6	RIPTIDE BUILDERS
52	705	1075596	644155.5	229.9	319.25	DOB CORP. DEV.
53	709	1075812	644584.7	238.8	320	OLYMPIA CHEESE CO LLC
54	722	1069718	644272.3	198.3	153.75	EDDIE TRUE
55	726	1062030	641769.5	96.5	344	JOHN KELLEHER
56	727	1065088	643898.7	105.4	553	MILLER LAND AND TIMBER
57	768	1080488	633442	232.2	259	WASH. LAND YACHT HARBOR
58	769	1080488	633442	232.2	270	WASH. LAND YACHT HARBOR
59	779	1067530	643919.1	149	380	JOSEPH AND LORI WARGACKI
60	782	1068119	644980	104.86	75	Brownlee
61	783	1082923	638635	224.206	196	DAVID HILL & GOSPEL OUTREACH OF OLYMPIA
62	805	1083618	649212	210.166	117	WILLIAM AND JUDY BELENSKI
63	838	1081065	651952	211.314	80	TOM BRUSS
64	840	1070515	652343	279.4	170	MANCE AND SONS DEVELOPERS INC
65	841	1070515	652343	279.4	170	MANCE AND SONS DEVELOPERS INC
66	844	1070781	646589.3	252.5	180	RALPH WHITE
67	858	1073819	642195.8	233.1	198	BRUNO BETTI
68	881	1082978	641270	232.8	243	JOHN NULY
69	944	1067704	647161	155.096	150	MIKE WILLIS
70	964	1062926	644505.8	83.2	545	ANITA HARKINS
71	1009	1060371	641240.7	111.3	350	GREG MUELLER
72	1024	1064795	637931	108.3	195	DARRYL SELNESS
73	1035	1077794	630447.4	225.2	254	HOOVER CONST. CO.
74	1036	1077801	630878	226.7	286	SOUTH SOUND UTILITIES
75	1039	1063756	631234.5	178.6	240	ST. MARTINS ABBEY

	B	C	D	E	F	G
1	**Well ID**	**X**	**Y**	**Elevation**	**Depth (ft)**	**Owner**
76	1087	1085051	651796	141.9	150	FIELD, PETER
77	1090	1084895	651166.4	186.9	188	SIERRA MADRE DEV LLC
78	1091	1084895	651166.4	186.9	189	SIERRA MADRE DEV LLC
79	1098	1065374	657823	162.3	187.5	NORM GOODRUM
80	1107	1070655	657610	125.8	173	MANCE AND SON RD
81	1111	1074750	659660.3	69.2	227.25	JOHN SUTICH
82	1117	1074683	658781	145.5	191	DENNIS BURKE
83	1120	1073350	658821	89.945	107.5	BARALYN GRANT
84	1128	1071941	656233	206.226	118	MANCE & SON RD / MARVIN GARDENS WATER SYSTEM
85	1129	1070618	656289	158.398	152	ROBERT PIERCE
86	1144	1062295	656707.1	35.3	286	CHARLES ALLAIRE
87	1155	1064320	654611.8	106.5	206	ROBERT DAYTON
88	1156	1066719	652263.9	198.7	177	STEVE STUCHINER
89	1159	1064325	653923.4	90.2	160	ASSOCIATION OF OUTDOOR RECREATION CLUBS
90	1164	1065974	654910	75.3	160	WILLIE ALLEN
91	1190	1062521	651309	39.2	178	FRIEND & FRIEND
92	1197	1063979	651198.8	174.2	158	PAULC ARLSON
93	1202	1082070	632548.2	267.5	325	MEADOW WATER CO
94	1203	1081764	632076	264.8	307	GRAYS HARBOR ENTERPRISES INC
95	1204	1081764	632076	264.8	336	HODGES HOMES INC
96	1207	1082441	653220	58.295	123	DON AND LINDA MALATESTA
97	1224	1077301	644064.1	251.34	170	
98	1241	1067754	648483	148.7	215	THORPE, DOROTHY
99	1243	1072234	661689.7	70.6	196	Sam Tollifson
100	1277	1076643	657632.8	107.6	218	Mance & Son residential Developers Inc.
101	1278	1082136	651401.4	201.3452	106	Matt Ripplinger
102	1279	1082113	652553.9	142	198	Terry Heinz
103	1280	1079384	655783.4	115	155	Blythe Larsen
104	1281	1067922	661267.8	157.6	118	Kevin Downey
105	1282	1063458	661178.2	159	127	Stephen & Terri Anderson
106	1283	1083705	647694.8	265	138	
107	Glacier Park	1075684	649516	248.2	596	GLACIER PARK CO
108	Lacey MW-11	1073816	642532.8	232.12	140	Lacey
109	Lacey S07	1064747	629969.8	187.442	488	Lacey
110	Lacey S15	1079908	652455.6	235.662	140	Lacey
111	Lacey S16	1079937	652479.6	238.822	141	Lacey
112	Lacey S19 (HP1)	1072576	648744.7	305	653	Lacey
113	Lacey S21	1078305	629705.1	264.902	329	Lacey
114	Lacey S22	1078300	629883.4	266.072	333	Lacey
115	Lacey S28	1078256	629870.4	265.352	338	Lacey
116	Lacey S31 (HP2)	1072736	648609.3	296	656	Lacey
117	Lacey TW - Betti	1073551	643373.7	225.1	398	Lacey
118	Lacey TW-BC3	1079977	652463.4	230	572	Lacey
119	Lacey TW-MC	1080072	645688.1	242.7	668	Lacey
120	Lacey TW-MR	1072315	649392.2	282.8	628.5	Lacey
121	Landfill MW-1	1075984	639614.9	220.58	200	Landfill
122	Landfill MW-10D	1077481	640752	227.51	260	TC-Landfill
123	Landfill MW-11	1078000	639554.1	225.07	130	Landfill
124	Landfill MW-12D	1076508	642983.3	220.18	250	Landfill
125	Landfill MW-13D	1079237	640600.1	214.04	230	TC-Landfill
126	Landfill MW-6R	1078030	639491.2	227.87	200	Landfill
127	Landfill MW-9D	1079966	639812.4	252.53	255	TC-Landfill
128	MW-1	1076316	642684	219.46	155	LOTT
129	MW-10	1074903	643502	224.89	140	LOTT
130	MW-11	1074897	642391	228	160	LOTT
131	MW-12	1074893	642690	227	360	LOTT
132	MW-14	1075991	642641	218.04	390	LOTT
133	MW-15	1076002	642742	219.2	100	LOTT
134	MW-16	1076203	642738	219.34	110	LOTT
135	MW-20	1074874	641507	219.22	225	LOTT
136	MW-21	1073574	641077	227.16	310	LOTT
137	MW-23	1077296	643061	204.54	312	LOTT
138	MW-25	1075647	641496	228.95	190	LOTT
139	MW-26	1077568	644799	233.18	150	LOTT
140	MW-27	1075465	642077	220.16	170	LOTT
141	MW-28	1074790	641129	224.85	180	LOTT
142	MW-3a	1075924	642566	219.17	135	LOTT
143	MW-5	1076096	642379	219.09	125	LOTT
144	MW-6	1076201	643157	218.97	103	LOTT
145	MW-7	1075959	642881	218.91	120	LOTT
146	MW-8	1075400	642506	218.7	138	LOTT
147	MW-9	1075575	642394	218.69	136	LOTT

Well ID	Depth to Top of Unit (ft bgs)	Depth to Bottom of Unit (ft bgs)	Lithology
4	0	5	Qvr
4	5	92	Qvt
4	92	151	Qva
11	0	15	Qvr
11	15	21	Qvt
11	21	81	Qva
11	81	187	Qf
11	187	226	Qc
15	0	19	Qvr
15	19	115	Qvt
15	115	164	Qva
15	164	287	Qf
15	287	343	Qc
15	343	527	LCU
15	527	596	TQu
17	0	13	Qvr
17	13	34	Qvt
17	34	131	Qva
17	131	232	Qf
17	232	239	Qc
20	0	26	Qvr
20	26	47	Qva
20	47	133	Qf
20	133	142	Qc
21	0	38	Qvt
21	38	73	Qva
21	73	151	Qf
21	151	195	Qc
22	100	132	Qva
22	334	390	LCU
22	0	10	Qvr
22	10	100	Qvt
22	132	248	Qf
22	248	334	Qc
24	110	148	Qf
24	0	55	Qvt
24	55	110	Qva
29	48	82	Qva
182	111	203	Qf
182	0	3	Qvr
182	3	69	Qvt
182	69	111	Qva
182	203	223	Qc
195	153	179	Qc
195	63	70	Qva
195	0	6	Qvr
195	6	63	Qvt
195	70	153	Qf
196	0	131	Qvt
215	0	15	Qvt
215	15	128	Qvt
215	128	162	Qva
215	162	232	Qf
256	316	355	LCU
256	355	390	TQu
256	0	10	Qvr
256	10	97	Qvt
256	97	111	Qva
256	111	232	Qf
256	232	311	Qc
258	0	31	Qvr
258	31	84	Qvt
258	84	134	Qva
258	134	217	Qf
258	217	227	Qc
312	0	11	Qvr
312	11	95	Qvt
312	95	150	Qva
312	150	290	Qf
312	290	369.5	Qc
312	369.5	530	LCU
312	530	590	TQu
315	2	107	Qvt
322	53	113	Qf
322	113	200	Qc
322	200	210	LCU
329	0	17	Qvr
329	17	70	Qvt
329	70	107	Qva
329	107	247	Qf

Well ID	Depth to Top of Unit (ft bgs)	Depth to Bottom of Unit (ft bgs)	Lithology
329	247	258	Qc
329	258	260	LCU
331	80	129	Qf
331	129	136	Qc
331	0	15	Qvr
331	15	61	Qvt
331	61	80	Qva
346	16	108	Qva
346	0	16	Qvr
346	58	108	Qf
346	108	194	Qc
346	194	320	LCU
346	320	371	TQu
355	10	41	Qva
355	41	120	Qf
355	120	154	Qc
384	10	104	Qva
384	104	205	Qf
384	205	280	Qc
384	280	476	LCU
384	476	510	TQu
415	59	96	Qva
427	0	18	Qvr
427	18	119	Qva
471	93	109	Qva
471	36	93	Qvt
478	22	79	Qvt
478	0	22	Qvr
478	116	164	Qva
478	164	287	Qf
478	287	309	Qc
479	19	76	Qvt
479	0	19	Qvr
479	76	168	Qva
479	168	268	Qf
479	268	293	Qc
480	0	58	Qvt
480	58	148	Qva
480	148	164	Qf
480	164	218	Qc
481	0	80	Qvt
481	80	134	Qva
481	134	192	Qf
481	192	203	Qc
503	156	192	Qf
503	192	240	Qc
504	0	3	Qvr
504	3	26	Qvt
504	26	120	Qva
504	120	199	Qf
504	199	212	Qc
530	0	58	Qvt
532	0	13	Qvr
532	13	54	Qvt
532	54	71	Qva
536	0	101	Qvt
536	101	127	Qva
536	127	248	Qf
536	248	255	Qc
550	0	7	Qvr
550	7	50	Qvt
550	50	182	Qva
550	182	188	Qf
562	0	25	Qvr
562	25	64	Qvt
562	64	106	Qva
562	106	190	Qf
562	190	260	Qc
564	175	257	Qc
564	0	25	Qvr
564	25	80	Qvt
564	80	125	Qva
564	125	175	Qf
565	90	156	Qf
565	0	3	Qvr
565	3	40	Qvt
565	40	90	Qva
587	0	75	Qvt
587	75	97	Qva
587	97	183	Qf

Well ID	Depth to Top of Unit (ft bgs)	Depth to Bottom of Unit (ft bgs)	Lithology
601	0	105	Qvt
601	105	149	Qva
601	149	174	Qf
624	82	115	Qva
624	115	150	Qf
624	150	171	Qc
624	5	82	Qvt
655	0	22	Qvr
655	22	118	Qvt
655	118	146	Qva
656	0	14	Qvr
656	14	102	Qvt
656	102	164	Qva
656	164	220	Qf
656	220	230	Qc
659	0	23	Qvr
659	23	88	Qvt
659	88	140	Qva
659	140	230	Qf
660	0	14	Qvr
660	14	105	Qvt
660	105	170	Qva
660	170	217	Qf
660	217	228	Qc
661	86	108	Qva
661	0	86	Qvt
662	0	5	Qvr
662	5	121	Qvt
662	121	163	Qva
662	163	225	Qf
662	225	290	Qc
662	290	292	LCU
667	45	82	Qva
703	100	151	Qva
703	151	233	Qf
703	0	100	Qvt
703	253	261	Qc
705	0	30	Qvr
705	30	138	Qva
705	138	248	Qf
705	248	317	Qc
709	0	30	Qvr
709	30	137	Qva
709	137	248	Qf
709	248	320	Qc
722	54	116	Qvt
722	0	3	Qvr
722	3	47	Qvt
722	116	149	Qf
722	149	153	Qc
726	324	344	TQU
726	0	47	Qvt
726	47	65	Qf
726	65	222	Qc
726	222	324	LCU
727	40	70	Qva
727	70	130	Qf
727	130	186	Qc
727	186	472	LCU
727	472	553	TQu
768	0	19	Qvr
768	19	71	Qvt
768	71	105	Qva
768	105	241	Qf
768	241	259	Qc
769	0	36	Qvr
769	36	78	Qvt
769	78	98	Qva
769	98	226	Qf
769	226	270	Qc
779	0	45	Qvr
779	45	95	Qvt
779	95	150	Qf
779	270	365	LCU
779	365	380	TQu
782	15	35	Qvt
782	35	75	Qva
783	82	96	Qva
783	187	196	Qc
805	0	24	Qvr

