Wastewater Treatment System Groundwater Assessment for Edison, Washington

DEPARTMENT OF ECOLOGY
State of Washington

April 2018

Publication No. 18-03-007

Publication and contact information

This report is available on the Department of Ecology's website at
https://fortress.wa.gov/ecy/publications/SummaryPages/1803007.html

Data for this project are available at Ecology's Environmental Information Management (EIM) website: EIM Database. Search Study ID bcar006.

The Activity Tracker Code for this study is 13-026.

For more information contact:

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Washington State Department of Ecology – https://ecology.wa.gov

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Cover photo
Edison Wastewater Treatment System drainfield area and school playfield, looking east.
Photo by Barbara Carey.

Wastewater Treatment System Groundwater Assessment for Edison, Washington

by

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Water Resource Inventory Area (WRIA) and 8-digit Hydrologic Unit Code (HUC) numbers for the study area:

WRIA
- 3 (Lower Skagit—Samish)

HUC number
- 17110002

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Abstract

The Washington State Department of Ecology conducted a study of groundwater and effluent at the Edison Wastewater Treatment System (WWTS) in Edison, WA. The purpose of the study was to:

- Establish background water quality for parameters of interest – including nitrate-N, fecal coliform bacteria (FC), and total coliform bacteria (TC) – for comparison with conditions downgradient of the drainfields.
- Assess whether Washington State Ground Water Standards (Chapter 173-200 WAC) are being met at the property boundary.
- Reassess performance with regard to antidegradation of water quality.

Eight groundwater monitoring wells and 1 hand-driven piezometer were installed in the drainfield area in late summer 2014. Water quality samples were subsequently collected from these wells, 2 existing wells, and the facility effluent on 9 occasions between October 2014 and April 2016. Water levels were measured continuously at the new monitoring wells and manually on a monthly basis at all wells.

Based on monthly depth to water measurements, the horizontal groundwater flow direction was generally from east to southwest during November-May and from south to north during June-September. In October, groundwater flow radiated outward from the center of the site. The vertical groundwater gradient was downward except in late summer or early fall.

Groundwater FC and TC results were mostly below detection limits except for February and April 2016, when TC were found in all well samples, including the upgradient well. These high levels were likely due to naturally occurring TC transported by heavy precipitation.

Groundwater results for nitrate and TC were within the 95% tolerance interval recommended in the *Implementation Guidance for the Ground Water Quality Standards*, except for nitrate at 2 wells, 1 downgradient and 1 crossgradient. The calculated tolerance limit for nitrate-N at the Edison WWTS site, 0.069 mg/L, is only 0.7% of the 10 mg/L criteria in the Ground Water Standards. The maximum nitrate-N concentrations at the 2 wells with exceedances were 0.292 and 3.10 mg/L.

Extremely high concentrations of chloride, bromide, sodium, ammonium-N, and other ions noted in the southern and western perimeter wells are probably related to local intermixing of groundwater and seawater. Low concentrations of most water quality parameters in the monitoring wells closest to the drainfields indicate that the wastewater discharge was not degrading groundwater quality and may in fact have been diluting the underlying highly saline groundwater. Recommendations are included for ongoing monitoring.

Acknowledgements

The author of this report thanks the following people for their contributions to this study:

- Skagit County Planning and Development: Alison Mohns, Ron Palmer, and Matt Kaufman for assistance with sampling the Wastewater Treatment System (WWTS) effluent and providing detailed information on WWTS operation.
- Burlington-Edison School District: John Leander and Edison School staff.
- Washington State Department of Ecology, Northwest Regional Office:
    - Tonya Lane, Maia Hoffman, and Stephanie Allen for providing useful insights on the report
    - Chris Martin for field assistance and helpful suggestions on the report
- Washington State Department of Ecology, Information Technology Services Office:
    - Adam Oestreich for developing water level contours from monitoring well data
- Washington State Department of Ecology, Environmental Assessment Program:
    - Kirk Sinclair for co-designing and co-implementing the study, including assistance with field installations, sampling, data analysis, and interpretation
    - Martha Maggi and Eugene Freeman for report review
    - Niamh O'Rourke for field assistance
    - Nancy Rosenbower, MEL[1], for help with laboratory communications and sample logistics
    - Edlin Limmer, MEL, for microbiological analysis
    - Karin Feddersen, MEL, for laboratory contracting assistance
    - Paul Anderson for help with sample transport
    - Leon Weiks for sample and container transport

[1] MEL = Manchester Environmental Laboratory, Manchester, WA.

Introduction

The community of Edison, Washington lies at an elevation close to sea level along Edison Slough near the point at which the slough meets Samish Bay (Figure 1). Domestic wastewater in the Edison community historically received minimal, if any, treatment. On-site sewage systems for many homes previously discharged minimally treated wastewater to street drains that flowed directly into Edison Slough (Ecology, 2013a). A sanitary survey in the 1990s reported a septic tank failure rate of 65%.

The community began planning for a more centralized wastewater treatment system and received financial assistance from the Washington State Department of Ecology (Ecology), a Community Development Block Grant, and the Rensselaerville Institute. The community decided against an outfall discharge to surface water in order to protect commercial shellfishing operations in Samish Bay.

In 1996, Edison completed construction of a treatment facility and drip infiltration disposal field to treat and manage sewage from 200 area homes, 7 restaurants, and the Edison School. The new treatment facility was served by a septic tank effluent pumping (STEP) system which included new septic tanks for homes and pumps for transferring liquid domestic wastewater to the collection system and ultimately to the gravel filter for treatment.

Edison added an upflow infiltration trench in 1998 as an additional disposal option to increase disposal capacity. By 2001, geotechnical engineers verified that the original drip system was located above a relatively impervious layer that prevented adequate infiltration of the wastewater. The community constructed a second drainfield in 2003 (Figure 2).

The current system, called the Edison Wastewater Treatment System (WWTS), consists of a recirculating gravel filter, ultraviolet (UV) disinfection, 2 drainfield areas, and an infiltration trench. It serves approximately 85 connections including 7 food commercial users and one elementary/middle school without a cooking cafeteria (Mohns, November 29, 2017). Restaurants and the school are required to have grease traps.

Drainfield 1 lies approximately 200 feet south of Edison Slough (Figure 2). It is 26,600 square feet in area and consists of polyethylene pipes extending lengthwise in the field at 6-8-inch depth (HWA, Geosciences, 2002). The pipes are on 24-inch centers and fitted with low-velocity emitter pipes. The current allowable discharge to Drainfield 1 is 2,000 gallons/day (Ecology, 2013a).

Drainfield 2, completed in 2003, consists of 6 zones of perforated PVC pipe in 2 lines running east-west in the southern portion of the site (Figure 2). The discharge lines are housed inside a gravelless chamber at a depth of 1.5 feet (Figure 3). Each zone is approximately 250 feet long. A computer program allows effluent to discharge to one zone at a time via a solenoid valve. If the groundwater height exceeds a preset level, the system does not allow effluent to discharge to that zone. The timing and flow to each zone is operator adjustable. The current allowable discharge to Drainfield 2 is 18,000 gallons/day (Gray & Osborne, 2003b).

