Work Plan

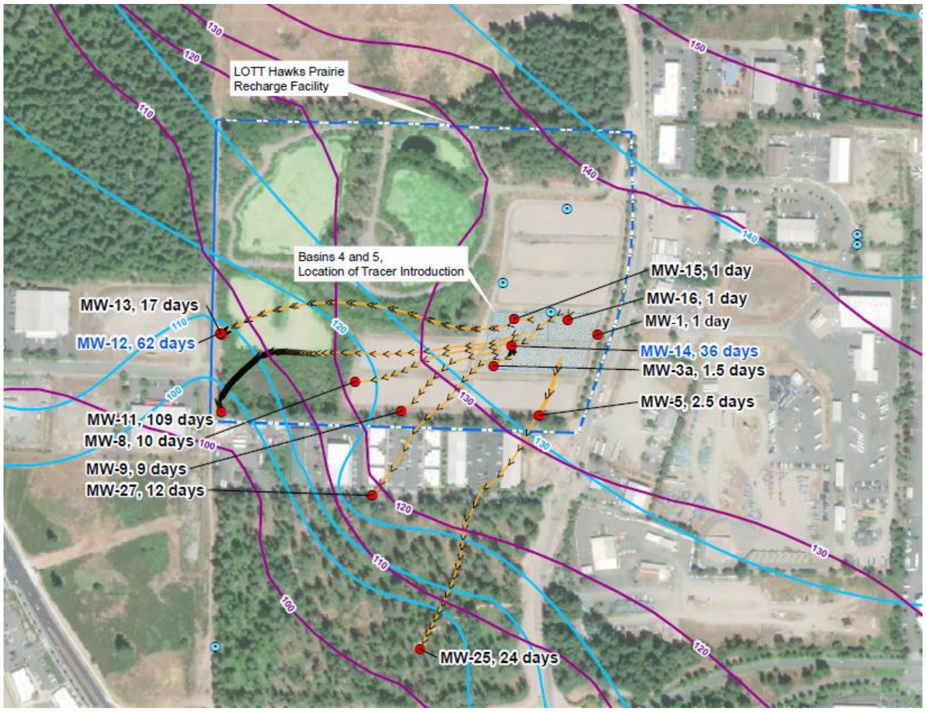
Groundwater Modeling Predictive Simulations (Task 2.1.4 continued)

and

Residual Chemical Fate and Transport (Task 2.1.5)

LOTT Clean Water Alliance

Reclaimed Water Infiltration Study



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Acronyms and Abbreviations

cm	centimeter
ERA	Ecological Risk Assessment
f_{oc}	organic carbon fraction
ft	foot or feet
g/cm^3	grams per cubic centimeter
HHRA	Human Health Risk Assessment
hr	hour
LOTT	LOTT Clean Water Alliance
K_d	distribution coefficient
K_{oc}	organic carbon partition coefficient
MGD	million gallons per day
MWRWP	Martin Way Reclaimed Water Plant
N/A	not applicable
ng/L	nanograms per liter
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
RWIS	Reclaimed Water Infiltration Study
TQu	Tertiary unconsolidated and undifferentiated sediments
WAC	Washington Administrative Code

1.0 Introduction

This section summarizes the background for the project as a whole, and identifies the objectives for the specific efforts outlined in this work plan.

1.1 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 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 infiltration basins at the LOTT Hawks Prairie Ponds and Recharge Basins property (referred to in this work plan as the LOTT Hawks Prairie property). LOTT's long-range plan for future wastewater management includes additional use of reclaimed water for beneficial 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"). Residual chemicals may include 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). As described in the RWIS scope of work (HDR 2014a), the RWIS components include:

- Surface water, groundwater, and reclaimed water quality monitoring to determine water quality and evaluate occurrence and concentration of residual chemicals.
- Tracer testing at the LOTT Hawks Prairie property 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 time beyond the spatial and temporal extent identified through tracer testing and at a variety of recharge rates typical of future operational capacity of the reclaimed water recharge facility at Hawks Prairie.
- Fate and transport groundwater modeling to estimate residual chemical concentrations to downgradient receptors at 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.
- Cost/benefit analysis of various options for reclaimed water treatment.

1.2 Objectives

The objective of the RWIS is to improve the current understanding of the fate, transport and risks of reclaimed water and residual chemicals in reclaimed water that is infiltrated at the LOTT Hawks Prairie property. This work plan describes the methods and analyses to complete Tasks 2.1.4 (groundwater modeling predictive simulations) and 2.1.5 (fate and transport evaluation). Objectives for these two tasks are as follows:

1.2.1 Groundwater Modeling

The purpose of the groundwater model is to calculate the flow velocity and flow paths of reclaimed water that infiltrates into groundwater. A numerical groundwater model has been constructed and calibrated for this purpose (HDR 2019b). The calibrated model will be used to predict flow paths and travel times beyond the spatial and temporal extent identified through the tracer testing and water quality monitoring conducted in 2018 (Task 2.1.3) (HDR 2019a). The model will be used to determine the percentage of groundwater composed of reclaimed water that arrives at potential downgradient receptors (i.e., at potential groundwater well locations or surface water bodies).

1.2.2 Fate and Transport of Residual Chemicals

The purpose of this task is to predict the exposure point concentrations of residual chemicals, which will be applied in the refined human health risk assessment (HHRA) and refined ecological risk assessment (ERA). This task includes using the calibrated groundwater flow model to simulate residual chemical movement throughout the groundwater flow system and estimate concentrations arriving at potential points of exposure. These simulations will consider current reclaimed water infiltration rates (and residual chemical concentrations) and future operating conditions at the Hawks Prairie property.

2.0 Proposed Methods and Analyses

This section details the methods proposed for the groundwater model predictive simulations and subsequent fate and transport evaluation in the groundwater flow system.

2.1 Groundwater Model Predictive Simulations

The calibrated numerical groundwater model will simulate the groundwater movement for three operating scenarios:

1) No reclaimed water recharge
2) Current recharge operations
3) Future recharge operations

Particle tracking, accounting for dispersion, will be used to estimate the groundwater flow paths from the LOTT Hawks Prairie recharge basins and the percentage of groundwater originating from infiltrated reclaimed water at surface water discharge locations and potential well locations. The percentage of reclaimed water at the discharge points will be used as a first step to estimate residual chemical concentrations at points of exposure, which is further described in **Section 2.2.3**.

2.1.1 Scenario 1: No Reclaimed Water Recharge

The calibrated groundwater model will be run simulating no infiltration of reclaimed water at the LOTT Hawks Prairie property. This scenario represents background or baseline conditions. As such, the following changes to the calibrated groundwater flow model are proposed:

- Background recharge rates will be applied to the LOTT Hawks Prairie property. This rate will be based on the Thurston County recharge dataset (primarily infiltrated stormwater).
- To better represent future conditions the recharge rate at the newly developed property north of the LOTT Hawks Prairie property will be assigned based on available data. This new development involved the transition of undeveloped areas to impermeable surfaces, including buildings and paved surfaces. Stormwater runoff generated from these impermeable surfaces remains onsite and is discharged through an infiltration gallery and infiltration pond. The calculation of the proposed recharge rate for predictive simulations is presented in **Appendix A** along with supporting information. This same recharge rate will then be applied in all scenarios.

