LOTT WASTEWATER ALLIANCE

HAWKS PRAIRIE RECLAIMED WATER SATELLITE

FINAL GROUNDWATER FLOW MODELING RESULTS

JANUARY 2004

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

SUMMARY

The Hawks Prairie Wetland Ponds/Recharge Basins site makes use of a series of eight groundwater recharge basins as the final step in the water recycling process for the LOTT Hawks Prairie Satellite Reclamation Project. The groundwater recharge plan calls for the infiltration of up to 5 million gallons per day (mgd) of Class A reclaimed water to the shallow aquifer system at a site in northwest Lacey, Washington (see Figure 1). The infiltrated water may be beneficially used to reduce declining groundwater levels during the summer.

The purpose of this report is to document the development of a groundwater flow model designed to analyze potential effects of the proposed LOTT Hawks Prairie Wetland Ponds/Recharge Basins project on the regional aquifer. The model is based on existing hydrogeologic data. Applications of the results of the modeling are limited to the extent of the data available and should be used as a tool in understanding the hydrogeologic conditions of the recharge area.

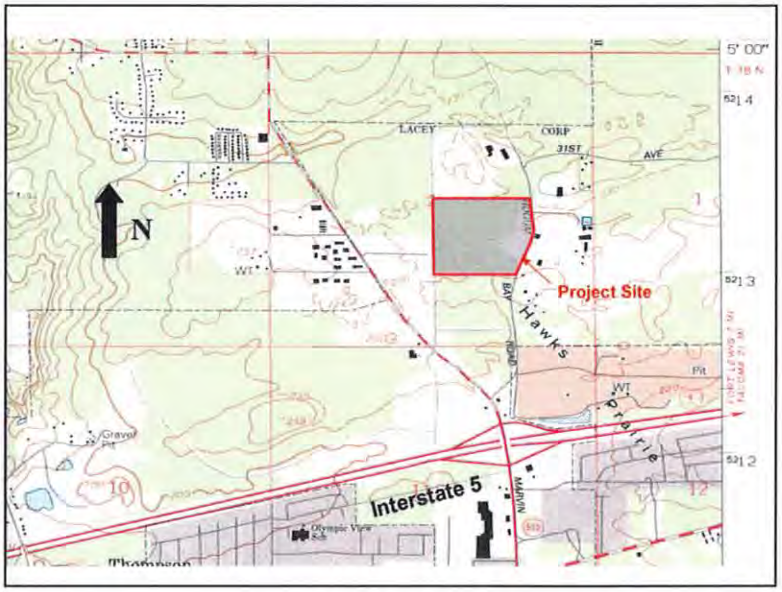


Figure 1 - Site Location

The objectives of the LOTT groundwater flow model are to:

- Provide a tool for predicting the height and extent of groundwater mounding beneath the recharge basins.
- Provide a tool for predicting the occurrence and fate of potential perched groundwater beneath the recharge basins.
- Provide a tool for evaluating the migration of groundwater from beneath the recharge basins toward natural discharge sites (travel time and flow volume).
- Provide a tool for evaluating the effects to groundwater quality from Class A reclaimed water recharge.
- Develop criteria for design of full-scale recharge basins.

The LOTT groundwater flow model is based on hydrogeologic data collected during the LOTT Groundwater Recharge Basin Pilot Test, existing data from the USGS report "Conceptual Model and Numerical Simulation of the Ground-Water-

Flow System in the Unconsolidated Sediments of Thurston County, Washington", Drost, et al, 1999, local and regional monitoring well logs, Thurston County Department of Health groundwater quality records, and site investigations. The accuracy and application of the groundwater flow model are limited to this data. Revised quantitative assessments should be performed when full-scale recharge basin data becomes available.

The LOTT groundwater flow model encompasses an area approximately 24,000 feet in an east-west direction and 21,000 feet in a north-south direction from the center of the recharge site shown on Figure 8. Three soil layers are included in the model to represent the stratigraphy of the shallow groundwater aquifer and overlying units. All water enters the model domain through aerial recharge (simulation of precipitation), and all water leaves the model at drain boundaries (except for several domestic water wells located west of the recharge site).

Predictive simulations indicate that the height of groundwater modeling beneath the LOTT recharge site is approximately 13-feet at a recharge rate of 1-mgd, and approximately 35-feet at a recharge rate of 5-mgd above static water levels. Particle tracking simulations indicate that water infiltrated at a 1-mgd recharge rate would migrate toward Woodland Creek (to the west) with an estimated travel time of approximately ten years. Similarly at a 5-mgd recharge rate, the simulations indicate that the infiltrated water would migrate toward Woodland Creek, with minor amounts migrating toward the north due to the larger mounding effect at the recharge point. The travel time to the closest point of discharge, Woodland Creek, is again estimated at approximately ten years. Modeling results confirmed that the added recharge has minimal effect on the amount of groundwater flow volume entering Woodland Creek with an increase of approximately 0.6% at 1-mgd and 3% at 5-mgd.

Contaminant transport was added to the model to estimate groundwater concentrations and travel times of nitrogen infiltrated by the recharge basins. Simulations indicate that an infiltrated nitrogen concentration of 5-mg/L causes only a minor localized increase to background groundwater nitrate concentration. The increased nitrate concentration extends to the property boundary at 1-mgd and within 1,200-feet of the property boundary at 5-mgd at which point the concentration returns to typical background levels.

CHAPTER ONE: INTRODUCTION

LOTT has incorporated groundwater recharge as part of its program to beneficially recycle highly treated wastewater as demonstrated in the 1996 LOTT Wastewater Resource Management Plan (Plan).

Eight acres of recharge basins will be incorporated with twelve acres wetland ponds to enable LOTT to fully recycle Class A reclaimed water generated at the Hawks Prairie Satellite Reclamation Plant. The recharge basins are sized to allow for infiltration of up to five million gallons per day (mgd) of Class A reclaimed water to the shallow aquifer system. The recharge basin site is located north of Interstate 5 on Hogum Bay Road in the Hawks Prairie area of Lacey, Washington. The facility shall be constructed under the Hawks Prairie Wetland Ponds/Recharge Basins A project. This report documents development of a groundwater model to identify potential hydrologic issues surrounding the project, including groundwater mounding height, migration of recharged water, nitrate transport, and impacts to surrounding wells and streams.

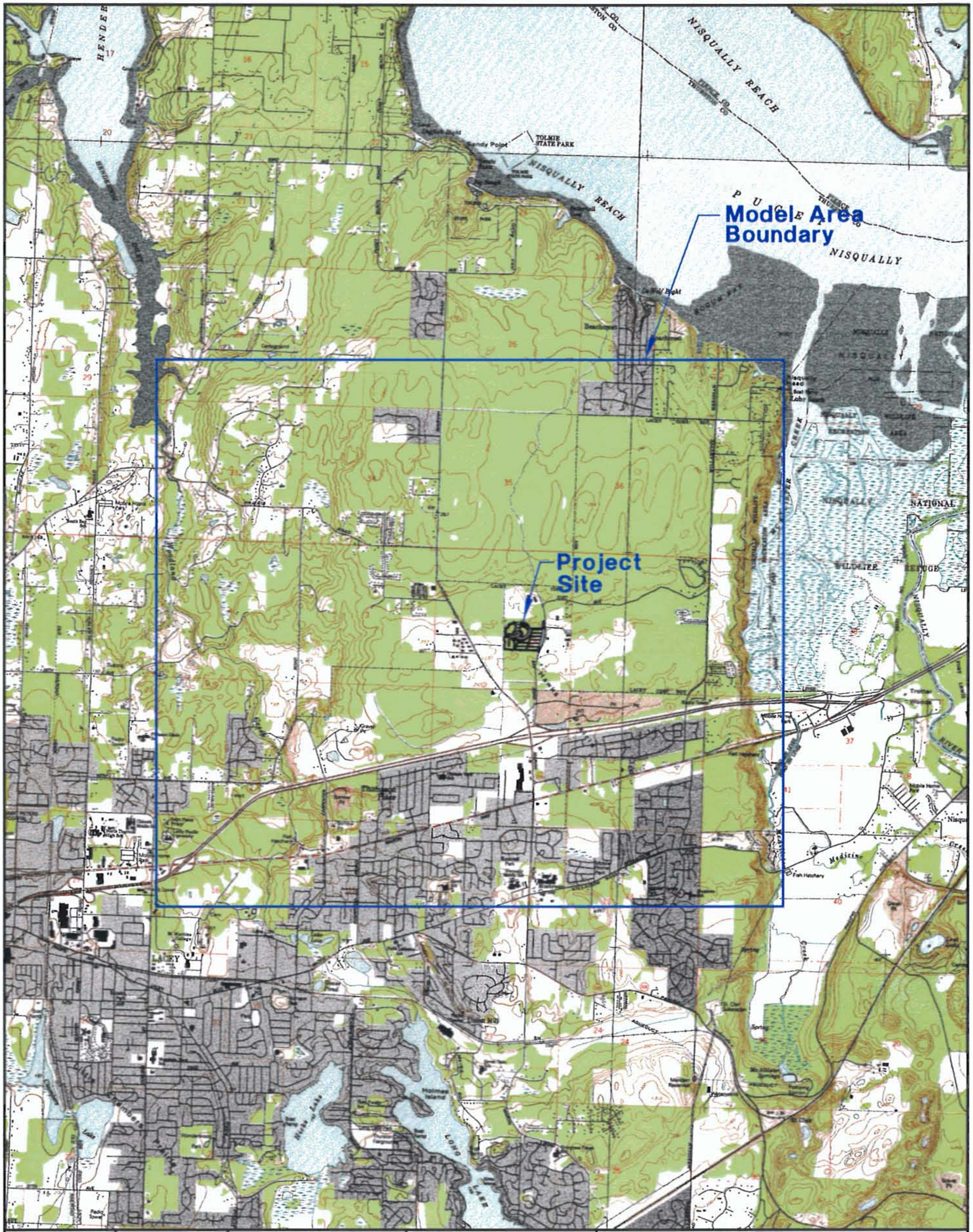
Water infiltrated in the basins shall migrate downward through the unsaturated zone to the shallow aquifer approximately 80 feet below the recharge basin surface. Pilot testing indicates that the water will then move laterally away from the basins toward aquifer discharge areas. The recharge model was developed to help determine where the water will migrate, how long it may take to reach the boundary, the amount of mounding expected below the recharge site, and impacts to groundwater quality.

As water is infiltrated, groundwater mounding is expected to occur within the shallow aquifer underlying the recharge basins. Some potential also exists for the creation of perched groundwater conditions above locally discontinuous low permeability strata overlying the shallow aquifer. The height of groundwater mounding is of concern because of potential impacts to the infiltration capacity of the infiltration basins and the potential problems a high water table might create in the surrounding area.

The height of the groundwater mounding within the shallow aquifer is primarily a function of the infiltration rate and the hydraulic conductivity of the surrounding aquifer materials. The height of perched groundwater mounding is largely dependent on the hydraulic conductivity of the low permeability strata creating the perched conditions, the hydraulic conductivity of the strata containing the perched groundwater, and the infiltration rate.

A recharge basin pilot study was initiated at the project site to provide infiltration performance data to calibrate the groundwater flow model for the project site. The study included the installation of two ½-acre recharge basins. Water was discharged to the surface of each basin at a rate of 350 gallons per minute (½-mgd) between the months of May and November 2002. The response of the shallow aquifer to the infiltration was monitored by four deep and one shallow monitoring wells installed around the pilot recharge basins. Based on the results of the recharge basin pilot study and groundwater flow modeling, design and operating criteria for the recharge basins was developed for the full scale Hawks Prairie Recharge Basins project.

The basis for the groundwater flow model documented in this report is on existing local hydrogeologic data and should be updated as more aquifer data becomes available (i.e. after construction and operation of the full scale recharge facility). The groundwater model covers a much larger area than the project site to provide for the use of natural hydrogeologic boundaries and to allow model solutions at the project site to be relatively uninfluenced by model boundary conditions. Figure 2 shows the area encompassed by the groundwater model. With construction and operation of the full-scale recharge facility, more will be learned about the underlying aquifer system, including the distribution and influence of low permeability strata. The groundwater flow model may be used as a tool for predicting results of the operation of the future recharge facility. However, the application and usefulness of the model is dependent upon the accuracy and consistency of the data. As further data becomes available, the model should be updated to reflect the information gathered.



DATE:	PROJECT NUMBER:	SCALE:		
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BROWN AND CALDWELL Olympia, Washington				**LOTT Recharge Basins Model Area Boundary**

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CHAPTER TWO: GROUNDWATER FLOW MODEL DESCRIPTION

The purpose of the groundwater flow model is to provide understanding to how the hydrogeology of the Hawks Prairie area of Thurston County responds to changes in surface infiltration at the project site. As defined by Anderson and Woessner, 1992, a groundwater flow model can be used for the purpose of simplifying the groundwater flow system, organizing the data, and creating a model so that the hydrogeologic system can be understood. The following sections describe the components of the groundwater flow model for the site area.