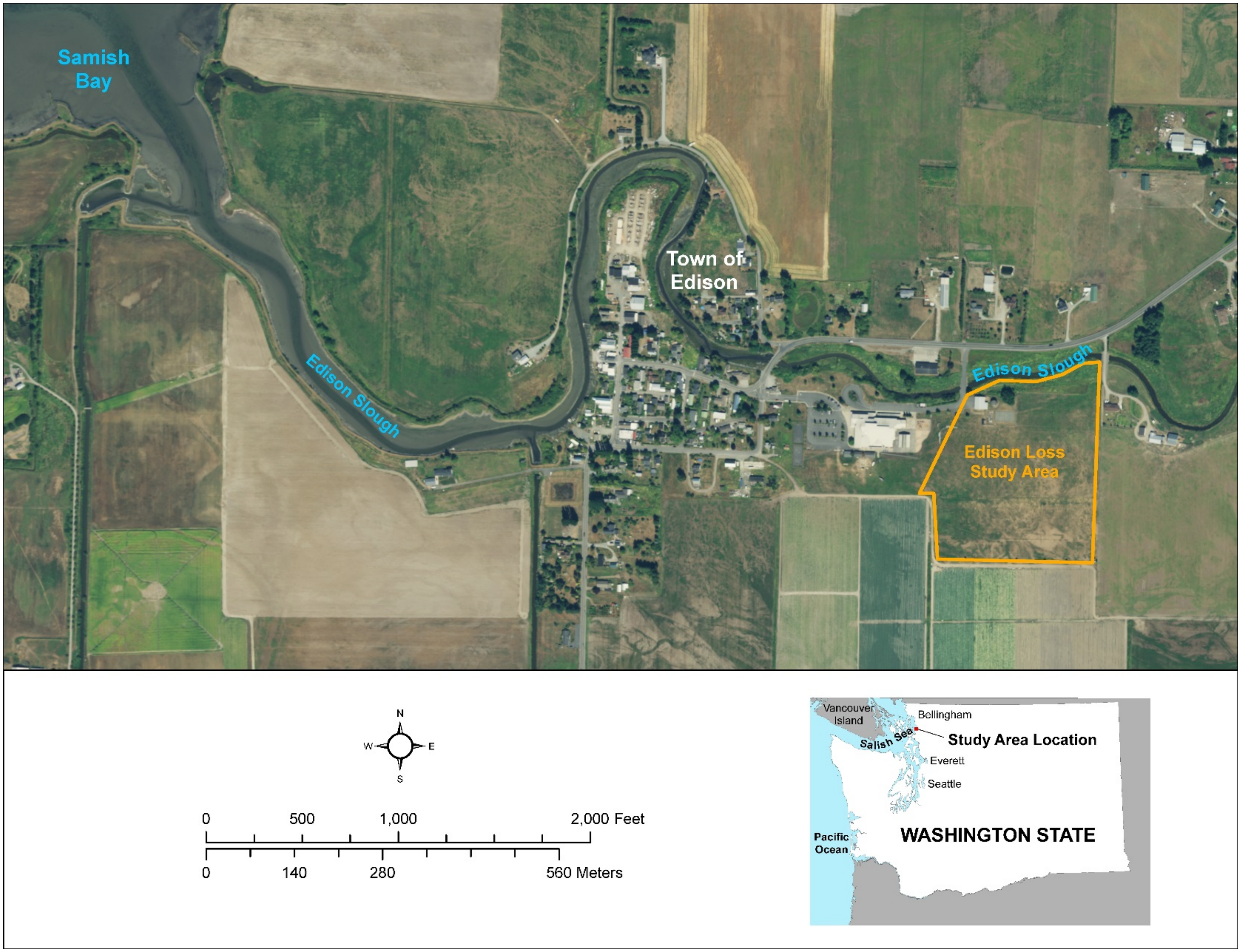

Figure 1. Edison, Washington vicinity and study location map.

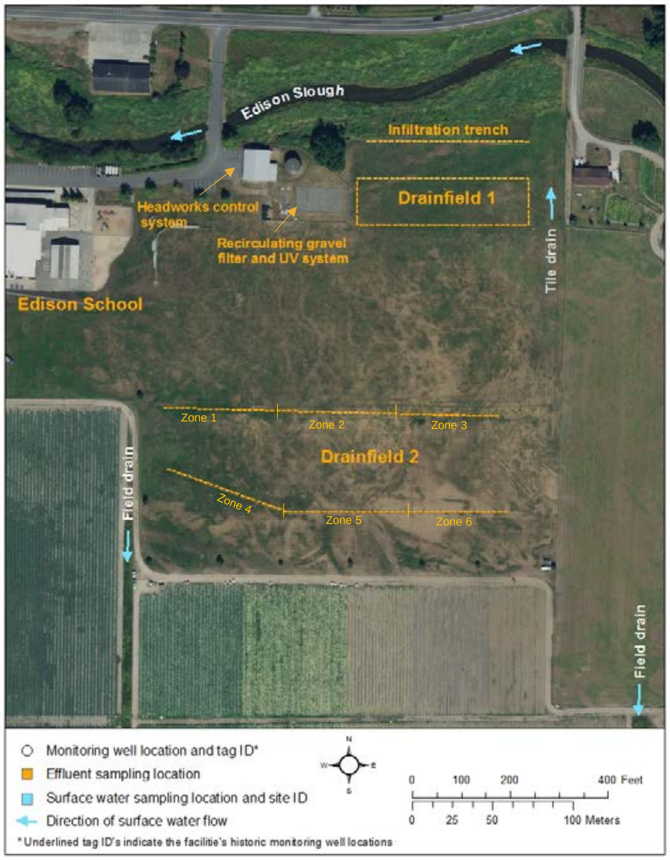

Figure 2. Edison Wastewater Treatment System (WWTS) facility and drainfield locations.

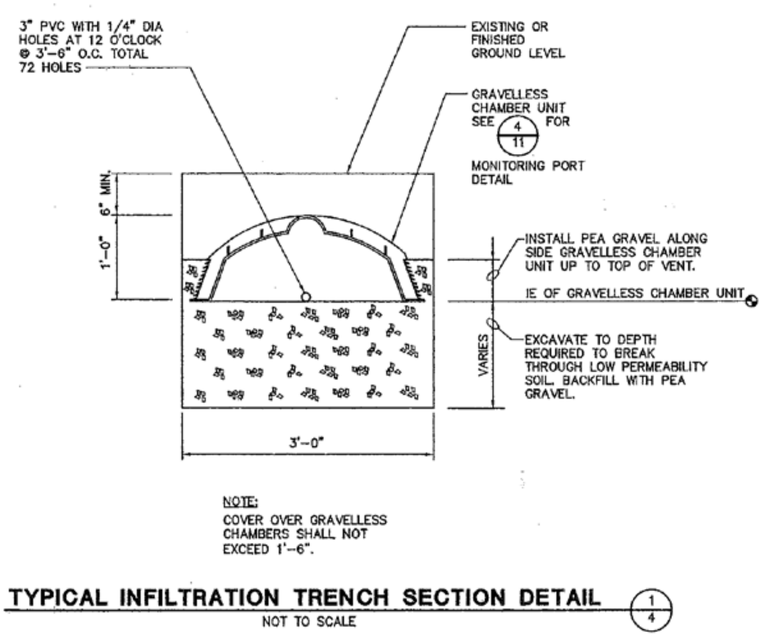

Figure 3. Drainfield 2 infiltration trench design cross-section.

Gray & Osborne, 2003a

The Skagit County Clean Water District--Edison Subarea (the Edison Subarea) manages the Edison WWTS and is the permittee for the State Waste Discharge Permit. The 2013 fact sheet that accompanied permit #ST0045515 states that a groundwater study was to be completed by Ecology to evaluate groundwater flow direction(s), establish background groundwater quality, and evaluate the effects of the facility on groundwater quality (Ecology 2013a). This report documents the results of the required groundwater study based on the *Quality Assurance (QA) Project Plan: Edison large on-site sewage system groundwater assessment* and addenda (Carey, 2014; Carey, 2015; Carey, 2016a).

The goals of this study included:

- Characterizing the hydrogeology of the site, including depth and direction of groundwater flow, hydraulic conductivity, and groundwater velocity.
- Establishing background groundwater quality.
- Summarizing the location and construction of existing water supply wells, if any, within 1 mile of the WWTS.
- Determining whether the facility is meeting Ground Water Quality Standards.
- Characterizing the effluent water quality, especially for parameters specified in Kimsey (2005) (total nitrogen, chloride, and inorganics) and 303(d) listed parameters for Edison Slough (pH, dissolved oxygen, and fecal coliform bacteria).
- Evaluating the potential water quality impacts of the WWTS on groundwater and any seasonal or tidal variation, including nitrate, fecal coliform bacteria, and total coliform bacteria.
- Evaluating whether 303(d) listed parameters are reaching Edison Slough from the facility: pH, dissolved oxygen, and fecal coliform bacteria.

Study area description

Physical setting and land use

The Edison WWTS study site lies along the south bank of Edison Slough, about 1,000 feet upstream of Samish Bay on the delta of the Samish River (Figure 1). The Samish Bay watershed encompasses 140 square miles of mostly lowland farms, fields, and timber land (Skagit County Public Works, 2012). The Samish River is the largest tributary to Samish Bay, but several creeks and sloughs, including Edison Slough, also discharge freshwater to the bay (Swanson, 2008).