Results of this analysis will include groundwater elevation maps for aquifer units including the Shallow (Qva) Aquifer, Sea Level (Qc) Aquifer, and Deep (TQu) Aquifer.

2.1.2 Scenarios 2 and 3: Reclaimed Water Aquifer Recharge at the LOTT Hawks Prairie Recharge Facility Under Current and Future Operations

The calibrated groundwater flow model will be run to simulate current and future operations at the LOTT Hawks Prairie property.

The following changes to the calibrated groundwater flow model are proposed for these scenarios:

- The recharge rate at the newly developed property north of the LOTT Hawks Prairie property will be assigned as described above in **Section 2.1.1**. The same rate will be applied in all three scenarios.
- **Scenario 2**: 1.5 MGD of recharge will be simulated, evenly divided over two adjacent basins, consistent with typical current operating conditions at maximum flow. Basins 5 and 6 are proposed to be the active basins as they are the operating pair located the most downgradient and are over sediments with the greatest hydraulic conductivity as supported by the timing of tracer arrival at MW-5 and MW-25 (HDR 2019a) and hydraulic conductivity values in the groundwater flow model (HDR 2019b). As such, they are expected to result in shorter travel times offsite.
- **Scenario 3**. 5 MGD of recharge will be simulated based on the original design capacity of the basins and the planned 2047 reclaimed water production capacity at the Martin Way Reclaimed Water Plant (Klein et al. 2019). This recharge will be evenly divided

over all eight basins, consistent with previous modeling efforts (Brown and Caldwell 2009).

The transport program MT3DMS will use the flow field established by the calibrated groundwater flow model to simulate the travel of reclaimed water through the groundwater system to downgradient discharge points. By accounting for dispersion during transport, the simulation will be used to estimate the percentage of reclaimed water arriving at points of exposure for Scenarios 2 and 3. A unit concentration of “1” will be introduced at the active infiltration basins so the simulated concentration represents the percentage of reclaimed water. The simulation is proposed to run until the percentage of reclaimed water simulated at the most downgradient discharge points reaches equilibrium or a maximum of 100 years. To determine when equilibrium is achieved, reclaimed water percentage versus time will be plotted at representative locations to identify when the reclaimed water percentage no longer increases.

To determine the percentage of reclaimed water arriving at discharge points and potential groundwater well locations, it is necessary for the transport simulations to account for dispersivity. Dispersivity will be estimated from tracer test data using the formulas below:

(1) $D_L = \alpha_l \cdot v = \frac{\sigma_L^2}{2t} = \frac{v^2 \cdot \sigma_t^2}{2t}$

(2) $\sigma_t = \frac{(t_{84} - t_{16})}{2}$

where:

D_L is the longitudinal dispersion coefficient

α_L is the longitudinal dispersivity

v is the advective velocity

t is time, and ty is the time when $C/C_{Max} = Y/100$, so t_{84} is the time when $C/C_{max} = 84/100$

σ_L^2 is the spatial variance

σ_t^2 is the temporal variance

The temporal variance (σ_t^2) can be calculated for each well directly from the breakthrough curves developed from the tracer test date. The time in equation (1) is the time of peak concentration at the monitoring well. Velocity will be calculated from the time of peak concentration and the particle trace distance to the well. It is proposed to run the model for the maximum and the minimum dispersivity values calculated to simulate a range of possible field conditions.

Horizontal transverse dispersivity will be initially assigned one order of magnitude lower than longitudinal dispersivity and refined through a sensitivity analysis. Vertical transverse dispersivity will be initially assigned two orders of magnitude lower as is the standard practice, but may be adjusted through sensitivity analysis as well (Zheng and Bennett 2002).

Results of this analysis will include groundwater elevation maps for aquifer units including the Shallow (Qva) Aquifer, Sea Level (Qc) Aquifer, and Deep (TQu) Aquifer under the two scenarios. Contour maps showing mounding will be generated by subtracting the baseline groundwater elevations from the groundwater elevations under current and future recharge rates. Maps will be presented showing reclaimed water flow paths and travel times in aquifer units receiving reclaimed water (this is anticipated to be the Shallow (Qva) Aquifer and Sea Level (Qc) Aquifer). Time of travel to surface water bodies that are locations of groundwater discharge will be shown on map figures and summarized in a table. The breakthrough curves showing percentage of reclaimed water versus time developed for representative locations will also be presented. Results from the simulation showing the percentage of groundwater originating from infiltrated reclaimed water will also be presented as a map figure. These figures will also show possible discharge points, including surface water bodies and groundwater wells (City of Lacey supply wells and wells included in the database provided by Thurston County (Hansen 2019)).

2.2 Residual Chemical Fate and Transport

Screening level risk assessments were conducted to identify residual chemicals of interest for further chemical fate and transport and risk evaluation. This task includes: assessment of background concentrations of residual chemicals of interest, and estimation of residual chemical concentrations in the groundwater flow system downgradient of the recharge basins.

2.2.1 Screening Level Risk Assessment Results

The screening level risk assessments considered all residual chemicals detected during Tasks 1 and 2 of the RWIS, and resulted in identification of 49 residual chemicals that require further evaluation in the modeling effort.

These screening level risk assessments are presented in *Screening-Level Human Health Risk Assessment for the LOTT Clean Water Alliance Reclaimed Water Infiltration Study* (Intertox 2019) and *Technical Memorandum: Ecological Risk Assessment Problem Formulation* (Windward Environmental 2019).

Residual chemicals of interest for further analysis were identified through the following methodology:

1. Both the HHRA and ERA established screening level “threshold” concentrations (Drinking Water Equivalent Levels (DWELs) in the HHRA and either ECOSAR or literature based benchmark concentrations in the ERA) for comparison to detected concentrations.
2. All samples of reclaimed water and pore water (i.e., subsurface water under the infiltration basins sampled via lysimeters) collected during the RWIS were compared to the screening level threshold concentrations. Residual chemicals of interest with one or more sampled concentrations over the screening level concentration were identified.
3. The ERA also identified chemicals of interest that may pose a risk regardless of detected concentration in reclaimed water and pore water. This includes persistent and bio-accumulative chemicals.
4. The HHRA identified chemicals detected within 10% of the screening level concentration to account for the potential cumulative effects of exposure to multiple

compounds that may act on the same endpoints and to provide an additional margin of safety to ensure that all chemicals that could contribute significantly to risk are included in the refined risk assessment.

5. Chemicals with laboratory detection limits greater than the screening level concentration were also identified in the HHRA as these compounds may be present in concentrations above the screening level concentration.

