B&L Woodwaste Site
Pierce County, Washington

Engineering Design Report (EDR)

Appendix C
Phase 1 Hydrogeologic Study Report

FINAL

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1.0 Introduction

This Hydrogeologic Study Report (Report) has been prepared to support implementation of the 2008 Cleanup Action Plan (CAP) for the B&L Woodwaste Site (Site). The hydrogeologic model described in this report will be used to support the phased implementation of the CAP. The CAP addresses the B&L Woodwaste Landfill (Landfill) that is located on the B&L Property. A plume of contaminated groundwater extends downgradient from the Landfill. Additional groundwater contamination is present on the B&L Property and extending onto the adjacent upgradient property and the property located to the west of the Landfill. Additionally, sediments in nearby agricultural drainage ditches have been affected by arsenic releases from the Landfill. All affected properties and media comprise the Site that is addressed by this Report. For convenience in describing the remedy, the Site has been subdivided into several areas. The following Cleanup Action Areas (CAAs) and remedy components have been defined for implementation of the 2008 CAP:

- Landfill/Ditch CAA. Installation of a perimeter slurry wall around the Landfill that is tied into both the existing landfill cap and a low-permeability soil unit located below the Landfill, the diversion of clean surface water and groundwater before it reaches the slurry wall, and the extraction and treatment of leachate from within the slurry wall to maintain hydraulic control by creating an inward hydraulic flow gradient. Once the slurry wall is installed, contaminated sediments in the adjacent agricultural drainage ditches will be excavated and disposed of at a permitted landfill.

- Wetlands CAA. A groundwater pump and treat system will be used to remove arsenic from the groundwater plume in the Wetlands CAA. Performance-based criteria will be used to assure compliance with MTCA requirements. It is anticipated that up to 120 million gallons of water may require treatment.

- End-of-Plume CAA. In-situ treatment will be used to precipitate out dissolved arsenic followed by monitored natural attenuation of groundwater that reaches 12th Street East. Performance-based criteria will be used to assure compliance with Model Toxics Control Act (MTCA) requirements. Only a thin layer of arsenic-contaminated groundwater remains above the cleanup level in the End-of-Plume CAA; without treatment this area would likely come into compliance as the effect of cleanups in the Landfill and Wetlands CAAs reached the End-of-Plume CAA. Treatment in the End-of-Plume CAA is, therefore, intended to reduce the restoration time frame by bringing the area into compliance within 2 to 5 years although treatment will be continued as long as needed based on the performance criteria.

The 2008 CAP was issued by the Washington State Department of Ecology (Ecology) and requires implementation of several cleanup actions that comprehensively address remediation of the Site. The 2008 CAP is being implemented in a phased program as follows:

- Phase 1: Part 1 focuses on source control on the Landfill site itself and includes the construction of the slurry wall containment system and associated structures such as the interceptor trench.

- Phase 1: Part 2 focuses on the End-of-Plume CAA and is intended to halt the migration of arsenic at 12th Street East.

- Phase 2: This phase addresses remediation of groundwater contamination that exists outside the footprint of the Landfill (where source control has now blocked future releases) and upgradient of the End-of-Plume CAA (where further migration has also been blocked). Specific components of Phase 2 include the following:

- Installation of a groundwater extraction system both within the contained area of the Landfill and in areas outside the Landfill.

- Installation, start-up, and optimization of a treatment system for the extracted groundwater.

- Cleanup of the contaminated agricultural ditch.

- Development of a long-term operations, maintenance, and ,monitoring program, including installation of new monitoring wells.

- Implementation of institutional controls, including deed restrictions.

Upon completing Phase 2, long-term operation and maintenance of the cleanup action will commence under Ecology. Hydrogeologic modeling will support the work to be completed during Phases 1 and 2. This report summarizes tasks performed as part of Phase 1 activities described in the Hydrogeologic Study Work Plan (HSWP) found in the Groundwater Remediation Work Plan (GWRP; Floyd|Snider/AMEC 2009). This includes hydrogeologic and surface water data collection, the refinement of the existing conceptual hydrogeologic model, and the construction and operation of a numerical groundwater model. Results for the calibrated groundwater model are presented in this Report, while simulations incorporating the containment barrier and interceptor trench are presented in Addendum 1 of the Engineering Design Report (EDR). Subsequent reports will be prepared to document additional data collection and modeling to be performed as implementation of the 2008 CAP proceeds. The model domain is shown in Figure C.1.

2.0 Data Collection

The following descriptions of data collection are based on work performed during the 2008 predesign activities, as described in the HSWP.

2.1 MEASUREMENT LOCATIONS

2.1.1 Piezometer and Well Installation

A network of 38 piezometers and 5 wells was installed within the model domain area as part of the study. Additional wells were installed for other predesign study data objectives (refer to the GWRP). Well and piezometer installation and construction began in August 2008 and was completed in November 2008 by Cascade Drilling, Inc. of Woodinville, Washington. The following changes were made to the proposed network of measurement stations described in HSWP:

- PD-217 was eliminated due to access issues associated with active agricultural operations. It was determined that adequate coverage existed in this area with the addition of GW-1 and GW-2 (described below).
- PD-209A, PD-209B, GW-1, and GW-2 are existing wells within the hydrogeologic model boundary that were installed by others. These wells, for which construction details are unavailable, were named, surveyed, and incorporated into the study network.
- Pumping Well PD-104 was added due to field indications that the initial interceptor trench area pumping test well, PD-103, was located in an area of low transmissivity. The PD-104 location was thought to be more representative of groundwater entering the Landfill area from the adjacent uplands.
- PD-108, a boring located in the southwest portion of the Landfill intended to initially serve as a piezometer and potentially as an extraction well in Phase 2, was not completed as a monitoring well due to its proximity to an alternative barrier wall alignment. The boring was completed to its target depth, logged, and backfilled, and the hole in the protective cap was re-sealed in accordance with the HSWP.
- PD-72 was eliminated due to redundancy with PD-70 and PD-71 as pumping test observation wells.

Additional description and rationale for measurement locations can be found in the HSWP.

Piezometer and well construction and installation were conducted in accordance with procedures outlined in the HSWP and Samping Analysis Plan/Quality Assurance Project Plan (SAP/QAPP; refer to Appendix B of the GRWP: Floyd|Snider 2009). Borings for all constructed wells were logged to characterize subsurface geology and constrain model input parameters. Boring logs are included as Attachment C.1.

Following construction, all installations were surveyed by Barghausen Consulting Engineers, Inc. in November and December of 2008. Locations and elevations were surveyed using the North American Datum of 1983 (NAD 83/98) and the North American Vertical Datum of 1988 (NAVD 88). Refer to Figure C.2 and Table C.1 for construction details and location information for the entire hydrogeologic monitoring network, including monitoring wells installed prior to 2008.

2.1.2 Staff Gauges

In addition to piezometers and wells, 15 staff gauges were installed in the locations proposed in the HSWP as part of the August–November field work; the staff gauges were installed in accordance with the HSWP. Bank head pins were installed for staff gauges in the agricultural ditch system (PD-212, PD-214, PD-215, and PD-225), Hylebos Creek (PD-210 and PD-211), and Surprise Lake Drain (PD-216, PD-213, and PD-225) intended as discharge measurement stations (refer to Section 2.2.2). All staff gauges and head pins were surveyed by Barghausen Consulting Engineers, Inc. using the NAD 83/98 and NAVD 88. Refer to Figure C.2 and Table C.1 for installation specifications and staff gauge locations. Staff gauges SG-210, SG-211, and SG-225 were damaged during flooding in November 2008, and were reinstalled with reinforced posts and subsequently re-surveyed the following month.

2.1.3 Transducer Installation

Eleven 7/8-inch diameter unvented transducers (Solinst 3001 LT Levellogger Junior, M5/15) were installed in wells and transducers along an approximate flow path from the interceptor trench area through the Landfill, Wetlands, and End-of-Plume CAAs to Hylebos Creek (see Figure C.2 for location of transducers). Installation and calibration relative to water level measurements collected by hand were completed in accordance with the HSWP on October 30, 2008.

Additionally, one barometric logger (Solinst 3001 LT Barologger Gold, M1.5/F5) was installed in Well PD-109 within the Landfill to provide barometric compensation data. Per the HSWP, the transducer corresponding to SG-211 was installed in a PVC stilling well (PD-211TD) located in Hylebos Creek adjacent to SG-211.

The 11 transducers and the barometric logger were connected to a laptop computer to verify their functionality and that their battery capacity was full prior to their deployment. The clocks of all 11 transducers and the barometric logger were synchronized using a laptop computer. Each transducer was then suspended within the PVC casing of its respective piezometer, well, or stilling well using a static 0.025-inch diameter steel wire to ensure that a fixed distance was maintained between the transducer and the top of the piezometer, well, or stilling well casing. The barometric logger was suspended outside of the PVC casing but within the protective steel monument of PD-109 to shield it from the effects of wind and rain using steel wire as well.

2.1.4 Investigation-Derived Waste

Investigation-derived waste (IDW) was handled in accordance with the SAP/QAPP) as summarized below. IDW, including soil cuttings and water from well and piezometer installation borings within the Landfill, was containerized in Department of Transportation (DOT) approved 55-gallon drums for temporary storage prior to off-site disposal. Soil cuttings from borings outside areas of contaminated soil were placed at the ground surface in accordance with the SAP/QAPP. Containers were labeled with the date on which the waste was placed in the container and the boring(s) from which they were obtained. Containers were transferred to a designated temporary storage area and managed in accordance with applicable regulations and standards.

IDW was characterized relative to Dangerous Waste criteria by analytical sampling of representative samples submitted to Fremont Analytical in Seattle, Washington. IDW from borings advanced through the landfill cap was designated for off-site disposal based on analytical results (samples PD 107 5-7’, PD-107 12-14’, PD 108 5-7’, and PD-108 10-12’). The IDW generated was disposed off-site along with other waste from the predesign investigations as dangerous (hazardous) and non-regulated waste, as applicable based on the waste characterization results. The waste characterization analytical laboratory results and waste manifests are included in Appendix B to this EDR as Attachment B.2.

2.2 REGULAR DATA COLLECTION

2.2.1 Water Level Measurements

A program of regular measurement of water levels in piezometers, monitoring wells and staff gauges was implemented to meet the hydrologic data objectives described in the HSWP. Water levels were measured in accordance with the HSWP and following standard procedures described in the SAP/QAPP. Water levels were measured during monthly field events, beginning in October 2008. Water levels will continue to be measured monthly on an ongoing basis throughout Phase 1.

Water level measurements observed in the field between October 2008 and February 2009 are presented in Table C.2. Upper and Lower Sand Aquifer potentiometric surface maps created from depth to water measured during the October 2008 through February 2009 monthly monitoring events are presented in Figures C.3 through C.12.