Well ID	Depth to Top of Unit (ft bgs)	Depth to Bottom of Unit (ft bgs)	Lithology
805	24	56	Qvt
805	56	117	Qva
838	0	5	Qvr
838	5	31	Qvt
838	31	80	Qva
840	0	37	Qvt
840	37	170	Qva
841	0	37	Qvt
841	37	170	Qva
844	0	112	Qvt
844	112	148	Qva
844	148	180	Qf
858	0	9	Qvr
858	9	71	Qvt
858	71	163	Qva
858	163	188	Qf
858	188	198	Qc
881	0	70	Qvt
881	70	145	Qva
881	145	235	Qf
881	235	243	Qc
944	16	138	Qva
944	138	150	Qc
964	49	160	Qc
964	160	449	LCU
964	449	545	TQu
1009	146	160	Qc
1024	183	195	Qc
1035	0	48	Qvt
1035	48	100	Qva
1035	100	231	Qf
1035	231	254	Qc
1036	0	50	Qvt
1036	50	110	Qva
1036	110	228	Qf
1036	228	285	Qc
1036	285	286	LCU
1039	0	43	Qvr
1039	43	55	Qvt
1039	55	93	Qva
1039	93	172	Qf
1039	173	184	Qc
1039	184	240	LCU
1087	0	30	Qvt
1087	30	109	Qf
1087	109	150	Qc
1090	95	119	Qva
1090	54	95	Qvt
1090	119	171	Qf
1090	171	188	Qc
1091	95	119	Qva
1091	119	171	Qf
1091	54	95	Qvt
1091	171	189	Qc
1098	0	99	Qvt
1098	99	158	Qva
1098	158	187	Qf
1107	0	65	Qvt
1107	65	161	Qva
1107	161	173	Qf
1111	0	25	Qvt
1111	25	77	Qva
1111	77	197	Qf
1111	197	224	Qc
1117	0	68	Qvr
1117	68	104	Qvt
1117	104	143	Qva
1117	143	172	Qf
1117	172	190	Qc
1120	1	99	Qvt
1128	22	88	Qvt
1129	4	110	Qvt
1144	0	34	Qvt
1144	34	279	Qf
1144	279	286	Qc
1155	0	78	Qvt
1155	78	200	Qf
1155	200	206	Qc
1156	0	55	Qvt
1156	157	172	Qc

Well ID	Depth to Top of Unit (ft bgs)	Depth to Bottom of Unit (ft bgs)	Lithology
1159	37	160	Qf
1159	0	37	Qvt
1164	0	51	Qvt
1190	0	42	Qvt
1197	0	76	Qvt
1202	0	68	Qvt
1202	68	97	Qva
1202	97	170	Qf
1202	170	294	Qc
1203	258	303	Qc
1203	201	258	Qc
1203	0	65	Qvt
1203	65	101	Qva
1203	101	201	Qf
1204	197	336	Qc
1204	0	80	Qvt
1204	80	122	Qva
1204	122	197	Qf
1207	90	123	Qc
1207	76	90	Qf
1224	0	120	Qvt
1224	120	170	Qva
1241	0	65	Qvr
1241	65	88	Qva
1241	88	202	Qf
1241	202	215	Qc
1243	184	196	Qc
1243	160	184	Qf
1243	86	160	Qva
1243	0	86	Qvt
1277	0	29	Qvr
1277	29	35	Qvt
1277	35	165	Qva
1277	165	190	Qf
1277	190	218	Qc
1278	0	16	Qvr
1278	16	56	Qvt
1278	56	105	Qva
1278	105	106	Qf
1279	170	184	Qc
1279	0	56	Qvr
1279	56	92	Qvt
1279	92	108	Qva
1279	108	139	Qf
1279	139	170	Qc
1279	184	198	Qc
1280	0	69	Qvt
1280	69	101	Qva
1280	101	139	Qf
1280	139	154	Qc
1281	0	67	Qvt
1281	67	118	Qva
1282	86	127	Qva
1283	0	63	Qvr
1283	63	137	Qvt
1283	137	138	Qva
Glacier Park	0	27.5	Qvr
Glacier Park	27.5	115	Qvt
Glacier Park	115	164	Qva
Glacier Park	164	287	Qf
Glacier Park	287	343	Qc
Glacier Park	343	527	LCU
Glacier Park	527	596	TQu
acey MW-1	0	7	Qvr
acey MW-1	7	52	Qvt
acey MW-1	52	130	Qva
acey MW-1	130	140	Qf
Lacey S07	325	419	LCU
Lacey S07	419	488	TQu
Lacey S15	0	6	Qvr
Lacey S15	6	83	Qvt
Lacey S15	83	139	Qva
Lacey S15	139	140	Qf
Lacey S16	0	9	Qvr
Lacey S16	9	96	Qvt
Lacey S16	96	141	Qva
cey S19 (HF	0	50	Qvr
cey S19 (HF	50	201	Qva
cey S19 (HF	201	332	Qf
cey S19 (HF	332	402	Qc

Well ID	Depth to Top of Unit (ft bgs)	Depth to Bottom of Unit (ft bgs)	Lithology
cey S19 (HF	402	541	LCU
cey S19 (HF	541	653	TQu
Lacey S21	0	85	Qvt
Lacey S21	85	117	Qva
Lacey S21	117	244	Qf
Lacey S21	244	327	Qc
Lacey S21	327	329	LCU
Lacey S22	0	87	Qvt
Lacey S22	87	123	Qva
Lacey S22	123	265	Qf
Lacey S22	265	331	Qc
Lacey S22	331	333	LCU
Lacey S28	0	83	Qvt
Lacey S28	83	123	Qva
Lacey S28	123	259	Qf
Lacey S28	259	333	Qc
Lacey S28	333	338	LCU
cey S31 (HF	0	50	Qvr
cey S31 (HF	50	70	Qvt
cey S31 (HF	70	197	Qva
cey S31 (HF	197	297	Qf
cey S31 (HF	297	400	Qc
cey S31 (HF	400	498	LCU
cey S31 (HF	498	656	TQu
cey TW - Be	0	33	Qvr
cey TW - Be	33	92	Qvt
cey TW - Be	92	155	Qva
cey TW - Be	155	234	Qf
cey TW - Be	234	393	Qc
cey TW - Be	393	398	LCU
acey TW-BC	0	5	Qvr
acey TW-BC	5	62	Qvt
acey TW-BC	62	140	Qva
acey TW-BC	140	239	Qf
acey TW-BC	239	352	Qc
acey TW-BC	352	438	LCU
acey TW-BC	438	572	TQu
acey TW-M	0	62	Qvr
acey TW-M	62	108	Qvt
acey TW-M	108	135	Qva
acey TW-M	135	260	Qf
acey TW-M	260	380	Qc
acey TW-M	380	494	LCU
acey TW-M	494	668	TQu
acey TW-M	0	40	Qvr
acey TW-M	40	63	Qvt
acey TW-M	63	187	Qva
acey TW-M	187	265	Qf
acey TW-M	265	389	Qc
acey TW-M	389	507	LCU
acey TW-M	507	628.5	TQu
andfill MW-	10	165	Qva
andfill MW-	125	165	Qf
andfill MW-	165	200	Qc
ndfill MW-1	10	135	Qva
ndfill MW-1	135	236	Qf
ndfill MW-1	236	260	Qc
ndfill MW-	10	125	Qva
ndfill MW-	125	130	Qf
ndfill MW-1	0	44	Qvr
ndfill MW-1	44	91	Qvt
ndfill MW-1	91	102	Qva
ndfill MW-1	102	236	Qf
ndfill MW-1	236	250	Qc
ndfill MW-1	10	90	Qva
ndfill MW-1	90	213	Qf
ndfill MW-1	213	230	Qc
ndfill MW-(	10	140	Qva
ndfill MW-(	140	180	Qf
ndfill MW-(	190	200	Qc
ndfill MW-9	0	50	Qvr
ndfill MW-9	183	238	Qf
ndfill MW-9	238	250	Qc
ndfill MW-9	50	183	Qva
MW-1	20	95	Qva
MW-1	95	155	Qf
MW-10	0	30	Qvr
MW-10	30	140	Qva
MW-11	47	160	Qva
MW-12	0	10	Qvr

Well ID	Depth to Top of Unit (ft bgs)	Depth to Bottom of Unit (ft bgs)	Lithology
MW-12	10	28	Qvt
MW-12	28	142	Qva
MW-12	142	280	Qf
MW-12	280	358	Qc
MW-12	358	360	LCU
MW-14	0	22	Qvr
MW-14	22	117	Qva
MW-14	117	290	Qf
MW-14	290	365	Qc
MW-14	365	390	LCU
MW-15	20	100	Qva
MW-16	20	105	Qva
MW-16	105	110	Qf
MW-20	72	190	Qva
MW-20	0	72	Qvt
MW-21	0	10	Qvr
MW-21	10	30	Qvt
MW-21	30	140	Qva
MW-21	140	195	Qf
MW-21	195	310	Qc
MW-23	0	32	Qvr
MW-23	32	42	Qvt
MW-23	42	107	Qva
MW-23	107	245	Qf
MW-23	245	312	Qc
MW-25	0	10	Qvr
MW-25	10	18	Qvt
MW-25	18	169	Qva
MW-25	169	190	Qf
MW-26	0	70	Qvr
MW-26	70	73	Qvt
MW-26	73	130	Qva
MW-26	130	150	Qf
MW-27	0	18	Qvr
MW-27	18	34	Qvt
MW-27	34	130	Qva
MW-27	130	150	Qf
MW-28	70	180	Qva
MW-28	0	70	Qvr
MW-3a	20	127.5	Qva
MW-3a	127.5	135	Qf
MW-5	20	105	Qva
MW-5	105	125	Qf
MW-6	20	103	Qva
MW-7	94	100	Qf
MW-7	20	94	Qva
MW-8	92	99	Qf
MW-8	20	92	Qva
MW-9	37	99	Qva
MW-9	0	37	Qvr

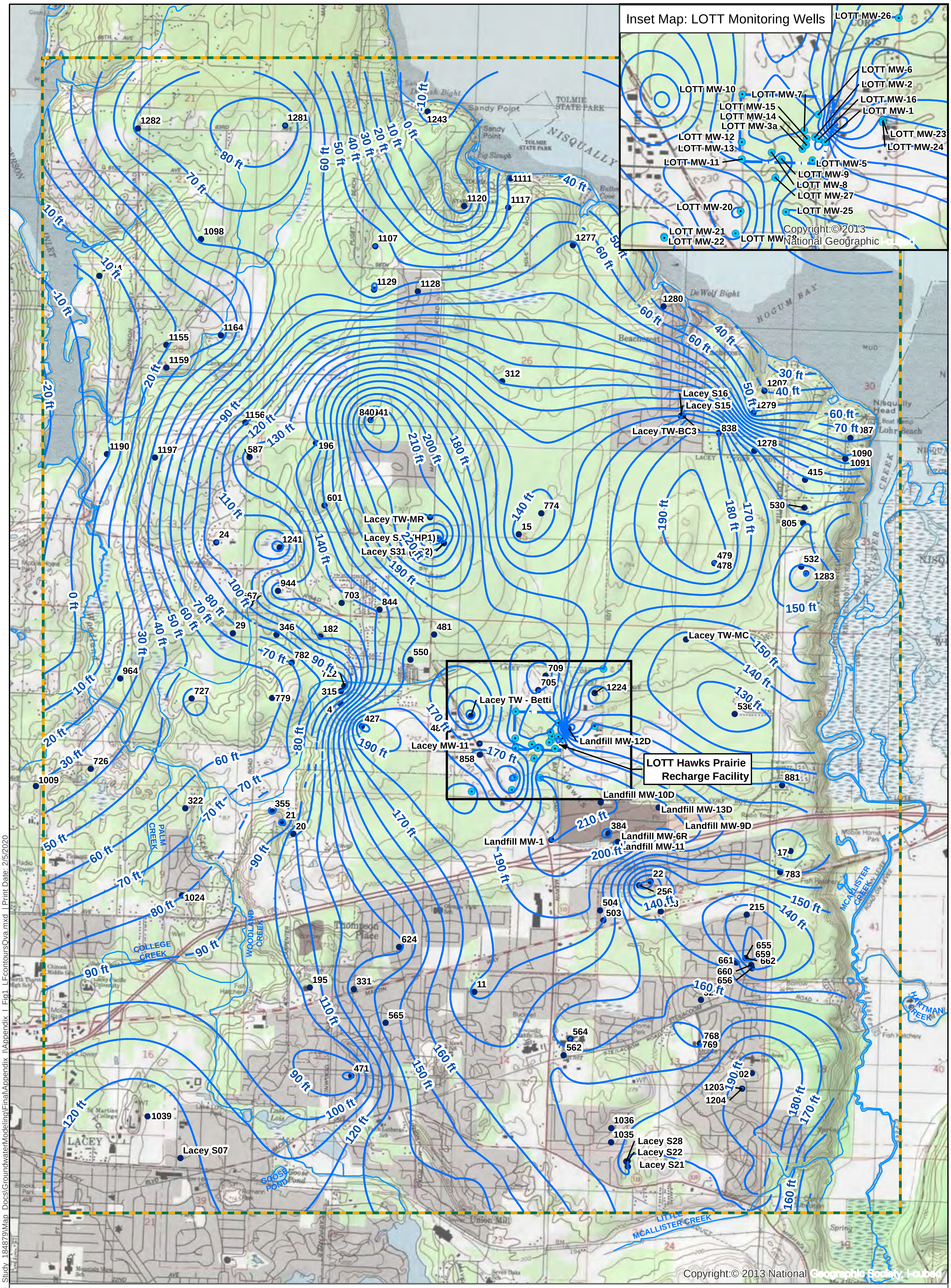
Appendix H – Well Logs Referenced for Hydrostratigraphic Model

(Provided electronically)

This page intentionally left blank.

Appendix I – Hydrostratigraphic Model Layer Contours, Shallow through Deep Aquifer

This page intentionally left blank.