The results of this analysis include identification of residual chemicals of interest for further chemical fate and transport assessment and risk evaluation. A total of 49 residual chemicals of interest were identified, as presented in **Tables 2** and **3.**

2.2.2 Assess Residual Chemical of Interest Background Concentrations

Observed concentrations of residual chemicals of interest in groundwater and surface water not influenced by reclaimed water were reviewed to assess the presence of residual chemicals that may occur in local area waters due to sources other than reclaimed water infiltration. This assessment considered data obtained during the Task 1 water quality characterization effort (i.e., groundwater and surface water quality data collected in 2015) and the Task 2.1.3 tracer test and water quality monitoring effort (i.e., data collected in 2018). For the purpose of this analysis, “background” water quality monitoring locations are defined as locations not influenced by the infiltration of reclaimed water. The locations of interest are:

- Groundwater
    - Hawks Prairie area, outside of the known and potential flow path of reclaimed water. In the Task 1 groundwater quality characterization effort, 15 of the wells sampled in the Shallow (Qva) Aquifer are located north of the LOTT Hawks Prairie property and are clearly outside of the predominantly southwestern flow path of reclaimed water infiltrated at this site. These 15 wells were considered to reflect “background” water quality conditions in the Hawks Prairie area. None of the Sea Level (Qc) Aquifer wells sampled in this area were included in the “background” assessment, due to the heterogeneity of the Kitsap Formation that separates these aquifers in this area and the potential for reclaimed water introduced into the Qva to eventually be conveyed to the Qc.
    - Tumwater area. Thirty (30) wells were sampled in the Tumwater area as part of the Task 1 effort. As no reclaimed water recharge is occurring in this area, all of these wells were included in the “background” water quality assessment.
    - MW-26. The sole monitoring well located upgradient of the LOTT Hawks Prairie property that was sampled throughout 2018, as part of the Task 2.1.3 tracer test and water quality monitoring effort, was monitoring well MW-26. The data from this well was included in the “background” assessment.
- Surface Water
    - Tumwater area. The Task 1 surface water quality characterization effort included sampling at six locations along the Deschutes River and its tributaries, as well as six locations along Woodland Creek and its tributaries. Because of potential

influences by reclaimed water, the Woodland Creek data were excluded from the “background” analysis. However, data from all six locations along the Deschutes River (i.e., in the Tumwater area) were considered.

In total, 52 sampling locations were considered to represent “background” water quality conditions (i.e., not influenced by reclaimed water infiltration). Of this total, 46 are groundwater sampling locations, and six are surface water. Water quality data from Tasks 1 and 2.1.3 were reviewed to evaluate if any of the 49 residual chemicals recommended for inclusion in the refined risk assessments were present at the 52 “background” sampling locations. Presence or absence of these residual chemicals at the “background” locations is depicted in **Table 3**. For comparison, also presented in this table is a summary of residual chemical presence/absence in the groundwater monitoring wells directly downgradient of the LOTT Hawks Prairie property (i.e., locations that are most likely influenced by reclaimed water infiltration).

In summary, this data review indicated that 15 of the 49 residual chemicals of interest were detected at a minimum of one of the 52 “background” sampling locations. Of these 15 chemicals:

- Seven were detected at one location.
- Two (albuterol and TCEP) were detected at two locations.
- Four (cotinine, quinoline, 4-nonylphenol, and TCPP) were detected at three locations.
- One (sucralose) was detected at 18 locations.
- One (acesulfame-K) was detected at 24 locations.

These detections suggest spatially distributed loading that varies significantly by chemical, making it difficult to predict or estimate chemical concentrations beyond what was directly observed. Given the limitations of the data, observed results, and the purpose of this assessment, the background concentration of all residual chemicals of interest will be implemented as zero for the groundwater model predictive simulations.

However, the observed “background” concentrations will be considered in the refined HHRA and ERA, as a point of comparison for Scenario 1 (no infiltrated reclaimed water). The maximum observed “background” concentrations will also be added to the simulated concentrations of residual chemicals of interest at downgradient receptor locations to assess the overall risk of the total residual chemical concentration at those locations.

2.2.3 Predictive Simulations to Estimate Downgradient Residual Chemical Concentrations

Predictive simulations will be completed to estimate the concentrations of residual chemicals of interest in groundwater migrating away from the LOTT Hawks Prairie property. Estimates will be completed for all chemicals of interest identified in the screening level risk assessment as discussed above. Simulated downgradient concentrations will inform the refined HHRA and ERA. This predictive analysis will be performed in two steps.

Step 1: Conservative Transport within Groundwater

In the first step of the analysis, residual chemicals of interest in the screening level risk assessment will be simulated as conservative constituents. Concentrations will be estimated by multiplying the maximum concentration detected in reclaimed water by the percentage of groundwater comprised of reclaimed water, as calculated in Task 2.1.4 (as described in **Section 2.1.2** above). For hormones and per-and polyfluorinated alkyl substances (PFAS) chemicals that were identified as chemicals of interest for the refined HHRA and/or ERA but were not detected in reclaimed water, the minimum reporting limit (MRL) will be used as the assumed initial concentration in reclaimed water.

The most conservative point of exposure for the HHRA is defined as the closest downgradient location that is off-site (i.e., not on LOTT property) where it would be reasonable and legal to install a domestic water supply well in the shallow aquifer. Per the Reclaimed Water Rule (WAC 173-219-360 [Table 3]), this would be a minimum of 200 feet away from the infiltrations basins (e.g., if an individual, permit-exempt well were drilled in this location). While this is unlikely, because the area immediately surrounding the Hawks Prairie property is within the City of Lacey’s retail water service area, this is taken as a conservative approach to the refined HHRA.

For the ERA, the most conservative point of exposure is defined as the location of groundwater discharge to surface water having the highest simulated concentration of a chemical of interest. These concentrations simulated as discharging to surface water bodies will be based on the groundwater contribution only, and will not consider mixing with other water sources (such as upstream flow, tidal influence, etc.)

This step will also be used to predict at downgradient locations the contribution that infiltrated reclaimed water provides of other conservative constituents beyond residual chemicals (e.g., nitrate).

Step 2: Additional Attenuation Mechanisms

If the estimated concentration from Step 1 at the most conservative point of exposure is above the screening level risk assessment threshold concentration, then a second step of fate and transport analysis, considering sorption and degradation (if the constituent is non-conservative), will be simulated to more realistically estimate downgradient concentrations to inform the refined HHRA and ERA. This second step of analysis will utilize the calibrated groundwater flow model and the transport code MT3DMS.

Biodegradation will be approximated as a first-order, irreversible reaction. The reaction half-life is the only model parameter required to simulate degradation. Half-life values will be determined through literature review with a priority on peer reviewed journal articles.

Organic solutes at trace concentrations sorbing to organic carbon are typically modeled as a linear isotherm (Zheng and Bennett 1995). Parameters required to model sorption include bulk density of subsurface sediments, effective porosity, organic carbon partition coefficient, and the organic carbon fraction of the aquifer. Bulk density and organic matter content was measured in four samples collected during lysimeter installation. Observed bulk density in samples collected at the Hawks Prairie property ranged from 2.04 to 2.27 grams per cubic centimeter (g/cm^3), which is slightly less than the typical range of 2.65 to 2.80 g/cm^3 for most soil minerals (West

1995). For sediments with no bulk density measurements, the value of 2.65 g/cm^3 is proposed. The observed organic matter content from samples collected at the Hawks Prairie property was low, ranging from 0.6 to 1.0 percent, with an average of 0.7 percent (HDR 2017b). In the absence of data, a value of 0.05 percent is suggested as a conservative assumption (Payne et al. 2008). Effective porosity was a calibrated parameter in groundwater model development and is documented in *Groundwater Flow Model Development and Calibration* (HDR 2019b). Organic partition coefficients specific to the residual chemical of interest will be determined through literature review with a priority on peer reviewed journal articles.