Background information describing surface water hydrology and land use in the study area are described in Carey (2014). The elevation of the site is roughly 3 to 10 feet above sea level (HWA Geosciences, 2002). The groundwater is typically 1 to 3 feet below ground surface during the winter months (Ecology Discharge Monitoring Record (DMR) data, 2013-2014). The drainfield area is relatively flat, with the northern section sloping gently northward toward Edison Slough (Ecology, 2013a). The southern section slopes slightly toward the southwest.

Tide gates installed in the slough 1,000 feet west (downstream) of the site are designed to allow some salt water to enter the slough (HWA, Geosciences, 2002). Recently tide gates have been operated to maintain a higher water elevation in Edison Slough than in previous years (Palmer, 2014), which could cause an increase in the elevation of groundwater at the site.

Drinking water for the Edison area is supplied by the Blanchard Water Association. There are no drinking water wells within 1 mile of the site (Ecology, 2013a).

Climate

The study area has a temperate marine climate. Winters are mild and wet; summers are cool and dry. Figure 4 shows the total monthly precipitation for Bow, Washington during and immediately preceding the study. The Bow precipitation site is approximately 2 miles north of the Edison WWTS site:
https://www.wunderground.com/personal-weather-station/dashboard?ID=kwabow6.

Figure 4 also shows the long-term average precipitation for 1956-2005 at Mount Vernon, Washington, the closest location with a long-term record. This climate station is approximately 8.3 miles southeast of the Edison WWTS site. Precipitation is typically concentrated during October through March, although in 2014, significant rain began in September.

The monthly precipitation at Bow was higher than the Mount Vernon average during both high-rainfall periods. For October 2014-March 2015, the departure from the long-term average was 5.2 inches; for September 2015-March 2016, the departure was 6.1 inches. Rainfall during the spring and early summer of 2015 at Bow was lower than the Mount Vernon normal. Precipitation at coastal Edison may be somewhat higher, on average, than slightly inland Mount Vernon. We could not compare the precipitation at Mount Vernon for 2014-2016 with its long-term average because the data record ends in 2005.

Based on rainfall, conditions during the high water table winter seasons represented normal to less favorable than normal for subsurface effluent discharge.

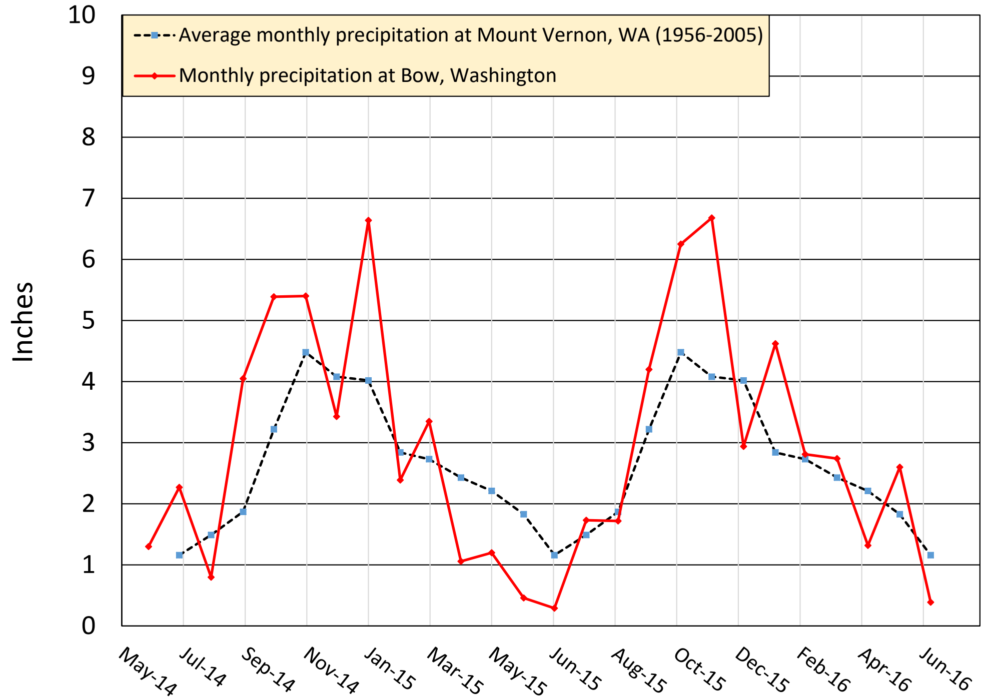

Figure 4. Monthly precipitation at Bow, Washington for June 2014-July 2016* and average monthly precipitation at Mount Vernon, Washington for 1956-2005**

https://www.wunderground.com/personal-weather-station/dashboard?ID=kwabow6

***Site No. 455678, Western Regional Climate Center (Longitude: -122.368173, Latitude: 48.449871) https://wrcc.dri.edu/cgi-bin/cliMAIN.pl?wa5678.*

Geologic and hydrogeologic setting

Edison lies in the western part of the Northwest Cascades system, which includes the northwest corner of Washington and southwest corner of British Columbia (Brown et al. 1987). The metamorphic rock underlying the area is bounded to the east and southwest by thrust faults and to the northwest by the lower Fraser River (Dragovich, 1998a).

The local area has had a complex and tectonically active history as described by Dragovich et al. (1998a and 1998b). Mountains created by folding and faulting were more recently covered by Pleistocene glaciers. Meltwater from the advance of the Puget Lobe glacier carved out the Samish River Valley and partially filled both the Samish and Skagit valleys. Glacial deposits underlie the more recent valley-fill deposits near Edison.

As the Puget Lobe retreated, marine water entered Puget Sound, including the study area, resulting in deposits of glaciomarine drift up to an altitude of 350 feet. In the 10,000 years since the last glaciation, the Skagit Valley has been filled and shaped by fluvial, estuarine, and deltaic material processes.

Cross-sections based on well logs east of Edison indicate mostly clay and silt in the upper 10-20 feet, with some sand layers and occasional abandoned river channels (Dragovich, 1998b). These deposits are described as alluvium (fluvial overbank flood deposits composed of sand, silt, clay, and rarely peat). Underlying the alluvium in the Edison area, Dragovich et al. (1998b) describe deltaic estuarine deposits of sand, silt, and clay, commonly shell-bearing.

The material observed in split-spoon samples from monitoring wells drilled for this study indicate that the Edison WWTS site is underlain by very fine material as shown in cross-section A-A' (Figure 5). Samples from wells AHT087, AHT085, and samples to 20 feet depth at AKY472, were classified as silt or silty clay.

The coarsest materials found in split-spoon samples, sand with silt, were found at 5-10 foot depth at AHT090. This well is located approximately in the middle of Drainfield 2. HWA Geosciences, Inc. (2002) also found sand at 3-4.5 feet in test pits that extended to 6 feet near AHT090 and AHT085. However, slit spoon samples from AHT085 did not encounter the sand layer found in the 2002 test pits.

A thin layer of fill material placed in the southwest area of Drainfield 2 before it was constructed (Gray and Osborne, 2003) probably did not explain the coarser samples collected at AHT090.

The well closest to Edison Slough, AKY469, also contained coarser material close to the surface than most of the well samples.