Path: G:\Projects\Washington\LOTT_CWA_201266\GW_Recharge_Study_184879\Map_Docs\Groundwater\Modeling\Final\Appendix_I\Appendix_I_Fig1_LFcontoursQva.mxd | Print Date: 2/5/2020

Layer 3 (Qva) Surface Elevation Contours (ft)

Well Logs Used in Hydrostratigraphy Model

- Study ID
- LOTT Monitoring Wells
- LOTT Hawks Prairie Recharge Facility
- Groundwater Model Domain
- Streams

Hydrostratigraphy Model Layer Elevation Contours
Model Layer 3 (Qva)

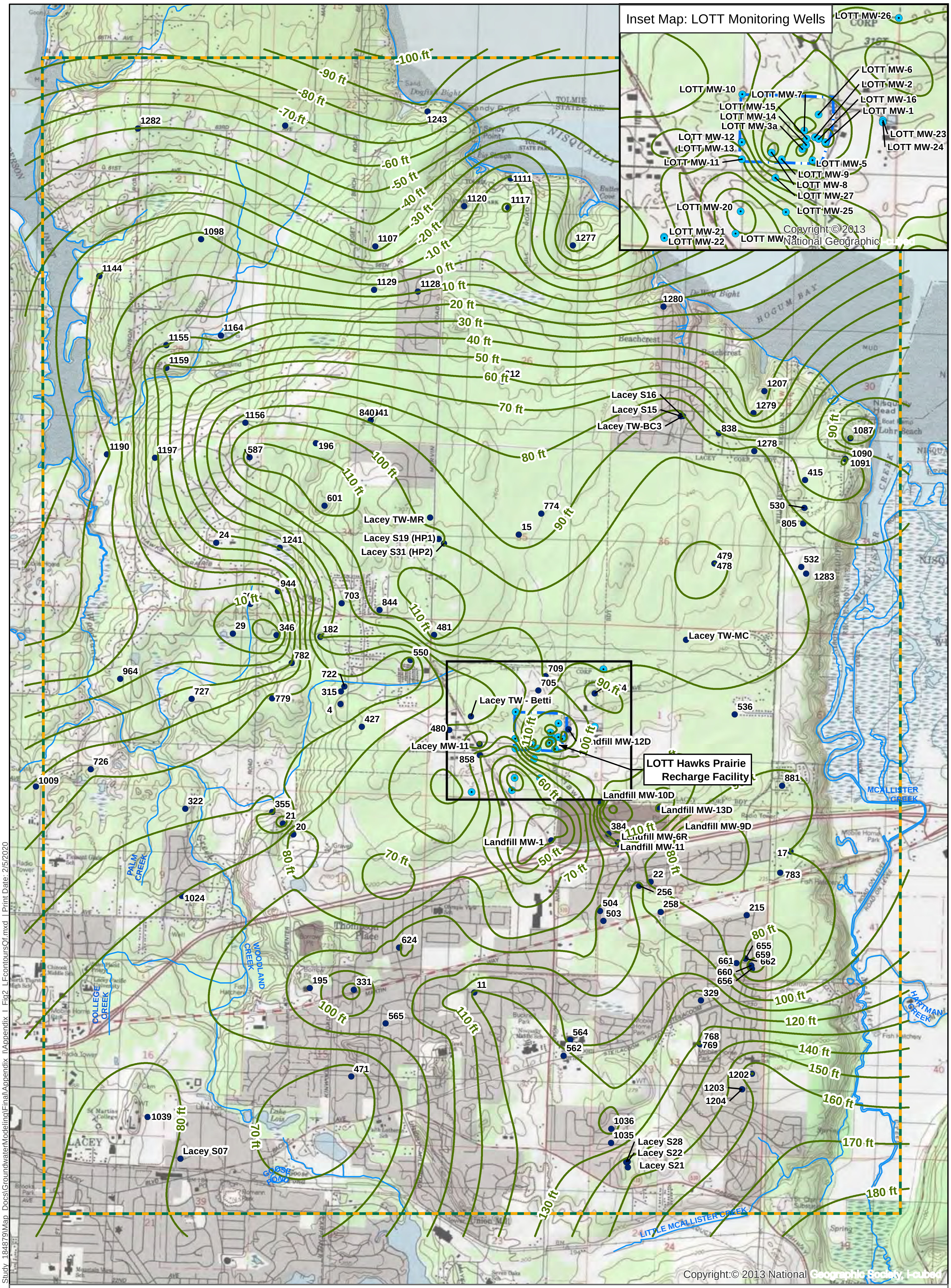
Note:
1. Elevation datum is NAVD88 (ft).
2. Wells located from WA Dept. of Ecology, City of Lacey, Thurston County, and LOTT Clean Water Alliance. Wells are located to the centroid of the quarter-quarter section; where available well locations were corrected to address given on well log.

Miles
0 1

LOTT Clean Water Alliance

HDR

Source: WA Dept. of Ecology (2015), City of Lacey (2014), WSDOT (2013)



Layer 4 (Qf) Surface Elevation Contours (ft)

Well Logs Used in Hydrostratigraphy Model

- Study ID
- LOTT Monitoring Wells
- LOTT Hawks Prairie Recharge Facility
- Groundwater Model Domain
- Streams

Hydrostratigraphy Model Layer Elevation Contours
Model Layer 4 (Qf)

Note:

1. Elevation datum is NAVD88 (ft).
2. Wells located from WA Dept. of Ecology, City of Lacey, Thurston County, and LOTT Clean Water Alliance. Wells are located to the centroid of the quarter-quarter section; where available well locations were corrected to address given on well log.

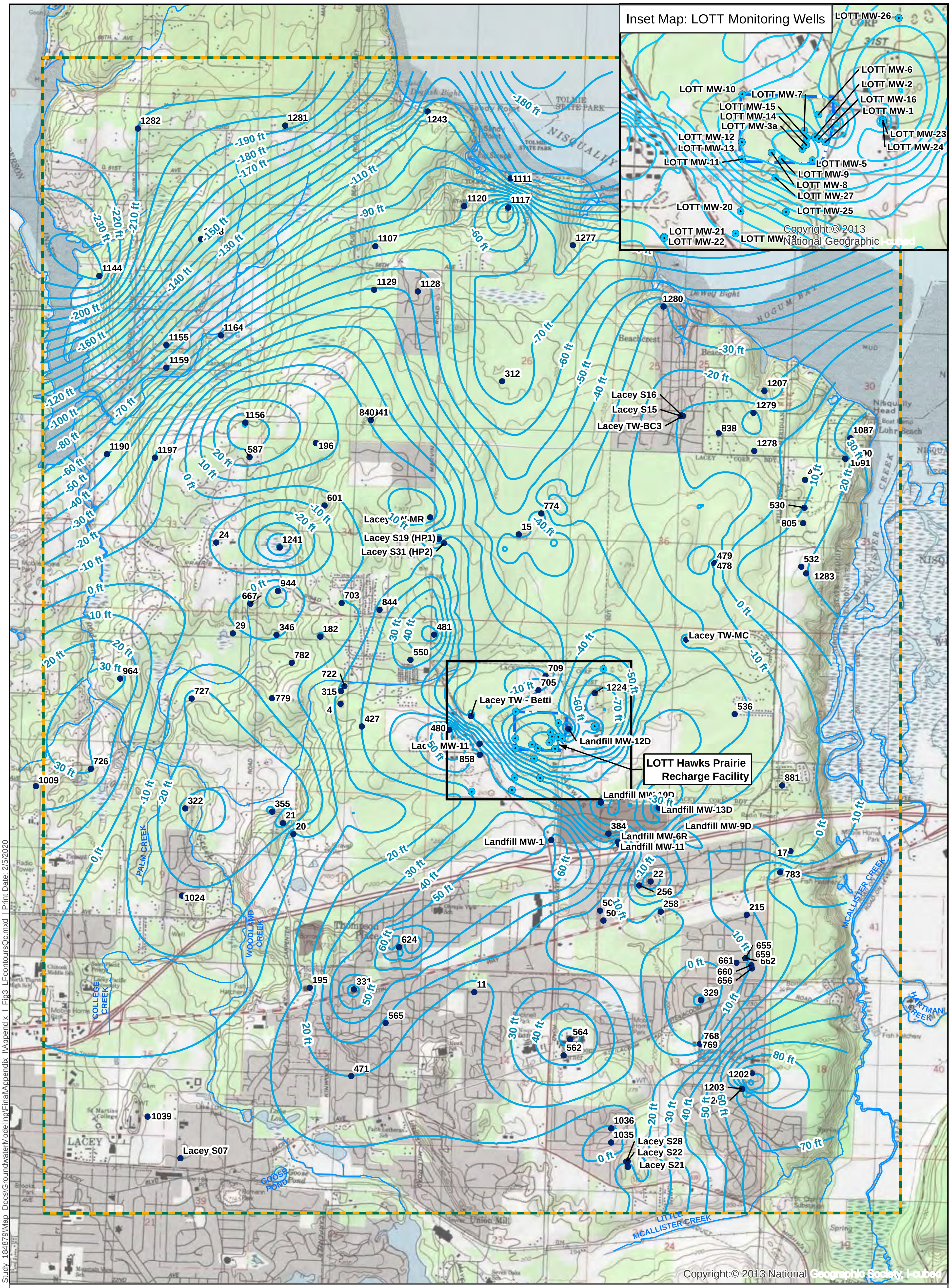
Miles

0 1

LOTT Clean Water Alliance

HDR

Source: WA Dept. of Ecology (2015), City of Lacey (2014), WSDOT (2013)



Path: G:\Projects\Washington\LOTT_CWA_201266\GW_Recharge_Study_184879\Map_Docs\GroundwaterModeling\Final\Appendix_I\Appendix_I_Fig3_LFcontoursQc.mxd | Print Date: 2/5/2020

Layer 5 (Qc) Surface Elevation Contours (ft)

Well Logs Used in Hydrostratigraphy Model

- Study ID
- LOTT Monitoring Wells
- LOTT Hawks Prairie Recharge Facility
- Groundwater Model Domain
- Streams

Hydrostratigraphy Model Layer Elevation Contours
Model Layer 5 (Qc)

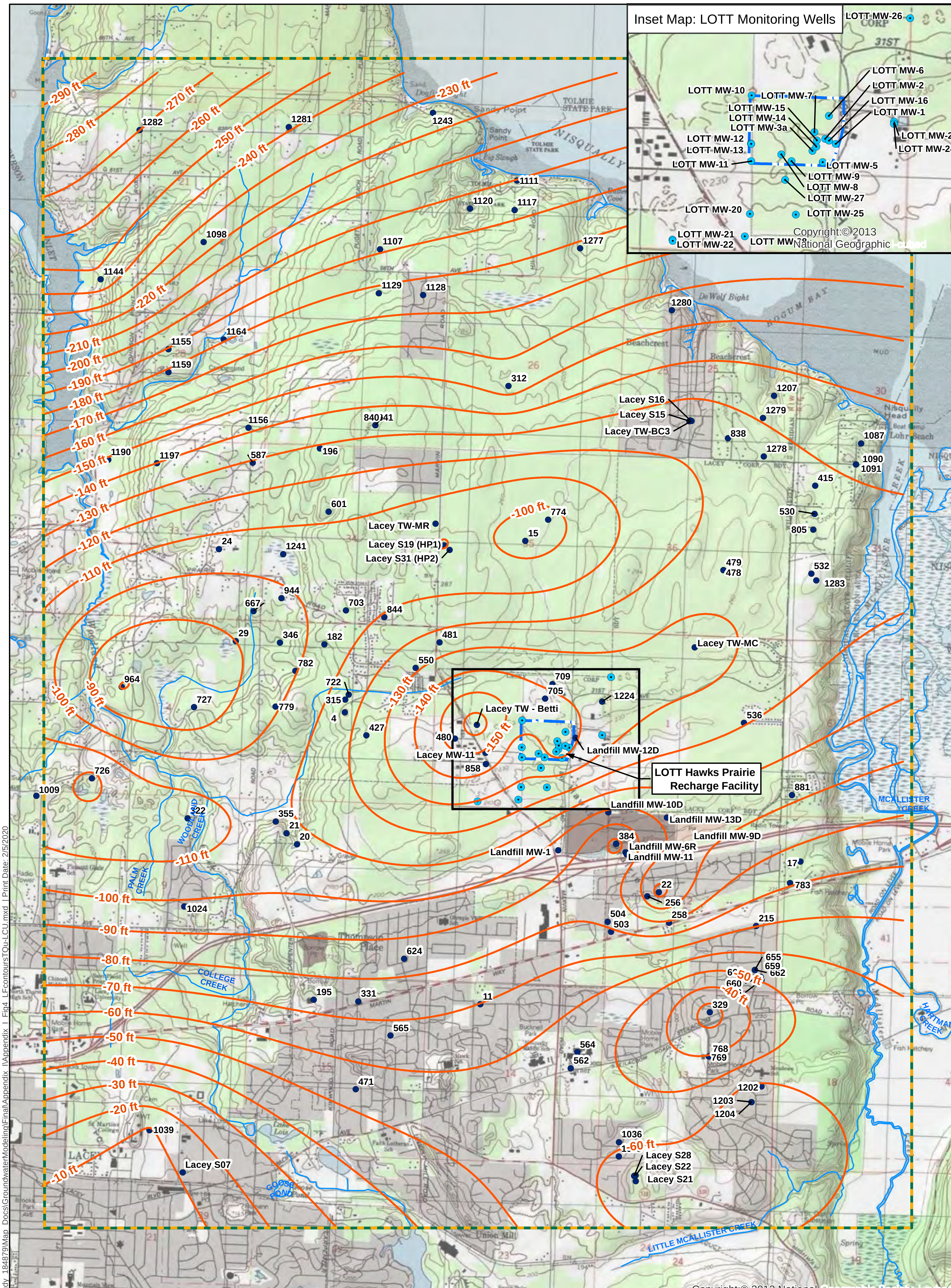
Note:
1. Elevation datum is NAVD88 (ft).
2. Wells located from WA Dept. of Ecology, City of Lacey, Thurston County, and LOTT Clean Water Alliance. Wells are located to the centroid of the quarter-quarter section; where available well locations were corrected to address given on well log.

Miles
0 1

LOTT Clean Water Alliance

HDR

Source: WA Dept. of Ecology (2015), City of Lacey (2014), WSDOT (2013)



Layer 6 (LCU) Surface Elevation Contours (ft)

Well Logs Used in Hydrostratigraphy Model

- Study ID
- LOTT Monitoring Wells
- LOTT Hawks Prairie Recharge Facility
- Groundwater Model Domain
- Streams

Hydrostratigraphy Model Layer Elevation Contours
Model Layer 6 (TQu - Lower Confining Unit (LCU))

Note:
1. Elevation datum is NAVD88 (ft).
2. Wells located from WA Dept. of Ecology, City of Lacey, Thurston County, and LOTT Clean Water Alliance. Wells are located to the centroid of the quarter-quarter section; where available well locations were corrected to address given on well log.

