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ATTACHMENT

Attachment A. Slug Test Analyses.
1 Introduction

The Horseman’s Trail Planned Residential Development (PRD) is a 112-lot subdivision proposed on a site located near Mukilteo (Township 28N Range 4E Sections 32 and 33), within the Snohomish County Urban Growth Area. The site occupies 23 acres south of Picnic Point Road and north of 136th Place SW. The property is forested with mature second growth coniferous and deciduous trees and has considerable topographic relief. This report has been prepared in support of the Draft Environmental Impact Statement for the PRD proposal (Snohomish County Planning and Development Services 2008).

The objective of the studies described in this report is to identify potential impacts to groundwater conditions from the proposed development. The report is based on investigations and observations at the site by Associated Earth Sciences, Inc. (1998, 2005, 2006a and 2006b), supplemented by additional borings, field and laboratory tests (Anthony Burgess Consulting 2013a), and groundwater modeling.

2 Geology and Hydrostratigraphy

2.1 Investigations

Subsurface conditions of the Horseman’s Trail site have been explored by three monitoring wells (MW) to observe groundwater conditions, and by six borings (EB), and 28 exploration pits (EP) to evaluate geologic conditions and infiltration properties. Details, including logs, are presented in reports prepared by Associated Earth Sciences Inc (1998, 2005, 2006a, 2006b), and Anthony Burgess Consulting (2013a). The locations of these investigations are shown on Figure 2-1. The borings and monitoring wells were completed to depths of up to 218 feet below ground surface. The test pits were excavated with a track-mounted hydraulic excavator to depths ranging between 4 and 17 feet below ground surface, and were backfilled with the excavated material after logging.

2.2 Recessional Outwash

The recessional outwash is typically sand and gravel, deposited by glacial meltwater during the retreat of the most recent glaciation. On the Horseman’s Trail site, this unit is thin, and has been identified only in EP-17 in the southeastern part of the site (AISI 2005). No groundwater was encountered during the excavation of this exploration pit.

2.3 Vashon Till

The Vashon till is the most widespread near-surface glacial deposit underlying the site upland and surrounding area. It is a dense silty sand with gravel and cobbles. The till is an aquitard, restricting the downward movement of infiltrating water. However, the upper 3 to 5 feet are typically weathered, and root growth and other near-surface processes result in an increased permeability in this zone.
2.4 Advance Outwash (Qva)

The advance outwash directly underlies the Vashon till, and was deposited by meltwaters in advance of the Vashon glaciation about 15,000 years ago. It is typically sand with variable amounts of silt and gravel. On the Horseman’s Trail site, the full thickness of the advance outwash was encountered in MW-1, extending from 43 feet below ground surface (bgs) to 216 feet bgs, for a total thickness of 173 feet. The base of the advance outwash was encountered at elevation 237 feet msl. Monitoring well MW-3, located on 61st Avenue West (adjacent to Horseman’s Trail to the north) encountered only pre-Vashon deposits that underlie the advance outwash. Ground surface at this location is about elevation 240 feet msl. The base of the advance outwash on Horseman’s Trail, about 200 feet to the south of the monitoring well, is therefore above this elevation. Exploration boring EB-6 was terminated in fine sand at elevation 237.5 feet msl due to heaving sand in the boring. This is interpreted as indicating that the boring extended below the water table, and that the final depth was at or close to the base of the advance outwash and the less-permeable underlying pre-Vashon sediments. Based on these borehole data, the base of the advance outwash appears to be nearly constant across the Horseman’s Trail property, between elevation 237 feet msl and elevation 240 feet msl.

2.5 Pre-Vashon Deposits

A series of glacial and non-glacial deposits underlie the Vashon glacial sequence. The uppermost sequence encountered in MW-3 consists of silty sand with silt seams, resulting in a lower permeability than the overlying advance outwash. The pre-Vashon deposits restrict the downward movement of groundwater which results in the lateral flow of groundwater in the advance outwash.

3 Groundwater Observations

Groundwater level observations have been collected since March 2006 using a manual water level probe. In addition, pressure transducers with data loggers were installed in the monitoring wells to provide continuous readings of water levels over selected periods. Figures 3-1, 3-2 and 3-3 present the data graphically for MW-1, MW-2 and MW-3, respectively.

The water level in monitoring well MW-1, located near the southern property boundary and screened in the advance outwash, has shown a gradual increase of about one foot over the period of observation. This is consistent with other observations in the Puget Sound area that have shown groundwater levels rising following a period of below-normal rainfall from 2000 to 2005. The water level has shown seasonal fluctuation of 0.1 to 0.2 foot, being highest in summer, and lowest in the late fall and winter. This is about six months out of phase with the precipitation, which is highest in the late fall and winter, and lowest in summer. Short-term fluctuations (of the order of a few days) have been up to 0.6 foot in response to significant precipitation events.