2.1 HYDROGEOLOGY

The shallow aquifer is hosted by unconsolidated sediments that underlie the project site and the remainder of the model area. As described in Technical Memorandum 1202 (Brown and Caldwell, 1997), the uppermost of these sediments is the Vashon recessional gravel outwash (Qvr), a highly permeable, sandy gravel that is approximately 20 feet thick at the recharge basins site. Beneath the Qvr is the Vashon till (Qvt) layer. The Qvt is a low permeability unit consisting of unsorted sand, gravel, and boulders in a matrix of silt and clay. Geologic studies performed at the recharge basin site have found the Qvt layer to be generally absent. The investigation included eight exploratory excavations, infiltrometer testing, and the drilling of seven monitoring wells. Below the Qvt layer is a layer made up of the combination of Vashon advance outwash (Qva) and a local unit named the Hawks Prairie gravel (HPg). The combined Qva/HPg, herein called Qva, unit has a relatively high permeability and hosts the regional shallow aquifer. Beneath the Qva unit is the Kitsap Formation (Qf), a low permeability confining unit composed of silty sand and clay that forms the lower boundary of the shallow aquifer. Below the Qf, is a formation deposite of pre-Vashon glacial origin (Qc). This layer is typically thin (15 ft) and sits on top of a layer of fine to coarse grained sediments (know as the TQu layer) that extends to the bedrock. The Qc and TQu layers contain the deep aquifer which is used extensively for industrial and potable supplies in the area.

The presence, thickness, and permeability of the Qvt has a significant influence on the ability of the regional soils to infiltrate water to the shallow aquifer. If the Qvt exists directly below the Qvr, it may perch a portion of the infiltrated water. However, if the Qvt has a discontinuous distribution that allows the infiltrated water to migrate toward areas with higher hydraulic conductivity, perched groundwater should not be significant. Figures 3 and 4 present the location and generalized cross section depicting the relationship of the hydrogeologic units underlying the project area.

2.2 HYDROGEOLOGIC BOUNDARIES AND SHALLOW AQUIFER FLOW SYSTEM

The shallow aquifer system represented in the model area is bounded on the northern and eastern margins by seepage faces (or springs) along the bluffs that overlook the Puget Sound and McAllister Creek. To the west, the aquifer system is bounded by Woodland Creek where, at least on a seasonal basis, limited groundwater is discharged to the creek. Based on available data, the southern edge of the model area is bounded by a partial groundwater divide, shown as the 175-ft elevation water level contour in the south-central portion of Figure 5.

The lower boundary of the model area is formed by the top of the Kitsap Formation, which is assumed to be impermeable relative to the materials within the overlying shallow aquifer system. The upper boundary of the model is an aerial recharge boundary, through which precipitation infiltrates to recharge the shallow aquifer system. This study is limited to modeling the Qvr, Qvt, and Qva layers. Table 1 provides hydrogeologic information pertaining to the upper layers included as part of this model.

Table 1 - Hydrogeologic Soil Characteristics As Applied to Model

Model Layer	Description	Horizontal Hydraulic Conductivity (feet/day)	Vertical Hydraulic Conductivity (feet/day)	Regional Thickness (feet)	Thickness At Recharge Basins Site (feet)
1	**Qvr** – Vashon Recessional Outwash. Moderately to well-sorted glacial sand and gravel	150	15	Generally located at ground surface, varies in thickness from 0 to 100 feet	Generally located at ground surface, varies in thickness from 4 to 17 feet
2*	**Qvt** – Vashon Till. Unsorted sand, gravel, and boulders in a matrix of clay	20	2	Generally found beneath the Qvr, varies in thickness from 0 to 150 feet	Generally found beneath the Qvr, varies in thickness from 2 to 6 feet
3	**Qva** – Vashon Advance Outwash. Poorly to moderately well-sorted, well-rounded gravel in a matrix of sand.	320	32	Generally found immediately beneath the Qvt, except where the Qvt is absent, varies in thickness from 0 to 250 feet	Generally found immediately beneath the Qvr (Qvt generally absent) thickness of approximately 300 feet

*Where Qvt unit is absent, model layer 2 is assigned the properties of model layer 1

Flow directions of groundwater in the project area display a radial pattern, with the hub of the radial pattern located near the center of the landmass of Johnson Point Peninsula. Figure 5 depicts USGS groundwater elevations and flow directions in the shallow aquifer within model area. It should be noted that the water level contours shown on Figure 5 are based on data from a very limited number of wells, with some data collected over a period of six months (May to October 1988), while other data represents non-static conditions, and still other data were collected at the time of well completion. Water level elevations depicted on Figure 5 may not represent current water level conditions and should be updated when operational data becomes available.

2.3 HYDRAULIC PROPERTIES

The shallow aquifer system was modeled as having three major components, the Qvr, the Qvt, and the Qva (Section 2.1). Each of these soil units can be generally characterized with respect to hydraulic properties, including hydraulic conductivity. Hydraulic conductivity is probably the best understood of the aquifer hydraulic properties, and typical ranges for each unit are provided below.

The Qvr, which forms the surface of the model area is highly permeable and displays rapid infiltration properties. Estimates of the hydraulic conductivity of the Qvr range from 14 to 2,100 feet per day (ft/d), with a median value of 160-ft/d (Drost, et al, 1998). The second unit, the Qvt, has a low permeability and in places limits infiltration forming a groundwater perching unit. The hydraulic conductivity of the Qvt ranges from about 5 to 89-ft/d. However, the values for the Qvt represent only the coarse-grained portions of the unit where it is utilized for limited groundwater production, and the true median value is probably much less than indicated by available data (Drost, et al, 1998). The third unit, the Qva, is highly variable, with hydraulic conductivity values ranging from about 7 to 130,000-ft/d, with a median value of 150-ft/d.

As the ranges of hydraulic conductivity estimates above illustrate, there is a high degree of variability within each of the major hydrogeologic units. A three-layer model with assignable hydraulic property zones was utilized to allow flexibility in appropriately modeling the aquifer system.

The groundwater flow model was constructed by incorporating data collected at or near the project site with regional data compiled by the USGS. Model hydraulic parameters are generally consistent with those presented in the USGS groundwater flow model of Thurston County, Washington.

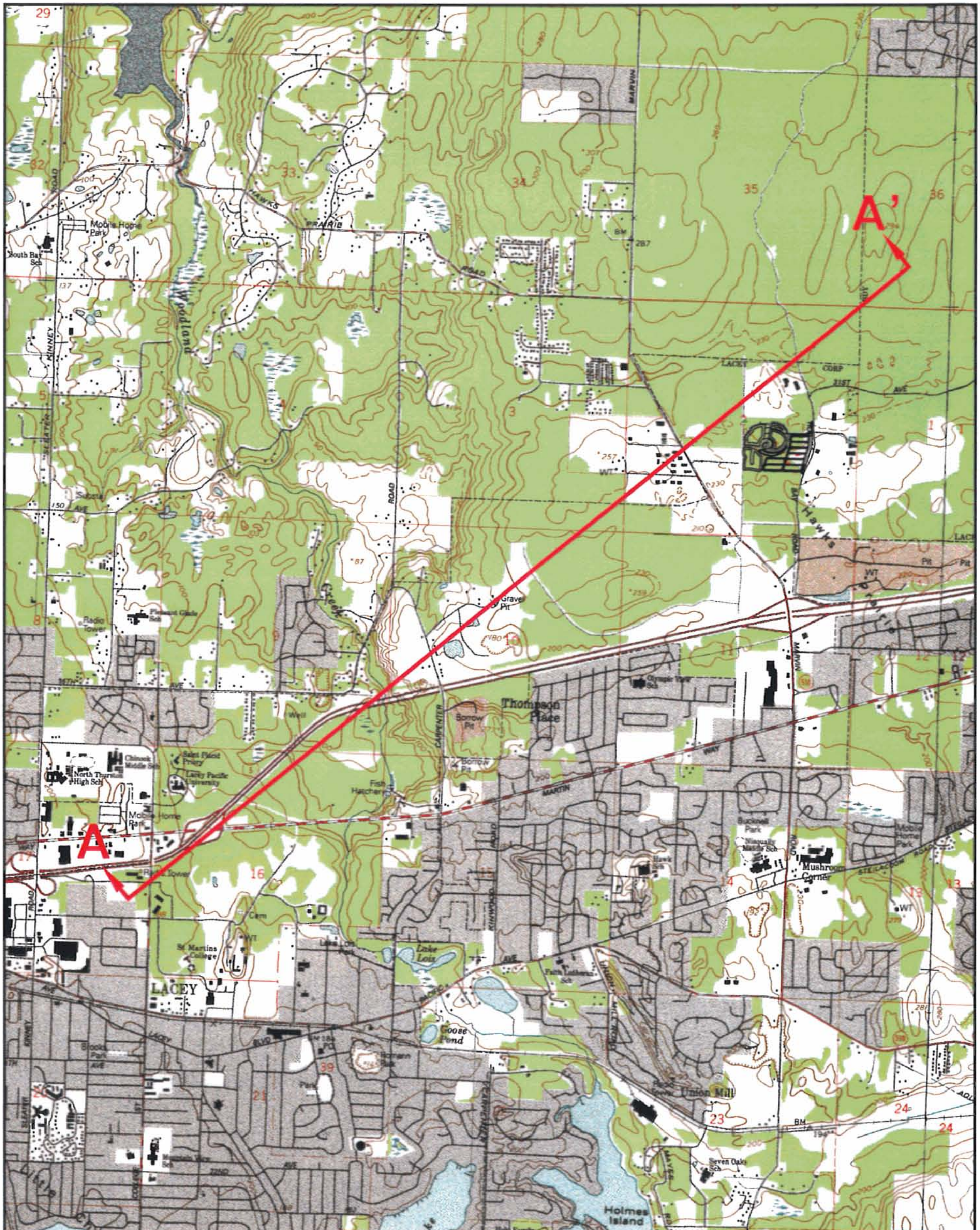

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Figure 3

Cross-Section A-A' Location Map

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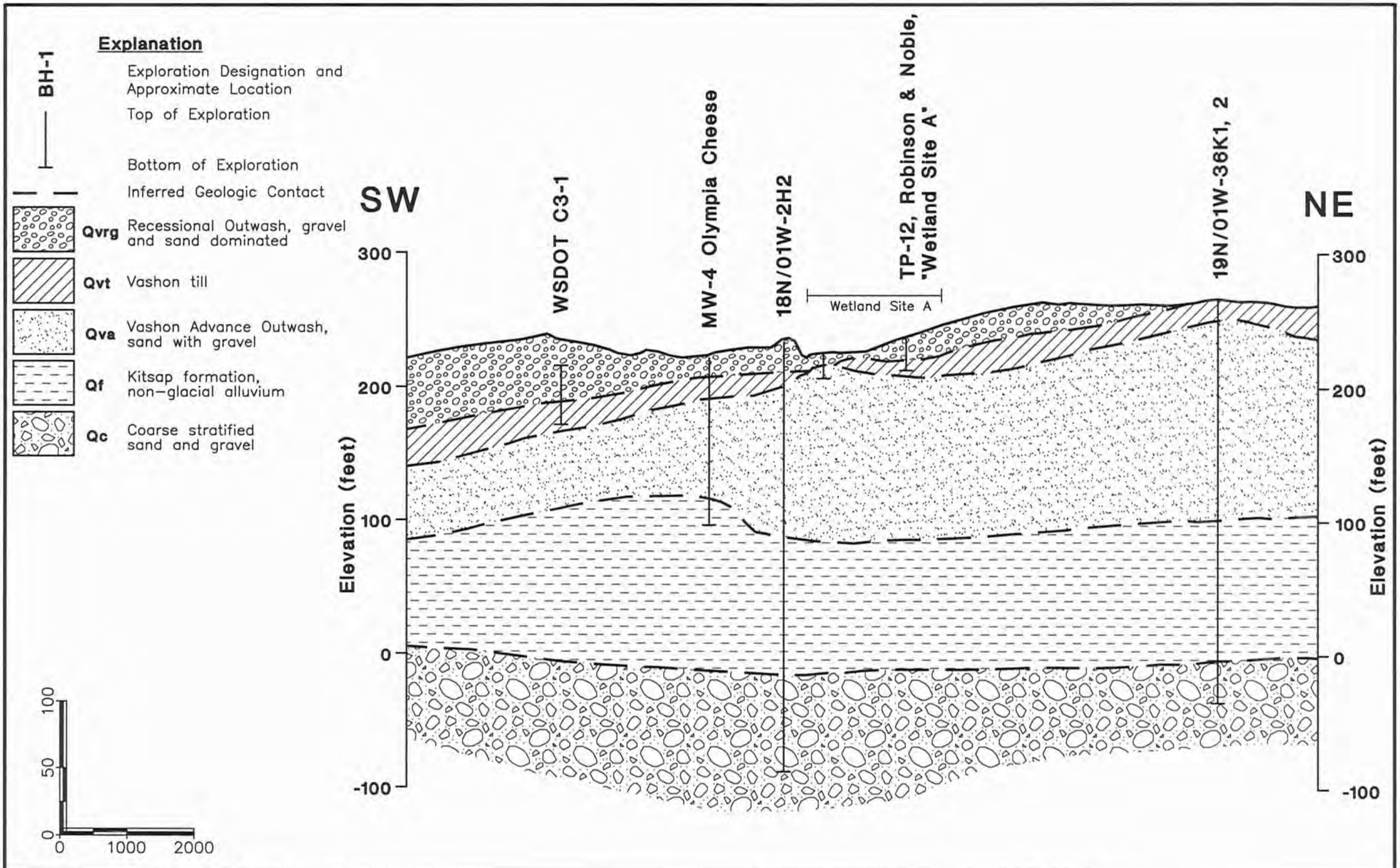