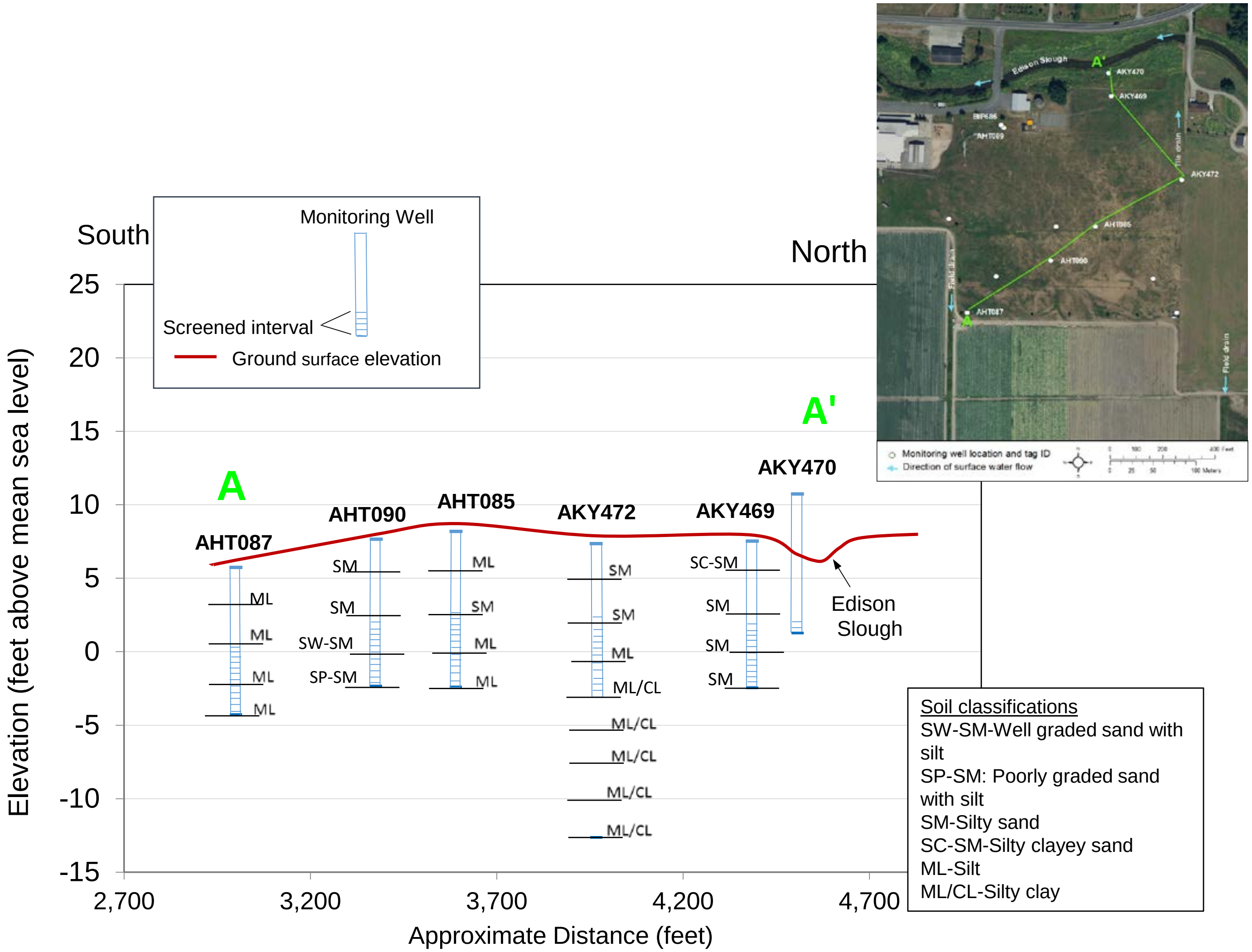

Figure 5. Soil classifications for samples projected on land surface cross-section A-A’.

Study Methods

The monitoring scheme designed to meet the study objectives included several activities:

- Install 8 monitoring wells and 1 piezometer; re-furbish 2 existing wells.
- Measure depths to groundwater and surface water elevation.
- Sample groundwater for water quality parameters of interest.
- Conduct hydraulic tests.

These activities are described below.

Well construction

The monitoring well network consisted of 12 wells (8 shallow purpose-built wells, 1 deep pre-existing well, 1 new piezometer, and 2 existing piezometers) (Figure 6). The monitoring well locations and construction specifications were chosen to:

- Determine the groundwater flow direction both horizontally and vertically.
- Describe the subsurface hydrostratigraphy and determine hydraulic properties.
- Obtain samples representative of the most recent groundwater reaching the aquifer (top of the water table).

The 8 purpose-built monitoring wells were installed by Holocene Drilling, Inc., Puyallup, Washington, on August 29, 2014, using a 4¼-inch inside diameter hollow stem auger (8-inch outside diameter). Seven wells were completed at 9-10 foot depths, and one well was drilled to 15 feet (AHT089). The wells were installed according to Chapter 173-160 WAC http://apps.leg.wa.gov/WAC/default.aspx?cite=173-160. Figure 7 shows the standard construction plan for the shallow monitoring wells. See Appendix A, Table A-1, for a summary of well locations and construction information. Links to well logs in Ecology's EIM database are listed in Table A-2.

The groundwater network included an existing 2-inch diameter well 38-feet deep, BIP686, located 5 feet north of well AHT089. An additional 1.5-inch diameter stainless steel drive point piezometer, AKY470, was manually installed to a depth of 5.5 feet near Edison Slough on September 16, 2014 using a fence-post driver (Figure 8).

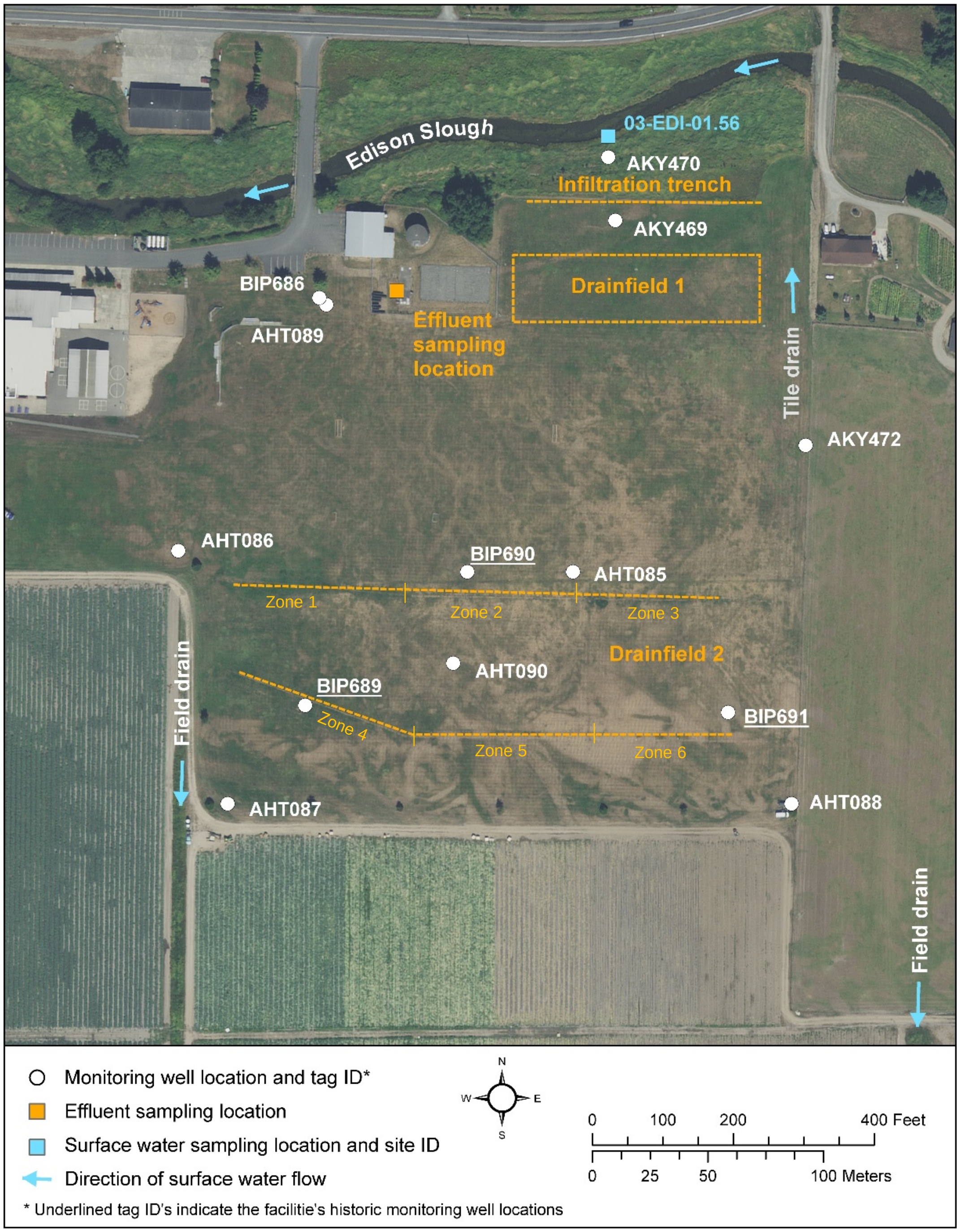

Figure 6. Monitoring well locations and surface water drainage features.