Simulated concentrations will be compared to results from water quality sampling conducted in 2018 (HDR 2019a). This comparison will involve the calculation of attenuation factors needed to reproduce observed concentrations. The estimated attenuation factor for simulated concentrations is the ratio of the simulated concentration at a monitoring well of interest to the simulated concentration in reclaimed water. This analysis will help inform uncertainty in the fate and transport of residual chemicals of interest.

Results from this analysis will include maps showing estimated concentrations of residual chemicals assuming conservative transport (Step 1) for infiltration rates of 1.5 and 5 MGD. Summary tables will be presented and include concentration simulated at the most conservative points of exposure relative to both the HHRA and ERA, for all residual chemicals of interest. Additional maps and tables will be presented for those residual chemicals that merited the second step of analysis.

2.2.4 Sensitivity Analyses

Sensitivity analyses are planned to help bound the results of fate and transport modeling. As described below model parameters will be varied to assess the sensitivity of the model results to each parameter. The results of the sensitivity analyses will provide ranges of outcomes which will identify the most likely and the most conservative results based on model parameter constraints by either field data or literature-derived values.

Screening Simulations

When simulating the fate and transport of residual chemicals, the model includes dispersion which accounts for the effects of a tortuous flow path and the heterogeneity of the aquifer material at scales smaller than the model grid cells. The range of dispersion used in the initial fate and transport model was derived from the tracer test conducted at the Hawks Prairie Recharge Facility in 2018 (HDR, revised February 2020). The modeling is planned to simulate the conservative chemical transport under two conditions (scenarios), at current operational recharge rates of 1.5 million gallons per day (mgd) and at maximum operational recharge rates of 5 mgd. As discussed in Section 2.2.1 above, a base scenario without any artificial recharge or residual chemicals being introduced through recharge will be the point of comparison. Both of the transport scenarios will be simulated using a low, average, and high dispersivity value based on the tracer test results. The average dispersivity runs will be used as the base runs for the sensitivity analyses of other parameters. The planned variation in dispersivity is a sensitivity analysis of one of the two primary drivers of conservative transport in the aquifer.

The second primary driver, advection, is the subject of the flow model calibration as was tested through several sensitivity analyses of hydraulic conductivity and pumping rates of simulated wells during calibration and the effective porosity calculated from the tracer tests. The calibrated model is the best fit simulation to the data (groundwater levels and stream base-flow) given the reasonable constraint on regional groundwater recharge and understanding of aquifer properties. Varying the flow model parameters and stresses of hydraulic conductivity and pumping rates from the base case for predictive fate and transport modeling would require significantly more effort than is planned and would not result in better understanding of the potential for residual chemicals to arrive at potential receptors since the changes would result in a flow model that is no longer calibrated.

However, a case can be made that regional (background) recharge rates will vary in the future (potentially due to climate change and development). For this reason a sensitivity analysis of recharge is recommended. Four additional simulations can be undertaken (two for each transport scenario) where background recharge is increased to simulate changes towards a wetter climate, or decreased to simulate changes towards a drier climate. For this effort the background recharge will be increased and decreased from the calibrated rates in these simulations by 1.25 times and 0.75 times to account for the possible variability.

Effective porosity is constrained by the tracer test data, but the effects of increasing and decreasing it can be informative regarding timing of contaminant transport in the model. Two additional model runs per scenario, one at twice and one at half the calibrated effective porosity will be conducted to bound arrival times.

The range of results of the initial screening modeling will be compared to concentrations of residual chemicals at the recharge basins prior to infiltration. The baseline (average, most likely) condition will be used for the comparison; the extremes from the sensitivity will identify if there is a potential for the constituent to arrive at concentrations of concern if the variables being tested are not accurately constrained. Concentrations of residual chemicals that have been consistently detected in the reclaimed water will be used in the comparison. It is anticipated that some residual chemical concentrations will be below risk criteria before reaching potential receptors due to the dilution imparted by dispersion. The residual chemicals which are not eliminated from consideration by the conservative simulations (using only advection and dispersion processes) will be subjected to refined simulations where the processes of degradation and sorption are also considered. Dispersivity values used during these recharge sensitivity runs, effective porosity runs, and for refined simulations (described below) that include degradation and sorption, would be done using the average dispersivity value determined based on the breakthrough curves of bromide from the tracer test. A summary planned simulations is presented in **Table 1**.

Table 1 - Summary of Predictive Groundwater Simulations

		Scenario (Reclaimed Water Infiltration Rate)	
Sub-Scenario (with modified variable identified)	**Notes Regarding Variable Modification**	**2 (Current Operating Conditions; 1.5 mgd)**	**3 (Future Operating Conditions; 5.0 mgd)**
a Baseline	Baseline conditions for all variables	2a	3a
b Low Dispersivity	Minimum dispersivity – “safety factor”	2b	3b
c High Dispersivity	Maximum dispersivity + “safety factor”	2c	3c
d Low Recharge	Baseline recharge x 0.75	2d	3d
e High Recharge	Baseline recharge x 1.25	2e	3e
f Low Porosity	Baseline porosity x 0.5	2f	3f
g High Porosity	Baseline porosity x 2.0	2g	3g

Note: Scenario 1 is defined as “no reclaimed water infiltration”. For this scenario, the groundwater flow model is not used. “Background” concentrations of residual chemicals will be based on Task 1 sampling results (see Section 2.2.2). Scenarios 2 and 3 are a function of reclaimed water infiltration rate, with sub-scenarios (i.e., “a” through “g”) then defined based on modifications of various parameters.

Refined simulations

The refined simulations will likely rely upon literature values for first order decay and sorption parameters for the remaining residual chemicals. As such, it is appropriate to conduct sensitivity analyses of these parameters. The sensitivity analyses will likely range according to the values presented in the literature for each individual residual chemical. The variability in these parameters will be identified once the individual residual chemicals that continue into refined simulations are known.

Table 2. Residual Chemicals Identified for Inclusion in Refined Risk Assessment

Chemical	Category or Pharmaceutical Class	Risk Group	Reason for Inclusion in Refined Risk Assessment
Original Data Source:	*(Intertox 2019)*	*(Intertox 2019, Windward 2019)*	*(Intertox 2019, Windward 2019)*
1,4-Dioxane	Industrial chemical	Human Health	Exceeded DWEL (reclaimed water and pore water)
4-Nonylphenol	Surfactant	Human Health, Ecological	Triggered based on exceedance factor (Ecological), exceeded DWEL in pore water (Human Health)
Acesulfame-K	Sugar substitute	Human Health	Greater than 10% of DWEL
Albuterol	Anti-asthmatic	Human Health	Greater than 10% of DWEL
Androstenedione	Steroid hormone	Human Health	Included as may act on same physiological endpoint or through the same mechanism of action
Atenolol	Beta blocker	Human Health	Greater than 10% of DWEL
Carbamazepine	Antiseizure	Human Health	Greater than 10% of DWEL
Chloramphenicol	Antibiotic	Human Health	Exceeded DWEL (reclaimed water)
Cotinine	Nicotine degradate	Human Health	Greater than 10% of DWEL
Diazepam	Anti-inflammatory	Human Health	Greater than 10% of DWEL
Diclofenac	Anti-inflammatory	Human Health, Ecological	Persistent and bioaccumulative, greater than 10% of DWEL
Dilantin	Antiseizure	Human Health	Greater than 10% of DWEL
Estradiol - 17 beta	Estrogenic hormone	Human Health	Exceeded DWEL (porewater), Triggered based on exceedance factor (Ecological)
Estriol	Hormone	Human Health	Included as may act on same physiological endpoint or through the same mechanism of action
Estrone	Estrogenic hormone	Human Health	Exceeded DWEL (reclaimed water)