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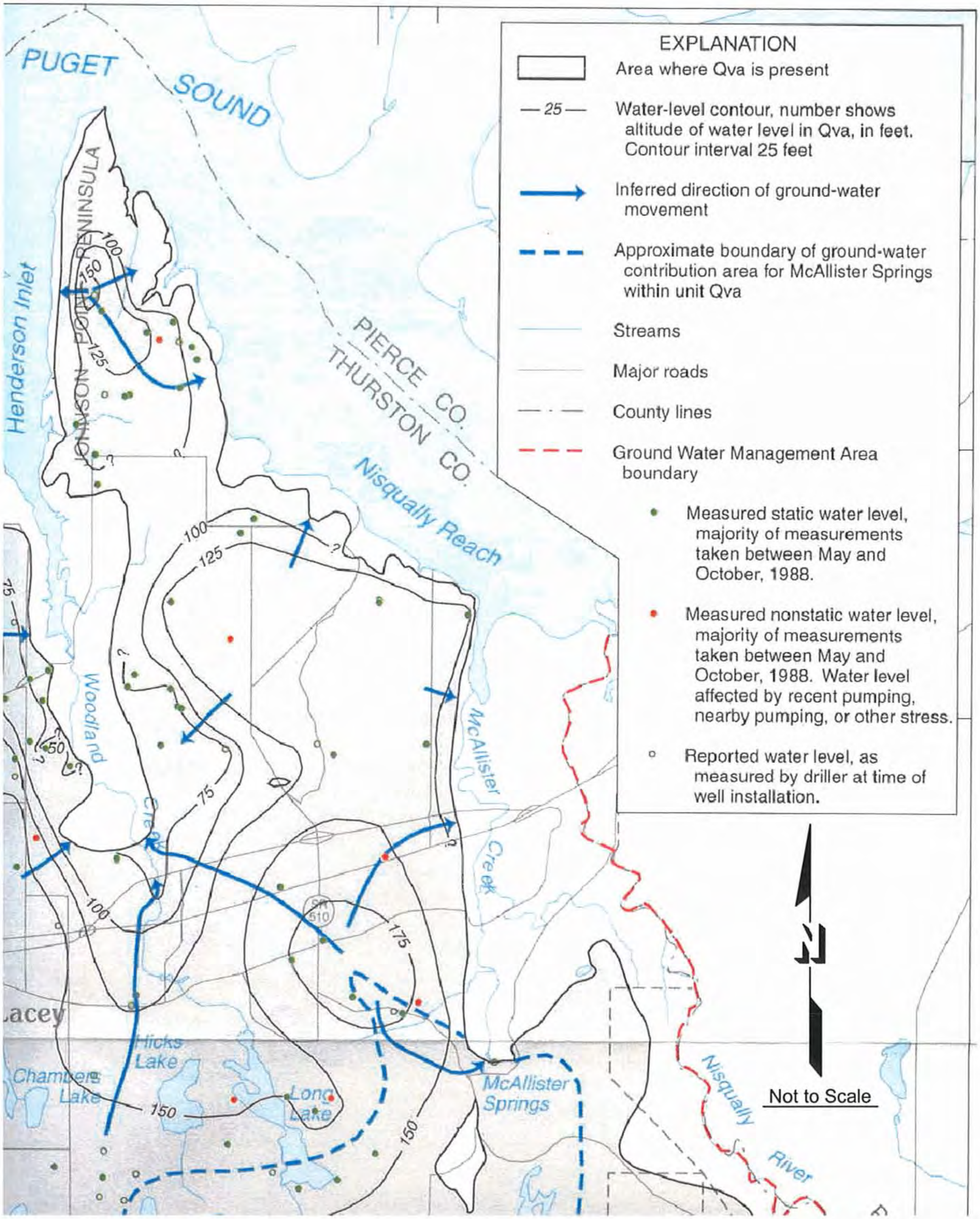
Figure 4

Geological Cross-Section of the Hawks Prarie Wetland Ponds/Recharge Basins Site



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Note: Image from Drost, et. al, 1998

Figure 5

Regional Groundwater Level Elevations and Flow Directions

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CHAPTER THREE: RECHARGE BASIN PILOT TEST

This section presents results from the operation of the Recharge Basin Pilot Test project.

3.1 OVERVIEW

Preliminary recharge feasibility investigations had shown that the surficial soil characteristics of the Hawks Prairie Wetland Ponds/Recharge Basins site were suitable for basin recharge. The purpose of the Recharge Basin Pilot Test project was to confirm the preliminary investigation results by determining the capacity and efficiency of the selected project site to infiltrate surface water. Two half-acre recharge basins were constructed (see Figure 6) in the winter of 2001-2002 for the purpose of testing the following (for a complete description of the Recharge Basin Pilot Test plan see the Hawks Prairie Groundwater Recharge Basins A- Basis of Design Technical Memorandum, Brown and Caldwell, August 2001):

- Surface soil characteristics, infiltration rate, and the type of imported sand most suitable for placement on the base of the recharge basin.
- Response of hydrogeologic conditions to the infiltration of additional surface water, including aquifer mounding and perching.
- Operational characteristics of the recharge basins.
- Determination of design features for use in the full-scale facility.

Once constructed, testing of the pilot recharge basins consisted of pumping approximately 350 gallons per minute (gpm) from a production well located on the Nutria property to the distribution header in each basin. Testing began in March 2002 and continued through November 2002. The pilot recharge basins were alternately flooded and dried on a seven day schedule. During flooding, 350-gpm was distributed on the half-acre surface of the basin simulating the maximum anticipated infiltration rate required by the full-scale facility. The pilot recharge basin was then flooded for seven consecutive days after which the programmable controller switched flow to the second basin and allowed the first to dry. The purpose of drying is to allow the clogging layer that develops on the surface of the sand to dry and crack thereby regenerating the basins ability to infiltrate water. Four deep and one shallow monitoring wells were drilled in a circular pattern around the Recharge Basin Pilot Test site (see Figure 6). The purpose of the monitoring wells was to record groundwater level and for the collection of groundwater quality data.

The parameters monitored during testing included:

- Flow rate of source water into each basin.
- Flooding and drying times.
- Response of groundwater level to the infiltrated water.

3.2 RESULTS

Results from the Recharge Basin Pilot Test project confirmed the site characteristics determined during the preliminary investigation.

It was assumed that when the water was discharged into the recharge basin that a thin sheet of ponded water would form over the entire half-acre area. This would have created a wetting surface equal to the basin area. Assuming an inflow rate into the basins of 350-gpm and an infiltration area of half-acre, the infiltration rate in the basin would equal 3 feet per day. However, the recharge basins did not develop a thin sheet over the entire surface. On average, the recharge basins had a wetting surface of only ¾ of the basin surface area. This amounts to infiltration rates greater that expected or approximately 4 feet per day. The higher infiltration rate documented during the Recharge Basin Pilot Test may allow LOTT the ability to use fewer basins for infiltration when the facility is constructed to full-scale.

The pilot test also investigated two grades of sand for use as a top layer in the recharge basins. The sand layer acts as a filter to collect and trap particles before entering the soil strata. One basin had twelve inches of course graded sand placed in the bottom while the second had six inches of course graded sand as a base with another six inches of fine graded sand place on top. Performance of each type of sand was based on ability to trap suspended material while remaining in place. Both types of sand trapped particles as expected, however, the twelve inches of coarse graded sand did not shift as much as the fine graded sand. Twelve inches of coarse graded sand was selected for use in the full-scale design.

Hydrogeologic conditions, i.e. groundwater mounding, were continuously monitored using a pressure transducer connected to an electronic data logger located in each of the five monitoring wells. The groundwater level data was downloaded weekly and analyzed for changes in groundwater mounding. Figure 7 shows the resulting change in groundwater level due to seasonal variation and the additional surface recharge in three of the deep monitoring wells. Monitoring wells 1 and 2 show a general decreasing trend in groundwater level due to the transitional change from the wet season to the dry. Additional surface recharge seems to have a greater effect on monitoring well 5. This could be due to the mound generally sliding in a south-southwest direction. The results from the groundwater monitoring wells were used during groundwater flow model calibration by comparing the results from the model to the observed findings in the field.

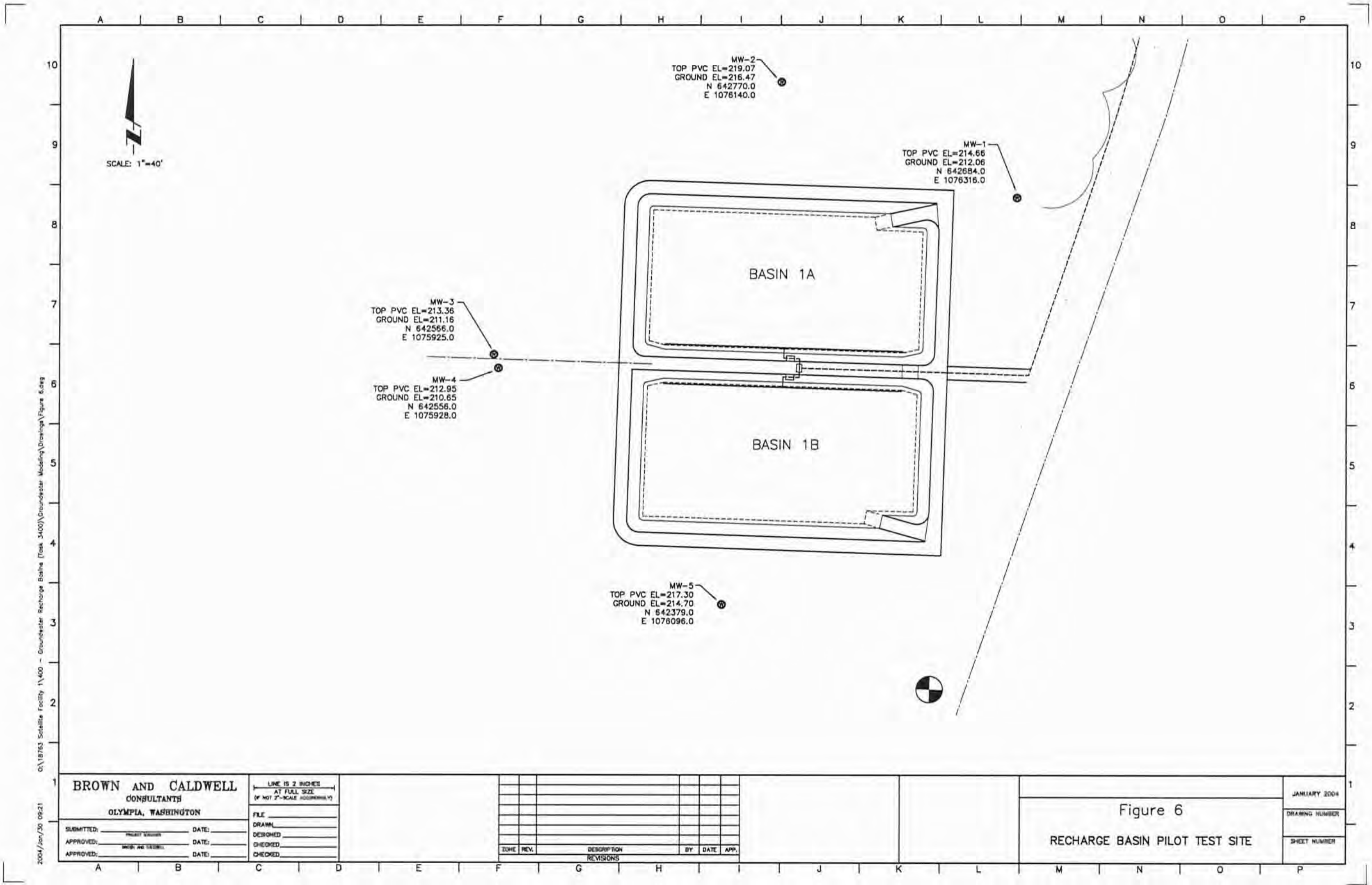
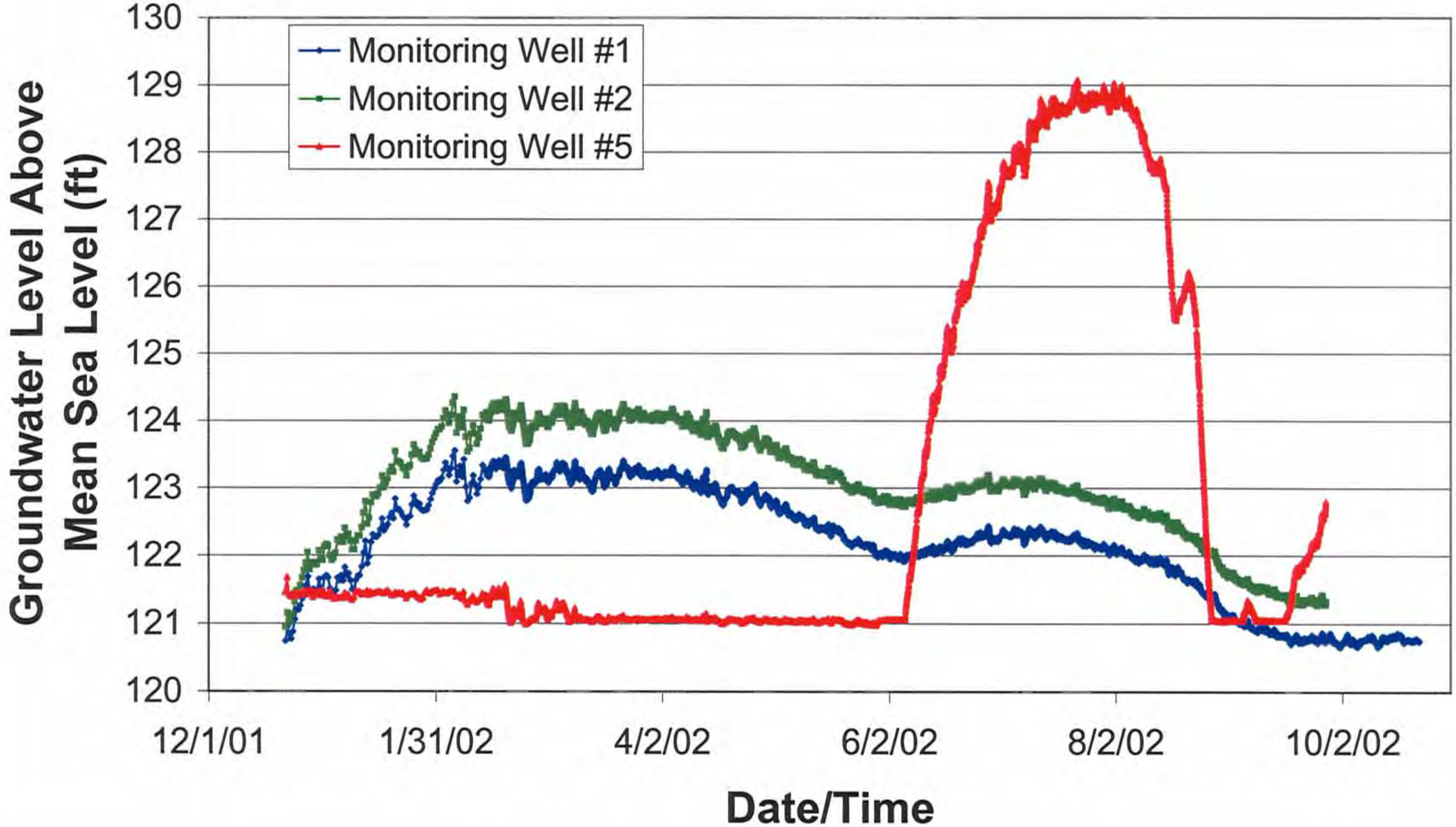