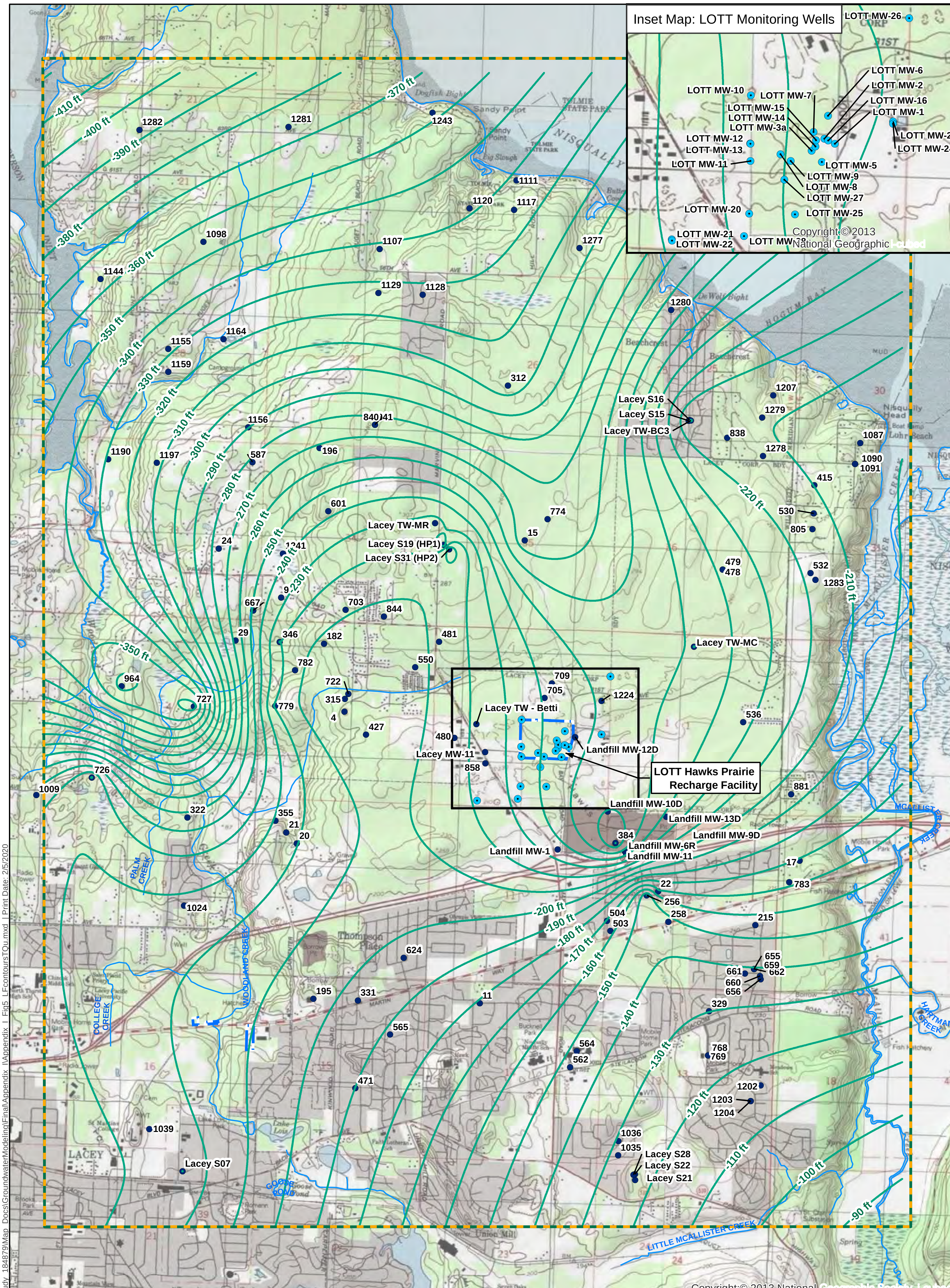
Miles
0 1

LOTT Clean Water Alliance

HDR

Path: G:\Projects\Washington\LOTT_CWA_201266\GW_Recharge_Study_184879\Map_Docs\GroundwaterModeling\Final\Appendix_I\Appendix_I_Fig4_LFcontoursTQu-LCU.mxd | Print Date: 2/5/2020

Source: WA Dept. of Ecology (2015), City of Lacey (2014), WSDOT (2013)



- Layer 7 (TQu) Surface Elevation Contours

Well Logs Used in Hydrostratigraphy Model

- Study ID
- LOTT Monitoring Wells
- LOTT Hawks Prairie Recharge Facility
- Groundwater Model Domain
- Streams

Hydrostratigraphy Model Layer Elevation Contours
Model Layer 7 (TQu)

Note:
1. Elevation datum is NAVD88 (ft).
2. Wells located from WA Dept. of Ecology, City of Lacey, Thurston County, and LOTT Clean Water Alliance. Wells are located to the centroid of the quarter-quarter section; where available well locations were corrected to address given on well log.

Miles
0 1

LOTT Clean Water Alliance

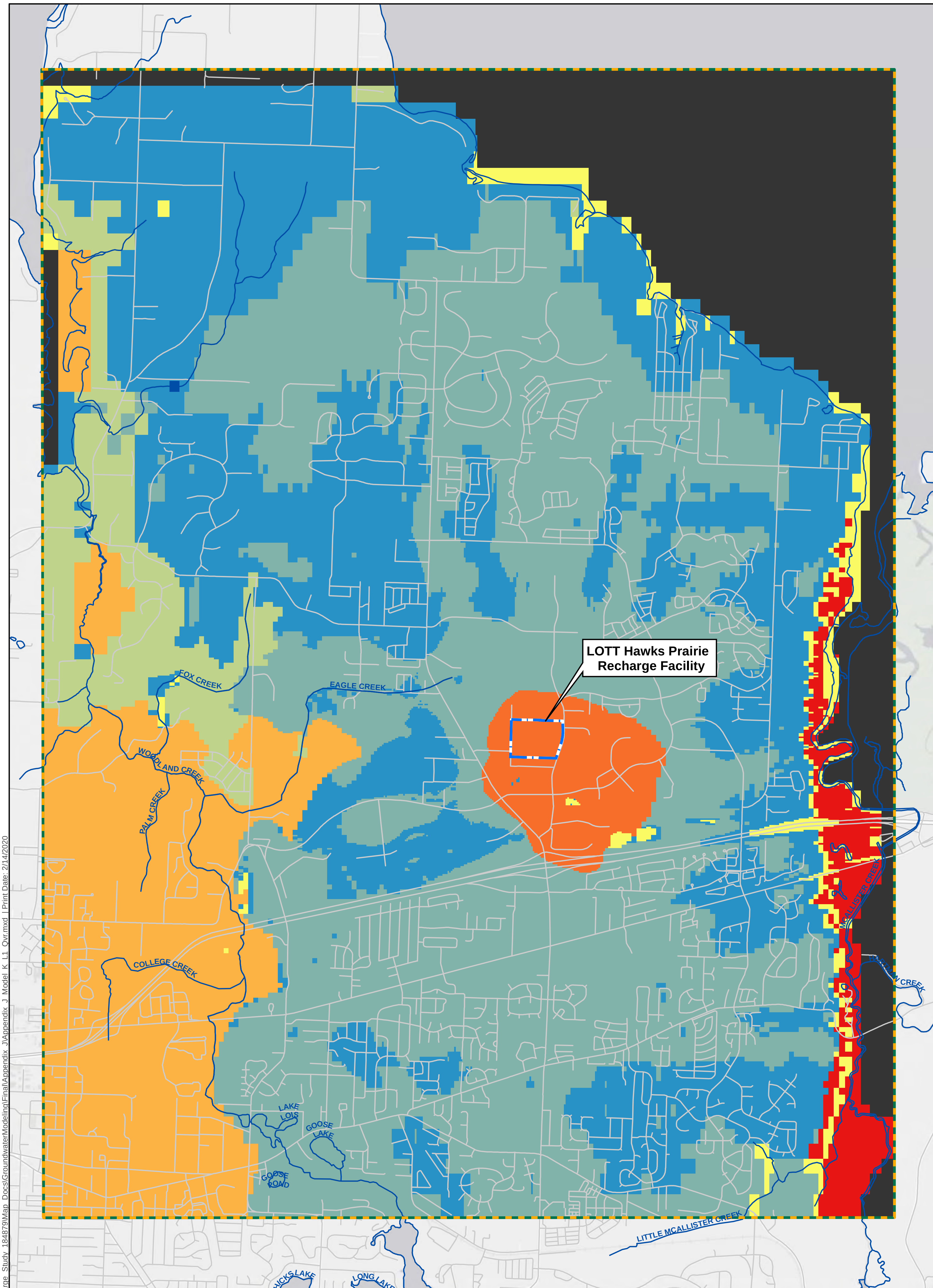
HDR

Path: G:\Projects\Washington\LOTT_CWA_201266\GW_Recharge_Study_184879\Map_Docs\GroundwaterModeling\Final\Appendix_I\Appendix_I_Fig5_LFcontoursTQu.mxd | Print Date: 2/5/2020

Source: WA Dept. of Ecology (2015), City of Lacey (2014), WSDOT (2013)

Appendix J – Model Hydraulic Conductivity Zonation by Layer

This page intentionally left blank.



Hydraulic Conductivity (ft/day)

- 0.05
- 2
- 7
- 20
- 80
- 120
- 150
- 200

- Inactive Model Cells
- Groundwater Model Domain
- LOTT Hawks Prairie Recharge Facility
- Roads
- Streams

Model Hydraulic Conductivity
Layer 1 - Vashon Recessional Outwash (Qvr)

Miles

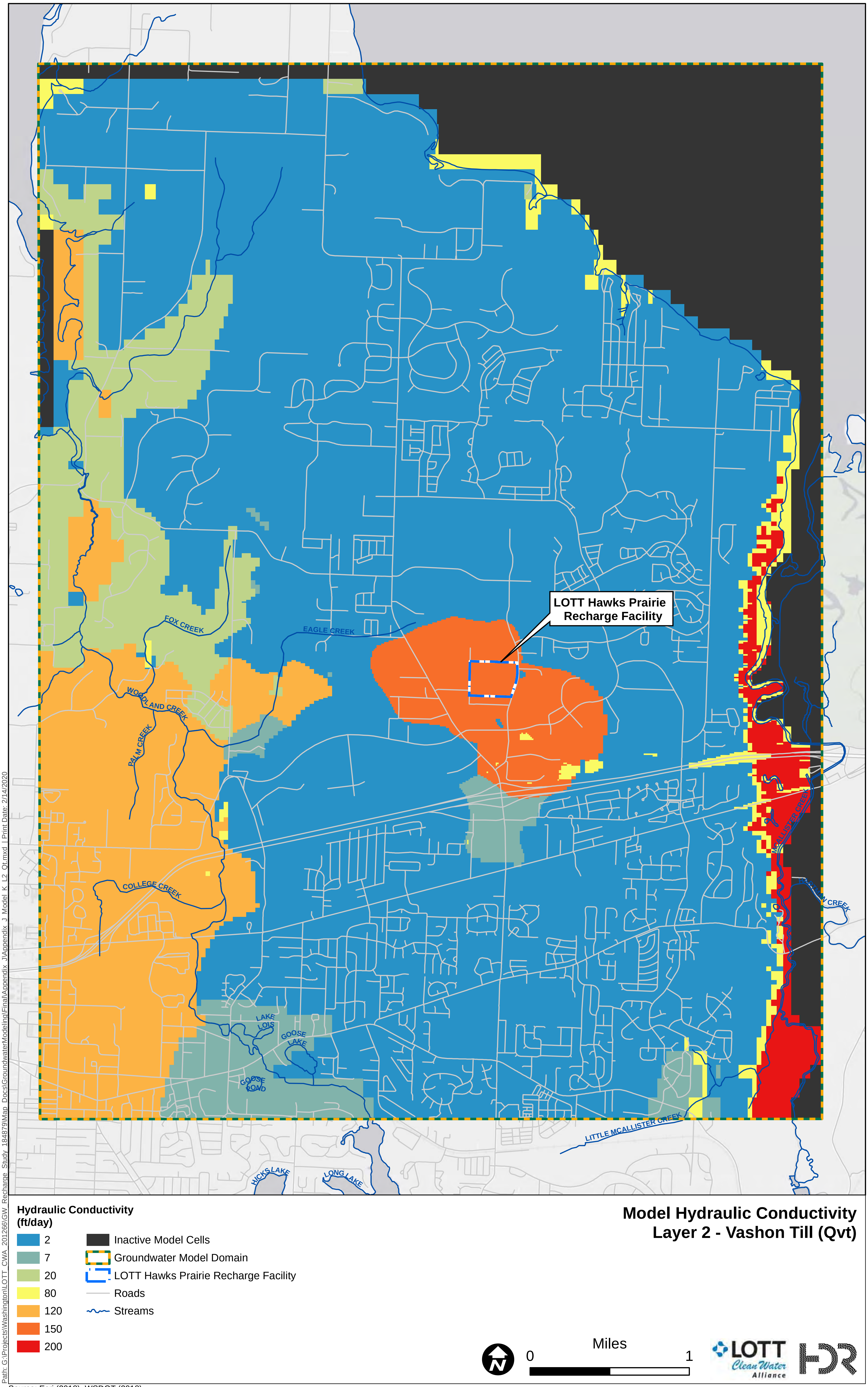
0 1

LOTT Clean Water Alliance

HDR

Path: G:\Projects\Washington\LOTT_CWA_201266\GW_Recharge_Study_184879\Map_Docs\GroundwaterModeling\Final\Appendix_J\Appendix_J_Model_K_L1_Qvr.mxd | Print Date: 2/14/2020