2.2.2 Discharge Monitoring

Surface water discharge measurements and synoptic runs were completed as part of quarterly events in October 2008 and February 2009. Discharge data were collected from multiple locations along Hylebos Creek (PD-210 and PD-211), Surprise Lake Drain (PD-216, PD-213, and PD-225), and the agricultural ditch system (PD-212, PD-214, PD-215, and PD-225). Discharge measurements were conducted in accordance with the HSWP and following standard U.S. Geological Survey (USGS) methods for streamflow gauging. The discharge measurements consisted of measuring depth and flow velocity across stream transects perpendicular to the flow direction. All stream transect locations are clearly marked by bank head pins. Depth and flow velocity were measured at 1-foot intervals across stream transects with a Marsh-McBirney flow meter. A summary of discharge measurement results is presented in Table C.3 and discharge measurement worksheets are included as Attachment C2.

Data from discharge measurements were used to perform synoptic runs, or comparisons of streamflow discharge at points along a stream to evaluate whether a given reach of a stream is gaining (i.e., receiving water from adjacent groundwater) or losing (i.e., discharging water into adjacent groundwater) at the time of the discharge measurement. This evaluation was performed as part of numerical model construction and calibration.

Data collected to date are insufficient to support development of stage-discharge rating curves. Data will continue to be collected to support development of stage-discharge rating curves.

2.2.3 Transducer Upload

The internal data loggers in the transducers record a water level measurement once per hour and the internal data logger in the barometric logger records a barometric pressure reading once per hour. Hourly data dating back to the time of installation was transferred from the 11 transducers and the barometric logger to a laptop during the November 2008 and January 2009 water level measurement events. The transducers and the barometric logger were inspected during data load events and their remaining battery and storage capacity verified and recorded on field forms. All 11 transducers and the barometric logger appear to be fully functional and are free of damage following these two events.

2.3 HYDROGEOLOGIC TESTING

2.3.1 Pumping Tests

Pumping tests were conducted in wells located near the anticipated interceptor trench alignment and in the End-of-Plume area on October 7, 2008 and October 8, 2008, respectively, to provide estimates of aquifer characteristics. The two pumping tests were completed in general accordance with the HSWP, and following standard methods for constant-rate discharge tests, American Society for Testing and Materials (ASTM) Method D4050-96 (ASTM 2008). Pump test results are summarized in Table C.4 and the data analyses are included as Attachment C3.

A variable-speed 4-inch Grundfos submersible pump with 20 gallons per minute (gpm) capacity was employed for both pumping tests, and pumping rates were measured by filling a graduated container and measuring the filling time. Based on detailed characterization of areas of contaminated groundwater (refer to the Arsenic Characterization Study, Appendix A to the EDR), the groundwater from the pumping well was deemed suitable for discharge to the ground surface in accordance with the HSWP. During pumping, water was conveyed by a hose to locations approximately 100-feet cross-gradient from the pumping well and discharged onto the ground.

Electronic data was logged continuously for the duration of the pumping tests. Aquifer transmissivity and storativity were calculated from pump test drawdown and recovery data using the Theis approximation for unconfined aquifers. (USACE, 1999) Analyses of both drawdown and recovery data were performed using Aquifer Win 32 software Version 3.28 by Environmental Simulations, Inc.

In consultation with Ecology, the pumping test planned for PD-103 was instead conducted at PD-104 due to apparent anomalously low transmissivity at PD-103 based on soil classification. Additionally, drawdown data could not be collected from PD-104 during the interceptor trench area pumping test due to a transducer malfunction apparently caused by interference from the pump motor. Recovery data were collected from PD-104 during this pumping test using a backup transducer.

For the pumping test that was carried out as planned in PD-101, drawdown and recovery data from observation wells PD-70 and PD-71 were nearly identical. Consequently, only PD-70 was used as the observation well for estimating aquifer characteristics for the End-of-Plume area.

Based on pumping test results, estimates of hydraulic conductivity were between approximately 0.30 to 11 ft/d (1.0 x 10-4 to 3.7 X 10-3 cm/s) in the area upgradient of the Landfill and 54 to 220 ft/d (1.9 x 10-2 to 7.8 X 10-2 cm/s) in the End-of-Plume area of the Wetlands. These results are consistent with previous estimates of aquifer characteristics at the Site.

2.3.2 Infiltration Tests

A basin flooding test was performed in the stormwater pond to assess infiltration capacity, as described in the HSWP. The test was conducted on September 18, 2008, at which time the stormwater pond was dry. The test basin was constructed and installed according to the HSWP and following procedures outlined by the U.S. Environmental Protection Agency (USEPA 1981 and 1984). The 3-meter diameter, circular basin was constructed by placing aluminum flashing into a narrow, 6-inch deep excavated trench at the test basin perimeter. The trench was backfilled using the excavated sediments. Bentonite was also used to improve the seal between the aluminum flashing of the basin and the backfilled sediments.

Water was pumped from a clean, upgradient monitoring well (D-11A) into a 500-gallon tank and transferred into the constructed basin on September 17, 2008 for pre-test sediment saturation. On September 18, 2008, only a few inches of water remained in the basin; water level readings (Table C.5) were collected over about an hour, showing no change in basin water level. The test basin was refilled with water from the tank. Water levels were then monitored and recorded from two staff gauge locations within the basin, one along the south sidewall and one within the basin center, at 3- to 15-minute intervals for a total duration of 3 hours. As shown by the data of Table C.5, initial readings showed negligible infiltration. Subsequent readings showed a measurable drop in water level; however, leakage from the side of the basin was noted. Leakage was partially plugged later in the test. It appears that the measurements were affected by leakage from the basin ring.

The rate of infiltration from the existing detention pond appears to be very low, based on the negligible drop in water level that occurred over the first 1.25 hours of measurements on

September 18, 2008. Based on these observations, it was concluded that the infiltration rate from the detention pond is substantially lower than the rate needed for the pond to function as an infiltration site for the groundwater interceptor system. It was decided to terminate testing rather than repair the ring for extended test runs. The very low infiltration rate is consistent with observed stormwater basin sediments throughout the detention pond. These sediments generally include compacted silty sand and sand with silt with coarse gravel and cobbles. Test data indicate that modifications to the pond are needed to support infiltration.

3.0 Conceptual Site Model

3.1 HYDROSTRATIGRAPHY AND AQUIFER PROPERTIES

Field investigations performed during the 2008 predesign activities provided hydrogeologic information that led to refinements of the Site conceptual model. Data collected during the study allowed accurate delineation of major hydrostratigraphic units, including the Upper Sand Aquifer and the Lower Silt Aquitard, as well as characterization of aquifer properties within the Landfill and Wetlands areas. Information contained in boring logs detailing the spatial extent and depth of the Upper Sand Aquifer and Lower Silt Aquitard were incorporated directly into the numerical groundwater model geometry. Likewise, parameters derived from aquifer pump tests provided confidence in hydraulic conductivity values in the model for locations upgradient of the Landfill and in wetlands areas. Additionally, the 2008 predesign investigations confirmed gaps in the Lower Silt Aquitard in both the southwest corner and the eastern side of the Landfill, which were also represented in the model design (refer to Section 5.3.2 through Section 5.3.3).

A full description of the site conceptual model is provided in the EDR Section 3.1.1. Detailed cross-sections were developed for key portions of the model area and are presented in Addendum 1 to the EDR.

3.2 GROUNDWATER FLOW DIRECTIONS AND GRADIENTS

Depth to groundwater measured in wells between October 2008 and February 2009 were used to calculate groundwater elevations and generate potentiometric surface maps (Figures C.3 through C.12). Groundwater flow directions in the Upper Sand Aquifer are generally north-northwesterly, from the upland bluff east of the Landfill to the Wetlands area north and west of the Landfill. North and east of the Landfill, groundwater flows westerly towards Hylebos Creek.

Horizontal groundwater gradients are steeper in areas of the upland bluff east of the Landfill and flatten beneath the Landfill and in the Wetlands. Horizontal gradients in the Upper Sand Aquifer range from approximately 0.0025 to 0.005 in the vicinity of the Landfill. Horizontal gradients beneath the Wetlands are generally less than 0.001. Horizontal gradients in the transition area between the upland bluff and the Landfill are typically greater than 0.006.

Vertical gradients between the Lower and Upper Sand Aquifers are generally neutral or slightly downward in the areas upgradient of the Landfill and transition to neutral followed by increasingly strong (0.1) upward gradients on the north side of the Landfill in the Wetlands areas.

3.3 SURFACE WATER AND GROUNDWATER INTERACTIONS

Streamflow data gathered from the agricultural ditch network, Hylebos Creek, and Surprise Lake Drain indicate that the shallow groundwater system and surface water are in hydraulic communication within the model domain. Furthermore, a single reach may change between gaining or losing depending on a variety of factors including changes in seasonal groundwater elevation and surface water stage.

The limited data available indicate that there are both gaining and losing surface water reaches across the model domain. Because only one round of discharge data was available, accurately determining the magnitude of the flux between surface water and shallow groundwater has proven problematic. Surface water discharge data collected in October 2008 contains irregularities due to near-zero velocity eddies in Hylebos Creek, Surprise Lake Drain, and in the ditches adjacent to the Landfill. Changes in volumetric flow calculated from streamflow data suggest that neighboring reaches within these drainage networks transition from gaining to losing conditions (or losing to gaining) over short distances. While the presence of gaining and losing reaches within the model domain area is likely, the abrupt transitions between adjacent reaches as well as the magnitude of the calculated groundwater-surface water fluxes between surface water features and the Upper Sand Aquifer are not likely. This issue will continue to be evaluated as work proceeds for the hydrogeologic study.

3.4 STEADY-STATE WATER BALANCE

A comprehensive water budget for the model was developed using estimates for recharge, evapotranspiration (ET), and groundwater flux into and out of the model domain. However, only very limited surface water stream gauging data was available for drainages within the model domain. The data available only encompassed one season; ttherefore, calculations based upon the data indicated unreasonable fluxes between surface water and shallow groundwater. Field measurements also indicated volumetric surface storage of water in the stream network (i.e., stream velocity equal to zero), which did not support the development of a steady-state water balance model. Consequently, flux estimates for groundwater-surface water interactions were used in development of the water balance model.

4.0 Numerical Model Development

The project team developed a numerical model to simulate groundwater flow conditions for the B&L Landfill study area. The numerical groundwater model is designed based on the current conceptual model. The model is intended to serve as a decision-making tool to help understand the physical flow system and advective transport, evaluate various remedial design scenarios, and assess potential effects of the remedial actions specified in the CAP on water resources.

4.1 NUMERICAL MODEL CODE

The USGS Modular Three-Dimensional Finite-Difference Groundwater Flow Model (MODFLOW-2000) was selected to simulate groundwater flow within the Site. In order to represent surface water drainages, the DRAIN and RIVER head dependent boundary conditions within MODFLOW were used to simulate the agricultural ditches, Surprise Lake Drain, and Hylebos Creek (Refer to Section 4.5). MODFLOW (McDonald and Harbaugh 1988, Harbaugh and McDonald 1996, and Harbaugh et al. 2000 [2000 Version]) is a well-documented program that is publically available and extensively used in the environmental industry to characterize and assess groundwater flow. MODLFOW has been used successfully to simulate groundwater flow in many subsurface environments similar to that within the model domain for this project. The code was developed by the USGS to simulate groundwater flow in a three-dimensional, heterogeneous, and anisotropic medium. MODFLOW uses a block-centered finite difference approach for the numerical solution of the three-dimensional partial differential equation for flow through a saturated porous media with constant fluid density.