Chemical	Category or Pharmaceutical Class	Risk Group	Reason for Inclusion in Refined Risk Assessment
Ethinyl Estradiol - 17 alpha	Contraceptive hormone	Human Health, Ecological	Triggered based on exceedance factor (Ecological), exceeded DWEL (reclaimed water and porewater) (Human Health)
Fipronil	Insecticide	Ecological	Triggered based on exceedance factor
Fluoxetine	Antidepressant	Human Health	Greater than 10% of DWEL
Gemfibrozil	Antilipidemic	Human Health, Ecological	Persistent and bioaccumulative, greater than 10% of DWEL
Lopressor	Beta Blocker	Human Health	Greater than 10% of DWEL
Meclofenamic Acid	Anti-inflammatory	Ecological	Persistent and bioaccumulative
N-Nitroso dimethylamine (NDMA)	Industrial solvent	Human Health	Exceeded DWEL (reclaimed water and porewater)
Norethisterone	Steroid hormone	Human Health	Exceeded DWEL (reclaimed water and porewater)
Perfluoro butanoic acid- PFBA	Perfluorochemical	Human Health, Ecological	Included as may act on same physiological endpoint or through the same mechanism of action, persistent and bioaccumulative
Perfluoro octanesulfonate-PFOS	Perfluorochemical	Human Health	Included as may act on same physiological endpoint or through the same mechanism of action
Perfluoro octanesulfonic acid - PFOS	Perfluorochemical	Human Health	Included as may act on same physiological endpoint or through the same mechanism of action
Perfluoro octanoic acid - PFOA	Perfluorochemical	Human Health, Ecological	Persistent and bioaccumulative, greater than 10% of DWEL
Perfluoro-1-butanesulfonate	Perfluorochemical	Human Health	Included as may act on same physiological endpoint or

Chemical	Category or Pharmaceutical Class	Risk Group	Reason for Inclusion in Refined Risk Assessment
			through the same mechanism of action
Perfluoro-1-butanesulfonic acid	Perfluorochemical	Human Health, Ecological	Included as may act on same physiological endpoint or through the same mechanism of action, persistent and bioaccumulative
Perfluoro-1-hexanesulfonate	Perfluorochemical	Human Health	Included as may act on same physiological endpoint or through the same mechanism of action
Perfluoro-1-hexanesulfonic acid	Perfluorochemical	Human Health	Included as may act on same physiological endpoint or through the same mechanism of action
Perfluoro-n-decanoic acid	Perfluorochemical	Human Health	Included as may act on same physiological endpoint or through the same mechanism of action
Perfluoro-n-heptanoic acid	Perfluorochemical	Human Health	Included as may act on same physiological endpoint or through the same mechanism of action
Perfluoro-n-hexanoic acid	Perfluorochemical	Human Health, Ecological	Exceeded DWEL (reclaimed water and porewater), persistent and bioaccumulative
Perfluoro-n-nonanoic acid (PFNA)	Perfluorochemical	Human Health, Ecological	Persistent and bioaccumulative
Perfluoropentanoic acid	Perfluorochemical	Human Health, Ecological	Exceeded DWEL (reclaimed water and porewater), persistent and bioaccumulative
Primidone	Anti-convulsant	Human Health	Greater than 10% of DWEL
Progesterone	Steroid hormone	Human Health	Included as may act on same physiological

Chemical	Category or Pharmaceutical Class	Risk Group	Reason for Inclusion in Refined Risk Assessment
			endpoint or through the same mechanism of action
Quinoline	Phosphate pesticide	Human Health	Exceeded DWEL (reclaimed water)
Sucralose	Sugar substitute	Ecological	Triggered based on exceedance factor
Sulfamethoxazole	Sulfa antibiotic	Human Health	Greater than 10% of DWEL
TCEP	Flame retardant	Human Health	Greater than 10% of DWEL
TCPP	Flame retardant	Ecological	Triggered based on exceedance factor
TDCPP	Flame retardant	Human Health, Ecological	Triggered based on exceedance factor (Ecological), Exceeded DWEL (reclaimed water) (Human Health)
Testosterone	Steroid hormone	Human Health	Included as may act on same physiological endpoint or through the same mechanism of action
Theobromine	Caffeine degradate	Ecological	Triggered based on exceedance factor
Theophylline	Anti-asmathic	Human Health	Greater than 10% of DWEL
Thiabendazole	Fungicide	Human Health	Greater than 10% of DWEL
Triclosan	Antimicrobial	Ecological	Persistent and bioaccumulative

Note:
DWEL = Drinking Water Equivalent Level

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Table 3. Summary of Residual Chemical Concentrations and "Background" Detections

Chemical	**Minimum Reporting Limit (MRL)** [a] (ng/L)	**Max Detected Concentration in Reclaimed Water** (ng/L)	**Screening Concentration** (ng/L)	**Detected in "Background" Groundwater Quality Characterization**	**Detected in "Background" Surface Water Characterization**	**Detected in Groundwater Monitoring Wells Near Hawks Prairie Basins** [b]
Source:	*(HDR 2019a)*	*(HDR 2017c, HDR 2019a)*	*(Intertox 2019, Windward 2019)*	*(HDR 2017a, HDR 2019a)*	*(HDR 2017b)*	*(HDR 2014b, HDR 2019a)*
1,4-Dioxane	70-100	850	370	Not Sampled	Not Sampled	Yes
4-Nonylphenol	100-500	3,100	20,000 (HHR), 500-600 (ER)	Yes	No	Yes
Acesulfame-K	20	13,000	120,000	Yes	Yes	Yes
Albuterol	5	11	7.5	No	No	Yes
Androstenedione	5-10	<10	Not detected, no screening concentration established	No	No	No
Atenolol	5	230	1,000	No	Yes	Yes
Carbamazepine	5-25	730	330	Yes	Yes	Yes
Chloramphenicol	10-50	24	4.1	No	No	No
Cotinine	10	130	800	No	Yes	No
Diazepam	5	9.3	83	No	No	No
Diclofenac	5-25	260	830 (HHR), 421,600-1,500,000 (ER)	No	No	Yes
Dilantin	20	130	1,200	No	No	No
Estradiol - 17 beta	5-25	14	0.26 (HHR), 2-21,200 (ER)	No	No	Yes
Estriol	10-50	< 50	Not detected, no screening concentration established	Not Sampled	Not Sampled	No
Estrone	5-25	1.9	0.058	No	Yes	No
Ethinyl Estradiol - 17 alpha	5	64	0.083 (HHR), 0.1-17,500 (ER)	No	No	No
Fipronil	2	51	11-16	Not Sampled	Not Sampled	Not Sampled
Fluoxetine	10	210	960	Yes	No	No
Gemfibrozil	5-25	710	5,000	No	No	No
Lopressor	20	900	1,000	No	No	No
Meclofenamic Acid	5	300	9,000	No	No	Yes
N-Nitroso dimethylamine (NDMA)	2	7.3	0.86	Not Sampled	Not Sampled	Yes
Norethisterone	5	5.9	1.4	No	No	No
Perfluoro butanoic acid- PFBA	10	<10	7,000	No	Not Sampled	Yes
Perfluoro octanesulfonate-PFOS	5	<5	70	No	Not Sampled	No
Perfluoro octanesulfonic acid – PFOS	5	<5	70	No	Not Sampled	No
Perfluoro octanoic acid - PFOA	5	22	70 (HHR), 134,100-16,000,000 (ER)	No	Not Sampled	Yes
Perfluoro-1-butanesulfonate	5	13	2,000	Yes	Not Sampled	Yes
Perfluoro-1-butanesulfonic acid	5	13	610,000	Yes	Not Sampled	Yes
Perfluoro-1-hexanesulfonate	5	< 5	Not detected, no screening concentration established	No	Not Sampled	No
Perfluoro-1-hexanesulfonic acid	5	< 5	Not detected, no screening concentration established	No	Not Sampled	No
Perfluoro-n-decanoic acid	5	< 5	Not detected, no screening concentration established	No	Not Sampled	No
Perfluoro-n-heptanoic acid	5	< 5	70	No	Not Sampled	Yes