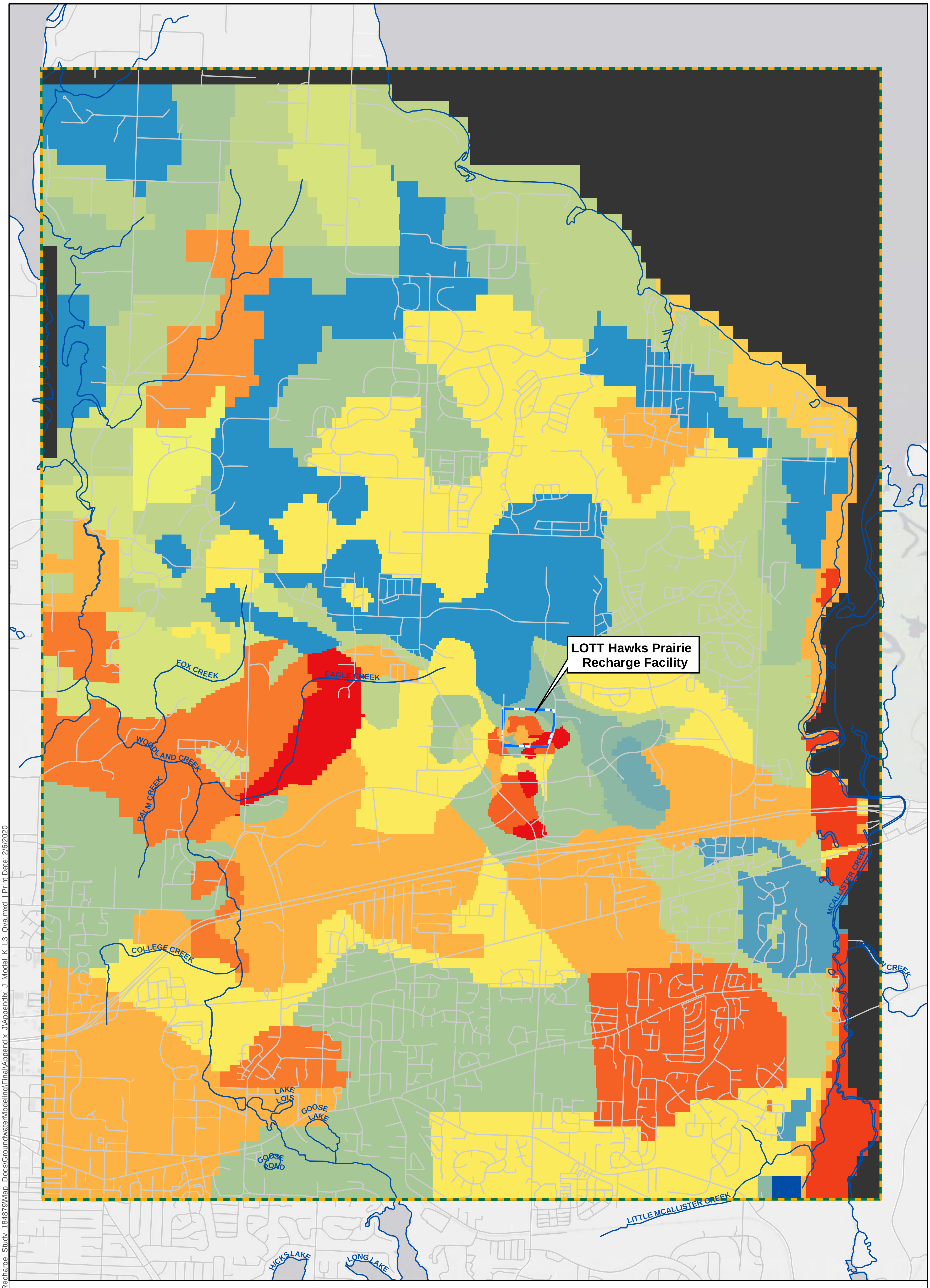
Source: Esri (2018), WSDOT (2018)



Model Hydraulic Conductivity
Layer 2 - Vashon Till (Qvt)

Path: G:\Projects\Washington\LOTT_CWA_201266\GW_Recharge_Study_184879\Map_Docs\GroundwaterModeling\Final\Appendix_J\Appendix_J_Model_K_L2_Qt.mxd | Print Date: 2/14/2020

Source: Esri (2018), WSDOT (2018)



Path: G:\Projects\Washington\LOTT_CWA_201266\GW_Recharge_Study_184879\Map_Docs\GroundwaterModeling\Final\Appendix_J\Appendix_J_Model_K_L3_Qva.mxd | Print Date: 2/6/2020

Hydraulic Conductivity (ft/day)

0.05		50	
1		60	
2		80	
3		100	
7		120	
10		140	
15		200	
20		225	
30		Inactive Model Cells	

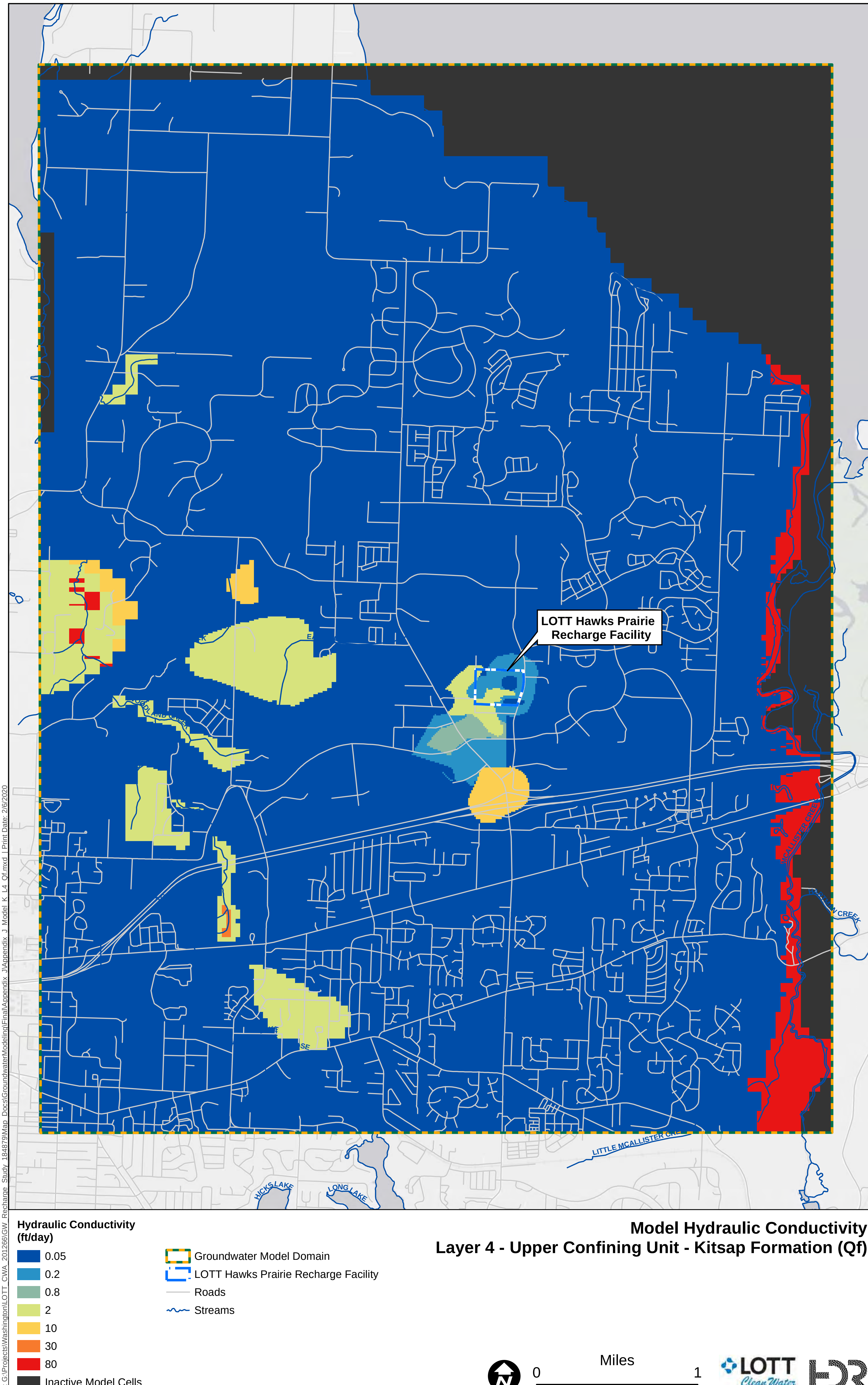
Groundwater Model Domain
LOTT Hawks Prairie Recharge Facility
Roads
Streams

Model Hydraulic Conductivity Layer 3 - Shallow (Qva) Aquifer

Miles
0 1

LOTT Clean Water Alliance
HDR

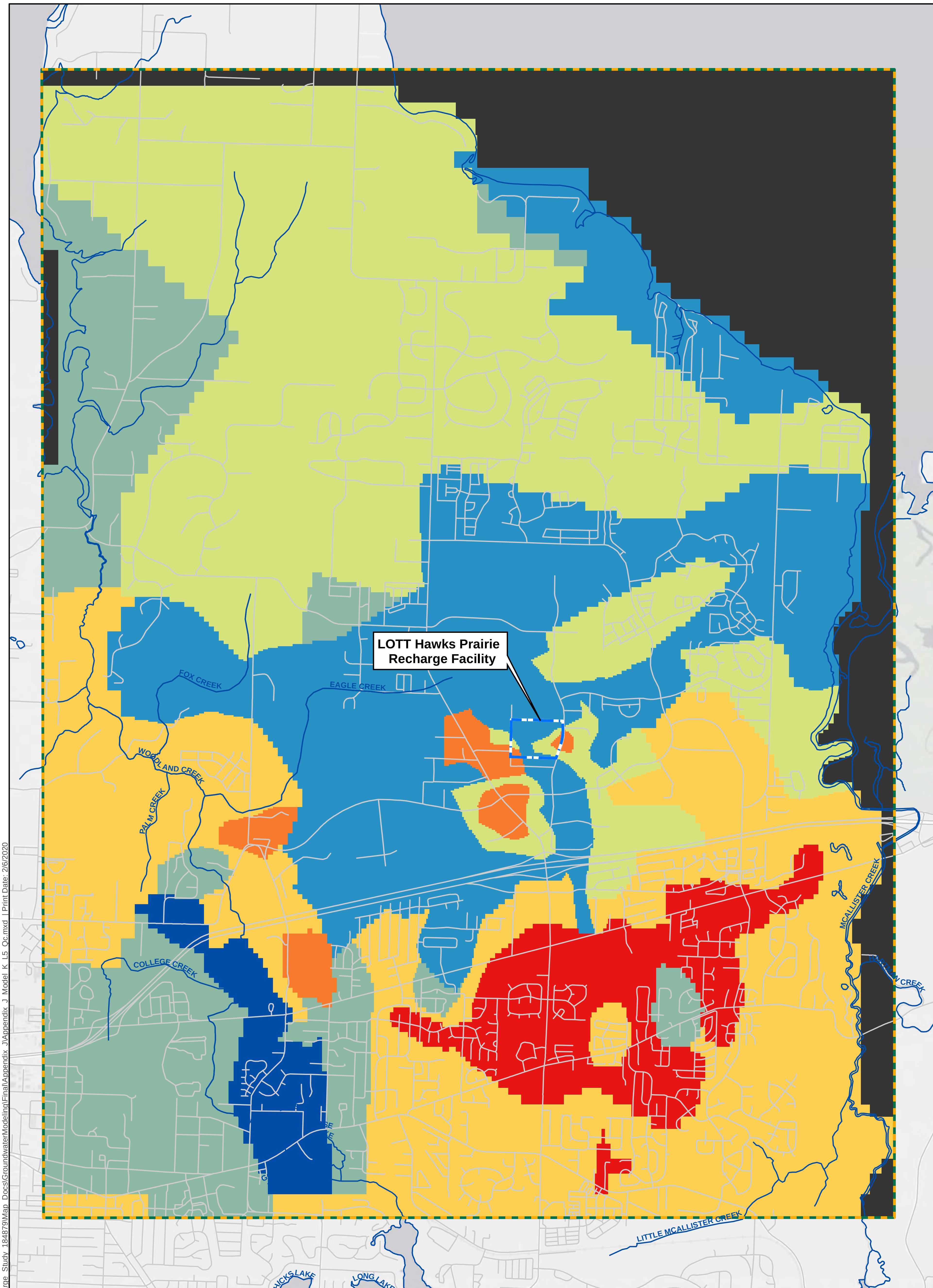
Source: Esri (2018), WSDOT (2018)



Model Hydraulic Conductivity
Layer 4 - Upper Confining Unit - Kitsap Formation (Qf)

Path: G:\Projects\Washington\LOTT_CWA_201266\GW_Recharge_Study_184879\Map_Docs\GroundwaterModeling\Final\Appendix_J\Appendix_J_Model_K_L4_Qf.mxd | Print Date: 2/6/2020

Source: Esri (2018), WSDOT (2018)



Model Hydraulic Conductivity
Layer 5 - Sea-Level Aquifer (Qc)

Hydraulic Conductivity (ft/day)

- 0.5
- 3
- 10
- 30
- 80
- 120
- 500

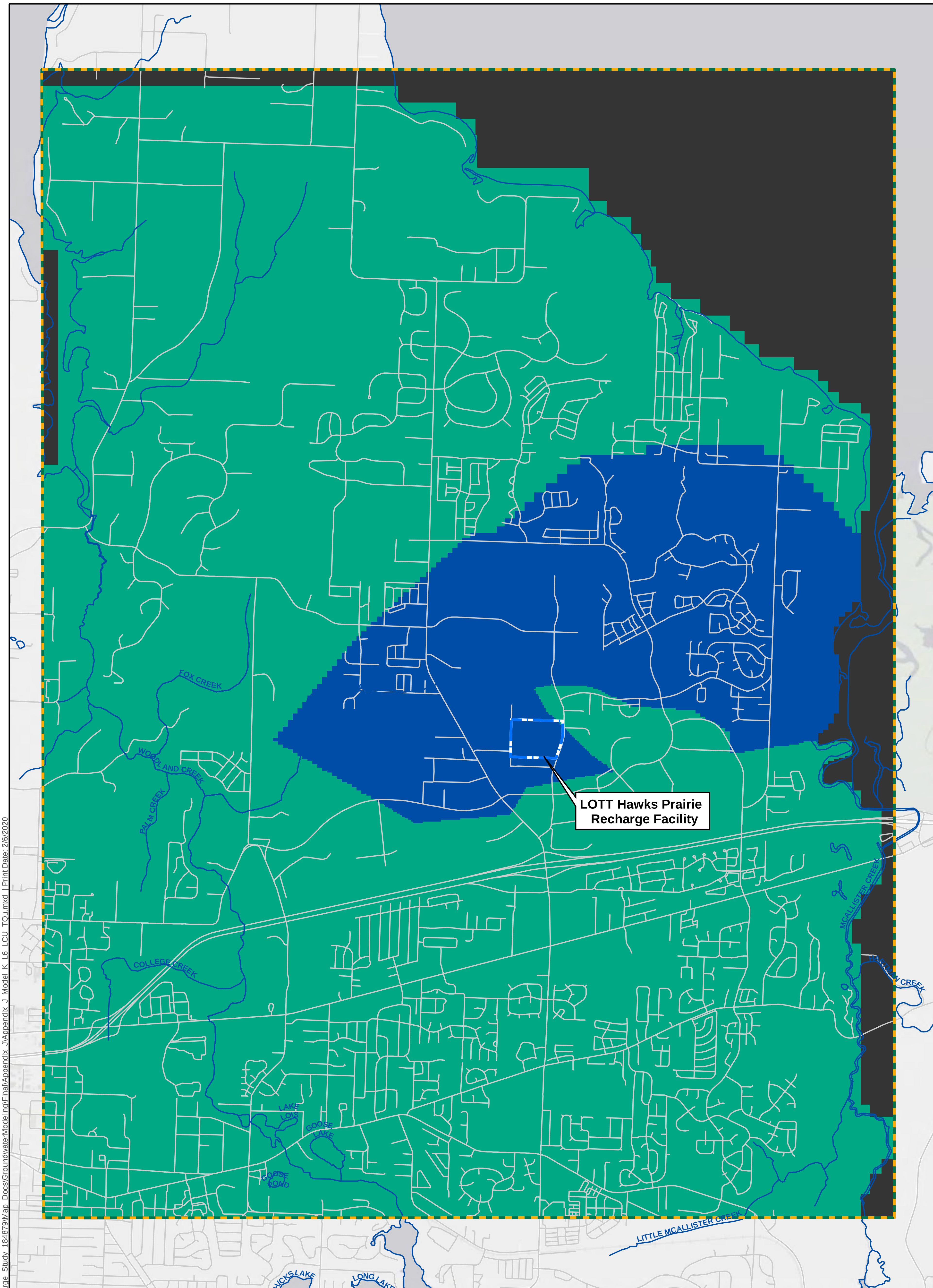
- Inactive Model Cells
- Groundwater Model Domain
- LOTT Hawks Prairie Recharge Facility
- Roads
- Streams