Advective groundwater movement was simulated using the particle tracking code MODPATH Version 3.0 (Pollock, 1994). MODPATH is a three-dimensional, particle-tracking code that uses output from MODFLOW to calculate particle velocity changes over time in three dimensions. MODPATH also calculates groundwater seepage velocities and groundwater flow directions, which allows comparisons between observed and simulated flow fields during the model calibration process.

4.2 MODEL DOMAIN

The model domain encompasses an area of approximately 290 acres and includes the B&L Property. Figure C.1 shows the entire model domain, which includes the Landfill/Ditch CAA, the Wetlands CAA, and the End-of-Plume CAA, and the surrounding areas, encompassing Hylebos Creek and the Surprise Lake Drain. External model boundaries were selected to ensure that simulated internal stresses would not inappropriately impact prescribed boundary conditions. The eastern model boundary generally parallels a north-south trending bluff and is located adjacent to Fife Way where alluvial valley deposits contact the base of the hillslope. All other model boundaries were located outward from their original locations proposed in the HSWP.

The northern model boundary was extended outward from its proposed location in the HSWP to coincide with a more suitable topographic boundary just below the confluence of East and West Hylebos Creek. The northwestern boundary was relocated to so that it paralleled the bluff located to the west of Hylebos Creek. The repositioning of the northwestern boundary allows numerical representation of potential throughflow beneath Hylebos Creek in the Upper Sand Aquifer. The southwestern model boundary was moved outward from its original location along Surprise Lake Drain. The increased area within this portion of the model domain allows numerical representation of throughflow beneath Surprise Lake Drain. The southern model boundary was relocated southward to orient the model boundary parallel to observed flow directions.

4.3 MODEL DISCRETIZATION AND GROUND SURFACE ELEVATION

The numerical model has a uniform horizontal grid spacing of 20 by 20 feet. This high-resolution grid spacing allows accurate representation of curvature in potentiometric surfaces, recharge and discharge to surface water features, and aquifer response due to pumping (Anderson and Woessner 2002). Despite using a high-grid resolution, the calibrated steady-state model maintained acceptable computation times.

Boring logs (Attachment C.1) were examined to construct model geometry consistent with major hydrostratigraphic units within the domain area. Based upon an interpretation of available lithologic data, model Layers 1 through 3 represent the Landfill, Upper Sand Aquifer, and Lower Silt Aquitard, respectively. The Lower Sand Aquifer is divided into two identical 15-feet thick units. Division of the Lower Sand Aquifer unit into two layers allows representation of the hanging barrier wall design within the numerical model (refer to Addendum 1). The table below provides a summary of each respective model layer and the corresponding hydrostratigraphic unit.

Layer	Unit Representation
1	Landfill
2	Upper Sand Aquifer
3	Lower Silt Aquitard
4	Lower Sand Aquifer
5	Lower Sand Aquifer

The vertical extent of the Lower Sand Aquifer could not be determined from the boring logs; therefore, the model bottom was set to 30-feet below the bottom of Lower Silt Aquitard. This depth was considered sufficient to minimize any boundary effects caused by the bottom of the model domain.

Light detection and ranging (LIDAR) bare-earth topographic data at approximately 6 x 6 foot resolution was obtained from the Puget Sound LIDAR Consortium (2008) for the entire model domain (available online at http://pugetsoundlidar.ess.washington.edu). The LIDAR data product was resampled to 20 x 20 foot spaced intervals and used to establish the ground surface elevation for the numerical model.

4.4 INITIAL MODEL PROPERTY ESTIMATES

4.4.1 Recharge and Evapotranspiration (ET)

Local precipitation data were used as the basis for estimating areal recharge in model calibration. Monthly precipitation totals between 1919 and 2008 were obtained for two weather stations in Tacoma, Washington (1919 to 1981: Tacoma #1, COOP ID 458278; and 1982 to 2008: Tacoma City Hall, COOP ID 458286). These two stations were selected because of their proximity to the Landfill and, when combined, provided nearly complete coverage of the available precipitation record. The data for the period of January 1919 through August 2008 were obtained from the National Climatic Data Center (National Climatic Data Center 2009). The data for September 2008 through December 2008 were provided by the Western Regional Climate Center through e-mail communication (Western Regional Climate Center 2009).

The average annual precipitation was calculated from the composite monthly dataset and used to estimate recharge rates for the numerical model. The annual average did not include years where at least one month contained missing data. These years included 1946, 1947, 1960, 1961, 1982, 1997, 1998, 2000, and 2002. The only exception is year 1996 when the monthly precipitation for June was missing. Because precipitation during the month of June is typically low, the missing data is not expected to significantly affect the annual precipitation total for 1996. Figure C.13 shows yearly totals and the average annual precipitation from 1919 to 2008. According to the data, the average annual precipitation is 36.7 inches. The maximum annual precipitation was 53.3 inches.

The model domain was divided into two different groundwater recharge zones to represent areas with different precipitation recharge potential: the Landfill and the remaining model domain. Over the Landfill, recharge was set to zero to reflect the presence of the Resource Conservation and Recovery Act (RCRA) cap. For the remaining model domain, the recharge rate was estimated as a fraction of the annual average precipitation. The initial recharge rate was estimated as 10 percent of the average annual precipitation rate. Through the calibration process, recharge was assigned as 8 percent of the annual average precipitation.

An ET rate of 20 inches/year with a root extinction depth of 3 feet was assigned to the Wetland area located north of the Landfill. Within the MODFLOW ET package, the ET rate occurs at a maximum when the water table rises to the top of a layer. ET decreases linearly to zero over the vertical length defined by the root extinction depth (McDonald and Harbaugh 1988). The ET rate was initially estimated based on annual average pan evaporation values for the region (KJC and AGI 1990) and then adjusted as part of model calibration process.

4.4.2 Hydraulic Conductivity

Initial hydraulic conductivity values were assigned based on results from available pump test data and interpretation of lithologic logs. Estimates of hydraulic conductivity from pump test data were between approximately 0.3 to 220 ft/d (1.04 x 10-4 to 7.8 x 10-2 cm/s) with lower values corresponding to areas upgradient of the Landfill and higher values characteristic of the Upper Sand Aquifer in the Wetlands areas. To represent anisotropy in the model, vertical hydraulic conductivity values were scaled to one tenth (1/10) of the hydraulic conductivity in the horizontal direction. Following model runs using initial parameter values, hydraulic conductivity values were adjusted as part of model calibration so that model output matched observed heads and flow directions (refer to Section 5.0).

Boring logs, aquifer tests, and contaminant concentration contours from predesign and previous site investigation activities were used to identify areas of higher hydraulic conductivity within Layer 2, the Upper Sand Aquifer. Two northwest-trending features that correspond to depositional sand channels were identified: a sand channel that intersects the southwest corner of the Landfill, and a sand channel at the eastern side of the Landfill that extends into the wetlands (refer to Section 5.3.2).

4.5 BOUNDARY CONDITIONS

Boundary conditions were assigned based on groundwater flow directions and gradients inferred from groundwater contour maps and the steady-state water balance model developed for the model domain area. The Landfill layer (Layer 1) consists of active cells in the area of the Landfill footprint surrounded by a no-flow boundary condition (not shown). Under this construction, saturation of the wood waste occurs as the water table rises from beneath the Landfill.

Figure C.14 shows constant head and constant flux boundary type distribution assigned to the remaining model layers. In Layer 2 (the Upper Sand Aquifer), a constant flux boundary condition and a constant head boundary condition were used to introduce water into the model domain as throughflow from both the north, northwest, east, and southeast (Figure C.14). A constant head boundary was assigned to cells in the southwest corner of the model so that groundwater would exit the model domain either as groundwater contributions to surface flow in Hylebos Creek and Surprise Lake Drain or as groundwater throughflow towards the southwest.

In Layer 3, a constant flux boundary was assigned along the east side of the model domain (Figure C.14). The flux into the model was minimal relative to fluxes used in the overlying Upper Sand Aquifer and underlying Lower Sand Aquifer. The constant flux boundary in Layer 3, however, allowed numerical representation of the low transmissivity typical for a silt aquitard.

Both Layers 4 and 5 represent the Lower Sand Aquifer and have identical boundary conditions. In each layer, a combination of constant flux boundaries and constant head boundaries allows groundwater to enter the model domain as throughflow from the north, northwest, east, and southeast. A constant head boundary, located along the southwest edge of the model, allows groundwater in the Lower Sand Aquifer to exit the domain as throughflow (Figure C.14).

Hylebos Creek, Surprise Lake Drain, and certain portions of the agricultural ditch network were simulated using the RIVER package of MODFLOW. For modeling purposes, the bottom elevation of each drainage was established using surveyed elevation data for each staff gauge location. Surface water staff gauge measurements were used to define stage elevation for each drainage reach in the numerical model. Stream Conductance parameters within the RIVER package were used to match simulated groundwater-surface water fluxes to reasonable values and to match observed and simulated heads for piezometer measurements adjacent to surface drainages. Stream Conductance for each river reach is calculated as,

$$C = \frac{K * L * W}{D}$$

where C is conductance (ft2/d), K is stream bed hydraulic conductivity (ft/d), L is length of each river reach (ft), W is stream width (ft), and D is thickness of the bed material (ft). Because the model was developed with uniform grid spacing, the length of each river reach was 20 ft. Stream width values were well constrained based upon data collected during stream gauging activities. Stream bed hydraulic conductivity values were estimated based upon observed streambed properties. Estimates were used for the thickness of the bed material considering the size and discharge of each drainage. Stream bed conductance values ranged from 28 to 1,000 ft2/d in the calibrated steady state numerical model.

The MODFLOW DRAIN package was used to simulate the reach of the agricultural ditch due north of the Landfill as well as the agricultural drain due west of the Autumn Village Apartments. These reaches were simulated using the DRAIN package in the model because field observations indicated these reaches are often dry during parts of the year. The DRAIN package assigns a head-dependent boundary condition that removes water from the aquifer once the simulated water table is higher than the drain head (Harbaugh and McDonald 1996). Conductance values, calculated using the same approach as with the RIVER package, varied from 20 to 200 ft2/d.

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5.0 Model Calibration

5.1 CALIBRATION TARGETS

The model was calibrated to match simulated potentiometric heads with observed groundwater level data at 62 calibration target locations (55 targets in Layer 2; 7 targets in Layer 4). Groundwater elevations and surface water stage data collected during the months of October 2008 through December 2008 were averaged to provide calibration targets for the steady state numerical model. Table C.6 provides a list of the target locations used during model calibration.