Monitoring well MW-2, also screened in the advance outwash and located near the northern property boundary, has shown similar water level
fluctuations to MW-1. The increase in water level over the period of observation has been about 0.8 foot, with a seasonal fluctuation of up to 0.4 foot that lags the precipitation cycle by 2 to 4 months. This well does not exhibit short-term fluctuation.

Monitoring well MW-3 is located off site to the north in Regatta Estates, and is screened in the pre-Vashon sediments underlying the advance outwash. It also shows an increase in groundwater level of about 0.8 foot over the period of observation. It shows medium-term fluctuations (on the order of a few weeks) up to one foot, which is significantly greater than observed in the wells screened in the advance outwash. The seasonal fluctuation lags the precipitation cycle by 1 to 2 months. Since the end of May 2008, the water level has shown a consistent decline that correlates with construction activities at the wastewater treatment plant that have included excavation dewatering.

4 Aquifer Properties

4.1 Field Tests

Slug tests were performed in the monitoring wells on April 18, 2008. The data were analyzed using the Bouwer-Rice method (Bouwer and Rice 1976) implemented in the software AQTESOLV Version 3.50 (HydroSOLVE 2003). Data plots and analyses are provided in Attachment A, and the results are summarized in Table 4-1.

Table 4-1. Estimates of hydraulic conductivity from slug tests.

<table>
<thead>
<tr>
<th>Location</th>
<th>Stratum</th>
<th>Test Method</th>
<th>Hydraulic Conductivity (ft/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MW-1</td>
<td>Advance outwash</td>
<td>Slug</td>
<td>1.5 to 2.1</td>
</tr>
<tr>
<td>MW-2</td>
<td>Advance outwash</td>
<td>Slug</td>
<td>0.6 to 3.6</td>
</tr>
<tr>
<td>MW-3</td>
<td>Pre-Vashon</td>
<td>Slug</td>
<td>0.5 to 0.8</td>
</tr>
</tbody>
</table>

4.2 Laboratory Tests

The ability of soil to transmit water is termed the hydraulic conductivity. The term permeability is often used synonymously for hydraulic conductivity, although groundwater scientists differentiate between the two terms. Estimates of the hydraulic conductivity of permeable soils can be made from laboratory grain size analyses. The Stormwater Manual for Western Washington (SMWW) published by the Department of Ecology (2005) provides a method (Volume III page 3-89 Equation 1) that can be used to estimate the saturated hydraulic conductivity ($K_{sat}$).

$$\log_{10}(K_{sat}) = -1.57 + 1.90D_{10} + 0.15D_{60} -0.13D_{90} – 2.08f_{\text{fin}}$$

where $D_{10}$, $D_{60}$, and $D_{90}$ are the grain sizes in millimeters (mm) for which 10 percent, 60 percent and 90 percent of the sample is more fine; $f_{\text{fin}}$ is the fraction of the soil by weight that passes the number-200 sieve; and $K_{sat}$ is in
units of cm/sec. The estimates of hydraulic conductivity for the advance outwash are summarized in Table 4-2.

Table 4-2. Estimates of hydraulic conductivity of the advance outwash from laboratory test data.

<table>
<thead>
<tr>
<th>Location</th>
<th>EB-1</th>
<th>EB-2</th>
<th>MW-2</th>
<th>EB-3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth (ft)</td>
<td>15.0</td>
<td>12.5</td>
<td>12.5</td>
<td>15.0</td>
</tr>
<tr>
<td>Equation 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D10 (mm)</td>
<td>0.13</td>
<td>0.03</td>
<td>0.12</td>
<td>0.02</td>
</tr>
<tr>
<td>D60 (mm)</td>
<td>0.57</td>
<td>1.08</td>
<td>0.5</td>
<td>0.46</td>
</tr>
<tr>
<td>D90 (mm)</td>
<td>3</td>
<td>9</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Fraction fines</td>
<td>0.074</td>
<td>0.15</td>
<td>0.079</td>
<td>0.163</td>
</tr>
<tr>
<td>K (ft/day)</td>
<td>88</td>
<td>34</td>
<td>80</td>
<td>37</td>
</tr>
<tr>
<td>Table 3.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>texture</td>
<td>sand</td>
<td>loamy sand</td>
<td>sand</td>
<td>loamy sand</td>
</tr>
<tr>
<td>K (ft/day)</td>
<td>16</td>
<td>4</td>
<td>16</td>
<td>4</td>
</tr>
<tr>
<td>Table 3.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D10</td>
<td>0.13</td>
<td>0.03</td>
<td>0.12</td>
<td>0.02</td>
</tr>
<tr>
<td>K (ft/day)</td>
<td>4.6</td>
<td>1</td>
<td>4.4</td>
<td>0.8</td>
</tr>
</tbody>
</table>

A laboratory measurement of the hydraulic conductivity of compacted Vashon till, representative of potential fill material was made using the falling head permeameter method. The hydraulic conductivity was calculated to be $3.9 \times 10^{-6}$ cm/sec (0.011 ft/day).