Figure 6

RECHARGE BASIN PILOT TEST SITE

Figure 7- Groundwater Level in Monitoring Wells 1, 2, and 5



CHAPTER FOUR: GROUNDWATER FLOW MODEL APPROACH AND ASSUMPTIONS

4.1 GROUNDWATER FLOW MODEL APPROACH

The approach used in modeling the groundwater flow system was to incorporate local hydrogeologic data collected during the initial investigation of the project site and the Recharge Basin Pilot Test into a larger-scale (i.e., model area) hydrogeologic model that utilizes data from the USGS publication on the hydrology and quality of groundwater in northern Thurston County (Drost, et al, 1998) and the groundwater flow model of Thurston County (Drost, et al, 1999). The USGS publications provided important information on the elevations, thickness, and hydraulic properties of the geologic units that form the three layers of the groundwater flow model (Qvr, Qvt, and Qva). The site hydrogeologic data includes lithologic information from boreholes and backhoe pits as well as water level elevations in monitoring wells.

Whereas the USGS model was constructed at a scale suitable to address regional Thurston County groundwater issues, the LOTT groundwater flow model was constructed at a scale that is appropriate to address the model objectives.

4.2 GROUNDWATER FLOW MODEL ASSUMPTIONS

This section summarizes the assumptions used to develop the groundwater flow model. These assumptions are necessary to bridge gaps in available data. The following list summarizes the assumptions used for the LOTT groundwater flow model:

- Groundwater flow directions (Figure 5) presented by the USGS (Drost, et al, 1998) represent a steady-state condition in the model area.
- Groundwater elevations can be reasonably represented by steady-state simulated water level conditions (i.e., water levels do not change significantly seasonally or during periods of above or below normal precipitation).
- Precipitation (aerial recharge) on the model domain can be reasonably represented by yearly averaged values.
- Groundwater is removed from the model domain only at seepage faces or as underflow to adjacent aquifer areas (i.e., groundwater is not removed by pumping, except as noted below).
- All groundwater enters the model domain through aerial recharge. A general head boundary was placed at the southeast corner of the model to simulate the conditions shown in Figure 5 (Figure 18 of Drost et al).
- Five domestic water systems were identified west of the recharge site. These wells, although pumping from much deeper than the zones influenced by the recharge (the deep aquifer located in the Qc and TQu layers), have been included to assess potential impact from elevated nitrogen levels in the recharge water.
- A nitrate concentration of 1.5-mg/L was assumed for the background groundwater quality in the Qva layer (shallow aquifer) based on limited data provided by the Thurston County Department of Health. A nitrate concentration of zero was assumed in the layers beneath the Qva.

CHAPTER FIVE: GROUNDWATER FLOW MODEL DESIGN

This section describes the methodology used in developing the LOTT groundwater flow model.

MODFLOW-SURFACT (Hydro-Geologic, 1996) was the hydrogeologic model chosen to simulate aerial recharge for the groundwater flow model. This model was chosen because it has appropriate capabilities for this project and is the industry standard for this type of modeling. MODFLOW-SURFACT (MODFLOW) utilizes the modular, three-dimensional, finite difference groundwater flow model MODFLOW, developed by McDonald and Harbaugh (1984), and incorporates additional modules that improve its robustness. The MODFLOW-SURFACT modules that are particularly applicable to the LOTT groundwater flow model are ones that provide improved re-wetting capabilities and provide the ability to model variable saturation. The rewetting capability allows previously dry cells (which become inactive in MODFLOW) to rewet and become active again. The ability to model variable saturation can be used to model perched groundwater aquifers. Groundwater Vistas (version 3.37, Environmental Simulations, Inc., 2002) was used as a pre- and post-processor for the groundwater flow model.

5.1 MODEL DOMAIN

A model grid was then designed for the LOTT groundwater flow model. The grid spacing is variable with 40-foot by 40-foot cells in the vicinity of the recharge site and as large as 1,200-foot by 1,000-foot cells near the model boundaries. Figure 8 shows the extent of the active portion of the model grid. Utilizing the variable spaced grid design allows for the incorporation of greater detail in the vicinity of the recharge facility where greater hydrogeologic data is available and a coarser level of detail away from the facility.

The model domain has 90 rows and 94 columns, which corresponds to 24,000-feet in an east-west direction and 21,000-feet north to south. The model is vertically separated into three layers, each representing one of the three primary lithologic units described in Section 2.1. Model layer 1 represents the Qvr, model layer 2 represents the Qvt, and model layer 3 represents the Qva with the bottom elevation extended to -100 feet relative to sea level. The model layers vary in thickness as described in Table 1.

To establish the top elevations for the model layers, USGS maps (Drost, et. al, 1998) depicting the surface elevation of the Qva and the thickness of the Qva, Qvt, and Qvr units were digitized. In the vicinity of the recharge facility, the digitized files were modified by replacing the coarser-scale USGS layer elevation and thickness data with the local data described in Section 2.1. The modified digitized data files were then gridded using Surfer® (Golden Software, 1996), and the appropriate thickness grids were then added to the Kitsap Formation altitude grid to obtain digital surfaces for the upper surfaces of the Qva, Qvt, and Qvr. The top of the Qvr generally coincides with the ground surface elevation, and the top of the Kitsap Formation forms the bottom of the model. The gridded surfaces were then imported into Groundwater Vistas for incorporation into the groundwater flow model.

5.2 BOUNDARY CONDITIONS

The northern, eastern, and western lateral model boundaries consist of drain cells in model layers 2 (Qt) and 3 (Qva). The drain cells represent seepage faces and springs along the eastern and western model boundaries, and represent underflow to the northern portion of the Johnson Point Peninsula along the northern boundary. A general head boundary was placed along the southeast corner to simulate inflow from recharge not within the current model domain. The southern model boundary in layer 3 and all lateral boundaries in layers 1 and 2 consist of no-flow cells. Figure 8 shows the location of the model boundaries in model layer 3.

5.3 HYDRAULIC PARAMETERS

Hydraulic properties in the groundwater flow model generally conform to those presented in the USGS groundwater flow model (Drost, et al, 1999) and are summarized in Table 2.

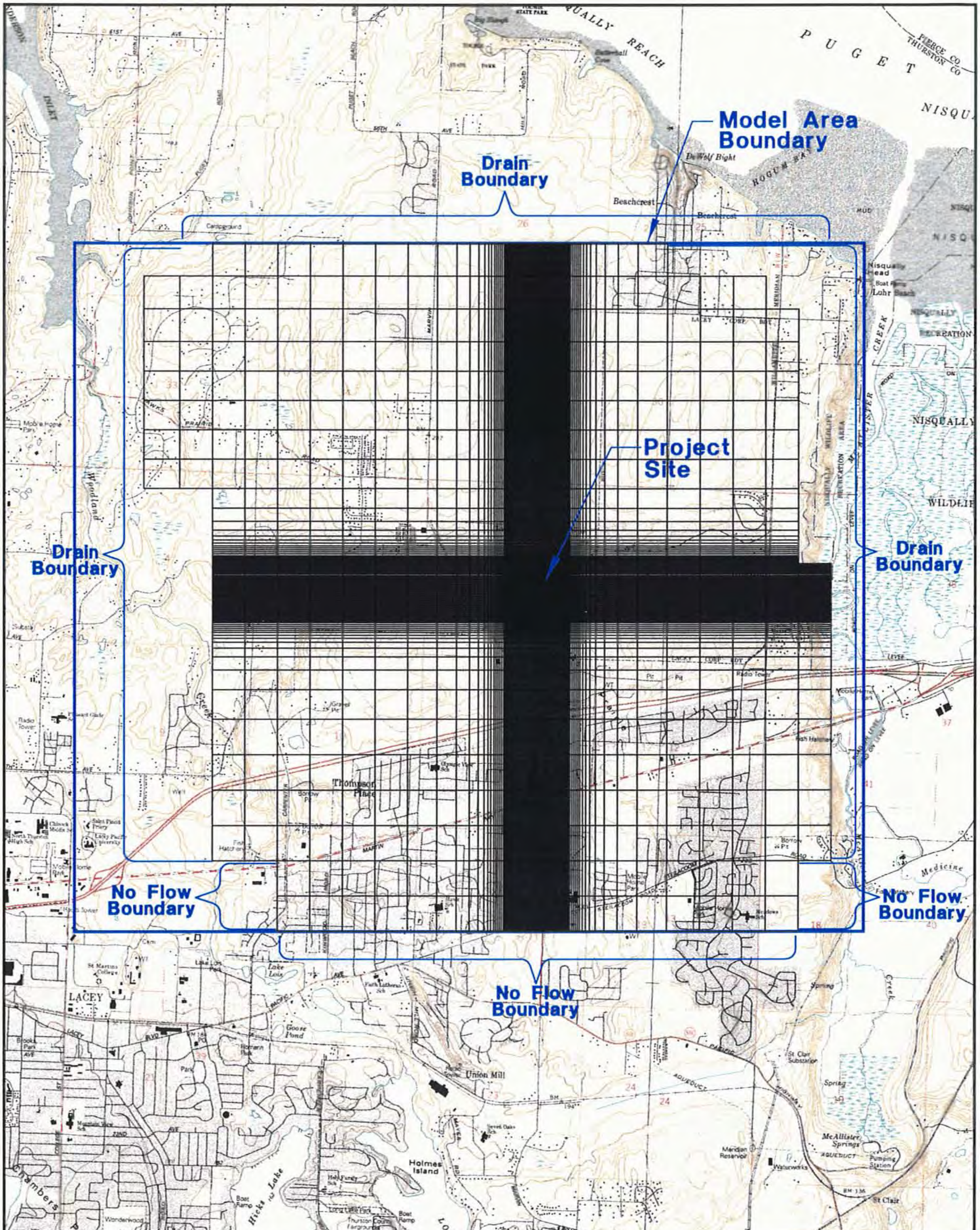


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Figure 8

LOTT Groundwater Model Grid and Boundary Conditions

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The Qva unit was assigned a horizontal hydraulic conductivity value of 320 feet per day (ft/d), the Qvt unit was assigned a value of 20-ft/d, and the Qvr was assigned a value of 150-ft/d. Vertical hydraulic conductivity was assigned a value equal to ten percent of the horizontal hydraulic conductivity for all units. Although these hydraulic conductivity values generally conform to layers, in the locations where the Qvt is absent (i.e., in the vicinity of the pilot test recharge basins), layer 2 was assigned the same hydraulic conductivity value as the Qvr. As indicated in Figure 14 of Drost et al, a zone corresponding in hydraulic conductivity to the Qvt was placed along the northwest side of layer 3.