Miles

0 1

Path: G:\Projects\Washington\LOTT_CWA_201266\GW_Recharge_Study_184879\Map_Docs\GroundwaterModeling\Final\Appendix_J\Appendix_J_Model_K_L5_Qc.mxd | Print Date: 2/6/2020

Source: Esri (2018), WSDOT (2018)



Hydraulic Conductivity (ft/day)

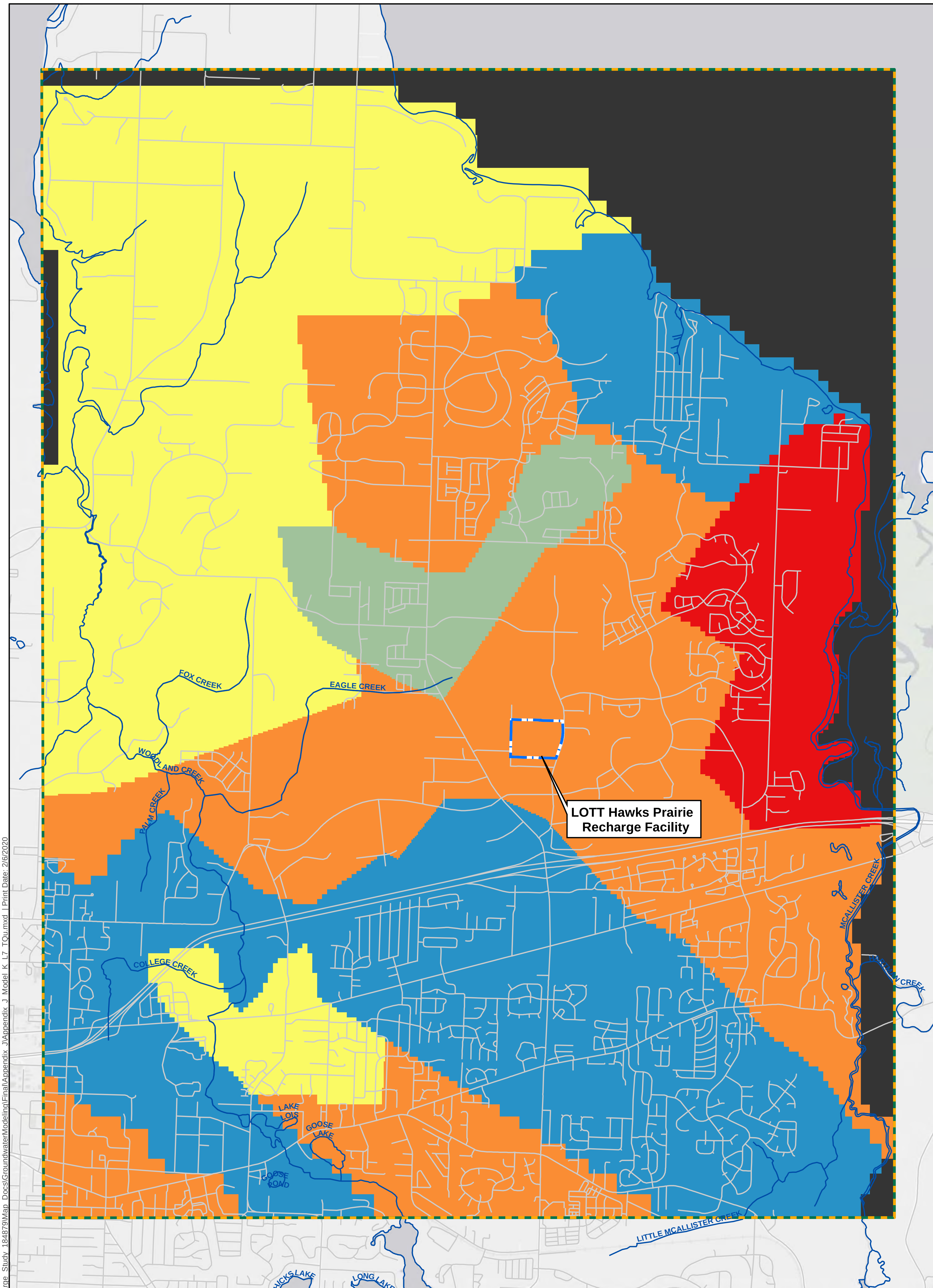
- 0.05
- 0.1
- Inactive Model Cells
- Groundwater Model Domain
- LOTT Hawks Prairie Recharge Facility
- Roads
- Streams

Model Hydraulic Conductivity
Layer 6 - Lower Confining Unit (TQu)

Miles
0 1

Path: G:\Projects\Washington\LOTT CWA 201266\GW Recharge Study 184879\Map Docs\GroundwaterModeling\Final\Appendix J\Appendix J Model K L6 LCU TQu.mxd | Print Date: 2/6/2020

Source: Esri (2018), WSDOT (2018)



Model Hydraulic Conductivity
Layer 7 - Deep Aquifer (TQu)

Hydraulic Conductivity (ft/day)

- 13
- 23
- 50
- 75
- 100
- Inactive Model Cells

- Groundwater Model Domain
- LOTT Hawks Prairie Recharge Facility
- Roads
- Streams

Miles
0 1

Source: Esri (2018), WSDOT (2018)

Path: G:\Projects\Washington\LOTT CWA 201266\GW Recharge Study 184879\Map Docs\GroundwaterModeling\Final\Appendix J\Appendix J Model K L7 TQu.mxd | Print Date: 2/6/2020

Appendix K – Daily Reclaimed Water Application Volumes

This page intentionally left blank.

	Basin 4	Basin 5
DATE	MGD	MGD
1/1/2018	0.45	0.38
1/2/2018	0.43	0.37
1/3/2018	0.32	0.26
1/4/2018	0.24	0.20
1/5/2018	0.44	0.36
1/6/2018	0.46	0.37
1/7/2018	0.47	0.38
1/8/2018	0.24	0.19
1/9/2018	0.17	0.14
1/10/2018	0.40	0.34
1/11/2018	0.52	0.44
1/12/2018	0.41	0.35
1/13/2018	0.42	0.36
1/14/2018	0.44	0.37
1/15/2018	0.45	0.37
1/16/2018	0.45	0.38
1/17/2018	0.46	0.40
1/18/2018	0.49	0.42
1/19/2018	0.45	0.39
1/20/2018	0.45	0.39
1/21/2018	0.46	0.40
1/22/2018	0.47	0.41
1/23/2018	0.53	0.46
1/24/2018	0.57	0.50
1/25/2018	0.56	0.40
1/26/2018	0.64	0.34
1/27/2018	0.70	0.36
1/28/2018	0.68	0.35
1/29/2018	0.73	0.38
1/30/2018	0.77	0.40
1/31/2018	0.74	0.38
2/1/2018	0.78	0.40
2/2/2018	0.78	0.43
2/3/2018	0.72	0.44
2/4/2018	0.72	0.44
2/5/2018	0.71	0.43
2/6/2018	0.67	0.41
2/7/2018	0.68	0.42
2/8/2018	0.71	0.44
2/9/2018	0.67	0.41
2/10/2018	0.68	0.42
2/11/2018	0.69	0.42
2/12/2018	0.66	0.40
2/13/2018	0.69	0.42
2/14/2018	0.72	0.44
2/15/2018	0.66	0.40
2/16/2018	0.68	0.42
2/17/2018	0.77	0.47
2/18/2018	0.73	0.45
2/19/2018	0.70	0.43
2/20/2018	0.71	0.43
2/21/2018	0.71	0.44
2/22/2018	0.73	0.45
2/23/2018	0.72	0.44
2/24/2018	0.75	0.46
2/25/2018	0.78	0.47
2/26/2018	0.76	0.46
2/27/2018	0.72	0.44
2/28/2018	0.68	0.41
3/1/2018	0.66	0.40
3/2/2018	0.64	0.39
3/3/2018	0.63	0.38
3/4/2018	0.70	0.42
3/5/2018	0.74	0.44
3/6/2018	0.73	0.44
3/7/2018	0.56	0.34
3/8/2018	0.60	0.36
3/9/2018	0.60	0.36
3/10/2018	0.70	0.42
3/11/2018	0.61	0.37
3/12/2018	0.57	0.34
3/13/2018	0.54	0.33
3/14/2018	0.59	0.36
3/15/2018	0.52	0.32
3/16/2018	0.58	0.36
3/17/2018	0.58	0.36
3/18/2018	0.58	0.36

	Basin 4	Basin 5
DATE	MGD	MGD
3/19/2018	0.58	0.36
3/20/2018	0.55	0.34
3/21/2018	0.59	0.36
3/22/2018	0.67	0.41
3/23/2018	0.65	0.40
3/24/2018	0.66	0.41
3/25/2018	0.63	0.39
3/26/2018	0.62	0.39
3/27/2018	0.63	0.38
3/28/2018	0.57	0.34
3/29/2018	0.55	0.33
3/30/2018	0.62	0.37
3/31/2018	0.62	0.37
4/1/2018	0.63	0.38
4/2/2018	0.63	0.38
4/3/2018	0.45	0.27
4/4/2018	0.55	0.33
4/5/2018	0.42	0.25
4/6/2018	0.60	0.36
4/7/2018	0.67	0.40
4/8/2018	0.72	0.43
4/9/2018	0.65	0.39
4/10/2018	0.63	0.38
4/11/2018	0.56	0.34
4/12/2018	0.52	0.32
4/13/2018	0.51	0.31
4/14/2018	0.64	0.38
4/15/2018	0.66	0.40
4/16/2018	0.60	0.36
4/17/2018	0.58	0.35
4/18/2018	0.56	0.34
4/19/2018	0.56	0.33
4/20/2018	0.56	0.33
4/21/2018	0.55	0.33
4/22/2018	0.55	0.33
4/23/2018	0.56	0.34
4/24/2018	0.30	0.18
4/25/2018	0.00	0.00
4/26/2018	0.29	0.18
4/27/2018	0.57	0.35
4/28/2018	0.65	0.40
4/29/2018	0.69	0.42
4/30/2018	0.68	0.42
5/1/2018	0.65	0.40
5/2/2018	0.66	0.41
5/3/2018	0.68	0.42
5/4/2018	0.69	0.43
5/5/2018	0.69	0.42
5/6/2018	0.69	0.43
5/7/2018	0.68	0.42
5/8/2018	0.36	0.23
5/9/2018	0.38	0.24
5/10/2018	0.43	0.26
5/11/2018	0.43	0.26
5/12/2018	0.47	0.28
5/13/2018	0.49	0.30
5/14/2018	0.52	0.31
5/15/2018	0.51	0.31
5/16/2018	0.50	0.30
5/17/2018	0.52	0.31
5/18/2018	0.41	0.24
5/19/2018	0.55	0.33
5/20/2018	0.64	0.39
5/21/2018	0.66	0.40
5/22/2018	0.64	0.39
5/23/2018	0.61	0.37
5/24/2018	0.63	0.38
5/25/2018	0.70	0.42
5/26/2018	0.55	0.33
5/27/2018	0.57	0.34
5/28/2018	0.61	0.36
5/29/2018	0.52	0.31
5/30/2018	0.55	0.33
5/31/2018	0.61	0.37
6/1/2018	0.53	0.32
6/2/2018	0.45	0.27
6/3/2018	0.39	0.23
6/4/2018	0.48	0.07