4.3 Flow Systems

4.3.1 Existing Conditions

A schematic of the recharge system under existing conditions is shown in Figure 4-1 and site geology is shown on Figure 4-2. The Horseman’s Trail site receives an annual average of about 37 inches of precipitation. Under existing conditions, about half of the precipitation evaporates or is transpired by the forest cover on the site. Nearly all of the remainder infiltrates to become groundwater recharge. A small amount of runoff and interflow occurs locally, but at the scale of the site, nearly all runoff infiltrates in a short period of time. In the area underlain by till, infiltrating water moves vertically downward through the weathered till. The underlying unweathered till is less permeable than the overlying weathered section. This causes some of the infiltrating water to move laterally, while the remainder enters the unweathered till and slowly leaks downwards to the underlying advance outwash. Water moving along the interface between the unweathered and weathered till enters the advance outwash where the till is eroded along the valley or ravine. In the permeable sand and gravel outwash, the infiltrating water moves downward until it reaches the water table. There is no evidence on the site of groundwater seeps, with the potential for surface erosion and/or instability, on natural slopes at the top of the unweathered till. This indicates that all of the infiltration enters the advance outwash.
Groundwater flow systems reflect the pattern of recharge (where water enters the system) and discharge (where water leaves the system). Groundwater flow in the advance outwash is from south to north and northwest, based on observations in monitoring wells. The aquifer is recharged by vertical flow of infiltration ("leakage") through the till, and by direct infiltration where the advance outwash is near the ground surface. In water table aquifers, local groundwater basins and flow patterns and typically reflect surface topography. Based on this premise, the groundwater divide is expected to run east-west, approximately aligned with 140th Street SW, which is midway between the Picnic Point Creek and Norma Creek drainage to the south. Surface water discharge from the advance outwash is to the wetland adjacent to the northwest corner of the site. The advance outwash also loses water by downward leakage into the less-permeable pre-Vashon deposits, and by lateral flow into the geologically recent valley alluvium, particularly within the side valley in which Picnic Point Road was constructed, in the area of Regatta Estates.

4.3.2 Developed Conditions
Grading of the site will result in exposure of advance outwash in some areas that were previously capped by till, and filling with excavated soil over some areas where outwash was exposed. Projected soil conditions following grading are shown in Figure 4-3. Recharge over the site area will be predominantly in the areas underlain by outwash, where infiltration will occur from roof downspouts, drainage swales, rain-garden and infiltration vaults. Only minor infiltration is anticipated for the areas underlain by till or areas where fill is placed.

The groundwater flow pattern for the developed conditions will be similar to existing conditions, with recharge over the site and adjacent area, and discharge to the wetlands and Picnic Point Creek.

5 Groundwater Model

5.1 Model Input
The objectives of groundwater modeling were to evaluate the impacts of infiltrating stormwater on the Horseman’s Trail site. The groundwater model used the software package Visual MODFLOW (Waterloo Hydrologic 2008) that is based on the USGS MODFLOW model (MacDonald and Harbough 1988). MODFLOW uses the finite difference method to solve the equation for groundwater flow. The area to be modeled (the model "domain") is divided into cells, both vertically and horizontally. Hydraulic properties can be assigned to single cells or groups of cells, allowing flexibility in simulating hydrogeologic conditions. Typically, cell size is smaller in the area of particular interest and is larger where detail is not as important. The model area, shown on Figure 5-1, consists of 2,200 cells.

The southern boundary of the model is a no-flow boundary based on the interpreted location of the groundwater divide between the Picnic Point Creek basin and the Norma Creek basin. The east and west model boundaries are no-flow boundaries based on the anticipated flow direction being generally
south to north. The northern boundary is a constant head boundary defined by the elevation of Picnic Point Creek. The wetland adjacent to the northwest corner of the site is modeled as a drain boundary condition with heads ranging from 209 feet msl in the west to 240 ft msl in the south and east. The presence of a wetland indicates that the water level remains nearly constant throughout the year, otherwise wetland conditions would not be prevail. The drain boundary condition allows discharge from the model at the specified boundary head, but, unlike a constant head boundary condition, does not allow flow into the model.