Specific yield and storativity were not used in the simulations because these parameters apply only to transient simulations. The effective porosity was assumed to be 0.30 (Pollock, 1994) in MODPATH particle tracking simulations performed to estimate the travel time of infiltrated water to the model boundaries. The effective porosity is consistent with generally accepted values (range of 0.25 to 0.35) for a gravelly sand (Kresic, 1997).

5.4 GROUNDWATER SOURCES AND SINKS

All water enters the model domain by aerial recharge, and leaves the model domain through the lateral boundaries described in Section 5.2. Aerial recharge, which represents the deep infiltration of precipitation, is distributed according to rates estimated by Drost, et al, 1999, (Figure 17, 1999). To estimate the aerial recharge, the long-term average precipitation, the surficial distribution of the geohydrologic units and a graphical precipitation-recharge relationship were used. Three aerial recharge zones conforming to the distribution presented by Drost, et al, 1999, were utilized in the groundwater flow model, with annual aerial recharge rates ranging from 23 to 28 inches per year.

5.5 MODEL GROUNDWATER BUDGET

The total background inflow from precipitation to the groundwater flow model, all from aerial recharge, is 2.3 million cubic feet per day. The proposed groundwater recharge inflow was then added to the background inflow in the area of the recharge basins. Flow simulations were calculated as steady-state, i.e. the system is in equilibrium. Therefore, the same volume of groundwater leaves the model domain at the drain boundaries.

5.6 CONTAMINANT FATE AND TRANSPORT

To assess groundwater quality impacts from the addition of water with potentially higher nitrogen concentration, simulations were performed using the fate and transport module MT3D (Zeng, 1990), version MT3DMS. This module used the output from MODFLOW to simulate the advection, dispersion and chemical reactions of contaminants in groundwater systems. As applied here, no chemical reactions or adsorption were implemented to permit a conservative estimate of potential nitrogen impacts. A longitudinal dispersivity of 500 feet was used corresponding to approximately 6.5% of the plume length. Transverse dispersion was estimated as one-tenth of longitudinal and vertical dispersion was one-tenth of the transverse. Transport simulations were conducted for a ten-year period of recharge starting from the steady state flow conditions.

Table 2 - Groundwater Flow Model Input Parameters

	Layer 1	Layer 2	Layer 3
Horizontal Hydraulic Conductivity	150 ft/d	20 ft/d	320 ft/d
Vertical hydraulic Conductivity	15 ft/d	2 ft/d	32 ft/d
Effective Porosity	0.3	0.3	0.3
Aerial Recharge due to Precipitation		$2,300,000 \text{ ft}^3/\text{d}$	
Site Recharge Rate		1 mgd and 5mgd	

CHAPTER SIX: GROUNDWATER FLOW MODEL CALIBRATION AND SENSITIVITY ANALYSIS

The following sections describe groundwater flow model calibration and the analysis of model sensitivity to changes in hydraulic parameters.

6.1 MODEL CALIBRATION

The groundwater flow model was calibrated using steady-state conditions by comparing documented groundwater flow directions and groundwater elevations with model-predicted elevations. Model calibration was accomplished by adjusting the model boundary drain parameter. Regional groundwater elevation contours presented on Figure 5 were used as a guideline for adjusting simulated groundwater directions in the model. The measured groundwater elevation of project site recorded by monitoring well MW-3, completed in December 2001, was used to adjust the head elevation.

The groundwater elevations and flow directions presented on Figure 5 are based on sparsely distributed measurement points (See Section 2.2), and the water level elevations were not all measured at the same approximate time. The sparse distribution of measurement points indicates that water levels and flow directions are subject to interpretation. Groundwater flow directions are not likely to change substantially over time, but groundwater elevations are likely to change both seasonally and yearly as precipitation amounts vary. For example, the observed water level elevation at MW-3 was 114-feet above mean sea level (amsl) in December 2001, but would be approximately 130-feet amsl if interpolated from the USGS data shown on Figure 5. As stated previously, the groundwater flow model should be continually calibrated to observed conditions.

6.2 SENSITIVITY ANALYSIS

A sensitivity analysis was performed to evaluate the sensitivity of the model output to uncertainties inherent in the input data. Values of aerial recharge rates, horizontal hydraulic conductivity of model layer 3, and drain conductance were increased and decreased to represent reasonable upper and lower limits of these parameters, and the simulation results were then qualitatively compared with general water level elevations and flow directions in the calibrated groundwater flow model.

In general, the model was found to be sensitive to changes in aerial recharge rates. Changing the recharge rate by up to 20 percent resulted in substantial changes in water level elevations, but little change in flow directions. The model showed some sensitivity to changes in the hydraulic conductivity value of model layer 3 (changes up to a factor of 3), but sensitivity results to this parameter were less than aerial recharge. Changes to the drain conductance created model instability problems (non-convergence) at a factor of 1.4 or greater, indicating that results are sensitive to changes in this model parameter.

CHAPTER SEVEN: GROUNDWATER FLOW MODEL SIMULATIONS

The following sections describe the model simulations performed to evaluate the effects on the underlying aquifer through two scenarios; infiltration of 1 and 5-mgd through the LOTT recharge facility. The aquifer effects evaluated included:

- Groundwater Mounding - height and radial distance of the groundwater mound and general flow directions.
- Travel Time to Boundaries - Woodland Creek, Eagle Creek, production wells, and the Nisqually bluff.
- Flow Volume - estimated at Woodland Creek, Eagle Creek, and the Nisqually bluff.
- Groundwater Quality Impacts - nitrate transport and concentration.

Steady state conditions were used for establishing the groundwater mounding and flux to boundaries. A transient solution was used to calculate the travel times and transport of nitrogen..

7.1 GROUNDWATER MOUNDING

Groundwater mounding height was evaluated by comparing the calibrated simulation groundwater elevation with the groundwater elevation generated by each of the predictive simulations. Results are presented in color shaded mounding contours shown on Figure 9 for 1-mgd of infiltration.

7.2 TRAVEL TIME TO BOUNDARIES

In addition, the simulated groundwater elevations from each of the two scenarios were also used as the basis for particle tracking analysis using the model MODPATH (Pollock, 1994). MODPATH simulates particle tracking by releasing particles into the aquifer flow field and then tracking their movements either forward or backward in time. An additional hydraulic parameter, effective porosity, was introduced to predict the groundwater flow velocity. In each MODPATH simulation, 3 particles were placed in a circular pattern around the simulated recharge facility and were released in model layer 3 (Qva). As described in Section 5.3, the effective porosity assumed for the MODPATH simulations was 0.30.

The MODPATH tool was used to develop the estimated travel time to the boundaries.

The Thurston County Department of Health requested that the model predict the estimated travel time to the water service wells shown in Table 3:

Table 3 – Water Service Wells in the Vicinity of the LOTT Wetland Ponds/Recharge Basins

Well Owner	Water Service	Thurston County Well ID	Well Depth From Surface (ft)	Geohydrologic Unit	Population	Pumping Rate (gpm)
Tolmie Cove	Tolmie Cove	18N/01W-03H02	233	Qc	125	5.5
Donald Anthony	Eagle Estates	18N/01W-03G01	151	Qva	53	2.3
Harold Parks	Tolmie Park	18N/01W-03B02	280	TQu[a]	195	8.7
Wilbur Lenard	Hawks Acres	18N/01W-03B01	223	Qc	231	10.3
Bruno Betti		18N/01W-03M02	218	Qc	1000	44

[a] TQu layer lies beneath the Qc layer and extends to bedrock.

As indicated in Table 3, only the Eagle Estates water service well is commissioned in the same layer (Qva) that the Class A reclaimed water shall be infiltrated into. The other wells are in the Qc and TQu layers which are below the Qva containing the shallow aquifer. Previous studies have shown that the Qf layer acts as a barrier between the Qva and Qc aquifers.

7.3 FLOW VOLUME

The model boundaries were used to quantify the flow volume leaving the model at Woodland Creek. Eagle Creek and Nisqually Bluff are not expected to be impacted.

7.4 GROUNDWATER QUALITY IMPACTS

Section 3, Article 3 of the 1997 Washington State Water Reclamation and Reuse Standards (Standards) require that Class A reclaimed water directly recharged into the aquifer, i.e. pumping of reclaimed water into a groundwater well, have a nitrogen limit of 10-mg/L (as N). Section 1, Article 3 of the Standards states that groundwater recharged by surface percolation shall have the following minimum treatment:

- Pre-treatment shall meet Class A reclaimed water.
- Secondary treatment process to include an additional step to reduce nitrogen prior to the final discharge to groundwater.

Article 3, Groundwater Recharge by Surface Percolation, does not set a limit on nitrogen. Rather, it places the decision upon Washington Departments of Health and Ecology on a case by case basis. The LOTT Hawks Prairie Wetland Ponds/Recharge Basins facility will incorporate the use of surface infiltration through recharge basins. This method of groundwater recharge provides another layer of potential treatment compared to direct recharge. During the Hawks Prairie Satellite Reclamation Plant design, the LOTT Wastewater Alliance decided to include a nitrogen reduction process and has established a maximum nitrate limit leaving the satellite reclamation plant of 3 to 5-mg/L (this is lower than the 10-mg/L required in the Standards). The actual concentration will be a frunction of the water temperature (colder supply equals higher nitrate levels).

The Thurston County Department of Health indicated that the background groundwater nitrate concentration in the area is extremely variable due to localized septic systems. A map of the nitrate concentrations provided by Thurston County Department of Health indicate that the nitrate levels in Hawks Prairie vary from 6.2 to 0.1-mg/L. Based on the background nitrate concentrations of the nearest wells, a 1.5-mg/L background nitrate concentration was assumed for the purposes of this model.

The model was used to simulate the effects to the background groundwater quality at infiltration rates of 1 and 5-mgd and a nitrate concentration of 5-mg/L.

7.5 SCENARIO 1- INFILTRATION OF 1-MGD

The infiltration of 1-mgd was simulated by establishing a new aerial recharge zone in model layer 1 (Qvr) located on the LOTT Wetland Ponds/Recharge Basins project site and applying steady state recharge equal to 1 mgd over that zone. The single recharge zone was modeled as three cells wide in a north-south direction and 10 cells long in an east-west direction, for a total area of 48,000 square feet (approximately 1 acre).

7.6 SCENARIO 2- INFILTRATION OF 5-MGD

The infiltration of 5-mgd was simulated by establishing an additional four new aerial recharge zones in model layer 1 (Qvr) for a total of 5 zones, each with the equivalent of 1-mgd of steady-state recharge (approximately 5 acres). The additional recharge zones were the same dimensions as the zone created for the 1-mgd simulation.

CHAPTER EIGHT: GROUNDWATER FLOW MODEL RESULTS

The following sections present the results of the predictive simulations described above in Chapter 7.

8.1 SCENARIO 1 - INFILTRATION OF 1-MGD

Scenario 1 consisted of continuously infiltrating 1-mgd through the recharge basins until the model reached equilibrium (approximately 10-years).

8.1.1 GROUNDWATER MOUNDING

The simulation of 1-mgd of recharge through the LOTT recharge basins created a mound 13-feet above the height of the average seasonal groundwater level underlying the facility. The seasonal groundwater level is assumed to be 90-feet below the recharge basin surface resulting in a mound elevation of 77-feet below ground surface. Figure 9 presents color shaded groundwater mounding contours in the model area for the 1-mgd recharge simulation. As shown in Figure 9, the area influenced by groundwater mounding is approximately 11,500-ft east to west and 12,000-ft north to south. The area affected by mounding greater than 5-ft is significantly smaller than the total area affected, encompassing the area only under the recharge basin site. Figure 10 presents a cross-sectional schematic of mounding for the 1-mgd recharge simulation.