Due to issues with streamflow data and surface storage discussed in Sections 3.3 and 3.4, target fluxes could not be established for stream reaches. As a result, model calibration focused on matching simulated and observed heads as well as flow directions while field-measured surface water stage data were used to maintain appropriate water elevations in the model's river boundary package.

Differences between the observed heads and simulated heads at calibration targets were used to calculate statistics for model residuals. Residual (R) is the difference between simulated and measured groundwater elevations at specific locations in the model domain (62 targets were used for calibration). During the calibration process, model parameter values were varied over an acceptable range to minimize calibration statistics such as the residual mean (RM), absolute residual mean (ARM), residual standard deviation (RSD), and residual sum of squares (RSS; Duffield et al. 1990). The ratio of the RSD to the range of observed head values across the entire model domain should be minimal for a calibrated model, indicating that the residual errors are a small component of the model response. A ratio of less than 10 percent is considered acceptable for groundwater flow and solute transport applications (Anderson and Woessner 2002).

5.2 CALIBRATION GOALS

Steady-state model calibration was evaluated both quantitatively and qualitatively using a suite of different criteria. Criteria included:

- visual comparison between groundwater elevation contour maps based on measured and simulated heads,
- visual evaluation of a scatter plot comparing measured and simulated heads,
- statistical evaluation of residuals,
- acceptable water balance error (less than 1 percent),
- ratio of RSD to the total head change across the domain of less than 10 percent,
- comparison of advective transport to observed plume dimensions.

5.3 RESULTS

5.3.1 Observed vs. Simulated Heads and Flow Paths

Figure C.15 shows simulated groundwater contours and particle tracking for Layer 2 (Upper Sand Aquifer) produced by the calibrated steady-state model. Generally, contours calculated by the numerical model reflect observed groundwater elevations and flow directions (Figure C.3 through C.12). To the north of 12th Street East, groundwater flows from northeast to southwest. In the south region of the model, including the area around the Landfill, groundwater flows to the northwest but gradually bends toward the west in the central and western portions of the model domain. Particle tracking, using release points in suspected constituent source areas, demonstrates that simulated advective transport replicates observed arsenic plume dimensions, as shown in Figure C.15.

Table C.6 provides calibration target values as well as the simulated groundwater heads and calculated residuals. Figure C.16 shows a scatter plot of simulated versus observed groundwater elevations. A correlation coefficient of 0.96 indicates a strong positive relationship between observed and simulated heads. A correlation coefficient equal to 1 would be the result of a model that perfectly replicates observed heads.

Calibration statistics based on residuals are shown in Table C.7. The average residual is minus 0.37 ft. The average absolute value of the residuals is 0.54 ft. The standard deviation of the difference between observed and simulated groundwater elevations is 0.50 ft. The model error, provided by the RSD divided by the total range in observed head, is 3.2 percent. The water balance error was minus 4.7 x 10-4 percent (not shown). Based upon statistical analyses of groundwater elevations and comparison of observed and simulated flow paths, the calibration results are considered acceptable.

5.3.2 Calibrated Parameter Distribution

Model calibration focused primarily on the adjustment of hydraulic conductivity to match observed and simulated groundwater elevations. In Layer 1 (the Landfill), a uniform conductivity of 0.1 ft/d was used to parameterize the wood waste (not shown). Figure C.17 shows calibrated hydraulic conductivity values for the Upper Sand Aquifer (Layer 2), the Lower Silt Aquitard (Layer 3), and the Lower Sand Aquifer (Layers 4 and 5). The Upper Sand Aquifer has a background hydraulic conductivity of 50 ft/d. The eastern sand channel has a conductivity value of 150 ft/d, whereas the southwestern sand channel feature has a conductivity value of 95 ft/d. The Lower Silt Aquitard (Layer 3) has a background conductivity of 0.23 ft/d. Areas where the sand channels cut through the Lower Silt Aquitard were parameterized with the same hydraulic conductivity values used in Upper Sand Aquifer (Layer 2). The Lower Sand Aquifer has a background hydraulic conductivity of 50 ft/d across the majority of the modeling domain.

Currently, the model is calibrated for only a steady-state condition. Once sufficient field data have been collected that include an entire wet through dry season cycle, a transient verification will be performed. The transient model will require estimates of additional parameters including storativity (S). Storativity will be estimated based on aquifer test results and literature values, and will be adjusted as part of the model calibration process so that seasonal changes in groundwater elevation and fluxes are accurately captured by the transient numerical model.

5.4 UNCERTAINTY AND SENSITIVITY ANALYSIS

Numerical models always contain uncertainty due to the both the inability to accurately estimate the magnitude and timing of system stresses as well as an inability to accurately quantify both spatial and temporal distribution of parameter values (Anderson and Woessner 2002). As an example, while pump tests are often performed to quantify hydraulic conductivity in known critical areas, hydraulic conductivity is rarely homogeneous throughout the entire model domain. Additionally, depending on the pumping rate and aquifer properties, tests may stress the aquifer over a limited spatial extent. As a result, conductivity values derived from aquifer tests may be indicative of the physical system only in areas where the pump test occurred.

For the Site numerical model, while conductivity is well characterized in areas where pump tests were performed, there remains uncertainty in other regions of the model domain. Consequently, hydraulic conductivity in portions of the model, such as the Lower Sand Aquifer or far northern areas of the domain, required parameter estimation based upon either lithological descriptions from available borings logs or the extrapolation of hydrostratigraphy from well characterized areas within the model domain.

Similarly, measurements of recharge to groundwater are typically unavailable for modeling exercises. Therefore, a standard approach is to calculate recharge using a constant proportion of precipitation and in the absence of other data begin with 10 percent of precipitation (Anderson and Woessner 2002). This fractionation approach accounts for potential recharge losses including precipitation runoff and evapotranspiration. Because it is not easily measured, recharge may be varied from the initial estimate during model calibration exercises to improve simulated results.

While it is impossible to completely characterize parameter distributions in both time and space, analyses can be performed to quantify model sensitivity due to the uncertainty associated with a given parameter. Results for sensitivity analyses, including both hydraulic conductivity and recharge rates, were performed for the Site model and are presented in Section 5.4.1.

5.4.1 Sensitivity Analysis

The calibrated groundwater model is not a unique solution. It is possible that the model would calibrate using different combinations of boundary conditions and parameter values. Sensitivity analyses were performed to assess the sensitivity of the model calibration to certain model inputs by adjusting the inputs within a plausible range and observing the effect on model error. Parameters and boundary condition analyzed to assess sensitivity included the background hydraulic conductivity for the Upper Sand Aquifer, the Lower Silt Aquitard, the Lower Sand Aquifer, the east sand channel, the southwest sand channel as well as recharge, and flux boundaries. Results are shown in Figures C.17 through C.23 and discussed below.

Sensitivity analysis was performed for the background hydraulic conductivity of the Upper Sand Aquifer by scaling the calibrated hydraulic conductivity by factors of 0.1, 0.5, 1, 1.5, and 2 where a scaling factor equal to 1 reproduces results from the calibrated model. The metric used to quantify model sensitivity in each run is the RSD divided by the observed range in head. As discussed in Section 5.3.1, this statistical metric provides quantification of model error. The same analysis was performed for background conductivity in layers corresponding to the Lower Silt Aquitard (Layer 3), the Lower Sand Aquifer (Layers 4 and 5), the east sand channel, and the southwest sand channel.

Sensitivity analyses indicate that model calibration is especially sensitive to decreases in hydraulic conductivity in the Upper Sand Aquifer (Layer 2; Figure C.16). In addition, model error also increases with increasing background hydraulic conductivity in both the Upper Sand Aquifer (Layer 2; Figure C.17) and the Lower Sand Aquifer (Layer 4 and 5; Figure C.18). In addition, both increases and decreases in hydraulic conductivity for the eastern sand channel result in an increase in model error (Figure C.19). However, the model is insensitive to changes in the hydraulic conductivity associated with the southwest sand channel (Figure C.20). Likewise, model results do not vary significantly in response to changes in the background hydraulic conductivity of the Lower Silt Aquitard (Layer 3; Figure C.21). In each of the previous cases, the lowest model error was associated with the hydraulic conductivity value used in the calibrated version of the model.

As with hydraulic conductivity, the calibrated recharge rate was scaled prior to running a suite of five simulations. Scaling factors applied to the calibrated recharge rate were .5, 0.75, 1, 1.25, and 1.875, respectively. The calculated error for each simulation was used to determine model sensitivity to changes in the model recharge rate. Results presented in Figure C.22 indicate the model is insensitive to changes in recharge over the evaluated range. Again, the lowest model error was associated with the recharge value used in the calibrated version of the model

Constant flux boundaries were also evaluated for influence on model sensitivity. Scaling factors applied to flux boundaries were 0.5, 0.95, 1, 1.05, and 1.5, respectively. Because different flux magnitudes are used in different portions of the model, the error metric is plotted as a function of the scaling factor. Results indicate that the model is sensitive to both increases and decreases in the flux boundary (Figure C.23). In this case, the 1.05 multiplier provides a slightly lower model error than the calibrated model; however, the difference is so small that the overall model results are not influenced.

5.4.2 Model Limitations

Calibration of the groundwater model demonstrates that it is capable of simulating groundwater flow under steady-state conditions for the model area within a reasonable range of error. Inherent in any numerical groundwater modeling effort is a degree of uncertainty. For example, there is a fair degree of uncertainty associated with the hydraulic conductivity of some units. In addition, transient verification of the model has not yet been completed and would improve confidence in the model's predictive capabilities. Transient calibration will be completed during the next phase of modeling and presented in future addenda to the EDR.

The numerical model described in this report is appropriate for use in decision making regarding design parameters for the barrier wall and interceptor trench.

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6.0 Barrier Wall and Interceptor Trench Representation

The containment barrier around the Landfill perimeter was represented using MODFLOW's Flow Barrier Package. Within the numerical model, the barrier wall was assigned a thickness of 2 feet and a hydraulic conductivity of 0.0003 ft/d (1 x 10-7 cm/s). This hydraulic conductivity is consistent with likely values for the permeability of the barrier wall. The groundwater interceptor trench on the upgradient side of the Landfill was simulated using MODFLOW's Drain Package (a head-dependent boundary). Model runs incorporating the barrier wall and interceptor trench were conducted for evaluation of these remedial measures and are presented in Addendum 1 to the EDR.