During initial model calibration, MW-1 and MW-2 were within the observed range. However, the observed groundwater elevation in MW-3 was significantly lower than the modeled elevation. The low groundwater elevation in this portion of Regatta Estates may be caused by utility trenches acting as drains, and therefore drain boundary elements were included in this area, with the head set about 7 feet below ground surface.

Recharge for existing conditions was determined using the Western Washington Hydrologic Model WWHM version 3 (2007). The land use and soil conditions used for the drainage analyses were also used for estimating groundwater recharge to ensure consistency between the surface water and groundwater analyses. Based on groundwater flow generated by WWHM, water year 1961 (October 1960 through September 1961) was selected as representative of average conditions. Water year 1971 (October 1970 through September 1971) generated the greatest groundwater flow volume, and was therefore selected as representing a wet year.

Using the land and soil types defined in WWHM the model area was divided into three recharge areas: existing residential, moderate till forest, (areas of Vashon till, with slopes between 5 percent and 15 percent) and steep outwash forest (areas of advance outwash with slopes greater than 15 percent). The existing residential recharge estimate was based on 50 percent of the infiltration to groundwater for flat (slope less than 5 percent) till lawn. Recharge values for average and wet years extracted from the WWHM analyses are summarized in Table 5-1.

Table 5-1. Recharge rates for existing conditions.

<table>
<thead>
<tr>
<th>Land use</th>
<th>Recharge (ins/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average year</td>
</tr>
<tr>
<td>Existing residential</td>
<td>3.5</td>
</tr>
<tr>
<td>Till forest</td>
<td>8.6</td>
</tr>
<tr>
<td>Outwash forest</td>
<td>11.1</td>
</tr>
</tbody>
</table>

For developed conditions of the Horseman’s Trail PRD site, the west and east Threshold Discharge Areas (TDAs) were analyzed separately in WWHM. A TDA is defined in the Ecology Stormwater Management Manual for Western Washington (2005) as “[A]n onsite area draining to a single natural discharge location or multiple discharge locations that combine within
one-quarter mile downstream (as determined by the shortest flowpath)." The procedure to determine recharge rates was as follows:

- The WWHM models constructed for the site drainage design (Anthony Burgess Consulting 2013b) were modified by adding elements to record the infiltration to groundwater.
- Low Impact Drainage (LID) credits for downspout infiltration of roof runoff were added back into the drainage basins where the infiltration would occur.
- Total infiltration to groundwater for the west and north/northwest basins in the west TDA, and for the east TDA was calculated. Recharge originated from areal infiltration and from infiltration from constructed facilities such as swales, ponds and vaults.
- For each of the two basins in the west TDA and for the east TDA, the area of development on till and/or fill was determined using land use data developed for the drainage analyses. Annual recharge rates for these areas were set to 3.5 and 4.5 inches for average and wet years respectively.
- The remaining volume of recharge was distributed over the area of outwash.

The recharge values for areas outside the site limits were not changed from the existing conditions. The recharge values for the developed site are summarized in Table 5-2.

Table 5-2. Developed site recharge values.

<table>
<thead>
<tr>
<th>TDA</th>
<th>Soil type</th>
<th>Recharge (inches)</th>
<th>Average year</th>
<th>Wet year</th>
</tr>
</thead>
<tbody>
<tr>
<td>West TDA</td>
<td>North/northwest basin</td>
<td>Outwash</td>
<td>13.1</td>
<td>19.3</td>
</tr>
<tr>
<td></td>
<td>West basin</td>
<td>Till, fill</td>
<td>3.5</td>
<td>4.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Outwash</td>
<td>33.1</td>
<td>46.5</td>
</tr>
<tr>
<td>East TDA</td>
<td>Till, fill</td>
<td>Outwash</td>
<td>3.5</td>
<td>4.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Outwash</td>
<td>165.7</td>
<td>236.5</td>
</tr>
</tbody>
</table>

TDA = Threshold Discharge Area

The recharge to groundwater for existing and developed conditions averaged over the respective TDAs is summarized in Table 5-3. The total increases in recharge (West TDA and East TDA) are 11.8 acre.ft and 15.2 acre.ft for average and wet year conditions, respectively.
Table 5-3 Summary of recharge for existing and developed conditions.