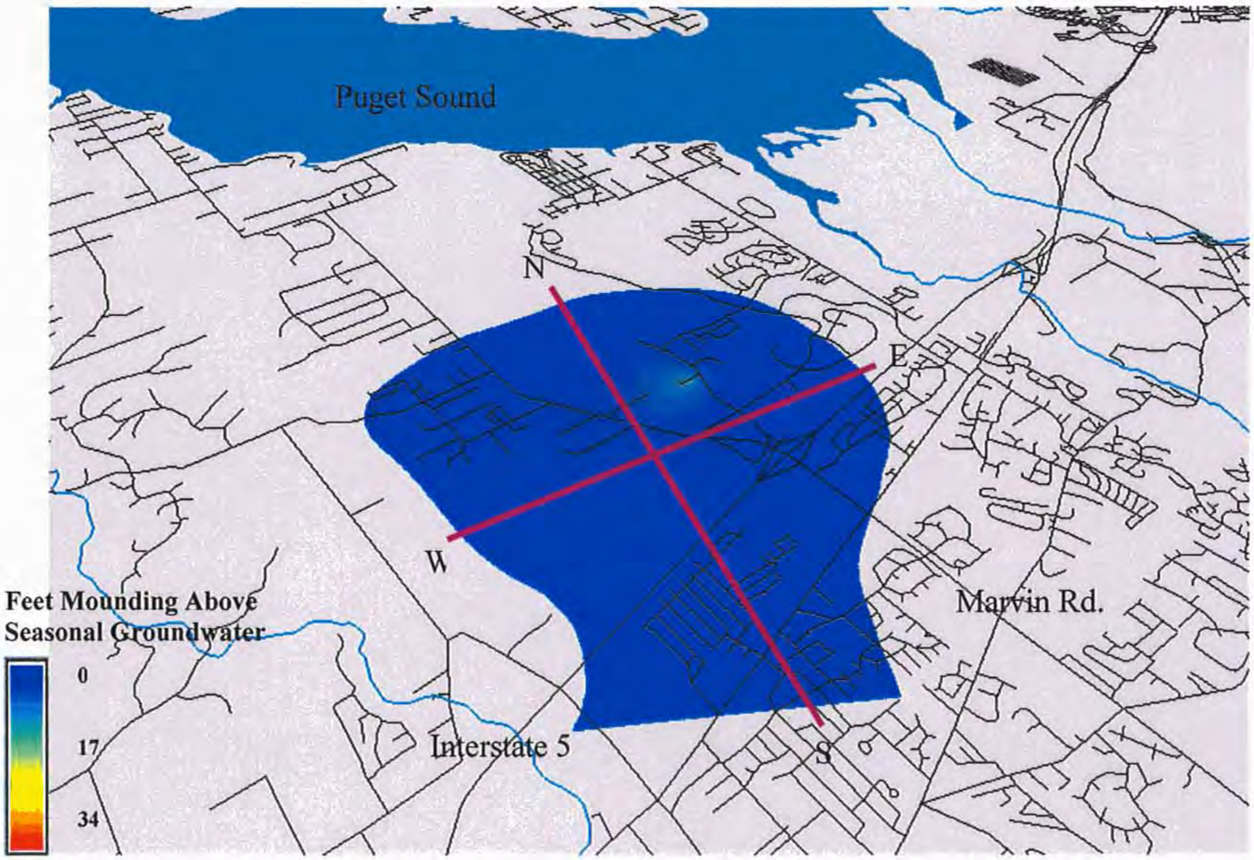

Figure 9 - Groundwater Mounding At One Million Gallons Per Day Recharge

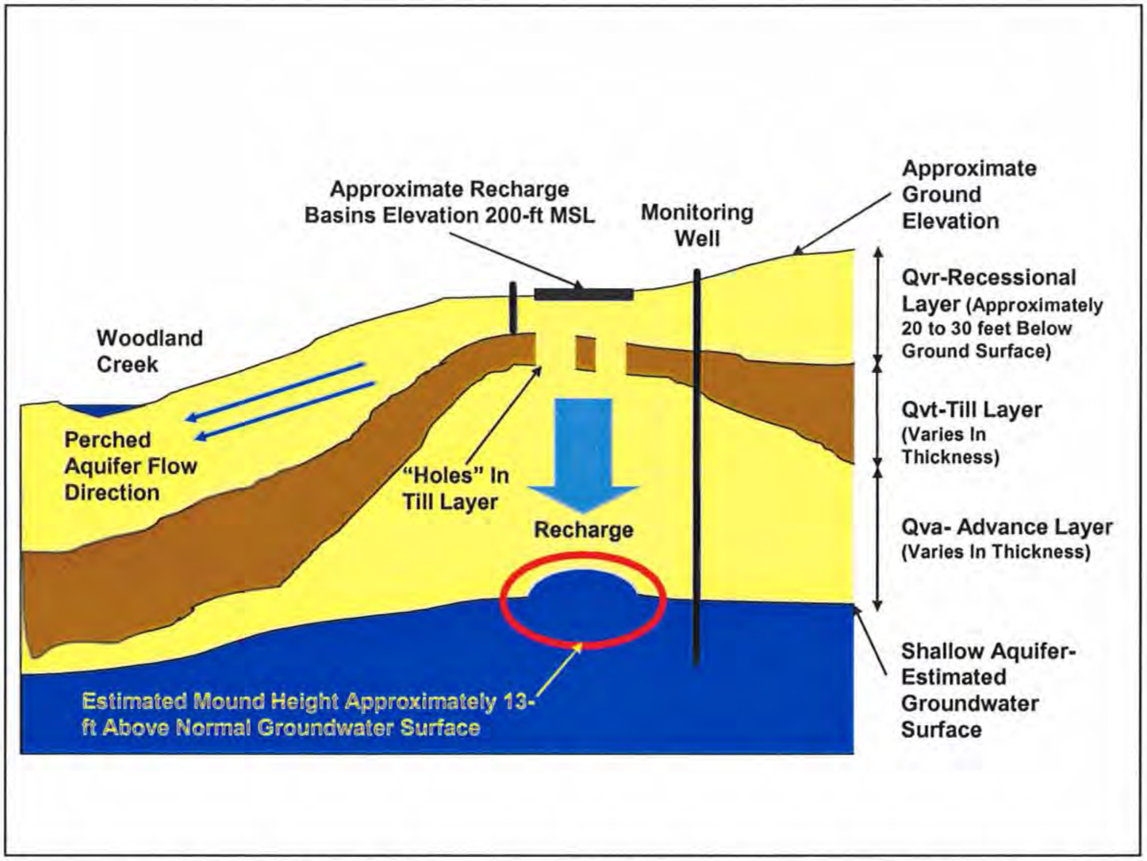

Figure 10 - Cross Sectional View of Mounding Results At One Million Gallons Per Day Recharge

8.1.2 TRAVEL TIME TO BOUNDARIES

Results of the MODPATH simulation for the 1-mgd recharge scenario indicate that the majority of the recharged water shall migrate toward Woodland Creek with smaller amounts migrating radially to the north and south. Based on the location of Eagle Creek and the hydrogeologic conditions in the area, the model indicates that groundwater recharge will not impact Eagle Creek.

Figure 11 illustrates the direction of groundwater flow and travel time to Woodland Creek and surrounding water systems. Shallow aquifer water levels are shown by the contours. Groundwater flow is from areas of higher head to lower head generally toward major streams and marine water body. Each arrow located on the groundwater flow path lines represents one year of travel time. As shown on Figure 11, the travel time to Woodland Creek is approximately 10-years at an infiltration rate of 1-mgd. Model results indicate that water infiltrated at the recharge basin site will follow water level contours and travel almost entirely toward the west and Woodland Creek. This result is similar to finding in Drost, et al, 1999, which found that the seepage along the Nisqually bluff is mainly attributed to the deep aquifer rather than the shallow. The shallow aquifer is confined between the Qvt and the Qf layers in the vicinity of the bluff minimizing the hydraulic conductivity of the aquifer. Figure 6 on page 16 of Drost, et al, 1999, provides a conceptual cross section of the Hawks Prairie area depicting the confinement of the shallow aquifer by the Qvt and Qf layers.

Initial modeling indicated a travel time to Woodland Creek of three years. As described in the following section, travel times to the boundaries are longer than previously reported. This is due to the fact that when the model was updated to determine the discharge volume and groundwater quality impacts, the model was expanded to include Woodland Creek and Nisqually bluff. Initially, the model was limited to a smaller scale and results were extrapolated to the boundaries.

Based on updated model results, the estimated travel time to the boundaries as shown on Figure 11 is as follows:

- Woodland Creek – 10-years.
- Nisqually Bluff – model indicates negligible flow toward the bluff.
- Tolmie Park – 5-years.
- Hawks Acres – 5.5-years.
- Alpine Mobile Estates – 4-years.
- Eagle Estates – 4.5-years.
- Bruno Betti – 2-years.

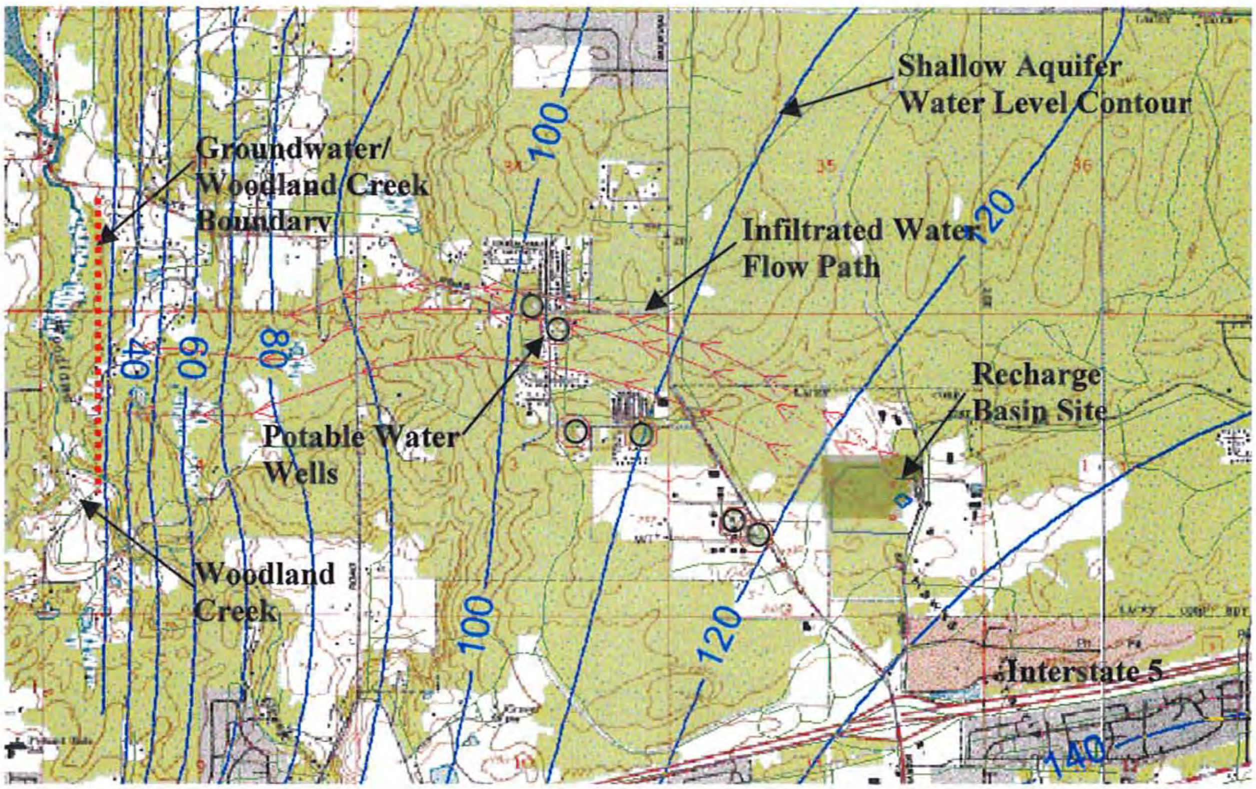

Figure 11 – Travel Time and Water Level Gradient At One Million Gallons Per Day Recharge

8.1.3 FLOW VOLUME

Water infiltrated at the LOTT recharge basin site will quickly travel through the Qvr to the Qvt layer. At this point, due to the discontinuous nature of the Qvt layer in the vicinity of the site, the infiltrated water will pass through the Qvt "holes" to the shallow aquifer located in the Qva. Due to the location and confining ability of the Qvt layer, a majority of Woodland Creek is isolated from the influence of the shallow aquifer (see Figure 10). Woodland Creek is largely influenced by the water trapped in the Qvr between the surface and the Qvt. However, water infiltrated at the recharge basin site will have a small influence on the creek. Modeling of the groundwater influence on Woodland Creek, without infiltration at the LOTT recharge basin site, estimates an inflow of 1.5 million cubic feet per day (cf/day) over a length of approximately 7,000-ft (shown as the dashed boundary line on Figure 11). Adding the LOTT recharge infiltration rate of 1-mgd to the model minimally increases of the groundwater influence by approximately 10,000-cf/day. This results in less than a 0.6 percent increase in the groundwater discharge to Woodland Creek during infiltration.

Eagle Creek is located north-northwest of the recharge basin site. Based on available hydrogeologic data, the creek is influenced by water perched between the surface and the Qvt (till layer). The creek normally is wet in the winter and dry during the summer months. Model results indicate that the water infiltrated at the LOTT groundwater recharge facility has a minimal effect on the perched aquifer and Eagle Creek.

Hydrogeologic studies performed by Drost, et al, 1999, indicate that the Nisqually bluff is a point of discharge for the deep aquifer. The bluff was included in this model as the eastern boundary. However, investigation of the hydrogeologic units near the bluff confirm that the Qf and Qvt layers actually blend together confining the Qva and the shallow aquifer. As mentioned previously, the majority of the flow toward the bluffs is from the deep aquifer because of the lack of presence of a confining layer. Modeling of the 1-mgd scenario results indicated minimal groundwater flow to the Nisqually bluff.