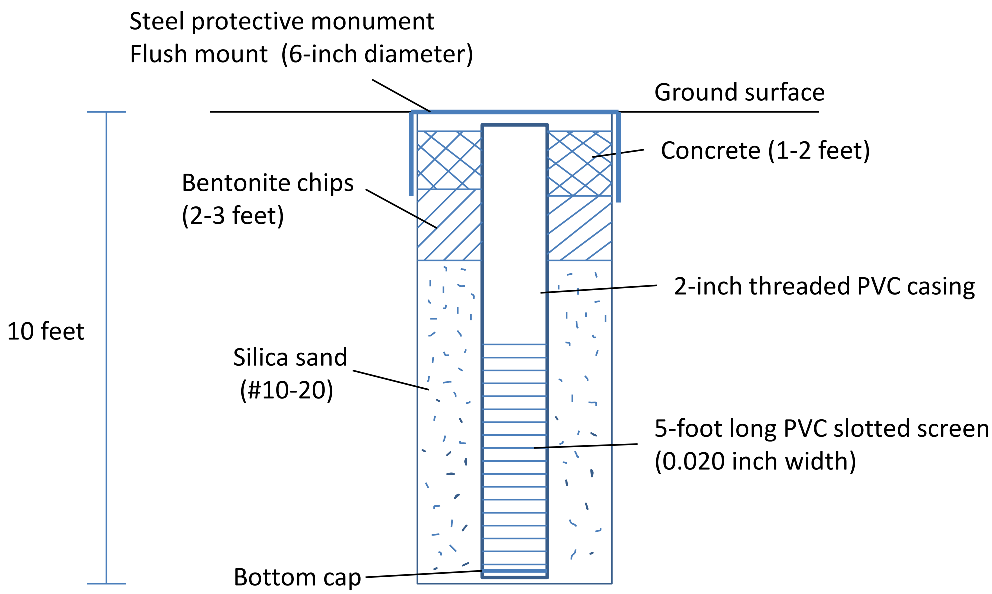

Figure 7. Well construction plan for 10-foot deep monitoring wells.

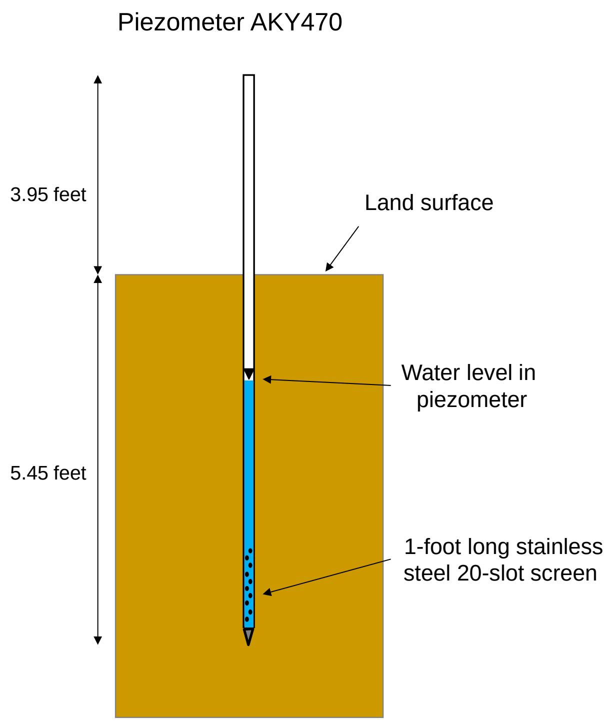

Figure 8. Piezometer AKY470 construction details.

Split-spoon core samples (18 inches long) were collected by Holocene Drilling at 2.5-foot intervals during installation of the 8 monitoring wells. Core samples were described and photographed on site and then placed in clean, labeled, plastic zip-lock bags. Samples were submitted to AMTest Laboratory in Seattle, Washington for particle size analysis. Samples were analyzed for particle size according to ASTM Method D422-63 (ASTM, 2007). Links to photographs and particle size analysis results are in Appendix A, Table A-2.

All of the newly constructed monitoring wells were developed by pumping the wells until the water removed from the borehole was free of sediment. A Washington State well tag with a unique ID number was attached to each well. The well tag ID also serves as the Location ID in the EIM database.

The Skagit County Public Works Department surveyed the elevations of the monitoring wells to the nearest 0.01 foot on September 11, 2014 (Table A-1). An existing 2-inch diameter stilling well, located in the Edison Slough near piezometer AKY470 was used to record the level of water in the slough (EIM Location ID 03-EDI01.56). The piezometer and stilling well were surveyed relative to the surveyed monitoring wells by EAP staff using a TopCon Autolevel and stadia rod.

Water level measurements

Manual static water level measurements were made monthly at each well from September 15, 2014 through July 27, 2016 according to standard operating procedures (SOP) EAP052 (Marti, 2009). Depth to water measurements in all wells were made within approximately 30 minutes, avoiding significant tidal or other external influences. Water level measurements were made before water quality samples were collected.

Pressure transducers were calibrated and installed on September 15-16, 2014. Transducers recorded water depth and temperature every 30 minutes in the Edison Slough stilling well and in all wells except BIP686. Procedures for calibration, installation, and operation of transducers were according to SOP EAP074 (Sinclair and Pitz, 2010).

Hydraulic testing

On July 27, 2016, we conducted aquifer hydraulic tests to estimate the horizontal hydraulic conductivity across the study site. The slug test method was used at each well to create an instantaneous change in water level, while high frequency measurements were collected using pressure transducers and data loggers. The procedures used were similar to those described in U.S. Geological Survey (2011) and Bouwer and Rice (1976).

Detailed procedures used for the slug tests are described in Appendix B.

Assumptions of the slug test that are relevant to the study site include (U.S. Geological Survey, 2011):

- Pressure transducer data logger is capable of measuring at a high enough frequency to record changes in the water level, especially immediately after the slug is removed.
- The column of water in the well completely covers the transducer and slug.
- The well is properly constructed and developed.
- Construction details are known (e.g., well depth, screen length, borehole radius, filter pack, and well radius).
- The water level in the well should recover within minutes or hours.

These assumptions were all met for tests in this study, except for wells AHT086, AHT087, AHT088, and AHT089 that did not recover within minutes or hours. Therefore, hydraulic conductivity estimates for these wells are not as accurate as those for wells that recovered quickly.

Water quality sampling and analysis

Groundwater and wastewater effluent samples were collected on 9 dates from October 14, 2014 through April 13, 2016 (Table 1). The sampling locations are shown in Figure 6.

Table 1. Groundwater and effluent sampling schedule.

Parameter	10/14-15/ 2014	12/8-9/ 2014	2/10-11/ 2015	4/22/ 2015	6/9/ 2015	8/12/ 2015	11/17-18/ 2015	2/9-10/ 2016	4/12-13/ 2016
Alkalinity	x		x		x		x	x	
Ammonium-N	x	x	x	x	x	x	x	x	x
Nitrite+Nitrate-N	x	x	x	x	x	x	x	x	x
Total persulfate N	x	x	x	x	x	x	x	x	x
Ortho-phosphate			x						
Total phosphate			x						
Chloride	x	x	x	x	x	x	x	x	x
Bromide	x	x	x	x	x	x	x	x	
Total dissolved solids	x		x		x		x	x	
Anions/Cations[1]			x						
Iron			x		x				
Sulfate					x				
DOC[2]	x		x		x		x	x	
Total coliform bacteria	x	x	x	x	x	x	x	x	x
Fecal coliform bacteria	x	x	x	x	x	x	x	x	x

[1] Anions/cations: sodium, magnesium, calcium, potassium
[2] DOC: dissolved organic carbon

Effluent samples

Effluent samples were collected by Skagit County Public Works sanitarians during each sampling event. Samples were typically collected after the sanitarians cleaned the UV disinfection light bulbs. Effluent samples were collected from an underground vault at the location shown in Figure 6. Effluent samples were analyzed for the same parameters as the groundwater samples at Ecology's Manchester Environmental Laboratory (MEL). Field measurements for pH and dissolved oxygen (DO) were not made for the effluent samples. Specific conductivity was analyzed at MEL.