<table>
<thead>
<tr>
<th></th>
<th>West TDA</th>
<th>East TDA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>15.589 ac</td>
<td>6.748 ac</td>
</tr>
<tr>
<td>ac.ft inches</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average year</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Existing</td>
<td>13.1</td>
<td>4.6</td>
</tr>
<tr>
<td>Developed</td>
<td>21.7</td>
<td>7.9</td>
</tr>
<tr>
<td>Increase</td>
<td>8.6</td>
<td>3.3</td>
</tr>
<tr>
<td>Wet year</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Existing</td>
<td>19.7</td>
<td>6.8</td>
</tr>
<tr>
<td>Developed</td>
<td>30.6</td>
<td>11.0</td>
</tr>
<tr>
<td>Increase</td>
<td>11.0</td>
<td>4.2</td>
</tr>
</tbody>
</table>

TDA = Threshold Discharge Area

The model domain covers an area 3,000 feet north to south and 2,500 feet east to west. The till unit is not included in the model since any groundwater occurring within or above the till is perched. The modeled saturated zone consists of the advance outwash and the underlying pre-Vashon sediments. The advance outwash extends from elevation 300 ft msl to 237 ft msl, and is represented by six layers ranging in thickness from 5.5 feet at the base to 20 feet at the top. The pre-Vashon unit extends from the base of the advance outwash to the base of the model at elevation 150 feet msl and is represented by three layers of equal thickness. Hydraulic conductivity values in the horizontal plane (Kx and Ky) and vertically (Kz) are presented in Table 5-4.

Table 5-4. Model hydraulic conductivity (K) values.

<table>
<thead>
<tr>
<th>Unit</th>
<th>Hydraulic conductivity (feet/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Kx</td>
</tr>
<tr>
<td>Advance outwash</td>
<td>10</td>
</tr>
<tr>
<td>Advance outwash: basal unit</td>
<td>2</td>
</tr>
<tr>
<td>Pre-Vashon sediments</td>
<td>5</td>
</tr>
</tbody>
</table>

5.2 Results

All analyses were run steady state with the average annual recharge values. This is appropriate since the groundwater observations in the advance outwash show only a slight seasonal variation.

5.2.1 Existing Conditions

Groundwater elevation contours for existing conditions are shown on Figure 5-2. The computed average conditions groundwater elevations at the monitoring wells are compared with the range of observed elevations in Table 5-5, and show an acceptable model calibration.
Table 5-5. Comparison of observed and computed groundwater elevations.

<table>
<thead>
<tr>
<th></th>
<th>Groundwater elevation (ft msl)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MW-1</td>
</tr>
<tr>
<td>Observed</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Computed</td>
<td>255.4</td>
</tr>
</tbody>
</table>

5.2.2 Developed Conditions

The groundwater elevation contours for developed conditions are shown on Figure 5-3. The groundwater elevations at the selected locations shown on Figure 5-4 for existing and developed conditions are presented in Table 5-6. Groundwater elevations were taken from layer 6 of the model since it represents the saturated portion of the advance outwash (layer midpoint 239.4 feet msl), except for MW-3 which was taken from layer 7 to represent the top of the pre-Vashon sediments (layer mid-point 222.65 feet msl). The increase in groundwater elevation is greatest in the northern and central areas of the site where there is infiltration from the swales and rain garden that recharge the advance outwash. The maximum groundwater elevation increase on site is about 2.4 feet at the proposed rain garden for average conditions and 2.6 feet for wet conditions. In the slope areas, the increases in groundwater head range from 2.3 and 2.2 feet at the northwest location, to 1.1 and 1.2 feet at the northeast location, for wet and dry years, respectively.

Table 5-6. Model-predicted groundwater elevations (feet msl) at selected locations.

<table>
<thead>
<tr>
<th>Location</th>
<th>Average year</th>
<th>Wet year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Existing</td>
<td>Developed</td>
</tr>
<tr>
<td>MW-1</td>
<td>255.4</td>
<td>256.2</td>
</tr>
<tr>
<td>MW-2</td>
<td>249.4</td>
<td>250.7</td>
</tr>
<tr>
<td>MW-3</td>
<td>233.3</td>
<td>233.4</td>
</tr>
<tr>
<td>Rain garden</td>
<td>247.1</td>
<td>249.5</td>
</tr>
<tr>
<td>East ravine</td>
<td>250.8</td>
<td>252.0</td>
</tr>
<tr>
<td>Northwest</td>
<td>243.3</td>
<td>245.6</td>
</tr>
<tr>
<td>Northeast</td>
<td>254.1</td>
<td>255.2</td>
</tr>
<tr>
<td>South</td>
<td>251.6</td>
<td>252.9</td>
</tr>
</tbody>
</table>

As shown in Table 5-6, development of the site will result in an overall increase in recharge to groundwater and increase in groundwater elevations. The inherent nature of groundwater systems is to reduce the variability of precipitation, because of the potential for storage in the aquifer, and the slow movement of groundwater compared with surface water. Thus, short-term (days to weeks) and seasonal fluctuations in groundwater elevations will be much less than the changes in precipitation and infiltration.