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Appendix C Tables
Phase 1 Hydrogeologic Study Report

FINAL

Table C.1
Water Level Measurement Location Construction Details

Location	Monument Type	Diameter (inches)	Northing (ft. NAD 83/98)	Easting (ft. NAD 83/98)	Measuring Point Elevation (NAVD88)	Ground Surface Elevation (NAVD88)	Depth to Top of Screen (ft. bgs)	Depth to Bottom of Screen (ft. bgs)	Aquifer or Water Body
North End and Hylebos Creek									
PD-210	Above ground piezo	1	703817.762	1185259.758	19.154	15.714	8.00	18.00	Upper Sand
SG-210	Staff gauge	NA	703819.587	1185254.116	15.576	8.884	NA	NA	Hylebos Creek
PD-211	Above ground piezo	1	703281.052	1185150.092	16.774	13.994	6.00	16.00	Upper Sand
SG-211	Staff gauge	NA	703286.154	1185137.093	15.181	11.361	NA	NA	Hylebos Creek
PD-211TD	Above ground piezo	1	703285.856	1185137.236	16.880	11.361	NA	NA	Hylebos Creek
PD-200	Above ground piezo	1	703432.233	1185702.110	15.864	12.864	3.00	18.00	Upper Sand
PD-209A	Above ground well	2	702899.187	1185072.731	17.131	15.574	NA	NA	Upper Sand
PD-209B	Above ground well	2	702896.569	1185068.508	17.062	15.672	NA	NA	Unknown
Fife Way									
PD-201	Flush	1	703536.077	1187254.520	40.049	40.049	12.00	27.00	Upper Sand
PD-202	Flush	1	702529.017	1187128.079	56.305	56.305	4.00	24.00	Upper Sand
PD-65	Flush	1	701319.661	1186546.326	30.924	30.924	4.00	24.00	Upper Sand
PD-203	Flush	1	700959.817	1186418.866	37.896	37.896	5.00	25.00	Upper Sand
Autumn Village Apartments									
GW-1	Flush	2	701562.790	1186475.029	19.052	19.052	NA	NA	Upper Sand
GW-2	Flush	2	701449.977	1186364.768	18.754	18.754	NA	NA	Upper Sand
SG-217	Staff gauge	NA	701294.301	1186165.519	18.981	NA	NA	NA	Drainage Ditch
Wetlands Approach from 12th Street									
PD-204	Above ground well	2	702917.316	1186546.417	17.566	14.936	15.00	25.00	Upper Sand
PD-101	Above ground well	4	702916.209	1186071.438	17.011	14.150	7.00	22.00	Upper Sand
PD-70	Flush	2	702918.212	1186061.179	14.283	14.283	5.20	20.20	Upper Sand
PD-71	Flush	2	702923.295	1186058.151	14.410	14.410	5.00	20.00	Upper Sand
PD-120	Flush	1	702915.097	1185943.911	13.856	13.856	11.00	21.00	Upper Sand
PD-121	Flush	1	702915.554	1185934.462	13.934	13.934	11.00	21.00	Upper Sand
PD-122	Flush	1	702915.129	1185924.186	13.863	13.863	11.00	21.00	Upper Sand
PD-130	Above ground piezo	1	702935.618	1185819.200	15.187	12.802	12.00	22.00	Upper Sand
PD-131	Above ground piezo	1	702938.177	1185889.610	14.532	12.502	12.00	22.00	Upper Sand
PD-132	Above ground piezo	1	702939.626	1185948.769	15.352	12.942	11.00	21.00	Upper Sand
PD-105	Above ground piezo	2	702914.152	1185899.584	16.162	13.511	12.00	22.00	Upper Sand
PD-106	Above ground piezo	2	702914.618	1185953.824	16.742	14.156	11.00	21.00	Upper Sand
MW-31A	Above ground well	2	702917.222	1185835.899	16.482	14.057	17.00	22.00	Upper Sand
MW-31B	Above ground well	2	702916.222	1185840.565	16.322	14.057	35.00	40.00	Lower Sand
PD-4	Above ground piezo	1	702994.798	1185895.931	15.297	12.292	5.00	20.00	Upper Sand
PD-6	Above ground piezo	1	703003.140	1185989.093	15.642	12.812	6.00	21.00	Upper Sand
MW-16	Above ground well	2	702799.199	1186173.741	15.799	13.364	10.00	15.00	Upper Sand
MW-17	Above ground well	2	702857.742	1185983.458	15.197	12.472	10.00	15.00	Upper Sand
PD-1A	Above ground piezo	1	702948.758	1185729.253	16.167	12.667	5.00	7.50	Upper Sand
PD-1B	Above ground piezo	1	702948.583	1185725.946	15.732	12.617	8.00	13.00	Upper Sand
PD-1C	Above ground piezo	1	702948.550	1185722.528	15.932	12.617	13.00	18.00	Upper Sand

Table C.1
Water Level Measurement Location Construction Details

Location	Monument Type	Diameter (inches)	Northing (ft. NAD 83/98)	Easting (ft. NAD 83/98)	Measuring Point Elevation (NAVD88)	Ground Surface Elevation (NAVD88)	Depth to Top of Screen (ft. bgs)	Depth to Bottom of Screen (ft. bgs)	Aquifer or Water Body
Wetlands Approach from Interurban Trail									
D-1U	Above ground well	2	702581.1467	1186263.532	15.154	13.764	8.10	13.10	Upper Sand
D-1L	Above ground well	2	702586.7477	1186260.328	15.084	13.514	25.30	30.30	Lower Sand
D-5U	Above ground well	2	702321.4743	1185708.409	17.364	13.339	8.50	13.50	Upper Sand
D-5L	Above ground well	2	702330.3977	1185710.997	17.189	13.589	25.30	30.30	Lower Sand
SG-219	Staff gauge	NA	702316.6903	1185698.609	17.199	13.019	NA	NA	Wetlands Surface Water
D-6A	Above ground well	2	702465.581	1185996.456	14.128	13.094	10.00	15.00	Upper Sand
D-6B	Above ground well	2	702460.2	1185997.9	14.541	13.044	28.00	33.00	Lower Sand
MW-13	Above ground well	2	702573.9139	1186104.435	15.434	13.304	9.50	14.50	Upper Sand
SG-218	Staff gauge	NA	702575.8661	1186101.037	17.109	12.904	NA	NA	Wetlands Surface Water
MW-14	Above ground well	2	702656.6904	1185883.564	15.201	12.746	10.00	15.00	Upper Sand
MW-15	Above ground well	2	702717.8081	1186011.709	15.319	12.754	10.00	15.00	Upper Sand
SG-220	Staff gauge	NA	702721.0418	1186008.695	16.064	12.134	NA	NA	Wetlands Surface Water
PD-50	Above ground piezo	1	702820.1843	1185778.645	14.766	12.296	7.00	17.00	Upper Sand
SG-221	Staff gauge	NA	702813.4476	1185791.855	16.046	11.946	NA	NA	Wetlands Surface Water
PD-51	Above ground piezo	1	702695.0286	1185752.702	15.199	12.129	5.00	15.00	Upper Sand
PD-52A	Above ground piezo	1	702501.0168	1185675.209	15.044	12.499	5.00	7.50	Upper Sand
PD-52B	Above ground piezo	1	702497.9331	1185674.567	15.104	12.299	8.00	13.00	Upper Sand
PD-52C	Above ground piezo	1	702494.3809	1185673.518	15.039	12.389	14.00	19.00	Upper Sand
Ditch along Interrurban Trail									
MW-30	Flush	0.75	702394.4934	1186126.763	18.516	18.516	16.00	21.00	Upper Sand
SG-227	Staff gauge	NA	702411.5585	1186120.317	17.594	13.504	NA	NA	Drainage Ditch
PD-212	Above ground	1	702003.3593	1185274.184	17.791	15.461	4.70	19.70	Upper Sand
SG-212	Staff gauge	NA	702015.8783	1185267.173	15.79	11.481	NA	NA	Drainage Ditch
Landfill and Perimeter Area									
PD-107	Extraction Well	6	702223.955	1186121.226	32.769	30.579	19.00	33.70	Upper Sand
PD-109	Extraction Well	6	701795.046	1186484.494	30.667	28.916	18.00	28.00	Upper Sand
SUMP	Sump	12	702118.073	1186206.479	50.896	48.126	NA	NA	Fill
SG-224	Staff gauge	NA	702370.460	1186139.077	18.464	14.564	NA	NA	Stormwater Pond
D-7A	Above ground well	2	702190.9768	1185698.422	15.854	15.269	9.50	14.50	Upper Sand
D-7B	Above ground well	2	702196.2509	1185699.323	16.429	15.169	28.00	33.00	Lower Sand
D-8A	Above ground well	2	701886.3802	1185691.527	16.174	14.954	10.00	15.00	Upper Sand
D-8B	Above ground well	2	701881.042	1185691.089	16.179	14.784	28.00	33.00	Lower Sand
SG-214	Staff gauge	NA	701843.8845	1185681.476	17.299	13.084	NA	NA	Drainage Ditch
PD-214	Above ground	1	701842.8007	1185673.02	17.674	15.564	5.00	20.00	Upper Sand
PD-215	Above ground	1	701558.881	1185850.799	19.324	16.609	4.20	19.20	Upper Sand
SG-215	Staff gauge	NA	701573.7788	1185851.475	17.634	13.059	NA	NA	Drainage Ditch
D-9A	Above ground well	2	701581.3487	1186172.041	17.164	15.514	8.50	13.50	Upper Sand

Table C.1
Water Level Measurement Location Construction Details

Location	Monument Type	Diameter (inches)	Northing (ft. NAD 83/98)	Easting (ft. NAD 83/98)	Measuring Point Elevation (NAVD88)	Ground Surface Elevation (NAVD88)	Depth to Top of Screen (ft. bgs)	Depth to Bottom of Screen (ft. bgs)	Aquifer or Water Body
Area East of Landfill									
MW-11A	Above ground well	2	702114.962	1186710.323	19.890	17.925	10.00	15.00	Upper Sand
MW-11B	Above ground well	2	702110.806	1186706.361	19.934	17.985	25.00	30.00	Lower Sand
PD-60	Above ground piezo	1	701995.337	1186678.210	20.134	17.096	4.00	19.00	Upper Sand
PD-61	Above ground piezo	1	702087.890	1186909.415	27.291	24.215	4.50	17.00	Upper Sand
PD-62	Above ground piezo	1	701824.995	1186617.214	20.365	17.636	5.00	20.00	Upper Sand
PD-104	Above ground well	4	701841.895	1186655.373	18.761	16.952	5.00	20.00	Upper Sand
PD-63A	Above ground piezo	1	701673.909	1186543.412	19.751	16.729	5.00	7.50	Upper Sand
PD-63B	Above ground piezo	1	701681.257	1186548.409	18.848	16.771	8.00	13.00	Upper Sand
PD-63C	Above ground piezo	1	701677.691	1186546.219	19.503	16.749	15.00	20.00	Upper Sand
PD-64	Above ground piezo	1	701620.047	1186657.786	22.285	19.544	5.00	20.00	Upper Sand
PD-38	Above ground piezo	1	701806.207	1186803.104	21.635	18.998	5.00	20.00	Upper Sand
PD-40	Above ground piezo	1	701719.309	1186767.139	22.531	19.670	5.00	20.00	Upper Sand
MW-23	Above ground well	2	701768.884	1186707.686	20.474	17.264	7.28	17.28	Upper Sand
D-10A	Above ground well	2	701754.648	1186794.841	21.534	19.501	10.00	15.00	Upper Sand
PD-80	Above ground piezo	1	701659.555	1186590.030	20.361	16.932	5.00	20.00	Upper Sand
PD-81	Above ground piezo	1	701641.860	1186594.973	20.568	17.393	5.00	20.00	Upper Sand
PD-82	Above ground piezo	1	701641.322	1186613.563	20.447	17.373	5.00	20.00	Upper Sand
PD-103	Above ground well	4	701644.963	1186604.073	18.617	17.095	4.15	16.50	Upper Sand
Agricultural Fields and Ditches									
PD-216	Above ground	1	700921.424	1185663.481	20.449	17.364	2.50	17.50	Upper Sand
SG-216	Staff gauge	NA	700922.658	1185643.972	17.264	12.534	NA	NA	Surprise Lake Drain
PD-213	Above ground	1	701411.858	1185013.037	18.254	15.724	5.00	15.00	Upper Sand
SG-213	Staff gauge	NA	701412.808	1185002.323	16.114	11.574	NA	NA	Surprise Lake Drain
SG-225	Staff gauge	NA	701481.300	1184602.442	16.092	11.626	NA	NA	Surprise Lake Drain/ Drainage Ditch