Groundwater samples

Groundwater samples were collected using a peristaltic pump according to the procedures described in EAP099 (Carey, 2016b) and the QA Project Plan (Carey, 2014). The sampling activities were performed from a cart that provided a workspace and sample storage space while moving between sampling stations. Figure 9 shows the weather-resistant field equipment set-up.

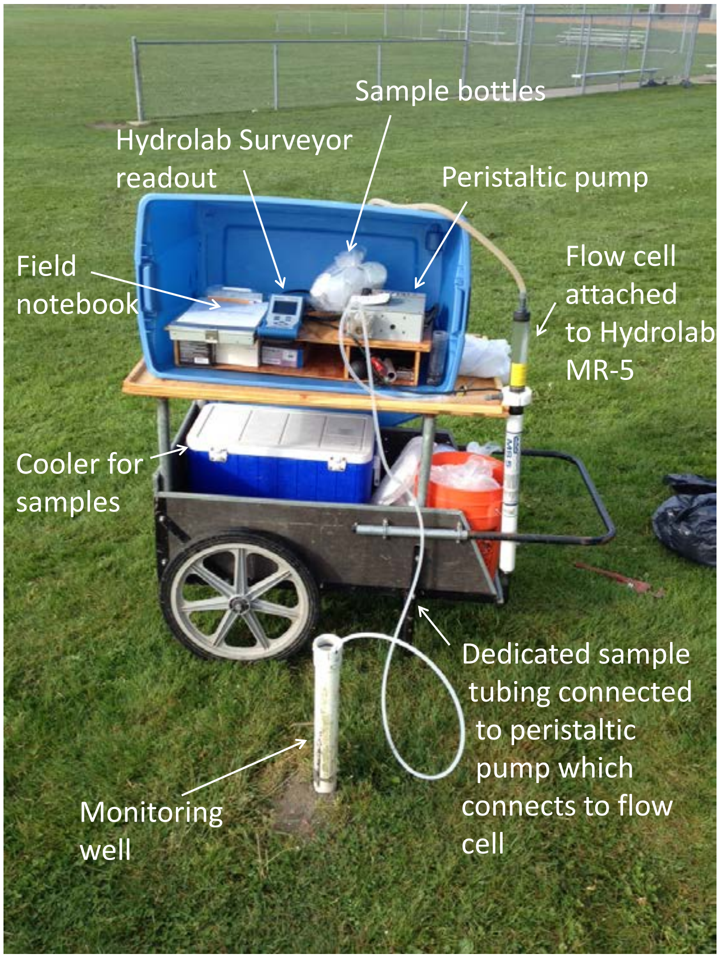

Figure 9. Field equipment set-up for sampling monitoring wells.

Project Quality Assurance

Soil sampling

Three subsamples were analyzed from four of the split-spoon samples. These subsamples were used to measure the range and precision of the particle size analyses. Results are shown in Appendix C, Table C-1. The relative standard deviation (RSD) for the 15 size classes ranged from 0.6-101%. Because there was little coarse material, the coarser size classes tended to have the highest RSD. The high variation among results for the three samples within each of the four splitspoon analyses indicates a relatively high uncertainty associated with estimates of hydraulic conductivity based on particle size analyses. This high variability among subsamples within each sample should be taken into account when using the particle size data for estimating hydraulic properties.

Water quality sampling

Field and laboratory quality assurance (QA) results are described in Appendix C. Field QA results for field parameters (pH, DO, and specific conductivity) were acceptable without qualification with the exception of April 2016 (Table C-2). DO and pH results for April 2016 were rejected due to an instrument malfunction.

Field QA results were acceptable for all laboratory analyses with the following exceptions (Table C-5):

- The nitrite+nitrate-N, total persulfate nitrogen (TPN), and dissolved organic carbon (DOC) results for June 9, 2015 did not meet the +/-10% relative percent difference (RPD) acceptance criteria for replicate samples with concentrations greater than 5 times the method detection limit. Therefore nitrite+nitrate-N and TPN data for this date are qualified as estimates (J) in Appendix E, Tables E-1 and E-2.
- The total coliform bacteria (TC) field blank result on April 12, 2016 was 110 cfu/100 ml. Therefore data for that date are qualified as estimates (J) in Tables E-1 and E-2.

Laboratory analyses were accepted without qualification based on laboratory QA measurements except for the following (Table C-3):

- Matrix spike results were outside the acceptance limits for calcium on February 10, 2016 and DOC on June 9, 2015. Results for these data are qualified as estimates (J) in Tables E-1 and E-2.

Results

Results of field sampling are described in this section in terms of (1) hydrogeologic conditions and (2) groundwater quality conditions.

Hydrogeologic conditions

Aquifer properties

Particle size distribution

Photographs of split-spoon soil samples and particle size distribution curves are available in the EIM database[2]with links for each monitoring well in Appendix A, Table A-2. Tabular results of particle size distributions and soil classifications are listed in Appendix D, Table D-1.

Most of the soil samples were classified as silt with sand and had more than 15% clay-sized particles (<4 um diameter). However samples from wells AHT090 and AKY469, as well as some samples from shallow depths from AKY472, AHT085, AHT086, and AHT089, were coarser than those from the other well borings and were classified as sand with silt.

Fill material added in the southwest corner of the site during construction of Drainfield 2 (Figure 6, Zones 1 and 4) did not appear to be present in drilling samples (Gray and Osborne, 2003a). Coarse layers at other locations on the site may be from fill added previously, or they may occur naturally.

Figure 10 shows the particle size results in a trilinear diagram. Results clustered in two main size classes, one centered in the silt range (deeper samples and those in the south and western areas) and one centered in the sand range (mainly samples from AHT090 and AKY469).

Slug tests for hydraulic conductivity analysis

Spreadsheet slug test input and output data and horizontal hydraulic conductivity (K_H) estimates for each well are provided in Appendix B (Halford and Kuniansky, 2002). These spreadsheets are also stored in the EIM database[1] under details for each well.

[1] https://www.ecology.wa.gov/Research-Data/Data-resources/Environmental-Information-Management-database