Table 5-3 shows the total increases in recharge (West TDA and East TDA) are 11.9 acre.ft (0.016 cfs) and 15.2 acre.ft (0.021 cfs) for average and wet
year conditions, respectively. Storm flows in Picnic Point Creek, are dominated by run-off. The increase in groundwater recharge will produce a negligible addition to storm flows in Picnic Point Creek. Further discussion is presented in the Off Site Analysis Report (Anthony Burgess Consulting Inc. 2013c).

6 References


Anthony Burgess Consulting Inc. 2013b. Targeted Drainage Report Horseman’s Trail PRD. Technical Appendix A to the Horseman’s Trail/Frognal Estates PRD Environmental Impact Statement, Snohomish County, WA.


Associated Earth Sciences, Inc. 2006b. Revised Supplementary Subsurface Exploration, Geologic Hazards, and Preliminary Geotechnical Engineering Study, Horseman’s Trail Development.


Figures
Horseman’s Trail PRD
Groundwater Conditions Report

Figure 2-1
Locations of Investigations
Figure 3-1

Groundwater Level Observations Near Southern Property Boundary

Groundwater Conditions Report

December 5, TCD, PLLC

Groundwater Elevation (ft)

Monthly Rainfall (Inches)

MW-1 Datalogger

Monthly Rainfall Alderwood Water District Office @ 35th + RG
Near Northern Property Boundary
MW-2 Groundwater Level Observations

Figure 3-2

Groundwater Conditions Report
Investigations & Field Work

MW-2 Groundwater Level Observations

Near Northern Property Boundary

MW-2 Datalogger
Monthly Rainfall Alderwood Water District Office at 35th + RG

Groundwater Elevation (ft)

Monthly Rainfall (Inches)

Figure 3-2
Figure 3-3
MW-3 Groundwater Level Observations
Off-site to the North in Regatta Estates

*Slug test performed 4-18-2008 @ 1200 hours.
Datalogger removed during testing.
*Dewatering at waste water treatment plant
beginning ~6/1/08.
Weathered till

Unweathered till

Sand and Gravel advance outwash

Silty sand advance outwash and pre-Vashon sediments

Precipitation

Evapotranspiration

Figure 4-1

Site Hydrologic System Schematic
Figure 4-2
Existing Conditions Site Geology
Figure 5-1
Groundwater Model Area
Figure 5-2
Existing Conditions
Model Groundwater Elevations
Figure 5-3
Developed Conditions
Model Groundwater Elevations
Figure 5-4

Groundwater Elevation Representative Locations: Existing and Developed Conditions
Attachment A

Slug Test Analyses
WELL TEST ANALYSIS

Data Set: F:\projects\abc\active\horsemans trail\groundwater\slug tests\MW-1 test 1 early.aqt
Date: 06/03/08
Time: 15:56:43

PROJECT INFORMATION

Company: Anthony Burgess Consulting Inc
Client: Horseman's Trail
Test Well: MW-1

AQUIFER DATA

Saturated Thickness: 20.21 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (MW-1 test 1)

Initial Displacement: 5.015 ft
Total Well Penetration Depth: 15.21 ft
Casing Radius: 0.0833 ft
Static Water Column Height: 15.21 ft
Screen Length: 5. ft
Wellbore Radius: 0.0833 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 1.51 ft/day
y0 = 5.556 ft
WELL TEST ANALYSIS

Data Set: F:\projects\abc\active\horsemans trail\groundwater\slug tests\MW-1 test 2 early.aqt
Date: 06/03/08 Time: 15:57:28

PROJECT INFORMATION

Company: Anthony Burgess Consulting Inc
Client: Horseman's Trail
Test Well: MW-1

AQUIFER DATA

Saturated Thickness: 20.21 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (MW-1 test 2)

Initial Displacement: 4.834 ft
Total Well Penetration Depth: 15.21 ft
Casing Radius: 0.0833 ft
Static Water Column Height: 15.21 ft
Screen Length: 5. ft
Wellbore Radius: 0.0833 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 2.093 ft/day
y0 = 4.864 ft
# WELL TEST ANALYSIS

Data Set: F:\projects\abc\active\horsemans trail\groundwater\slug tests\MW-1 test 2 mid.aqt  
Date: 06/03/08  
Time: 15:58:22

## PROJECT INFORMATION

Company: Anthony Burgess Consulting Inc  
Client: Horseman's Trail  
Test Well: MW-1

## AQUIFER DATA

- Saturated Thickness: 20.21 ft  
- Anisotropy Ratio (Kz/Kr): 1.