8.1.4 GROUNDWATER QUALITY IMPACTS

As stated in Section 7.1.4, the LOTT Wastewater Alliance decided to limit the amount of total nitrogen leaving the satellite reclamation plant to 5-mg/L. Modeling the nitrogen impacts of Class A reclaimed water on the background groundwater chemistry consisted of the following:

- Background groundwater nitrogen concentration of 1.5-mg/L.
- Infiltrated water nitrogen concentration of 5-mg/L.
- Nitrogen is neither adsorbed or decomposed (conservative).
- Nitrogen only moves in the groundwater by way of dispersion and advection (moves with velocity of groundwater).

As shown in Figure 12, the average concentration of nitrogen directly beneath the recharge facility is approximately 3-mg/L (an increase of 1.5-mg/L over background levels). However, the concentration decreases dramatically as the groundwater moves away from the site. At a minimal distance away from the site (500-ft), the nitrogen concentration returns to background levels (1.5-mg/L). Model results indicate that there is no measurable nitrogen increase at the water service wells described in Table 3.

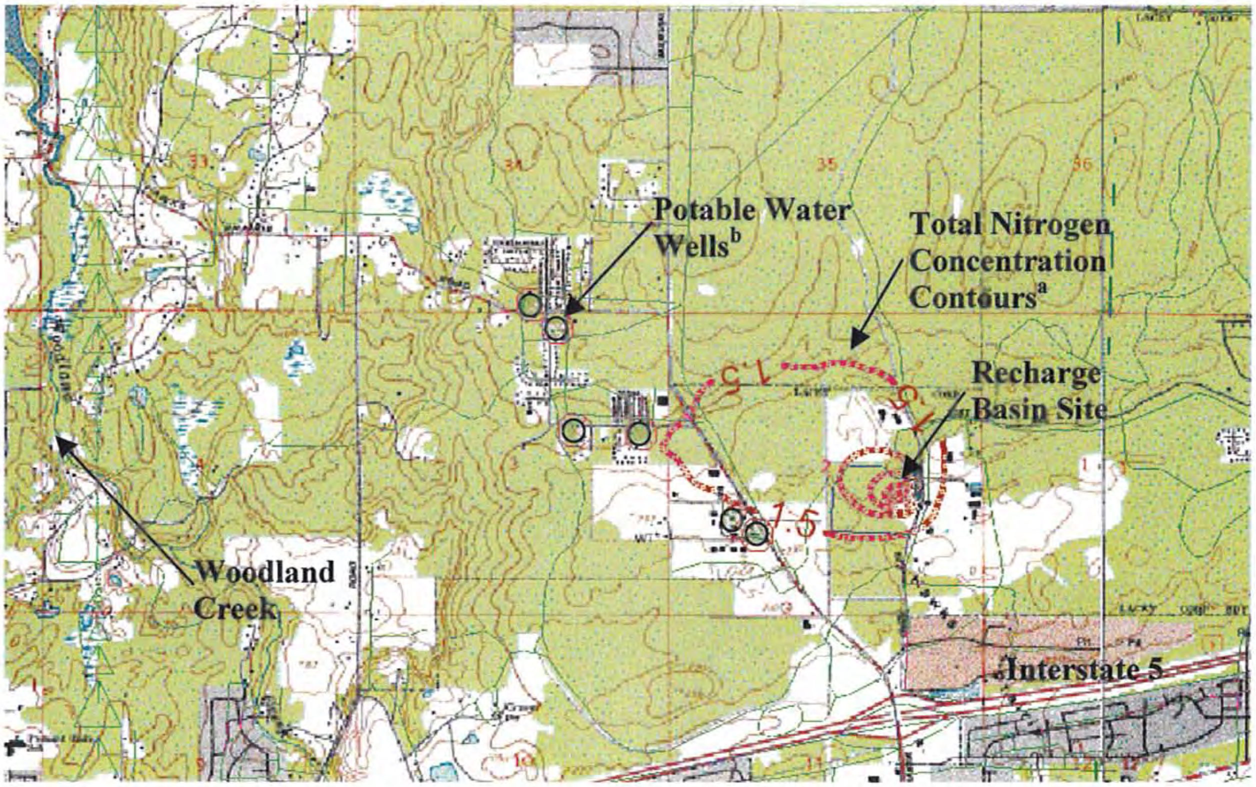

Figure 12 – Nitrogen Concentration Gradient At One Million Gallons Per Day Recharge

[a] Total nitrogen concentration contours are in ½-mg/L increments.
[b] ● Potable water production wells located within the vicinity of the recharge basin site - see Table 3 for well data.

8.2 SCENARIO 2- INFILTRATION OF 5-MGD

Scenario 2 consisted of continuously infiltrating 5-mgd through the recharge basins until the model reached equilibrium (approximately 10-years).

8.2.1 GROUNDWATER MOUNDING

Simulation of 5-mgd of recharge through the LOTT recharge basins resulted in a mound which increases the average seasonal height of the groundwater elevation by approximately 35-feet (seasonal groundwater level is 90-ft below the surface). This increase represents a mound height 55-feet below the ground surface. The color shaded groundwater mounding contours and aerial coverage of the recharge mound are presented on Figure 13. The total area influenced by the mound is approximately 16,000-ft east to west and 17,000-ft north to south. Figure 14 presents a cross-sectional view of groundwater mounding in the 5-mgd recharge simulation.

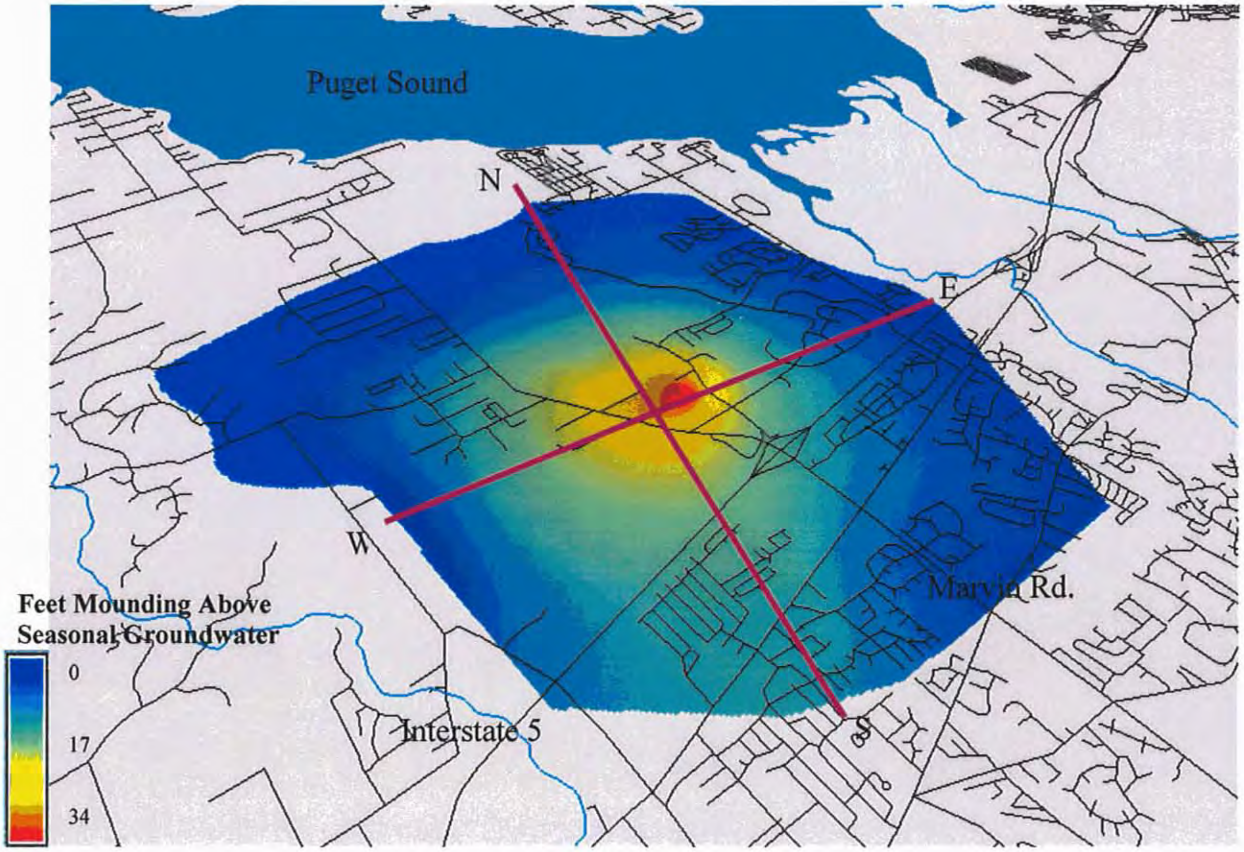

Figure 13 - Groundwater Mounding At Five Million Gallons Per Day Recharge

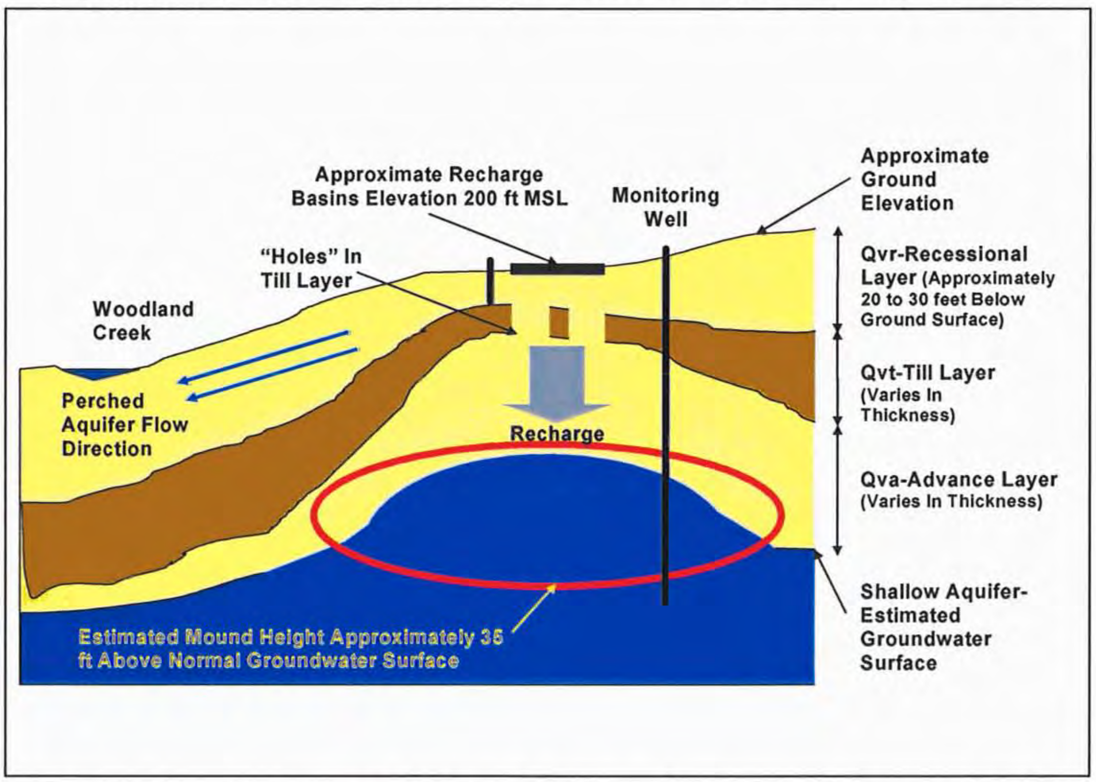

Figure 14 - Cross Sectional View of Mounding Results At Five Million Gallons Per Day Recharge

8.2.2 TRAVEL TIME TO BOUNDARIES

Particle transport modeling for the 5-mgd recharge simulation approximate that 95 percent of the infiltrated water will migrate toward Woodland Creek, and that relatively small amounts of recharged water would migrate northward along the peninsula and south-east toward the McAllister Creek drainage. The model indicated that approximately 10-years are required for the first particles to reach the Woodland Creek drainage. As mentioned in Section 8.1.2, groundwater recharge will not impact Eagle Creek.

Groundwater flow direction and travel time are shown on Figure 15. Symbols shown on Figure 15 are the same as described in Section 8.1.2. Groundwater tends to flow in the same direction as the 1-mgd scenario except that the flow path encompasses a larger area. This is due to the larger mound that develops with the higher recharge rate. Infiltrated water piles up below the recharge basins and is forced further from the center of the recharge facility. The hydraulic conductivity limits the horizontal travel time of the infiltrated water causing travel times at the higher infiltration rate that are similar to the 1-mgd scenario. Travel time to water service wells and model boundaries are the same as listed in Section 8.1.2. Again, less than 5 percent of the amount of flow was found to travel toward the Nisqually bluff or McAllister Creek drainage.