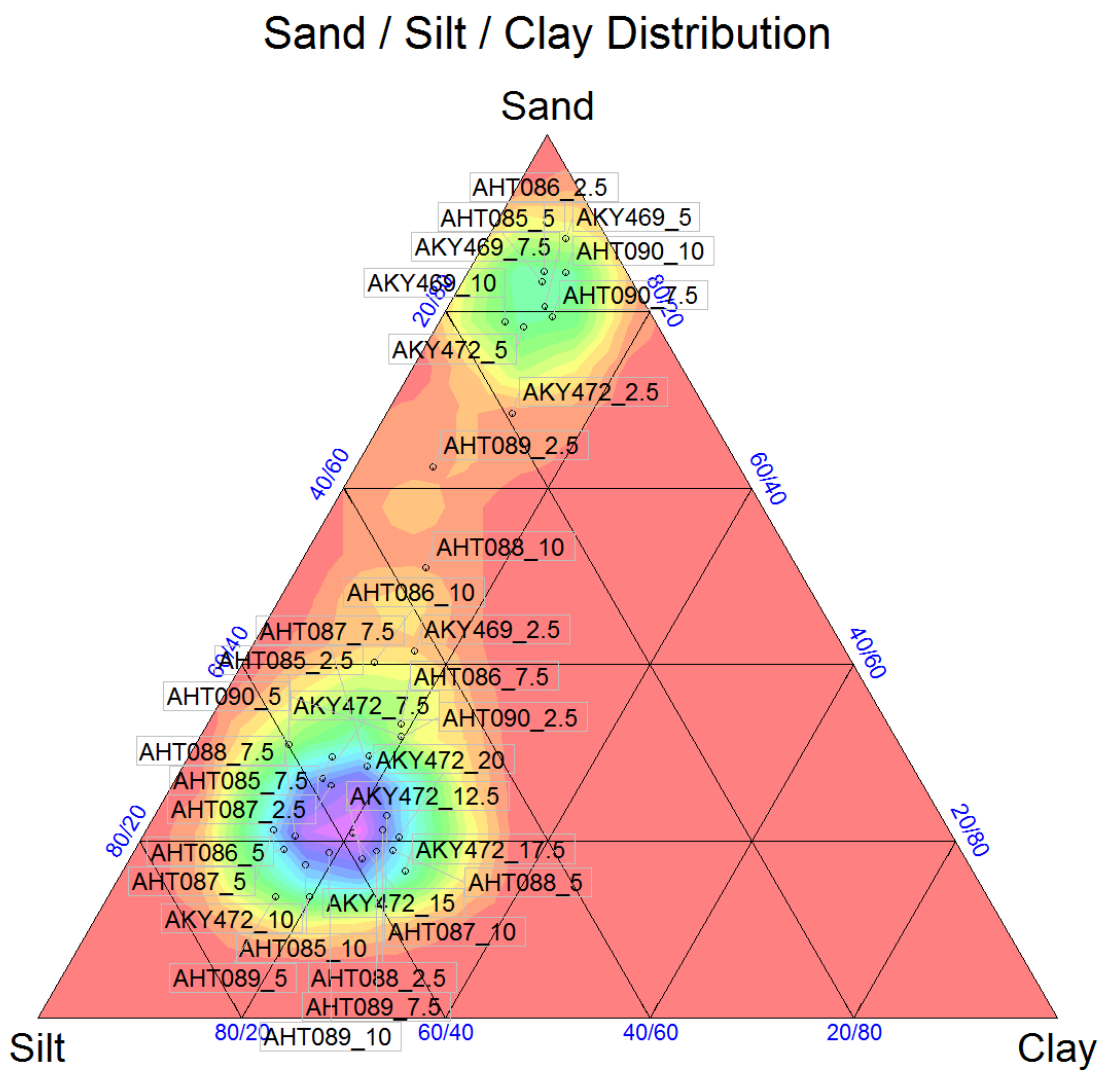

Figure 10. Trilinear diagram of soil particle distribution values of split-spoon samples. *Data are listed in Appendix D.*

Horizontal hydraulic conductivity (K_H) using particle size distribution

Two particle size distribution methods were used to estimate K_H. The Hazen method uses the effective grain size, d_{10}, the grain size on a size distribution curve which 10% of soil particles are finer and 90% are coarser (Equation 1 from Freeze and Cherry, 1979):

$$K = A\, d_{10}^2 \qquad \textit{Equation 1}$$

where

K = horizontal hydraulic conductivity (cm/sec)
A = 1.0
d_{10} = the particle size which 10% of soil particles are finer on a cumulative grain-size curve (mm)

The Kozeny-Carman method incorporates d_{10} as well as porosity in estimating K_H (Equation 2):

$$K = \frac{\rho g}{\mu}\left[\frac{n^3}{(1-n)^2}\right]\frac{d_{10}^2}{180} \qquad \textit{Equation 2}$$

where

ρ = fluid viscosity in g/cm (for water is 1 g/cm)
g = gravitational acceleration (981 cm/sec^2)
μ = viscosity in g/cm sec (for water is 1 g/cm s)
n = porosity in decimal percent
d_{10} = the grain size which 10% of soil particles are finer on a cumulative grain-size curve (mm)

The effective porosity for all samples was assumed to be 0.2 based on Stephens et al. (1998). Actual values for effective porosity are difficult to calculate accurately.

Results of K_H estimates using the two particle size methods ranged from 10^{-8} to 10^{-2} cm/sec and are shown in Table 2. The Hazen method, which does not take porosity into account, yielded results 1-2 orders of magnitude higher than results using the Kozeny-Carman method, which does include a porosity factor.

Monitoring well AHT090 had the highest K_H values for both particle size methods, 2 x 10^{-3} to 3 x 10^{-2} to cm/sec at 10 feet. This area may have received a small amount of fill material as part of constructing Drainfield 2 (Gray and Osborne, 2003a). However, most of the fill was added west and south of AHT090 and would not have affected the 5-10 foot depth. The southern and western wells (AHT086, AHT087, and AHT088) had the lowest K_H values, 10^{-8} to 10^{-5} cm/sec.

Particle size distributions for deeper samples at wells AKY472, AHT085, AHT086, AHT087, and AHT089 had such a large portion of fines that d_{10} values could not be determined. K_H values at shallower depths in these wells were the lowest observed.

Slug test results for K_H shown in Table 2 represent a composite value for the 5-10-foot screened interval and were 2-4 orders of magnitude higher than results based on particle size. The patterns of high and low K_H from slug tests were similar to patterns based on particle size. The slug test, a more direct method for testing aquifer properties than the particle size methods, may be more representative of groundwater conditions.

Table 2. Horizontal hydraulic conductivity (K_H) results based on three methods: Hazen, Kozeny-Carman, and Bouwer and Rice.

Well ID	Depth (ft)	d_{10} (mm)	Hazen K_H (cm/sec)[a]	Kozeny-Carman (cm/sec)[b]	Aquifer Slug Test K_H Bouwer & Rice--USGS spreadsheet (cm/sec)[c]
AKY469	2.5	0.0009	8.10E-07	6.81E-08	7.06E-03
	5.0	0.017	2.89E-04	9.81E-06	
	7.5	0.004	1.60E-05	1.09E-06	
	10.0	0.032	1.02E-03	6.98E-05	
AKY472	2.5	0.0025	6.25E-06	2.73E-07	1.76E-03
	5.0	0.007	4.90E-05	4.36E-06	
	7.5	0.0015	2.25E-06	6.81E-08	
	10.0	NA	NA	NA	
	12.5	NA	NA	NA	
	15.0	NA	NA	NA	
	20.0	NA	NA	NA	
AHT085	2.5	0.0045	2.03E-05	1.09E-06	3.53E-04
	5.0	0.007	4.90E-05	4.36E-06	
	7.5	0.0019	3.61E-06	6.81E-08	
	10.0	NA	NA	NA	
AHT086	2.5	0.017	2.89E-04	1.74E-05	3.53E-07
	5.0	0.001	1.00E-06	6.81E-08	
	7.5	0.00095	9.03E-07	1.70E-08	
	10.0	NA	NA	NA	
AHT087	2.5	0.0018	3.24E-06	2.21E-07	2.47E-06
	5.0	0.005	2.50E-05	2.73E-07	
	7.5	NA	NA	NA	
	10.0	NA	NA	NA	
AHT088	2.5	0.001	1.00E-06	6.81E-08	7.06E-07
	5.0	0.0009	8.10E-07	1.70E-08	
	7.5	0.002	4.00E-06	2.73E-07	
	10.0	0.0028	7.84E-06	6.13E-07	
AHT089	2.5	0.008	6.40E-05	4.36E-06	3.18E-04
	5.0	0.0019	3.61E-06	2.73E-07	
	7.5	NA	NA	NA	
	10.0	NA	NA	NA	
AHT090	5.0	0.007	4.90E-05	4.36E-06	2.12E-02
	7.5	0.046	2.12E-03	1.09E-04	
	10.0	0.17	2.89E-02	2.09E-03	

[a] Freeze, R.A. and J.A. Cherry, 1979.
[b] Bear, J., 1972.
[c] Bouwer and Rice, 1976. Values represent the 5-10 foot deep screened interval.

K_H values based on particle size were generally lower than values based on slug tests, indicating the degree of variation in K_H with depth (Table 2). In most boreholes, both Hazen and Kozeny-Carman estimates varied by 1-3 orders of magnitude across the 10-foot depth. The K_H values tended to be lowest at the deeper depths, especially 10 feet and below, as indicated by samples at 10, 12.5, 15, and 20 feet at AKY472. K_H values for these depths were 10^{-7} cm/sec based on particle size methods.

The portion of clay-sized particles was highest in the deep samples (23-32%) as shown in Appendix D. On the other hand, hydraulic conductivity values derived from particle size and slug testing at AHT090, which had a higher percentage of coarse material, were relatively high, with K_H values of 10^{-3} to 10^{-2} cm/sec at 7.5- and 10-foot depths.