## WELL DATA (MW-1 test 2)

- Initial Displacement: 4.834 ft  
- Total Well Penetration Depth: 15.21 ft  
- Casing Radius: 0.0833 ft  
- Static Water Column Height: 15.21 ft  
- Screen Length: 5. ft  
- Wellbore Radius: 0.0833 ft

## SOLUTION

- Aquifer Model: Unconfined  
- Solution Method: Bouwer-Rice  
- $K = 1.385$ ft/day  
- $y_0 = 1.986$ ft
WELL TEST ANALYSIS

Data Set: F:\projects\abc\active\horsemans trail\groundwater\slug tests\MW-1 test 3 early.aqt
Date: 06/03/08

PROJECT INFORMATION

Company: Anthony Burgess Consulting Inc
Client: Horseman's Trail
Test Well: MW-1

AQUIFER DATA

Saturated Thickness: 20.21 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (MW-1 test 3)

Initial Displacement: 4.97 ft
Total Well Penetration Depth: 15.21 ft
Casing Radius: 0.0833 ft
Static Water Column Height: 15.21 ft
Screen Length: 5. ft
Wellbore Radius: 0.0833 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 2.058 ft/day
y0 = 5.032 ft
WELL TEST ANALYSIS

Data Set: F:\projects\abc\active\horsemans trail\groundwater\slug tests\MW-1 test 3 mid.aqt
Date: 06/03/08 Time: 16:00:07

PROJECT INFORMATION

Company: Anthony Burgess Consulting Inc
Client: Horseman's Trail
Test Well: MW-1

AQUIFER DATA

Saturated Thickness: 20.21 ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (MW-1 test 3)

Initial Displacement: 4.97 ft
Total Well Penetration Depth: 15.21 ft
Casing Radius: 0.0833 ft
Static Water Column Height: 15.21 ft
Screen Length: 5. ft
Wellbore Radius: 0.0833 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice

K = 1.64 ft/day
y0 = 3.362 ft
WELL TEST ANALYSIS
Data Set: F:\projects\abc\active\horsemans trail\groundwater\slug tests\MW-2 test 1 early.aqt
Date: 06/03/08
Time: 16:01:20

PROJECT INFORMATION
Company: Anthony Burgess Consulting Inc
Client: Horseman's Trail
Test Well: MW-2

AQUIFER DATA
Saturated Thickness: 7.6 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (MW-2 test 1)
Initial Displacement: 0.8617 ft
Total Well Penetration Depth: 7.6 ft
Casing Radius: 0.08333 ft
Screen Length: 11.0 ft
Wellbore Radius: 0.08333 ft
Static Water Column Height: 7.6 ft

SOLUTION
Aquifer Model: Unconfined
K = 4.09 ft/day
Solution Method: Bouwer-Rice
y0 = 0.5824 ft
WELL TEST ANALYSIS

Data Set: F:\projects\abc\active\horsemans trail\groundwater\slug tests\MW-2 test 1 late.aqt
Date: 06/03/08
Time: 16:02:02

PROJECT INFORMATION

Company: Anthony Burgess Consulting Inc
Client: Horseman's Trail
Test Well: MW-2

AQUIFER DATA

Saturated Thickness: 7.6 ft
Anisotropy Ratio (Kz/Kr): 1

WELL DATA (MW-2 test 1)

Initial Displacement: 0.8617 ft
Static Water Column Height: 7.6 ft
Total Well Penetration Depth: 7.6 ft
Screen Length: 11 ft
Casing Radius: 0.08333 ft
Wellbore Radius: 0.08333 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 0.5509 ft/day
y0 = 0.01521 ft
WELL TEST ANALYSIS

Data Set: F:\projects\abc\active\horsemans trail\groundwater\slug tests\MW-2 test 2 early.aqt
Date: 06/03/08

PROJECT INFORMATION
Company: Anthony Burgess Consulting Inc
Client: Horseman's Trail
Test Well: MW-2

AQUIFER DATA
Saturated Thickness: 7.6 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (MW-2 test 2)
Initial Displacement: 1.199 ft
Total Well Penetration Depth: 7.6 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 7.6 ft
Screen Length: 11. ft
Wellbore Radius: 0.08333 ft

SOLUTION
Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 3.492 ft/day
y0 = 1.005 ft
WELL TEST ANALYSIS

Data Set: F:\projects\abc\active\horsemans trail\groundwater\slug tests\MW-2 test 2 mid.aqt
Date: 06/03/08
Time: 16:03:00

PROJECT INFORMATION

Company: Anthony Burgess Consulting Inc
Client: Horseman's Trail
Test Well: MW-2

AQUIFER DATA

Saturated Thickness: 7.6 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (MW-2 test 2)

Initial Displacement: 1.199 ft
Total Well Penetration Depth: 7.6 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 7.6 ft
Screen Length: 11. ft
Wellbore Radius: 0.08333 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 0.667 ft/day
y0 = 0.05302 ft
WELL TEST ANALYSIS
Data Set: F:\projects\abc\active\horsemans trail\groundwater\slug tests\MW-2 test 3 early.aqt
Date: 06/03/08  Time: 16:03:25