Chemical	**Minimum Reporting Limit (MRL)** [a] (ng/L)	**Max Detected Concentration in Reclaimed Water** (ng/L)	**Screening Concentration** (ng/L)	**Detected in "Background" Groundwater Quality Characterization**	**Detected in "Background" Surface Water Characterization**	**Detected in Groundwater Monitoring Wells Near Hawks Prairie Basins** [b]
Perfluoro-n-hexanoic acid	5	81	70	No	Not Sampled	Yes
Perfluoro-n-nonanoic acid (PFNA)	5	<5	70 (HRR), 40,500 (ER)	No	Not Sampled	Yes
Perfluoropentanoic acid	5	150	70	No	Not Sampled	Yes
Primidone	5-50	930	410	No	No	Yes
Progesterone	5	< 5	Not detected, no screening concentration established	No	No	No
Quinoline	5	28	3.3	Yes	Yes	Yes
Sucralose	100-500	90,000	1,500,000	Yes	Yes	Yes
Sulfamethoxazole	5	520	5,300	No	No	No
TCEP	10	240	500	Yes	Yes	Yes
TCPP	100	1,300	1,100-13,000,000	Yes	No	Yes
TDCPP	100	2,000	2,000 (HHR), 1,200 (ER)	No	Yes	Yes
Testosterone	5	7.4	200	No	No	No
Theobromine	10-50	66	400	No	No	Yes
Theophylline	20	120	660	No	No	No
Thiabendazole	5	600	1,300	No	No	Yes
Triclosan	10	130	7,100-15,100	No	No	Yes

Notes:

[a] Minimum reporting limits from 2018 water quality sampling (HDR 2019a).

[b] Based on data collected during startup monitoring in 2013 and water quality monitoring in 2018 (HDR 2014b, HDR 2019a).

Table 4. Summary of Parameters Assigned in Fate and Transport Modeling

Step of Analysis	Process	Process Details	Parameter	Source
1 and 2	Dispersion	No additional details	Dispersivity	2 dispersivities simulated (consistent with groundwater modeling in **Section 2.1** and **Table 1.**)
2	Degradation	Biodegradation (1st order reaction) (Zheng and Bennett 2002)	Half-life	Literature review
2	Sorption	All sorption models	Bulk density	HDR (2017) - Vadose zone (Qvr) only, West (1995)
2	Sorption	All sorption models	Effective porosity	Calibrated groundwater flow model (HDR 2019b)
2	Sorption	Organic Compounds $K_d = f_{oc} \cdot K_{oc}$ (Zheng and Bennett 2002)	Organic carbon partition coefficient (K_{oc})	Literature review
2	Sorption	Organic Compounds $K_d = f_{oc} \cdot K_{oc}$ (Zheng and Bennett 2002)	Organic carbon fraction (f_{oc})	HDR (2017) - Vadose zone (Qvr) only; Literature review for area; Payne et al. (2008)

3.0 Reporting

The analysis as described above, including both methods employed and results, will be documented in a technical memorandum. This includes changes to the calibrated groundwater flow model made for predictive simulations, model parameters assigned for fate and transport analysis, and associated assumptions. Results will be presented as described in the sections above; additional tables and figures may be developed if deemed useful in communicating findings. Reports will be presented as draft and edited to a final version based on comments received.

4.0 Assumptions

The following assumptions are inherent in the methods and analysis described in this work plan. They are deemed reasonable for the objectives of the study.

- The groundwater model only represents saturated media and does not include the vadose zone.
- Dispersivities calculated from the tracer test are representative of conditions throughout the model domain.
- The assigned model parameters are representative of real world conditions.
- The model transport parameters are spatially uniform (homogenous) in model layers unless otherwise noted.
- Infiltrated reclaimed water recharge rates are constant with time.
- Concentrations of residual chemicals in reclaimed water remains the same.
- HDR can reasonably rely on literature values for sorption and decay parameters for chemicals of interest.
- Biodegradation can be represented as a first order reaction.
- Sorption of residual chemicals of interest will primarily be on organic matter in the subsurface.
- The fraction of organic carbon, foc, will be assigned as 0.05 percent (0.0005) for geologic units for which there are no measurements or literature available.
- Bulk density will be assigned as 2.65 g/cm3, for geologic units for which there are no measurements or literature data available.
- Estimation of residual chemical concentrations in creeks to inform risk assessment will be based on the groundwater contribution only, and will not consider mixing with other water sources (such as runoff and slow flow contributions).

Other assumptions and limitations as described in the *Draft Technical Memorandum Steady-State Groundwater Model Development and Calibration (Task 2.1.4)* (HDR 2019b) are also applicable to this phase of work.

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Appendix A - Proposed Model Recharge Rates for New Hawks Prairie Development North of the LOTT Hawks Prairie Infiltration Facility

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Appendix A. Proposed Model Recharge Rates for New Hawks Prairie Development North of the LOTT Hawks Prairie Infiltration Facility

The new development of interest includes the conversion of 61 acres to impervious surfaces, a site map is provided below in **Figure A-1**. All generated runoff will be infiltrated onsite through an infiltration pond (also referred as the west basin) and an infiltration gallery or chamber (also referred to as the east basin), shown in **Figure A-2**. The west infiltration pond will infiltrate runoff generated by 15 of the 60.8 acres, runoff generated by the remaining 45.8 acres will be infiltrated in the east infiltration gallery as shown in **Figure A-3** (Barghausen 2017).