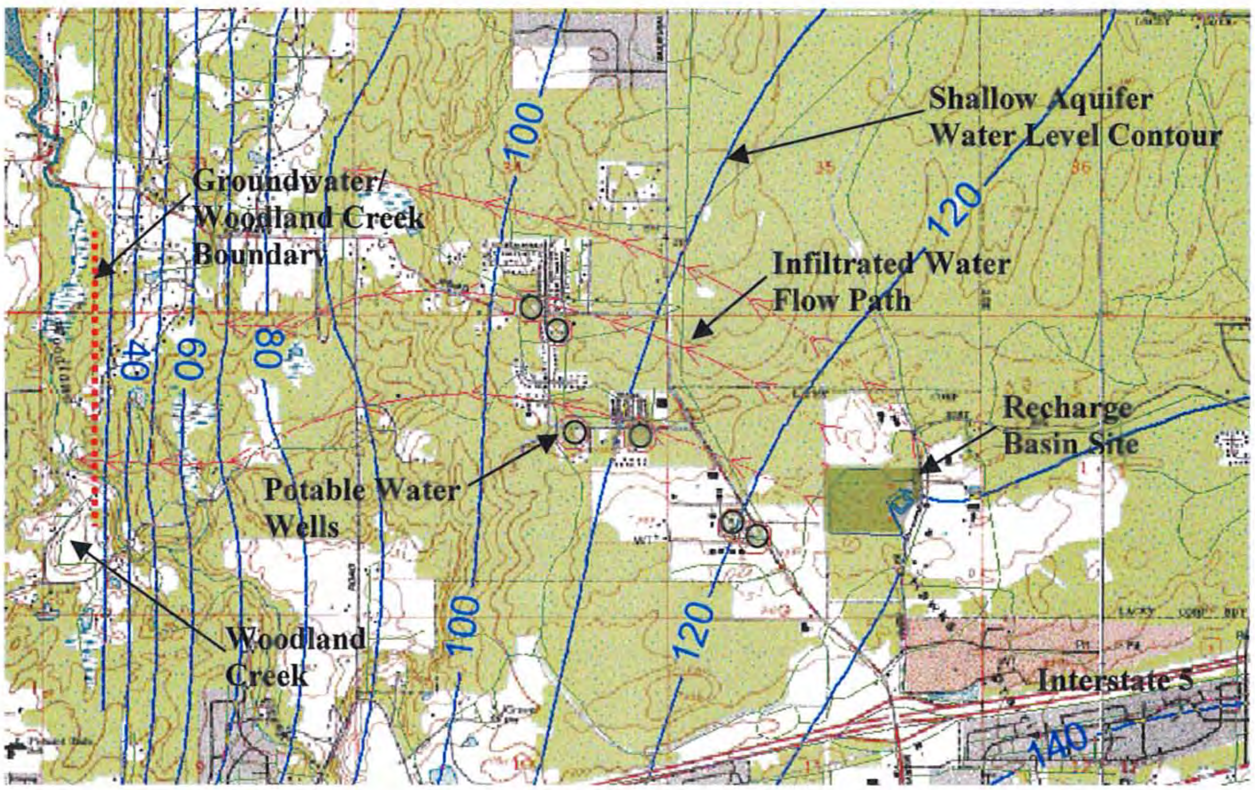

Figure 15 – Travel Time and Water Level Gradient At Five Million Gallons Per Day Recharge

8.2.3 FLOW VOLUME

As expected, the amount of inflow to Woodland Creek increased when the infiltration rate was changed from 1-mgd to 5-mgd. However, the model indicated that the resulting influence on the overall groundwater inflow the creek was still minimal, resulting in an increase of approximately 3 percent (50,000-cf/day)of the total 1.5 million cubic feet per day.

Model results at 5-mgd of infiltration were similar to those found at 1-mgd:

- Groundwater recharge does not seem to have any affect on Eagle Creek.
- Flow toward the Nisqually bluff is minimal.

8.2.4 GROUNDWATER QUALITY IMPACTS

Figure 16 shows the total nitrogen concentration contours for 5-mgd of infiltration. Similar to the 1-mgd scenario, the concentration of total nitrogen quickly drops to background levels (1.5-mg/L) within approximately 1,200-ft of the site. Concentration is the highest directly below the recharge facility with a 3-mg/L increase over background levels.

The model indicates that the increase in nitrogen at the closest potable water service well is between 0 and 0.5-mg/L.

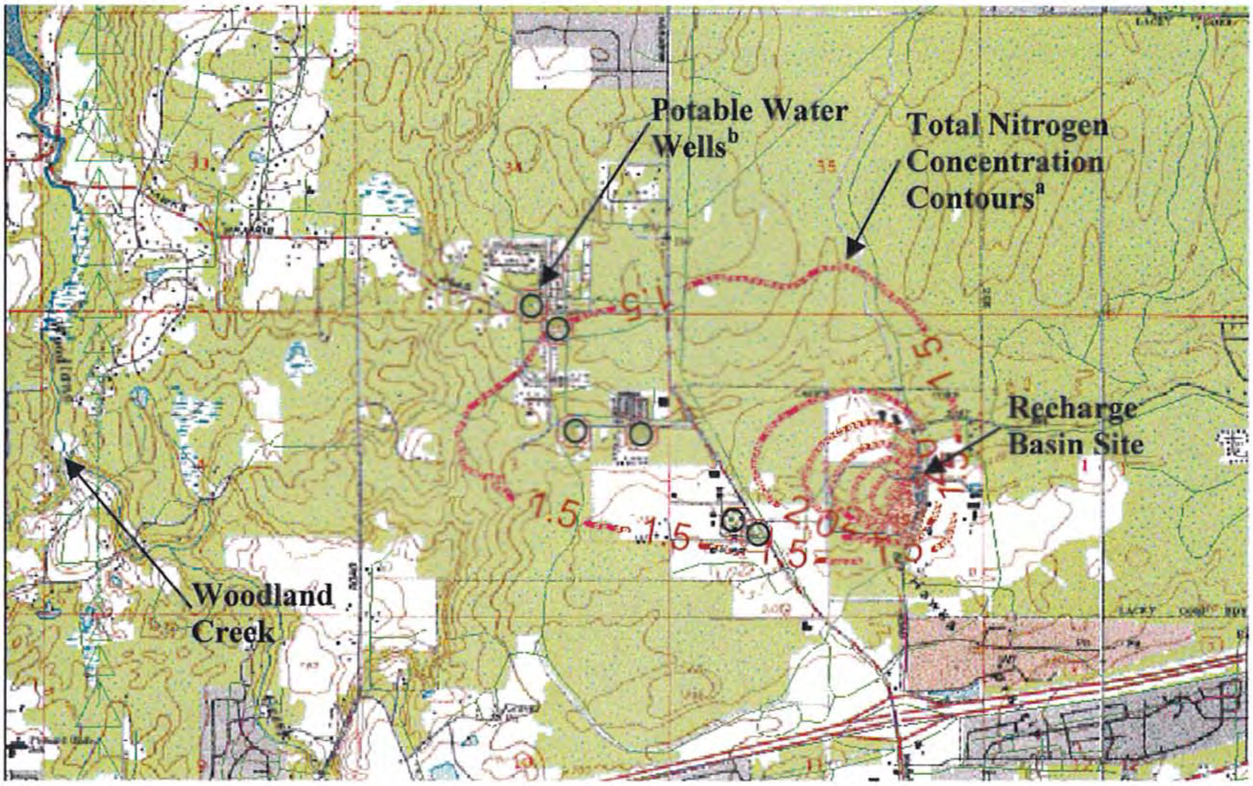

Figure 16 – Total Nitrogen Concentration Gradient At Five Million Gallons Per Day Recharge

[a] Total nitrogen concentration contours are in ½-mg/L increments.

[b] ● Potable water production wells located within the vicinity of the recharge basin site - see Table 3 for well data.

CHAPTER NINE: CONCLUSIONS AND RECOMMENDATIONS

A groundwater flow model using MODFLOW was constructed to aid in the evaluation of understanding the effects of infiltrating up to 5 mgd of Class A reclaimed water to the shallow aquifer in the Hawks Prairie area of Lacey, Washington. The groundwater flow model was constructed by incorporating data collected from the project site with regional data compiled by the USGS (Drost, et al, 1998 and 1999). Hydraulic conductivity values used in the groundwater flow model were similar to those used in the groundwater flow model that the USGS developed for northern Thurston County, Washington.

The groundwater flow model was then calibrated by comparing the model result to groundwater flow directions presented by the USGS (Drost, et al, 1998) and the measured groundwater elevation at the project site. Model groundwater elevations were then adjusted by changing the conductance values of the boundary drain values.

Two model scenarios were run to provide an estimate of the height of groundwater mounding beneath the project site at infiltration rates of 1 mgd and 5 mgd. Particle tracking simulations were then used to estimate the travel time required for water infiltrated through the recharge basins to reach Woodland Creek and surrounding water service wells.

The 1-mgd recharge simulation provided an estimated 13-foot increase in seasonal groundwater elevation beneath the recharge basins, and the 5 mgd recharge simulation provided an estimated 35-foot increase.

Particle tracking simulations performed with MODPATH indicate that the majority of infiltrated water will flow toward Woodland Creek, and that the infiltrated water will begin to reach the creek in approximately ten years at both infiltration rates. Model results confirmed that infiltration at the LOTT Wetland Ponds/Recharge Basins site does not significantly affect inflow to Woodland Creek.

A contaminant transport and dilution module was added to the model to estimate the impact of infiltrating water with a maximum nitrogen concentration of 5-mg/L. Results indicate that the infiltration of Class A reclaimed water will have a minimal impact of surrounding groundwater quality. For each infiltration scenario, groundwater quality returned to background levels within 1,200-ft of the site property line and at no time did the levels impact nearby water service wells.

9.1 MONITORING

The proposed recharge basin design includes installation of ten (10) groundwater monitoring wells installed around the site to track changes in the groundwater conditions. The wells will assist in identifying hydraulic characteristics of the surrounding groundwater system, quantify mounding caused by the recharge, and provide sampling points for monitoring groundwater quality.

Monitoring the water quality impacts of groundwater recharge with Class A reclaimed water is an important aspect of the project. Washington State Department of Health (Health) and Ecology (Ecology) requires sampling of the groundwater for components highlighted in Table 4 (Publication #96-02).

Sample collection will be performed using the groundwater monitoring wells. Ecology recommends using a positive displacement (bladder) or peristaltic pump with flow rates between 0.2 to 0.3 liters per minute to collect the samples. All collection equipment used in sampling will be made of inert material (i.e. Teflon, stainless steel, or PVC). The well will be purged prior to sampling, for a total of 5 percent of the casing volume, to reach equilibrium.

Source water quality will be continuously monitored at the satellite reclamation plant. Results will be displayed at the LOTT Budd Inlet Treatment Plant with alarms signaling non-compliance. The quality of the source water will also be measured prior to the recharge basins through grab sampling of wetland pond effluent. Wetland pond performance will be documented by comparing the quality of the source water leaving the satellite reclamation plant with samples taken prior to entering the recharge basins.

Table 4 - Washington State Department of Health and Ecology Groundwater Sampling Requirements for Surface Infiltration of Class A Reclaimed Water

Parameter	Units	Minimum Sampling Frequency	Sample Type
Static well water elevation	Feet above sea level	Quarterly[a]	Measurement
Temperature	°C	Quarterly[a]	Measurement
Dissolved Oxygen	mg/L	Quarterly[a]	Grab
Ph	Standard Units	Quarterly[a]	Measurement
Conductivity	umhos/cm	Quarterly[a]	Grab
Nitrate NO_3 (as N)	mg/L	Quarterly[a]	Grab
Nitrite NO_2 (as N)	mg/L	Quarterly[a]	Grab
TKN (as N)	mg/L	Quarterly[a]	Grab
Total Dissolved Solids	mg/L	Quarterly[a]	Grab
Total Coliform Bacteria	cfu/100mL	Quarterly[a]	Grab
Chloride	mg/L	Quarterly[a]	Grab
Cations/Anions: Calcium, Magnesium, Potassium, Sodium, Bicarbonate, Carbonate, Fluoride, Sulfate	mg/L	Yearly[b]	Grab
Total Metals: Arsenic, Cadmium, Chromium, Copper, Lead, Mercury, Nickel, Silver, Zinc[c]	ug/L	Yearly[b]	Grab
Total Trihalomethanes	mg/L	Quarterly[a]	Grab

[a] Quarterly is defined as: March, June, September, and December.
[b] Yearly is defined as March.
[c] Analytical method: Arsenic, EPA 206.3 or 206.2; Cadmium, EPA 2007.7 or 213.2; Chromium, EPA 200.7 or 218.2; Copper, EPA 200.7 or 220.2; Lead, EPA 239.2; Mercury, EPA 245.1 or 245.2; Nickel, EPA 249.2; Silver, EPA 272.2; Zinc, EPA 200.7 or 289.1.

9.2 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions are presented based on the results of the groundwater flow model evaluation and the available hydrogeologic data collected for the model area:

- Application of the results of the modeling is limited to the extent of the available data and should be used as an operating tool in understanding the hydrogeologic conditions of the recharge site.
- The groundwater flow model should be continually updated and refined over time when new data becomes available.
- Results from the model predict groundwater mounding of 13-feet and 35-feet above the seasonal static water level for the 1-mgd and 5-mgd scenario respectively.
- Infiltration increases inflow to Woodland Creek by 0.6 percent and 3 percent for 1-mgd and 5-mgd respectively.
- Travel time to Woodland Creek is ten years for both infiltration rates.
- Impacts to groundwater quality due to the infiltration of Class A reclaimed water containing up to 5-mg/L are minimal.

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