	Basin 4	Basin 5
DATE	MGD	MGD
6/5/2018	0.55	0.00
6/6/2018	0.59	0.00
6/7/2018	0.65	0.00
6/8/2018	0.73	0.00
6/9/2018	0.77	0.00
6/10/2018	0.75	0.00
6/11/2018	0.74	0.00
6/12/2018	0.74	0.00
6/13/2018	0.64	0.00
6/14/2018	0.71	0.00
6/15/2018	0.74	0.00
6/16/2018	0.64	0.00
6/17/2018	0.72	0.00
6/18/2018	0.27	0.00
6/19/2018	0.00	0.00
6/20/2018	0.29	0.00
6/21/2018	0.61	0.00
6/22/2018	0.67	0.00
6/23/2018	0.72	0.00
6/24/2018	0.73	0.00
6/25/2018	0.74	0.00
6/26/2018	0.63	0.00
6/27/2018	0.57	0.00
6/28/2018	0.62	0.00
6/29/2018	0.68	0.00
6/30/2018	0.68	0.00
7/1/2018	0.68	0.00
7/2/2018	0.67	0.00
7/3/2018	0.63	0.00
7/4/2018	0.68	0.00
7/5/2018	0.70	0.00
7/6/2018	0.70	0.00
7/7/2018	0.68	0.00
7/8/2018	0.67	0.00
7/9/2018	0.66	0.00
7/10/2018	0.64	0.03
7/11/2018	0.58	0.00
7/12/2018	0.61	0.00
7/13/2018	0.66	0.00
7/14/2018	0.68	0.00
7/15/2018	0.65	0.00
7/16/2018	0.66	0.00
7/17/2018	0.79	0.00
7/18/2018	0.83	0.00
7/19/2018	0.62	0.00
7/20/2018	0.65	0.00
7/21/2018	0.63	0.00
7/22/2018	0.62	0.00
7/23/2018	0.64	0.00
7/24/2018	0.57	0.00
7/25/2018	0.60	0.00
7/26/2018	0.61	0.00
7/27/2018	0.61	0.00
7/28/2018	0.65	0.00
7/29/2018	0.64	0.00
7/30/2018	0.64	0.00
7/31/2018	0.46	0.00
8/1/2018	0.49	0.00
8/2/2018	0.61	0.00
8/3/2018	0.60	0.00
8/4/2018	0.59	0.00
8/5/2018	0.59	0.00
8/6/2018	0.62	0.00
8/7/2018	0.51	0.00
8/8/2018	0.58	0.00
8/9/2018	0.65	0.00
8/10/2018	0.64	0.00
8/11/2018	0.66	0.00
8/12/2018	0.65	0.00
8/13/2018	0.65	0.00
8/14/2018	0.61	0.00
8/15/2018	0.60	0.00
8/16/2018	0.33	0.00
8/17/2018	0.00	0.00
8/18/2018	0.00	0.00
8/19/2018	0.00	0.00
8/20/2018	0.00	0.00
8/21/2018	0.00	0.00

	Basin 4	Basin 5
DATE	MGD	MGD
8/22/2018	0.22	0.00
8/23/2018	0.26	0.00
8/24/2018	0.55	0.00
8/25/2018	0.54	0.00
8/26/2018	0.51	0.00
8/27/2018	0.38	0.00
8/28/2018	0.50	0.00
8/29/2018	0.51	0.00
8/30/2018	0.49	0.00
8/31/2018	0.52	0.00
9/1/2018	0.40	0.00
9/2/2018	0.48	0.00
9/3/2018	0.51	0.00
9/4/2018	0.47	0.00
9/5/2018	0.50	0.00
9/6/2018	0.54	0.00
9/7/2018	0.51	0.00
9/8/2018	0.53	0.00
9/9/2018	0.53	0.00
9/10/2018	0.53	0.00
9/11/2018	0.42	0.00
9/12/2018	0.48	0.00
9/13/2018	0.51	0.00
9/14/2018	0.51	0.00
9/15/2018	0.53	0.00
9/16/2018	0.53	0.00
9/17/2018	0.40	0.00
9/18/2018	0.44	0.00
9/19/2018	0.47	0.00
9/20/2018	0.47	0.00
9/21/2018	0.48	0.00
9/22/2018	0.50	0.00
9/23/2018	0.51	0.00
9/24/2018	0.45	0.00
9/25/2018	0.36	0.00
9/26/2018	0.39	0.00
9/27/2018	0.47	0.00
9/28/2018	0.40	0.00
9/29/2018	0.41	0.00
9/30/2018	0.42	0.00
10/1/2018	0.38	0.00
10/2/2018	0.30	0.00
10/3/2018	0.41	0.00
10/4/2018	0.44	0.00
10/5/2018	0.42	0.00
10/6/2018	0.42	0.00
10/7/2018	0.44	0.00
10/8/2018	0.26	0.00
10/9/2018	0.00	0.02
10/10/2018	0.00	0.20
10/11/2018	0.00	0.24
10/12/2018	0.00	0.27
10/13/2018	0.00	0.00
10/14/2018	0.00	0.21
10/15/2018	0.00	0.44
10/16/2018	0.00	0.25
10/17/2018	0.00	0.00
10/18/2018	0.00	0.20
10/19/2018	0.00	0.44
10/20/2018	0.00	0.25
10/21/2018	0.00	0.00
10/22/2018	0.00	0.20
10/23/2018	0.00	0.42
10/24/2018	0.00	0.21
10/25/2018	0.00	0.00
10/26/2018	0.00	0.22
10/27/2018	0.00	0.51
10/28/2018	0.00	0.42
10/29/2018	0.00	0.00
10/30/2018	0.00	0.18
10/31/2018	0.00	0.44

Appendix L – Simulated Pumping Wells

This page intentionally left blank.

Well Name	Row	Column	Layer	Pumping Rate (gpm)
Lacey S15	25	209	3	58.97
Lacey S16	25	209	3	55.07
Lacey S21	251	198	5	114.04
Lacey S22	251	198	5	414.21
Lacey S28	251	198	5	127.71
Lacey S29	108	108	5	342.94
Lacey S07	251	12	7	911.47
Lacey S19	39	88	7	379.31
Lacey S31	40	92	7	216.37
	231	31	1	0.3
	246	32	1	1.22
	235	200	1	0.16
	229	243	1	1.22
	215	1	1	0.78
	214	1	1	1.1
	214	1	1	0.78
	215	1	1	0.78
	214	1	1	0.78
	245	44	1	0.19
	17	64	3	8.89
	90	45	3	1.41
	59	42	3	1.41
	31	57	3	6.1
	31	57	3	6.1
	206	211	3	0.3
	251	35	3	0.24
	21	63	3	13.43
	93	184	3	0.91
	9	3	3	0.49
	3	2	3	0.85
	208	220	3	0.67
	218	112	3	0.18
	206	217	3	0.73
	225	32	3	0.18
	27	40	3	13.96
	9	53	3	1.22
	208	210	3	7.84
	22	6	3	0.3
	40	19	3	9.23
	24	35	3	9.23
	24	35	3	9.23
	231	1	3	8.58
	230	1	3	8.58
	194	228	3	0.16
	91	226	3	0.16
	111	179	3	4.96
	87	160	3	2.57
	100	179	3	0.16
	84	28	3	0.16
	90	54	3	0.16
	152	5	3	0.16
	221	220	3	0.16
	232	207	3	0.16
	239	160	3	14.88
	245	123	3	0.16
	252	3	3	0.16
	253	151	3	0.16
	253	211	3	2.57
	251	193	3	0.16
	28	243	3	9.05
	30	242	3	0.16
	30	242	3	0.16
	31	242	3	0.16
	6	1	3	0.16
	7	3	3	0.16
	11	2	3	0.16
	5	7	3	0.16
	8	20	3	0.16
	8	7	3	0.16
	9	7	3	9.05
	9	4	3	0.16
	3	86	3	0.16
	7	58	3	0.16
	4	91	3	9.05

Well Name	Row	Column	Layer	Pumping Rate (gpm)
	5	98	3	0.16
	8	163	3	0.16
	15	26	3	50.84
	13	6	3	0.16
	17	7	3	0.16
	16	7	3	0.16
	19	7	3	0.16
	29	3	3	0.16
	45	16	3	9.05
	47	31	3	2.1
	53	35	3	0.16
	53	36	3	0.16
	54	47	3	0.16
	13	112	3	1.09
	7	1	3	1.78
	53	55	3	7.33
	49	47	3	7.33
	253	212	3	3.16
	13	105	3	1.09
	15	76	3	4.63
	15	76	3	4.63
	252	207	3	1.82
	15	9	3	0.49
	208	18	3	1.4
	237	166	3	34.8
	244	124	3	1.52
	4	70	3	0.91
	225	40	3	1.09
	225	40	3	1.09
	252	223	3	22.22
	24	35	3	5.42
	25	55	3	5.42
	21	227	3	0.3
	10	188	3	0.49
	3	6	3	0.16
	247	7	3	14.45
	100	19	3	13.59
	63	33	3	1.86
	25	66	3	29.05
	19	9	3	0.16
	53	27	3	0.16
	43	27	3	0.16
	52	30	3	0.16
	75	35	3	0.16
	48	56	3	0.19
	40	234	3	0.16
	47	31	3	0.19
	103	176	3	0.38
	100	11	3	0.26
	83	35	3	0.19
	97	35	3	0.19
	98	31	3	0.32
	90	35	3	0.19
	74	31	3	0.19
	74	28	3	0.19
	75	32	3	0.16
	57	24	3	0.19
	95	28	3	0.19
	102	14	3	0.19
	56	20	3	0.32
	108	11	3	0.19
	8	169	3	0.19
	4	103	3	0.19
	8	165	3	0.16
	5	108	3	0.19
	4	105	3	0.19
	9	178	3	0.26
	4	102	3	0.26
	8	154	3	0.26
	4	95	3	0.26
	4	95	3	0.19
	8	171	3	0.16
	8	175	3	0.16
	4	106	3	0.19

Well Name	Row	Column	Layer	Pumping Rate (gpm)
	4	98	3	0.19
	3	93	3	0.26
	8	178	3	0.26
	5	110	3	0.19
	5	110	3	0.16
	8	173	3	0.19
	8	166	3	0.19
	8	159	3	0.26
	48	36	3	0.26
	34	45	3	0.19
	38	43	3	0.26
	39	42	3	0.26
	34	45	3	0.19
	35	44	3	0.26
	40	43	3	0.26
	35	45	3	0.26
	33	46	3	0.19
	33	46	3	0.26
	51	29	3	0.19
	36	44	3	0.26
	50	33	3	0.26
	33	45	3	0.19
	46	30	3	0.16
	52	36	3	0.19
	54	36	3	0.19
	45	32	3	0.16
	48	32	3	0.16
	44	30	3	0.19
	39	40	3	0.26
	195	237	3	0.26
	249	131	3	0.38
	244	129	3	0.65
	232	42	3	0.32
	229	41	3	0.56
	230	40	3	0.19
	232	39	3	0.26
	230	38	3	0.26
	232	37	3	0.26
	232	41	3	0.26
	230	40	3	0.48
	230	39	3	0.19
	232	37	3	0.19
	232	41	3	0.26
	230	39	3	0.19
	252	232	3	0.19
	231	41	3	0.19
	230	37	3	0.26
	231	40	3	0.19
	231	35	3	0.22
	229	42	3	0.16
	229	42	3	0.16
	230	37	3	0.19
	232	40	3	0.26
	231	42	3	0.26
	232	42	3	0.26
	232	38	3	0.19
	232	36	3	0.16
	2	41	3	0.16
	2	46	3	0.26
	2	32	3	0.19
	28	244	3	0.19
	31	238	3	0.19
	33	241	3	0.19
	30	238	3	0.19
	30	243	3	0.32
	33	241	3	0.16
	32	242	3	0.16
	32	238	3	0.19
	29	239	3	0.19
	29	243	3	0.16
	30	240	3	0.19
	29	240	3	0.19
	33	236	3	0.19
	32	242	3	0.32

Well Name	Row	Column	Layer	Pumping Rate (gpm)
	31	241	3	0.19
	31	241	3	0.26
	32	241	3	0.19
	32	241	3	0.19
	38	232	3	0.19
	31	242	3	0.19
	32	242	3	0.19
	32	241	3	0.19
	38	236	3	0.19
	31	241	3	0.19
	2	30	3	0.19
	2	6	3	0.19
	2	7	3	0.19
	2	8	3	0.26
	2	3	3	0.19
	9	3	3	0.16
	4	1	3	0.19
	9	3	3	0.19
	3	2	3	0.19
	8	2	3	0.19
	8	3	3	0.19
	4	4	3	0.26
	6	1	3	0.19
	4	1	3	0.16
	9	2	3	0.19
	10	3	3	0.19
	4	1	3	0.19
	8	3	3	0.19
	8	1	3	0.19
	4	3	3	0.19
	4	3	3	0.26
	4	3	3	0.26
	5	1	3	0.16
	9	1	3	0.19
	7	8	3	0.19
	8	7	3	0.32
	5	7	3	0.16
	3	7	3	0.26
	5	10	3	0.19
	7	14	3	0.19
	3	11	3	0.32
	9	7	3	0.19
	6	27	3	0.19
	6	7	3	0.26
	4	8	3	0.19
	8	8	3	0.32
	7	16	3	0.19
	9	6	3	0.19
	7	19	3	0.19
	8	1	3	0.19
	6	29	3	0.26
	10	1	3	0.16
	5	20	3	0.19
	5	5	3	0.16
	8	6	3	0.19
	5	9	3	0.16
	5	10	3	0.19
	5	7	3	0.26
	6	19	3	0.26
	4	6	3	0.19
	8	10	3	0.19
	4	4	3	0.19
	8	1	3	0.19
	5	6	3	0.26
	6	12	3	0.16
	6	22	3	0.19
	5	16	3	0.26
	5	14	3	0.19
	6	6	3	0.26
	4	14	3	0.19
	7	7	3	0.26
	2	6	3	0.26
	5	22	3	0.16
	7	8	3	0.16

Well Name	Row	Column	Layer	Pumping Rate (gpm)
	3	6	3	0.26
	3	6	3	0.16
	4	6	3	0.19
	4	5	3	0.19
	3	4	3	0.19
	7	20	3	0.16
	4	6	3	0.39
	6	6	3	0.16
	3	7	3	0.32
	9	7	3	0.16
	4	5	3	0.32
	3	5	3	0.19
	10	2	3	0.19
	6	7	3	0.16
	4	19	3	0.19
	9	6	3	0.19
	6	22	3	0.16
	10	1	3	0.26
	10	7	3	0.16
	6	20	3	0.32
	5	20	3	0.19
	10	5	3	0.19
	6	6	3	0.19
	3	9	3	0.19
	8	5	3	0.19
	8	5	3	0.19
	6	19	3	0.16
	3	89	3	0.16
	10	5	3	0.39
	4	38	3	0.19
	3	36	3	0.39
	10	43	3	0.19
	3	44	3	0.19
	5	80	3	0.26
	10	22	3	0.19
	9	45	3	0.19
	7	33	3	0.26
	5	33	3	0.19
	6	43	3	0.16
	10	49	3	0.16
	6	33	3	0.26
	10	40	3	0.19
	6	52	3	0.19
	6	34	3	0.19
	10	22	3	0.26
	3	86	3	0.16
	6	74	3	0.26
	4	91	3	0.19
	4	37	3	0.19
	10	42	3	0.19
	10	19	3	0.19
	9	19	3	0.19
	6	49	3	0.16
	7	34	3	0.26
	6	87	3	0.19
	12	50	3	0.32
	11	50	3	0.26
	5	31	3	0.19
	5	38	3	0.19
	12	49	3	0.19
	11	23	3	0.26
	6	41	3	0.32
	10	49	3	0.19
	3	87	3	0.16
	8	16	3	0.19
	4	38	3	0.26
	10	22	3	0.26
	8	22	3	0.19
	3	92	3	0.16
	5	35	3	0.26
	9	20	3	0.19
	9	23	3	0.26
	6	56	3	0.19
	3	35	3	0.26