Runoff from building five (covering 3.55 acres) and a portion of building one will applied to the wetland on the southwest portion of the property through a dispersion trench. Insufficient detail is provided in the drainage report to estimate a model recharge rate for any water entering the groundwater system through the dispersion trench supplying the wetland mitigation area, so it will not be accounted for separately in the model (Barghausen 2017). Instead, the runoff volume from building five will be applied over the wetland area in the model. As shown in **Figure A-3,** all of building one is shown as contributing to the east infiltration gallery, consequently that is how it will be represented in the model.

The proposed model recharge was calculated as follows:

Model Recharge Rate = Water Volume/Active Infiltration Area/Time

*Water Volume = Average Annual Rainfall * Runoff Tributary Area*

Time = Model units are days, model operation is steady-state, no so need to integrate over a period of time

The proposed wetland rate was calculated as follows:

*Water Volume = Average Annual Rainfall * (Building 5 Area + Wetland Area)*

Equivalent Rainfall Over Wetland= Water Volume / Wetland Area

The Bidlake and Payne (2001) relationship for non-forest vegetation on soils formed on glacial outwash and other alluvium was applied on the equivalent rainfall to calculate the proposed model recharge rate: R = 0.806(Equivalent Rainfall) – 8.87*

Table A-1. Summary Information for Calculation of Model Recharge in Newly Developed Area

	Runoff Tributary Area (acres)	Active Infiltration Area (ft^2)	Rainfall (inches/year)[a]	Proposed recharge rate in model (ft/day)	Elevation of pond bottom (ft)
West Infiltration pond	15	88,370[b]	51.0	0.0861	199
East infiltration gallery	45.8	264 x 352 = 92,928	51.0	0.2410	210
Wetland	3.55 (building 5) + 3.0 (wetland)	130,680	51.0	0.0185	Ground surface
Impervious surfaces	--	--	51.0	0	--

[a] Average annual rainfall from the Olympia Airport USW00024227 gaging station from 1948 to 2016 (HDR 2019b)

[b] The infiltration footprint of the West Infiltration Pond was estimated from aerial imagery as shown in **Figure A-4** below, since it was not detailed in the drainage report (Barghausen 2017).

[c] 51 inches per year

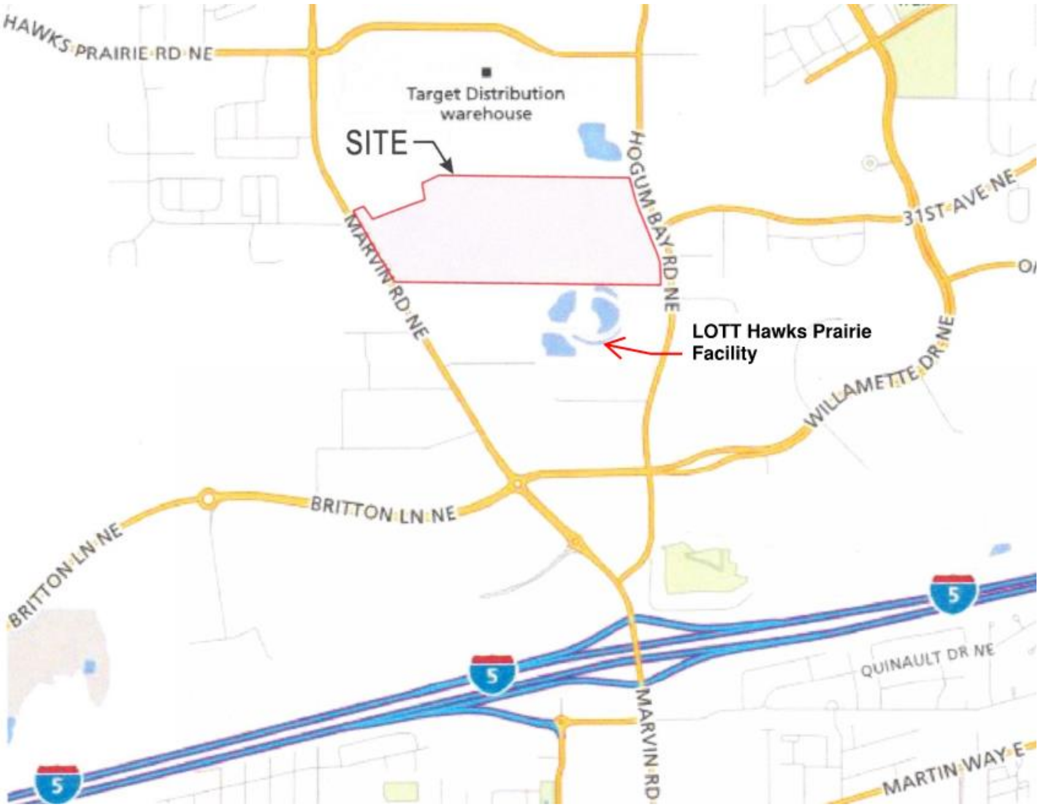

Figure A-1. Location of new development, called out as 'SITE' in the figure above. Reproduced from Barghausen (2017).

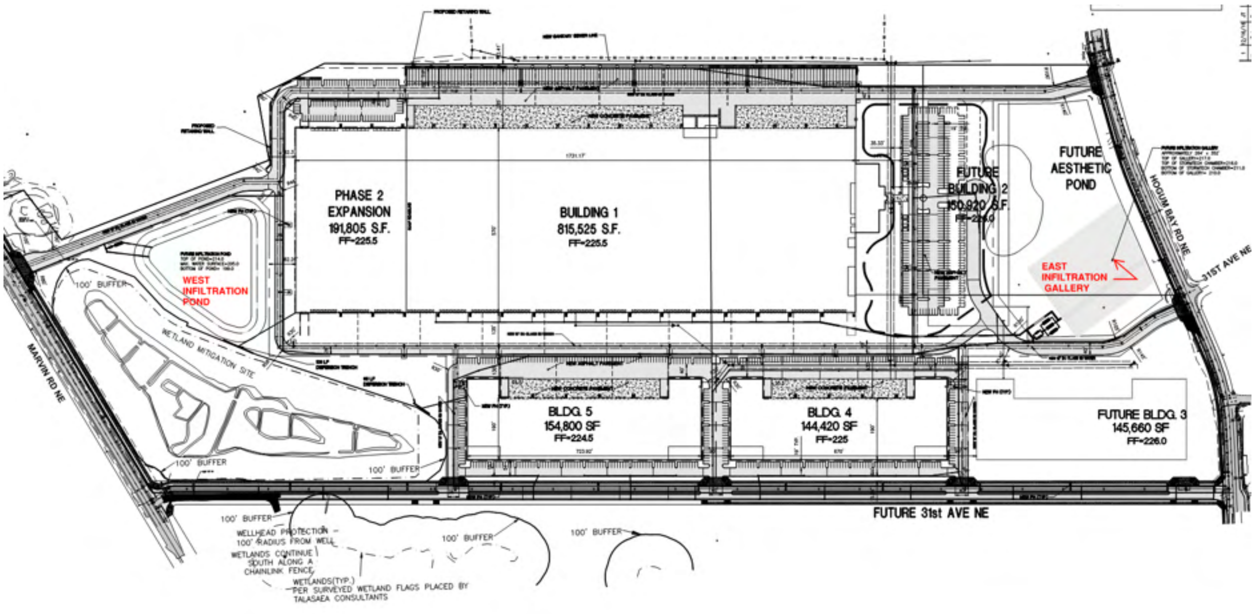

Figure A-2. Site Plan showing infiltration facilities. Reproduced from Barghausen (2017).