Abbreviations:

bgs	Below ground surface
ft	Feet
NA	Not applicable or not available

Table C.2
Water Level Measurements

	October 2008			Transducer Install Event			November 2008			December 2008			January 2009			February 2009		
Location	Date Taken	Time	Water Level (DTW or stage height in feet)[1]	Date Taken	Time	Water Level (DTW or stage height in feet)[1]	Date Taken	Time	Water Level (DTW or stage height in feet)[1]	Date Taken	Time	Water Level (DTW or stage height in feet)[1]	Date Taken	Time	Water Level (DTW or stage height in feet)[1]	Date Taken	Time	Water Level (DTW or stage height in feet)[1]
North End and Hylebos Creek																		
PD-210	10/3/2008	NA	5.94	NA	NA	NA	11/6/2008	13:26	4.81	12/4/2008	10:56	5.46	1/16/2009	12:45	4.45	2/25/2009	13:20	5.40
SG-210	10/3/2008	10:40	0.98	NA	NA	NA	11/6/2008	13:26	2.58	12/4/2008	10:56	1.19	1/16/2009	12:45	2.11	2/25/2009	13:20	2.01
PD-211	10/3/2008	NA	4.15	10/30/2008	15:05	3.73	11/6/2008	13:34	2.87	12/4/2008	10:58	3.20	1/16/2009	12:58	2.40	2/25/2009	13:25	3.02
SG-211	10/3/2008	NA	1.85	NA	NA	NA	11/6/2008	13:35	2.68	12/4/2008	10:58	1.50	1/16/2009	12:57	2.39	2/25/2009	13:25	2.22
PD-211TD	NA	NA	NA	10/30/2008	15:56	4.20	11/6/2008	13:35	2.72	12/4/2008	NA	NA	1/16/2009	13:10	3.34	NA	NA	NA
PD-200	10/3/2008	NA	3.48	NA	NA	NA	11/6/2008	13:35	1.50	12/4/2008	11:07	2.32	1/16/2009	13:00	1.53	2/25/2009	14:00	2.50
PD-209A	NA	NA	NA	NA	NA	NA	NA	NA	NA	12/4/2008	11:00	3.6	1/16/2009	13:03	2.67	2/25/2009	13:00	3.52
PD-209B	NA	NA	NA	NA	NA	NA	NA	NA	NA	12/4/2008	11.02	2.73	1/16/2009	13:04	1.99	2/25/2009	13:00	2.4
Fife Way																		
PD-201	10/2/2008	NA	21.25	NA	NA	NA	11/6/2008	10:27	20.89	12/4/2008	11:29	19.95	1/15/2009	10:25	17.95	2/24/2009	14:23	19.95
PD-202	39724.0	NA	28.1	NA	NA	NA	39758.0	0.4	28.1	12/4/2008	11:36	28.9	1/15/2009	10:38	28.1	2/24/2009	14:26	28.12
PD-65	10/3/2008	NA	13.95	NA	NA	NA	11/6/2008	10:42	13.85	12/4/2008	11:50	13.36	1/15/2009	10:55	12.04	2/24/2009	14:36	12.54
PD-203	10/3/2008	NA	16.00	NA	NA	NA	11/6/2008	10:53	15.86	12/4/2008	11:59	15.66	1/15/2009	10:58	14.88	2/24/2009	14:42	15.40
Autumn Village Apartments																		
GW-1	NA	NA	NA	NA	NA	NA	11/7/2008	13:45	NA[2]	12/4/2008	11:41	1.50	1/15/2009	10:38	0.80	2/24/2009	14:11	1.08
GW-2	NA	NA	NA	NA	NA	NA	11/7/2008	13:57	NA[2]	12/4/2008	11:48	0.06	1/15/2009	10:44	0.62	2/24/2009	14:18	1.08
SG-217	NA	NA	NA	NA	NA	NA	11/6/2008	11:27	1.02	12/4/2008	11:42	1.20	1/15/2009	10:40	0.99	2/24/2009	14:15	0.73
Wetlands Approach from 12th Street																		
PD-204	10/2/2008	NA	4.24	NA	NA	NA	11/6/2008	9:05	3.73	12/4/2008	14:33	3.55	1/16/2009	10:30	2.72	2/24/2009	12:54	3.01
PD-101	10/2/2008	NA	5.00	NA	NA	NA	11/6/2008	9:10	3.83	12/4/2008	14:17	3.87	1/16/2009	10:40	2.32	2/24/2009	12:57	3.90
PD-70[4]	10/2/2008	NA	1.81	NA	NA	NA	11/6/2008	9:15	0.66[3]	12/4/2008	NA	NA	NA	NA	NA	NA	NA	NA
PD-71[4]	10/2/2008	NA	2.14	NA	NA	NA	11/6/2008	9:14	0.89	12/4/2008	NA	NA	NA	NA	NA	NA	NA	NA
PD-120[4]	NA	NA	NA	NA	NA	NA	11/6/2008	9:22	0.40[3]	12/4/2008	NA	NA	NA	NA	NA	NA	NA	NA
PD-121[4]	NA	NA	NA	NA	NA	NA	11/6/2008	9:20	0.45[3]	12/4/2008	NA	NA	NA	NA	NA	NA	NA	NA
PD-122[4]	NA	NA	NA	NA	NA	NA	11/6/2008	9:36	0.39	12/4/2008	NA	NA	NA	NA	NA	NA	NA	NA
PD-130	NA	NA	NA	NA	NA	NA	11/6/2008	10:02	1.98	12/4/2008	14:13	2.05	1/16/2009	11:00	1.36	2/24/2009	13:14	2.10
PD-131	NA	NA	NA	NA	NA	NA	11/6/2008	9:46	1.34	12/4/2008	14:14	0.04	1/16/2009	10:56	0.69	2/24/2009	13:05	1.35
PD-132	NA	NA	NA	NA	NA	NA	11/6/2008	9:40	2.19	12/4/2008	14:15	2.22	1/16/2009	10:47	1.56	2/24/2009	13:10	2.24
PD-105	10/1/2008	NA	4.29	NA	NA	NA	11/6/2008	9:44	2.97	12/4/2008	14:05	3.02	1/16/2009	10:51	2.33	2/24/2009	13:08	3.08
PD-106	10/1/2008	NA	4.83	NA	NA	NA	11/6/2008	9:47	3.58	12/4/2008	14:00	3.62	1/16/2009	10:46	2.95	2/24/2009	13:09	3.65
MW-31A	10/1/2008	NA	4.61	10/30/2008	14:04	4.10	11/6/2008	9:50	3.23	12/4/2008	14:10	3.23	1/16/2009	11:01	2.67	2/24/2009	13:10	3.40
MW-31B	10/1/2008	NA	2.83	10/30/2008	14:06	2.41	11/6/2008	9:53	1.95	12/4/2008	14:11	2.02	1/16/2009	11:02	1.37	2/24/2009	13:10	1.91
PD-4	10/2/2008	NA	3.41	NA	NA	NA	11/6/2008	10:20	2.08	12/4/2008	14:04	2.12	1/16/2009	11:00	1.51	2/24/2009	13:05	2.20
PD-6	10/2/2008	NA	3.73	NA	NA	NA	11/6/2008	10:25	2.43	12/4/2008	14:06	2.47	1/16/2009	10:56	1.85	2/24/2009	13:00	2.53
MW-16	10/2/2008	NA	3.38	NA	NA	NA	11/10/2008	10:28	1.03	12/4/2008	14:36	2.42	1/16/2009	10:46	1.85	2/24/2009	13:35	2.56
MW-17	10/1/2008	NA	3.30	NA	NA	NA	11/10/2008	10:08	0.63	12/4/2008	14:21	2.07	1/16/2009	11:17	1.57	2/24/2009	13:30	2.10
PD-1A	10/2/2008	NA	4.40	NA	NA	NA	11/6/2008	10:10	2.91	12/4/2008	13:59	2.96	1/16/2009	11:07	2.38	2/24/2009	13:15	3.03
PD-1B	10/2/2008	NA	3.96	NA	NA	NA	11/6/2008	10:12	2.55	12/4/2008	13:59	2.54	1/16/2009	11:08	1.95	2/24/2009	13:15	2.63
PD-1C	10/2/2008	NA	4.85	NA	NA	NA	11/6/2008	10:14	2.80	12/4/2008	14:00	2.75	1/16/2009	11:09	1.73	2/24/2009	13:15	2.82
Wetlands Approach from Interurban Trail																		
D-1U	9/29/2008	NA	3.27	NA	NA	NA	11/6/2008	16:21	2.41[2]	12/4/2008	13:43	0.82	1/15/2009	14:58	1.19	2/24/2009	12:50	2.01
D-1L	9/29/2008	NA	1.15	NA	NA	NA	11/6/2008	16:20	0.35	12/4/2008	13:43	0.42	1/15/2009	14:58	NA[2]	2/24/2009	12:50	0.03
D-5U	9/29/2008	NA	5.00	NA	NA	NA	11/6/2008	15:19	4.06	12/4/2008	12:57	3.99	1/15/2009	18:34	3.30	2/24/2009	11:20	4.08
D-5L	9/29/2008	NA	3.65	NA	NA	NA	11/6/2008	15:18	2.60	12/4/2008	12:58	2.82	1/15/2009	13:38	1.76	2/24/2009	11:20	2.53
SG-219	10/1/2008	NA	0.00	NA	NA	NA	11/6/2008	15:19	0.00	12/4/2008	12:56	NA	1/15/2009	13:35	0.74	2/24/2009	11:20	0.00
D-6A	9/29/2008	NA	1.95	10/30/2008	11:51	1.51	11/6/2008	15:00	1.06	12/4/2008	13:24	0.86	1/15/2009	10:15	0.35	2/24/2009	12:10	0.96
D-6B	9/29/2008	NA	0.80	10/30/2008	11:53	0.58	11/6/2008	15:05	NA[2]	12/4/2008	13:23	0.25	1/15/2009	10:14	NA[2]	2/24/2009	12:10	0.0 [2]
MW-13	9/30/2008	NA	3.49	NA	NA	NA	11/6/2008	16:00	3.80	12/4/2008	13:29	2.23	1/15/2009	14:41	1.49	2/24/2009	12:40	2.31
SG-218	10/2/2008	NA	0.00	NA	NA	NA	11/6/2008	13:00	0.00	12/4/2008	13:29	0.04	1/15/2009	14:41	0.81	2/24/2009	12:40	0.02
MW-14	10/2/2008	NA	2.96	NA	NA	NA	11/10/2008	10:47	0.75	12/4/2008	13:15	1.40	1/15/2009	14:25	1.37	2/24/2009	11:50	1.70