PROJECT INFORMATION
Company: Anthony Burgess Consulting Inc
Client: Horseman's Trail
Test Well: MW-2

AQUIFER DATA
Saturated Thickness: 7.6 ft  Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (MW-2 test 3)
Initial Displacement: 1.183 ft  Static Water Column Height: 7.6 ft
Total Well Penetration Depth: 7.6 ft  Screen Length: 11. ft
Casing Radius: 0.08333 ft  Wellbore Radius: 0.08333 ft

SOLUTION
Aquifer Model: Unconfined  Solution Method: Bouwer-Rice
K = 3.624 ft/day  y0 = 0.9664 ft
WELL TEST ANALYSIS
Data Set: F:\projects\abc\active\horsemans trail\groundwater\slug tests\MW-2 test 3 mid.aqt
Date: 06/03/08 Time: 16:03:56

PROJECT INFORMATION
Company: Anthony Burgess Consulting Inc
Client: Horseman’s Trail
Test Well: MW-2

AQUIFER DATA
Saturated Thickness: 7.6 ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (MW-2 test 3)
Initial Displacement: 1.183 ft Static Water Column Height: 7.6 ft
Total Well Penetration Depth: 7.6 ft Screen Length: 11. ft
Casing Radius: 0.08333 ft Wellbore Radius: 0.08333 ft

SOLUTION
Aquifer Model: Unconfined Solution Method: Bouwer-Rice
K = 0.6997 ft/day y0 = 0.07168 ft
WELL TEST ANALYSIS
Data Set: F:\projects\abc\active\horsemans trail\groundwater\slug tests\MW-3 test 1 early.aqt
Date: 06/03/08

PROJECT INFORMATION
Company: Anthony Burgess Consulting Inc
Client: Horseman's Trail
Test Well: MW-3

AQUIFER DATA
Saturated Thickness: 23.86 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (MW-3 test 1)
Initial Displacement: 4.658 ft
Static Water Column Height: 23.86 ft
Total Well Penetration Depth: 23.86 ft
Screen Length: 10. ft
Casing Radius: 0.08333 ft
Wellbore Radius: 0.08333 ft

SOLUTION
Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 0.6275 ft/day
y0 = 4.358 ft
WELL TEST ANALYSIS

Data Set: F:\projects\abc\active\horsemans trail\groundwater\slug tests\MW-3 test 1 mid.aqt
Date: 06/03/08  Time: 16:05:57

PROJECT INFORMATION

Company: Anthony Burgess Consulting Inc
Client: Horseman's Trail
Test Well: MW-3

AQUIFER DATA

Saturated Thickness: 23.86 ft  Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (MW-3 test 1)

Initial Displacement: 4.658 ft
Total Well Penetration Depth: 23.86 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 23.86 ft
Screen Length: 10. ft
Wellbore Radius: 0.08333 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 0.4888 ft/day
y0 = 2.691 ft
WELL TEST ANALYSIS

Data Set: F:\projects\abc\active\horsemans trail\groundwater\slug tests\MW-3 test 2 early.aqt
Date: 06/03/08
Time: 16:06:32

PROJECT INFORMATION

Company: Anthony Burgess Consulting Inc
Client: Horseman's Trail
Test Well: MW-3

AQUIFER DATA

Saturated Thickness: 23.86 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (MW-3 test 2)

Initial Displacement: 0.6 ft
Total Well Penetration Depth: 23.86 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 23.86 ft
Screen Length: 10. ft
Wellbore Radius: 0.08333 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 0.8203 ft/day
y0 = 0.5704 ft
### WELL TEST ANALYSIS

Data Set: F:\projects\abc\active\horsemans trail\groundwater\slug tests\MW-3 test 3 early.aqt  
Date: 06/03/08  Time: 16:07:10

### PROJECT INFORMATION

Company: Anthony Burgess Consulting Inc  
Client: Horseman's Trail  
Test Well: MW-3

### AQUIFER DATA

Saturated Thickness: 23.86 ft  
Anisotropy Ratio (Kz/Kr): 1.

### WELL DATA (MW-3 test 3)

Initial Displacement: 1.295 ft  
Total Well Penetration Depth: 23.86 ft  
Casing Radius: 0.08333 ft  
Static Water Column Height: 23.86 ft  
Screen Length: 10 ft  
Wellbore Radius: 0.08333 ft

### SOLUTION

Aquifer Model: Unconfined  
Solution Method: Bouwer-Rice

\[ K = 0.7521 \text{ ft/day} \]  
\[ y_0 = 1.094 \text{ ft} \]