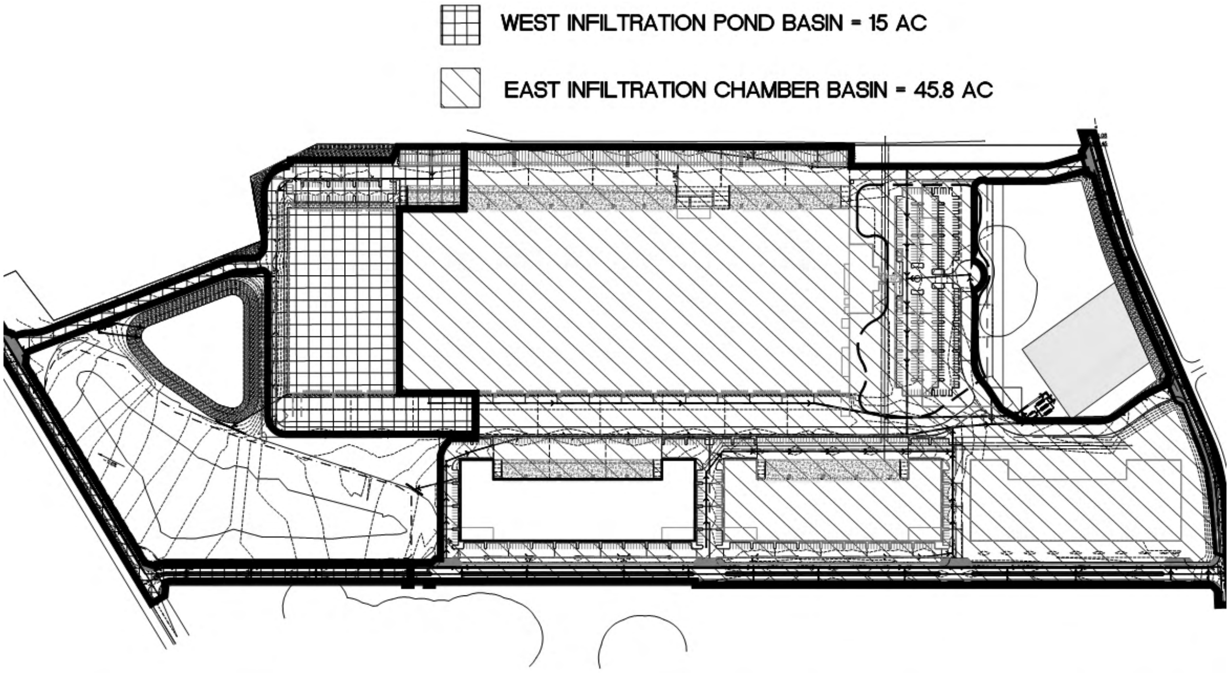

Figure A-3. Developed areas tributary to runoff infiltration facilities. Reproduced from Barghausen (2017).

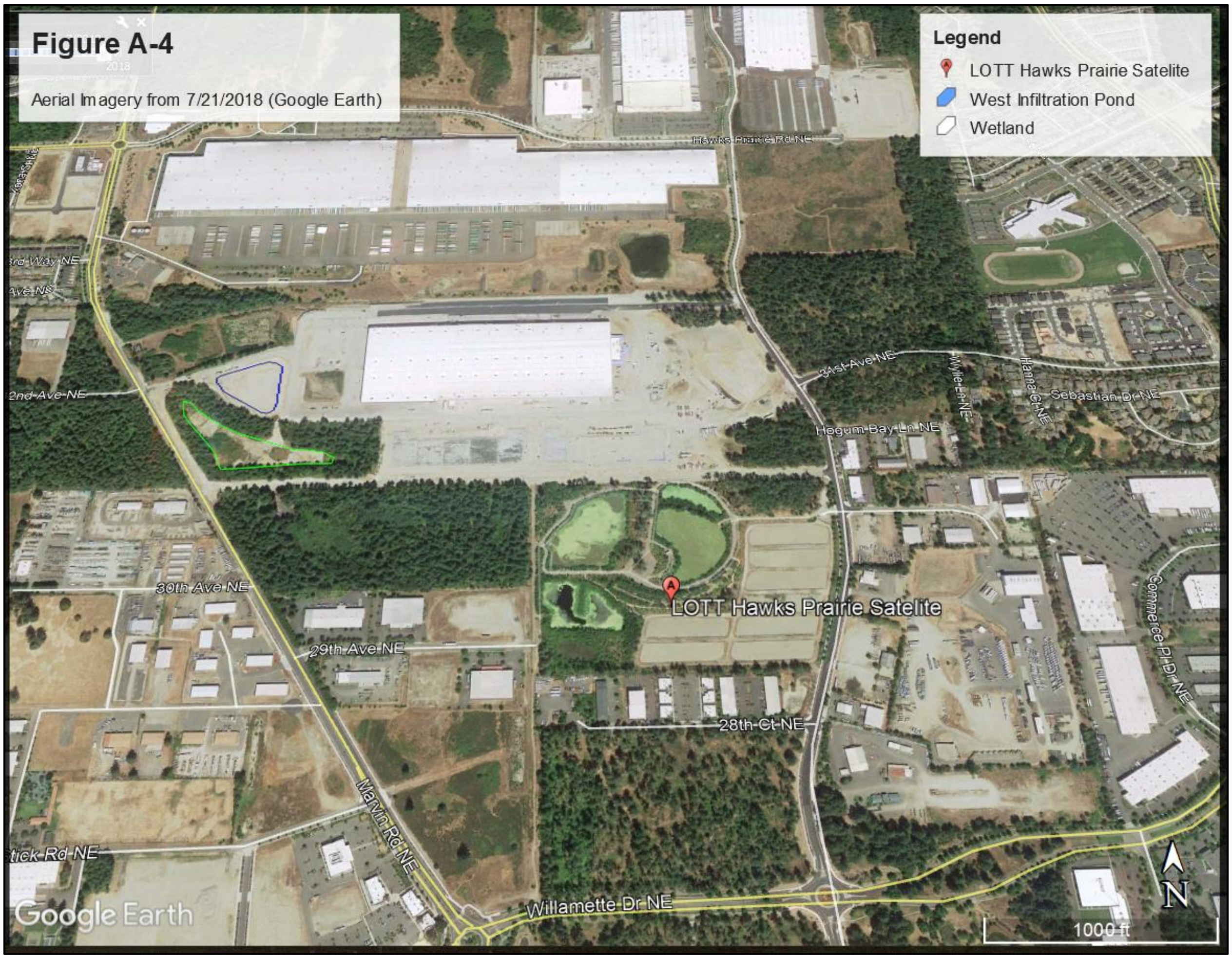

Figure A-4. Estimation of west infiltration pond area (outlined above in blue) and wetland area (above in green). Aerial Imagery from 7/21/2018 (Google Earth).