Well Name	Row	Column	Layer	Pumping Rate (gpm)
	3	32	3	0.19
	11	22	3	0.26
	11	50	3	0.16
	9	22	3	0.26
	5	36	3	0.16
	9	14	3	0.16
	4	31	3	0.19
	10	45	3	0.19
	10	46	3	0.26
	10	15	3	0.19
	8	51	3	0.19
	5	58	3	0.19
	8	23	3	0.19
	12	60	3	0.26
	12	22	3	0.19
	7	50	3	0.26
	3	38	3	0.19
	22	54	3	0.26
	20	49	3	0.19
	21	54	3	0.26
	21	49	3	0.19
	21	49	3	0.26
	14	6	3	0.26
	13	6	3	0.19
	13	8	3	0.19
	14	6	3	0.19
	20	6	3	0.16
	18	11	3	0.19
	17	11	3	0.26
	13	3	3	0.19
	17	7	3	0.19
	18	10	3	0.19
	14	6	3	0.19
	19	7	3	0.26
	26	7	3	0.19
	15	7	3	0.16
	13	7	3	0.19
	16	7	3	0.19
	13	10	3	0.19
	17	9	3	0.19
	18	8	3	0.16
	17	7	3	0.16
	15	7	3	0.19
	16	13	3	0.26
	17	14	3	0.19
	14	7	3	0.26
	16	7	3	0.19
	19	10	3	0.19
	19	8	3	0.19
	16	7	3	0.26
	17	12	3	0.19
	18	7	3	0.19
	14	5	3	0.19
	14	7	3	0.19
	13	9	3	0.19
	16	9	3	0.19
	35	1	3	0.19
	35	1	3	0.19
	26	3	3	0.19
	35	1	3	0.16
	27	3	3	0.16
	27	3	3	0.19
	28	3	3	0.16
	28	3	3	0.16
	36	1	3	0.19
	26	3	3	0.19
	46	24	3	0.16
	46	16	3	0.19
	45	23	3	0.19
	45	24	3	0.16
	90	29	3	0.19
	5	109	3	0.16
	37	234	3	0.19
	9	15	3	0.19

Well Name	Row	Column	Layer	Pumping Rate (gpm)
	13	25	3	0.19
	48	18	3	0.19
	2	37	3	0.19
	12	163	3	0.19
	13	164	3	0.19
	11	67	3	0.19
	29	243	3	0.19
	29	242	3	0.19
	2	21	3	0.19
	18	13	3	0.16
	2	56	3	0.16
	47	21	3	10.54
	14	18	3	0.62
	4	100	3	0.16
	48	27	3	0.16
	2	58	3	0.16
	7	1	3	0.16
	28	242	3	0.16
	4	105	3	0.16
	16	14	3	0.16
	2	15	3	0.16
	33	241	3	0.16
	5	84	3	0.16
	217	238	3	0.16
	217	238	3	0.16
	216	238	3	0.16
	215	238	3	0.16
	215	238	3	0.16
	214	237	3	0.16
	215	236	3	0.16
	215	237	3	0.16
	214	237	3	0.16
	213	236	3	0.16
	213	236	3	0.16
	212	236	3	0.16
	211	236	3	0.16
	216	237	3	0.16
	215	237	3	0.16
	14	19	3	0.16
	13	22	3	0.16
	6	3	3	0.16
	6	2	3	0.16
	16	58	3	0.16
	16	53	3	0.16
	3	35	3	0.16
	16	59	3	0.16
	17	58	3	0.16
	18	59	3	0.16
	18	59	3	0.16
	16	53	3	0.16
	7	3	3	0.16
	7	2	3	0.16
	3	52	3	0.16
	25	228	3	0.16
	28	224	3	0.16
	233	208	5	1.4
	11	107	5	10.14
	9	140	5	0.85
	49	41	5	0.91
	157	226	5	0.97
	24	240	5	0.55
	232	55	5	81.71
	232	63	5	81.71
	103	140	5	0.15
	211	21	5	0.61
	151	233	5	1.22
	20	10	5	33.83
	85	71	5	7.87
	217	96	5	0.61
	29	4	5	0.36
	222	105	5	0.61
	40	19	5	9.23
	184	228	5	0.16
	214	243	5	9.05

Well Name	Row	Column	Layer	Pumping Rate (gpm)
	231	244	5	0.16
	89	157	5	0.18
	95	162	5	17.36
	128	111	5	0.16
	124	100	5	0.16
	144	162	5	0.16
	56	47	5	0.16
	105	3	5	0.16
	108	5	5	0.16
	128	6	5	0.16
	209	20	5	0.16
	186	37	5	37.2
	221	70	5	0.16
	216	62	5	0.16
	208	185	5	0.16
	206	132	5	4.96
	184	196	5	0.16
	213	226	5	0.16
	221	223	5	0.16
	228	217	5	2.57
	228	82	5	0.16
	240	170	5	7.44
	239	165	5	9.05
	229	46	5	0.16
	246	14	5	14.45
	251	2	5	2.57
	20	232	5	6.51
	21	234	5	0.16
	27	242	5	0.16
	26	245	5	0.16
	26	245	5	0.16
	12	6	5	0.16
	8	135	5	0.16
	8	122	5	0.16
	24	33	5	0.16
	22	5	5	0.16
	51	1	5	0.16
	34	3	5	0.16
	219	140	5	9.91
	144	229	5	2.8
	145	229	5	2.8
	20	231	5	1.82
	25	243	5	1.82
	64	227	5	16.97
	107	220	5	16.97
	244	123	5	1.52
	244	123	5	1.52
	114	84	5	3.07
	250	162	5	17.1
	248	188	5	17.1
	225	45	5	1.09
	227	48	5	0.61
	39	2	5	18.69
	242	223	5	22.22
	242	220	5	22.22
	243	223	5	22.22
	242	221	5	22.22
	98	73	5	6.92
	56	50	5	8.78
	238	213	5	8.93
	237	212	5	8.93
	241	208	5	8.93
	160	229	5	0.62
	25	245	5	0.94
	28	241	5	0.16
	26	240	5	0.16
	228	236	5	10.04
	204	243	5	31
	205	243	5	31
	26	245	5	0.16
	27	240	5	1.55
	88	10	5	13.59
	33	208	5	247.98
	9	121	5	20.75

Well Name	Row	Column	Layer	Pumping Rate (gpm)
	61	4	5	0.16
	128	5	5	0.19
	86	5	5	0.16
	132	5	5	0.19
	185	17	5	0.19
	24	244	5	0.16
	117	3	5	0.16
	117	3	5	0.16
	96	3	5	0.26
	82	221	5	0.16
	85	5	5	0.19
	71	3	5	0.19
	67	3	5	0.19
	118	4	5	0.19
	118	4	5	0.26
	121	5	5	0.32
	104	1	5	0.26
	83	1	5	0.19
	118	3	5	0.19
	93	3	5	0.19
	99	2	5	0.26
	102	3	5	0.19
	123	8	5	0.16
	115	1	5	0.26
	109	3	5	0.19
	73	2	5	0.26
	54	1	5	0.26
	88	1	5	0.16
	55	1	5	0.26
	82	1	5	0.26
	102	2	5	0.26
	60	2	5	0.26
	60	2	5	0.26
	84	4	5	0.32
	85	1	5	0.16
	108	3	5	0.16
	91	1	5	0.19
	57	1	5	0.26
	92	4	5	0.52
	100	4	5	0.19
	62	1	5	0.26
	79	2	5	0.26
	113	5	5	0.26
	86	1	5	0.26
	76	1	5	0.26
	78	1	5	0.26
	55	1	5	0.26
	121	2	5	0.26
	93	1	5	0.19
	12	99	5	0.19
	8	141	5	0.16
	8	129	5	0.19
	8	143	5	0.19
	8	133	5	0.19
	8	130	5	0.16
	8	153	5	0.19
	8	146	5	0.19
	12	115	5	0.19
	8	139	5	0.19
	12	106	5	0.19
	8	157	5	0.16
	8	150	5	0.26
	12	101	5	0.26
	11	145	5	0.16
	8	148	5	0.19
	23	228	5	0.19
	23	229	5	0.19
	22	230	5	0.19
	24	225	5	0.26
	22	230	5	0.19
	22	227	5	0.19
	20	230	5	0.32
	20	227	5	0.26
	28	79	5	0.26

Well Name	Row	Column	Layer	Pumping Rate (gpm)
	29	76	5	0.19
	28	76	5	0.19
	29	78	5	0.19
	29	82	5	0.19
	28	84	5	0.19
	28	81	5	0.19
	221	240	5	0.26
	187	236	5	0.26
	164	230	5	0.19
	220	240	5	0.16
	226	126	5	0.52
	226	128	5	0.52
	230	122	5	0.52
	230	128	5	1
	231	127	5	0.52
	227	128	5	0.52
	228	128	5	0.52
	227	124	5	0.82
	229	124	5	0.52
	223	135	5	0.52
	223	138	5	0.52
	230	122	5	0.52
	232	128	5	0.52
	231	124	5	0.52
	229	128	5	1
	225	143	5	0.86
	225	135	5	0.86
	226	140	5	1.29
	253	30	5	0.54
	2	63	5	0.19
	27	242	5	0.19
	29	240	5	0.19
	28	244	5	0.19
	20	234	5	0.16
	23	236	5	0.26
	23	240	5	0.16
	21	237	5	0.19
	27	232	5	0.19
	25	243	5	0.16
	27	237	5	0.16
	26	244	5	0.19
	21	231	5	0.19
	28	240	5	0.19
	24	244	5	0.16
	26	244	5	0.19
	24	243	5	0.19
	20	231	5	0.19
	24	244	5	0.26
	26	245	5	0.16
	28	239	5	0.26
	27	244	5	0.19
	28	240	5	0.19
	27	242	5	0.19
	29	231	5	0.19
	26	239	5	0.16
	20	233	5	0.19
	28	234	5	0.19
	25	239	5	0.19
	21	235	5	0.19
	26	243	5	0.19
	25	243	5	0.19
	28	237	5	0.19
	25	239	5	0.19
	25	241	5	0.19
	26	242	5	0.19
	26	239	5	0.19
	22	238	5	0.19
	28	239	5	0.19
	22	238	5	0.26
	25	240	5	0.16
	30	238	5	0.19
	26	241	5	0.26
	21	237	5	0.19
	26	242	5	0.19

Well Name	Row	Column	Layer	Pumping Rate (gpm)
	21	235	5	0.16
	25	231	5	0.19
	27	239	5	0.19
	32	230	5	0.19
	30	231	5	0.16
	32	230	5	0.19
	34	230	5	0.16
	34	234	5	0.19
	33	235	5	0.19
	31	230	5	0.19
	32	232	5	0.26
	33	232	5	0.19
	35	234	5	0.19
	34	230	5	0.26
	37	230	5	0.26
	38	230	5	0.19
	35	232	5	0.26
	33	230	5	0.19
	33	234	5	0.19
	3	57	5	0.19
	3	80	5	0.16
	3	71	5	0.16
	3	77	5	0.16
	4	76	5	0.16
	3	61	5	0.19
	4	50	5	0.26
	3	82	5	0.16
	3	65	5	0.16
	4	47	5	0.19
	5	47	5	0.26
	3	53	5	0.19
	3	79	5	0.16
	3	73	5	0.16
	3	48	5	0.19
	3	52	5	0.19
	3	64	5	0.19
	25	5	5	0.19
	14	4	5	0.26
	23	6	5	0.19
	13	6	5	0.19
	23	3	5	0.19
	25	8	5	0.26
	14	4	5	0.26
	25	8	5	0.26
	18	28	5	0.19
	25	4	5	0.19
	21	4	5	0.19
	23	18	5	0.39
	21	6	5	0.39
	16	4	5	0.16
	35	2	5	0.16
	28	3	5	0.19
	44	1	5	0.16
	30	3	5	0.19
	52	1	5	0.26
	46	1	5	0.19
	36	2	5	0.16
	49	1	5	0.26
	41	1	5	0.19
	50	1	5	0.26
	34	3	5	0.19
	32	3	5	0.16
	38	27	5	0.19
	64	227	5	10.06
	64	227	5	10.06
	64	227	5	10.06
	33	5	5	0.19
	95	50	5	0.19
	29	7	5	0.19
	222	224	5	0.19
	9	153	5	0.19
	28	5	5	0.19
	11	158	5	0.19
	84	2	5	0.19

Well Name	Row	Column	Layer	Pumping Rate (gpm)
	29	225	5	0.19
	24	5	5	0.16
	12	6	5	0.16
	3	66	5	0.16
	22	238	5	0.16
	25	244	5	0.16
	52	2	5	0.16
	89	2	5	0.16
	14	3	5	0.16
	18	18	5	0.31
	40	231	5	0.16
	12	148	5	0.16
	8	137	5	0.16
	221	238	5	0.16
	220	238	5	0.16
	219	238	5	0.16
	219	238	5	0.16
	218	238	5	0.16
	223	238	5	0.16
	222	238	5	0.16
	221	238	5	0.16
	129	2	5	0.16
	25	225	5	0.16
	232	56	7	81.71
	229	43	7	0.73
	140	4	7	0.16
	178	2	7	0.16
	253	25	7	0.16
	253	193	7	0.16
	20	4	7	0.16
	36	151	7	0.16
	252	215	7	22.22
	228	223	7	0.3
	25	130	7	21.08
	174	241	7	31
	252	209	7	31.62
	252	193	7	0.62
	150	241	7	40.3
	41	212	7	31
	45	211	7	31
	32	177	7	88.03
	13	110	7	0.26
	13	115	7	0.19
	13	101	7	0.26
	13	110	7	0.19
	13	115	7	0.26
	13	107	7	0.19
	13	101	7	0.19
	13	100	7	0.26
	13	114	7	0.19
	171	3	7	0.16
	221	244	7	0.26
	219	244	7	0.26
	181	242	7	0.19
	217	244	7	0.16
	222	243	7	0.26
	21	4	7	0.19
	13	147	7	0.19
	35	6	7	0.19
	26	26	7	0.19
	16	91	7	0.16
	12	148	7	0.16