Table C.2
Water Level Measurements

	October 2008			Transducer Install Event			November 2008			December 2008			January 2009			February 2009		
Location	Date Taken	Time	Water Level (DTW or stage height in feet)[1]	Date Taken	Time	Water Level (DTW or stage height in feet)[1]	Date Taken	Time	Water Level (DTW or stage height in feet)[1]	Date Taken	Time	Water Level (DTW or stage height in feet)[1]	Date Taken	Time	Water Level (DTW or stage height in feet)[1]	Date Taken	Time	Water Level (DTW or stage height in feet)[1]
MW-15	10/1/2008	NA	3.39	NA	NA	NA	11/10/2008	10:00	0.75	12/4/2008	13:28	2.20	1/15/2009	14:46	1.40	2/25/2009	9:00	2.09
SG-220	10/2/2008	NA	0	NA	NA	NA	11/10/2008	10:00	2.57	12/4/2008	13:16	1.10	1/15/2009	14:38	1.89	2/25/2009	9:00	1.09
PD-50	10/2/2008	NA	2.95	NA	NA	NA	11/6/2008	15:20	1.75	12/4/2008	13:05	1.65	1/15/2009	14:10	0.75	2/24/2009	11:26	1.71
SG-221	10/2/2008	NA	0	NA	NA	NA	11/10/2008	15:23	0.92	12/4/2008	13:05	1.10	1/15/2009	14:10	1.88	2/24/2009	11:26	0.00
PD-51	10/2/2008	NA	3.49	NA	NA	NA	11/6/2008	15:22	2.24	12/4/2008	13:00	2.70	1/15/2009	14:06	1.24	2/24/2009	11:41	2.12
PD-52A	10/2/2008	NA	3.32	NA	NA	NA	11/6/2008	15:25	2.07	12/4/2008	13:06	1.86	1/15/2009	13:48	0.70	2/24/2009	11:26	1.92
PD-52B	10/2/2008	NA	3.33	NA	NA	NA	11/6/2008	15:25	2.17	12/4/2008	13:05	1.90	1/15/2009	13:48	1.14	2/24/2009	11:26	1.96
PD-52C	10/2/2008	NA	3.23	NA	NA	NA	11/6/2008	15:26	1.99	12/4/2008	13:03	1.81	1/15/2009	13:47	1.05	2/24/2009	11:26	1.87
Ditch along Interurban Trail																		
MW-30	10/1/2008	NA	5.65	NA	NA	NA	11/6/2008	14:35	4.76	12/4/2008	13:38	4.26	1/15/2009	14:37	0.39	2/24/2009	11:15	0.01
SG-227	10/2/2008	NA	0.00	NA	NA	NA	11/6/2008	14:35	0.90	12/4/2008	13:36	0.59	1/15/2009	14:35	0.81	2/242009	11:13	0.68
PD-212	10/3/2008	NA	4.59	NA	NA	NA	11/6/2008	14:59	3.35	12/4/2008	12:47	3.90	1/15/2009	12:54	3.25	2/25/2009	14:05	3.71
SG-212	10/2/2008	NA	0.75	NA	NA	NA	11/6/2008	14:56	1.49	12/4/2008	12:48	0.87	1/15/2009	12:53	1.10	2/25/2009	14:05	0.80
Landfill and Perimeter Area																		
PD-107	10/2/2008	NA	19.28	10/30/2008	11:05	18.76	11/6/2008	11:43	18.47	12/4/2008	9:33	17.85	1/16/2009	9:32	17.17	2/24/2009	9:45	17.51
PD-109	10/2/2008	NA	15.26	10/30/2008	9:55	14.97	11/6/2008	11:26	15.04	12/4/2008	9:21	14.94	1/16/2009	9:13	14.46	2/24/2009	9:37	14.26
SUMP	NA	NA	NA	NA	NA	NA	11/6/2008	12:40	35.65	12/4/2008	9:28	35.54	1/15/2009	9:42	35.13	2/242009	9:42	35.08
SG-224	NA	NA	NA	NA	NA	NA	11/6/2008	11:05	1.40	12/4/2008	9:27	NA	1/15/2009	9:47	NA	2/24/2009	9:50	NA
D-7A	9/30/2008	NA	3.00	NA	NA	NA	11/6/2008	11:57	2.05	12/4/2008	9:44	2.19	1/15/2009	9:52	1.75	2/24/2009	9:58	2.19
D-7B	9/30/2008	NA	2.82	NA	NA	NA	11/6/2008	11:58	3.16	12/4/2008	9:45	2.41	1/15/2009	9:54	2.10	2/24/2009	10:00	2.19
D-8A	9/30/2008	NA	2.50	10/30/2008	13:34	2.09	11/6/2008	11:56	1.27	12/4/2008	9:20	1.65	1/16/2009	9:43	1.35	2/24/2009	10:04	1.68
D-8B	9/30/2008	NA	2.38	10/30/2008	13:37	2.08	11/6/2008	11:57	1.27	12/4/2008	9:22	1.68	1/16/2009	9:47	1.32	2/24/2009	10:04	1.67
SG-214	10/2/2008	NA	0.90	NA	NA	NA	11/6/2008	12:07	1.05	12/4/2008	9:55	0.83	1/15/2009	9:59	0.90	2/24/2009	10:04	0.72
PD-214	10/3/2008	NA	3.81	NA	NA	NA	11/6/2008	12:06	2.76	12/4/2008	9:58	3.19	1/15/2009	10:00	2.78	2/24/2009	10:06	3.17
PD-215	10/3/2008	NA	4.84	NA	NA	NA	11/6/2008	12:10	3.75	12/4/2008	10:03	4.26	1/15/2009	10:09	3.83	2/24/2009	10:28	4.22
SG-215	10:00	NA	0.98	NA	NA	NA	11/6/2008	12:10	1.30	12/4/2008	10:04	1.17	1/15/2009	10:09	1.20	2/24/2009	10:30	0.90
D-9A	9/30/2008	NA	2.45	NA	NA	NA	11/6/2008	12:20	1.30	12/4/2008	9:58	1.59	1/15/2009	10:10	1.21	2/24/2009	10:35	1.52
Area East of Landfill																		
MW-11A	9/29/2008	NA	3.52	NA	NA	NA	11/6/2008	9:05	3.54	12/4/2008	9:00	3.06	1/15/2009	9:20	1.84	2/24/2009	11:10	2.25
MW-11B	9/29/2008	NA	3.70	NA	NA	NA	11/6/2008	9:05	3.60	12/4/2008	8:59	3.13	1/15/2009	9:19	1.90	2/24/2009	11:08	2.32
PD-60	10/2/2008	NA	4.80	NA	NA	NA	11/6/2008	9:15	4.56	12/4/2008	8:56	4.09	1/15/2009	9:16	3.26	2/24/2009	9:15	2.97
PD-61	10/2/2008	NA	10.83	NA	NA	NA	11/6/2008	9:21	10.72	12/4/2008	9:03	10.24	1/15/2009	9:24	8.96	2/24/2009	9:20	9.41
PD-62	10/2/2008	NA	4.91	NA	NA	NA	11/6/2008	9:02	4.70	12/4/2008	8:54	4.32	1/15/2009	9:07	3.62	2/24/2009	9:02	3.40
PD-104	10/2/2008	NA	3.33	NA	NA	NA	11/6/2008	10:05	3.11	12/4/2008	8:56	2.71	1/15/2009	9:12	2.00	2/24/2009	9:10	1.76
PD-63A	10/2/2008	NA	4.11	NA	NA	NA	11/6/2008	9:41	3.86	12/4/2008	8:33	3.58	1/15/2009	9:11	2.91	2/24/2009	9:05	2.98
PD-63B	10/2/2008	NA	3.18	NA	NA	NA	11/6/2008	9:42	2.91	12/4/2008	8:30	2.65	1/15/2009	9:14	1.96	2/24/2009	9:00	2.10
PD-63C	10/2/2008	NA	3.33	NA	NA	NA	11/6/2008	9:42	3.32	12/4/2008	8:32	2.84	1/15/2009	9:13	2.05	2/24/2009	9:02	2.15
PD-64	10/2/2008	NA	6.11	NA	NA	NA	11/6/2008	9:57	6.05	12/4/2008	8:51	5.59	1/15/2009	9:17	4.49	2/24/2009	9:10	4.71
PD-38	10/2/2008	NA	5.31	NA	NA	NA	11/6/2008	9:37	5.00	12/4/2008	8:46	4.67	1/15/2009	9:29	3.40	2/24/2009	9:16	3.79
PD-40	10/2/2008	NA	6.28	NA	NA	NA	11/6/2008	9:07	5.95	12/4/2008	8:44	5.60	1/15/2009	9:24	4.32	2/24/2009	9:12	4.61
MW-23	9/30/2008	NA	4.80	NA	NA	NA	11/6/2008	9:39	4.36	12/4/2008	8:49	3.91	1/15/2009	9:25	3.20	2/24/2009	9:15	2.91
D-10A	9/29/2008	9:10	5.12	10/30/2008	11:24	5.10	11/6/2008	11:06	4.79	12/4/2008	9:06	4.56	1/16/2009	10:01	3.21	2/24/2009	9:17	3.66
PD-80[4]	10/3/2008	NA	4.49	NA	NA	NA	11/6/2008	10:15	4.24	12/4/2008	8:41	3.92	NA	NA	NA	NA	NA	NA
PD-81[4]	10/3/2008	NA	4.63	NA	NA	NA	11/6/2008	10:17	4.40	12/4/2008	8:43	4.51	NA	NA	NA	NA	NA	NA
PD-82[4]	10/3/2008	NA	4.40	NA	NA	NA	11/6/2008	10:18	4.22	12/4/2008	8:50	3.86	NA	NA	NA	NA	NA	NA
PD-103	10/3/2008	NA	2.66	NA	NA	NA	11/6/2008	10:20	2.34	12/4/2008	8:45	2.05	1/15/2009	9:15	1.21	2/24/2009	9:07	1.35

Table C.2
Water Level Measurements

	October 2008			Transducer Install Event			November 2008			December 2008			January 2009			February 2009		
Location	Date Taken	Time	Water Level (DTW or stage height in feet)[1]	Date Taken	Time	Water Level (DTW or stage height in feet)[1]	Date Taken	Time	Water Level (DTW or stage height in feet)[1]	Date Taken	Time	Water Level (DTW or stage height in feet)[1]	Date Taken	Time	Water Level (DTW or stage height in feet)[1]	Date Taken	Time	Water Level (DTW or stage height in feet)[1]
Agricultural Fields and Ditches																		
PD-216	10/3/2008	NA	4.83	NA	NA	NA	11/6/2008	12:49	3.80	12/4/2008	10:15	4.35	1/15/2009	11:11	4.00	2/25/2009	11:08	4.16
SG-216	10/3/2008	13:40	0.72	NA	NA	NA	11/6/2008	12:49	1.72	12/4/2008	10:15	0.77	1/15/2009	11:10	3.55	2/25/2009	11:08	1.85
PD-213	10/3/2008	14:00	7.78	NA	NA	NA	11/6/2008	13:05	4.19	12/4/2008	10:25	4.88	1/15/2009	11:15	4.25	2/25/2009	11:30	4.73
SG-213	10/3/2008	9:30	0.14	NA	NA	NA	11/6/2008	13:05	1.28	12/4/2008	10:23	0.29	1/15/2009	11:15	0.92	2/25/2009	11:30	0.40
SG-225	10/3/2008	14:50	0.5	NA	NA	NA	11/6/2008	13:12	1.55	12/4/2008	10:33	0.16	1/15/2009	11:32	0.52	2/25/2009	11:40	0.25

Notes:

1 For wells and piezometers, water levels are depth to water from the measuring point. Staff gauge measurements are reported as distance from the bottom of the gauge (not necessarily ground surface).
2 Water level not consistent and unable to be accurately measured due to rapidly rising water level and/or water level rising above the measuring point.
3 Water level approximate due to instrument limitations; depth to water was less than 1 foot.
4 Locations were intended for other predesign data collection and were removed from the regular monitoring network due to redundancy.

Abbreviations:

DTW Depth to water
NA Not applicable or not available

Table C.3
Discharge Estimates (cfs)[1]

Location	October 2008	February 2009
Hylebos Creek		
SG-210	5.860	21.070
SG-211	6.090	22.380
Ditch System		
SG-212	0.126	0.239
SG-214	0.167	0.256
SG-215	0.033	0.190
Surprise Lake Drain		
SG-216	0.757	1.505
SG-213	0.555	1.789
Ditch System and Surprise Lake Drain		
SG-225	0.429	2.826

Note:

1 The difference between stations SG-212/SG-213 and SG-225 is assumed to be within the margin of error for discharge measurements and does not indicate the reach is a losing stream.

Abbreviations:

cfs Cubic feet per second

Table C.4
Pumping Test Results

Observation Well	Pumping Well	S[1]	T[1]	b[2]	K_h[3]		Solution
			ft²/day	ft	ft/day	cm/s	
PD-104	PD-104	NA	5.039	17	0.30	1.04E-04	Theis Recovery
PD-62	PD-104	NA	181.6	17	10.68	3.74E-03	Theis Recovery
PD-62	PD-104	0.0012	98.28	17	5.78	2.02E-03	Theis
PD-70	PD-101	NA	1961	21	93.38	3.27E-02	Theis Recovery
PD-70	PD-101	NA	1131	21	53.86	1.89E-02	Theis
FS-22	MW-17	NA	4230	19	222.63	7.79E-02	Theis Recovery
FS-22	MW-17	0.026	3405	19	179.21	6.27E-02	Theis

Notes:

1 Values for S, T from pump test solutions (refer to attachment C.2).
2 Values for b from boring logs and water level measurements.
3 Values for K_h (ft/day) calculated using $T = K_h*b$.

Abbreviations:

b	Saturated zone thickness
cm/s	Centimeters per second
ft	Feet
K_h	Horizontal hydraulic conductivity
S	Storativity
T	Transmissivity

Table C.5
Infiltration Test Results

Time	DTW (feet)[1] Basin Wall	DTW (feet)[1] Staff Gauge	Elapsed time (minutes)	Comments
Pre-test Measurements				
10:48	0.96	3.07	NA	Static water from pre-test overnight saturation.
10:58	0.96	3.07	NA	
11:08	0.96	3.07	NA	
11:19	0.96	3.07	NA	
11:28	0.96	3.07	NA	
11:38	0.96	3.07	NA	
11:46	0.96	3.07	NA	
Basin-flooding Measurements				
12:37	0.63	2.74	0	Initial readings after refilling basin.
12:40	0.63	2.74	3.0	
12:46	0.63	2.74	9	
12:53	0.63	2.74	16	
13:02	0.64	2.76	25	Level readings after observing small leak in basin near sheeting overlap at 13:02.
13:12	0.65	2.77	35	
13:16	0.665	2.775	39	
13:20	0.665	2.78	43	
13:25	0.67	2.785	48	
13:30	0.675	2.79	53	
13:35	0.68	2.80	58	
13:40	0.685	2.80	63	
13:45	0.695	2.81	68	
13:50	0.70	2.82	73	Level readings following repair with bentonite which reduced leakage rate.
13:55	0.71	2.82	78	
14:00	0.715	2.825	83	
14:05	0.715	2.825	88	
14:15	0.72	2.83	98	
14:25	0.73	2.84	108	
14:35	0.735	2.85	118	
14:50	0.745	2.86	133	
15:01	0.755	2.87	144	
15:15	0.765	2.88	158	
15:30	0.775	2.89	173	

Notes:

1 Water levels were measured from graduated marks on basin sheeting wall and central staff gauge for redundancy.

Abbreviations:

DTW	Depth to water
NA	Not applicable or not available

Table C.6
Steady-state Calibration Targets, Target Values, and Target Hydrostratigraphic Units

Well ID	Target Value (feet)	Hydrostratigraphic Unit	Simulated Groundwater Elevation (feet)	Residual (feet)
D-1U	12.99	Upper Sand Aquifer	14.03	-1.04
D-1L	14.44	Lower Sand Aquifer	14.77	-0.33
D-5U	13.01	Upper Sand Aquifer	13.70	-0.69
D-5L	14.17	Lower Sand Aquifer	13.96	0.21
D-6A	12.84	Upper Sand Aquifer	13.99	-1.15
D-6B	14.02	Lower Sand Aquifer	14.40	-0.38
D-7A	13.44	Upper Sand Aquifer	13.69	-0.25
D-7B	13.63	Lower Sand Aquifer	13.95	-0.32
D-8A	14.37	Upper Sand Aquifer	14.12	0.25
D-8B	14.40	Lower Sand Aquifer	14.14	0.26
D-9A	15.38	Upper Sand Aquifer	15.22	0.16
D-10A	16.71	Upper Sand Aquifer	17.23	-0.52
D-11A	16.52	Upper Sand Aquifer	16.08	0.44
D-11B	16.46	Lower Sand Aquifer	16.06	0.40
MW-13	12.26	Upper Sand Aquifer	13.96	-1.70
MW-14	13.50	Upper Sand Aquifer	13.54	-0.04
MW-15	13.21	Upper Sand Aquifer	13.83	-0.62
MW-16	13.52	Upper Sand Aquifer	13.93	-0.41
MW-17	13.20	Upper Sand Aquifer	13.72	-0.52
MW-23	16.12	Upper Sand Aquifer	16.95	-0.83
MW-30	13.63	Upper Sand Aquifer	14.10	-0.47
MW-31A	12.79	Upper Sand Aquifer	13.46	-0.67
MW-31B	14.06	Lower Sand Aquifer	13.37	-0.65
PD-1B	12.72	Upper Sand Aquifer	14.26	-0.20
PD-4	13.20	Upper Sand Aquifer	13.51	-0.31
PD-6	12.77	Upper Sand Aquifer	13.62	-0.85
PD-38	16.64	Upper Sand Aquifer	17.03	-0.39
PD-40	16.59	Upper Sand Aquifer	17.34	-0.75
PD-50	12.65	Upper Sand Aquifer	13.39	-0.74
PD-51	12.39	Upper Sand Aquifer	13.35	-0.96
PD-52B	12.64	Upper Sand Aquifer	13.31	-0.67
PD-60	15.65	Upper Sand Aquifer	16.12	-0.47
PD-61	16.69	Upper Sand Aquifer	17.14	-0.45
PD-62	15.72	Upper Sand Aquifer	16.23	-0.51
PD-63B	15.93	Upper Sand Aquifer	16.45	-0.52
PD-64	16.37	Upper Sand Aquifer	17.07	-0.70
PD-65	17.20	Upper Sand Aquifer	17.48	-0.28
PD-70	13.05	Upper Sand Aquifer	13.76	-0.72
PD-71	12.90	Upper Sand Aquifer	13.76	-0.86
PD-80	16.14	Upper Sand Aquifer	16.93	-0.79
PD-81	16.05	Upper Sand Aquifer	16.96	-0.91
PD-82	16.29	Upper Sand Aquifer	16.98	-0.69
PD-101	12.78	Upper Sand Aquifer	13.78	-1.00
PD-103	16.27	Upper Sand Aquifer	16.97	-0.70
PD-104	15.71	Upper Sand Aquifer	16.43	-0.72
PD-105	12.74	Upper Sand Aquifer	13.53	-0.79
PD-106	12.73	Upper Sand Aquifer	13.63	-0.90
PD-107	14.23	Upper Sand Aquifer	14.47	-0.24
PD-109	15.59	Upper Sand Aquifer	15.66	-0.07
PD-200	13.43	Upper Sand Aquifer	13.77	-0.34
PD-201	19.35	Upper Sand Aquifer	19.43	-0.08
PD-202	28.00	Upper Sand Aquifer	27.27	0.73
PD-203	22.05	Upper Sand Aquifer	22.23	-0.18
PD-204	13.73	Upper Sand Aquifer	14.45	-0.72
PD-209A	13.53	Upper Sand Aquifer	13.26	0.27
PD-210	13.75	Upper Sand Aquifer	13.59	0.16
PD-211	13.37	Upper Sand Aquifer	13.12	0.25
PD-212	13.84	Upper Sand Aquifer	13.27	0.57
PD-213	12.64	Upper Sand Aquifer	12.61	0.03
PD-214	14.42	Upper Sand Aquifer	14.16	0.26
PD-215	15.04	Upper Sand Aquifer	14.74	0.30
PD-216	16.12	Upper Sand Aquifer	15.10	1.02

Table C.7
Steady-state Model Calibration Statistics

Calibration Statistic	Value
Residual Mean (RM)	-0.37 (ft)
Absolute Residual Mean (ARM)	0.54 (ft)
Resdiual Standard Deviation (RSD)	0.50 (ft)
Residual Sum of Squares (RSS)	24.5 (ft^2)
RSD / Total Head Change	0.032 (unitless)

Abbreviation:

ft	Feet