Groundwater levels

Depth to water results from pressure transducers and manual water level elevation measurements in the monitoring wells are shown in Figure 11. The data are also available in Ecology's EIM system: EIM Database. The correlation (r^2) between 120 manual and transducer measurements was 0.999. This indicates reliable accuracy of transducer results. Results from AKY470 were not included in the comparison between manual and transducer results, because manual water level measurements were not close enough in time to the transducer measurement to capture the rapid tidal changes so close to Edison Slough.

Pressure transducers were removed from 4 wells on November 18, 2015, to prevent contamination of wells. The well caps used to accommodate cables holding the pressure transducers could have allowed water to overtop wells AKY469, AHT086, AHT087, and AHT088 (Figure 11-b, -c, -d, -g). Therefore, well caps were replaced with compression caps to avoid contamination. The remaining transducers continued to record depth to groundwater until they were removed on July 27, 2016 (AKY470, AKY472, AHT085, AHT089, and AHT090).

Continuous water level results from 3 wells (AHT086, AHT087, and AHT089) indicated that purging and sampling, even at flow rates of 0.3-0.4 L/min for 30 minutes, resulted in water level declines lasting up to 9 days as shown in Figure 11- a, -c, -e. This indicates very low hydraulic conductivity in the 5-10-foot screen depth at these locations.

The highest groundwater levels occurred from November-March each year. Water levels in most of the wells were at or above the tops of the wells in November 2015. Transducers in wells that were not flooded in November 2015 had winter water level depths of 0.5-3.4 feet below ground surface during both winters (AHT085, AHT089, AHT090) (Figure 11-a, -e, -f).

A vertical extension was installed on well AKY472 to allow water level measurements when the well was submerged. Transducer results indicated frequent episodes when the well was over-flowing (water level above land surface) from November to March during both winters (Figure 11-i).

During the winter of 2014-2015, groundwater levels were occasionally within 0.5 foot of ground surface in AKY469, AHT085, AHT086, and AHT090. Depth to water in other wells, excluding AKY470, were greater than one foot in the 2014-2015 winter. Water level elevations were frequently above ground surface at AKY470 during both winters. This well, which is cased to 4 feet above land surface, is in the area submerged by Edison Slough in the winter.

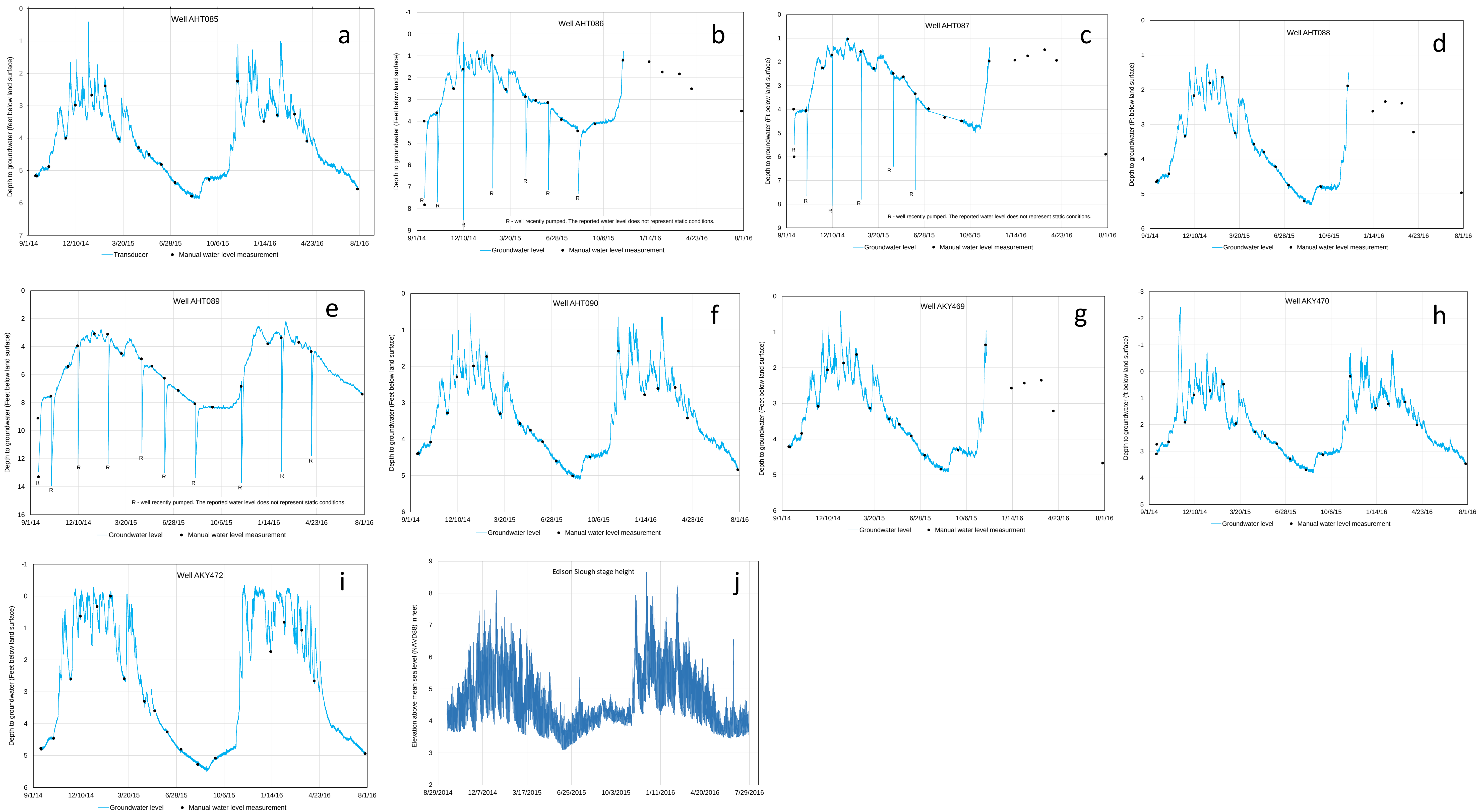

Figure 11. Groundwater depth below ground surface in the monitoring wells (a-i) and Edison Slough stage height (j).

R represents measurements following pumping and sampling. R values do not represent static water level conditions.

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Groundwater flow direction

The regional surface water flow direction in the delta area is toward Samish Bay. The regional groundwater flow direction tended to follow that of the surface water. Edison Slough is a surface water expression of the regional flow and is tidally affected. Therefore the flow direction between the surface water and groundwater, especially close to the slough, can be affected by the tidal elevation relative to the groundwater elevation.

In addition to the regional surface water/groundwater flow system, two agricultural drains conduct water away from the Edison Wastewater Treatment System (WWTS) drainfield area (Figure 6). The southwest corner drain flows south away from the site and connects with another drain that discharges to Edison Slough further downstream. A second drain discharges to Edison Slough in the northeast corner of the site.

Heavy wintertime precipitation, combined with the Edison WWTS effluent discharge, causes the water table elevation at the Edison WWTS site to rise nearly to the ground surface, and in some areas above the surface, in the winter. We did not investigate surface runoff to the corner drains, but overland flow was observed along the northeastern boundary of the site toward the northeast corner drain.

Water level contours

We calculated the average monthly groundwater elevations in the monitoring wells from well elevations recorded every half-hour to describe the groundwater flow direction at monthly intervals. We used an interpolation technique, spline with barriers, to illustrate the water levels across the site. This method uses water level measurements at a few locations within the same aquifer zone to approximate water levels across an area and generate a visual model. (ArcMap 10.3, http://desktop.arcgis.com/en/arcmap/latest/tools/3d-analyst-toolbox/how-spline-with-barriers-works.htm).

The model simulates a "barrier" at the Edison WWTS by preventing groundwater from flowing past Edison Slough in the northerly direction. Data from well AHT089 were not included in the model, because the well is completed 5 feet deeper than the other wells and may represent a different aquifer zone.

Water table elevation contours in Figure 12 indicate the horizontal groundwater flow direction in the 5-10-foot depth range during the winter and early spring (November-March) was mainly toward the agricultural drain in the southwest corner of the site. During the summer and early fall (May-September), groundwater flow was generally from south to north as well as toward the east and west. In October of both 2014 and 2015, groundwater flowed radially outward from the middle of the site.

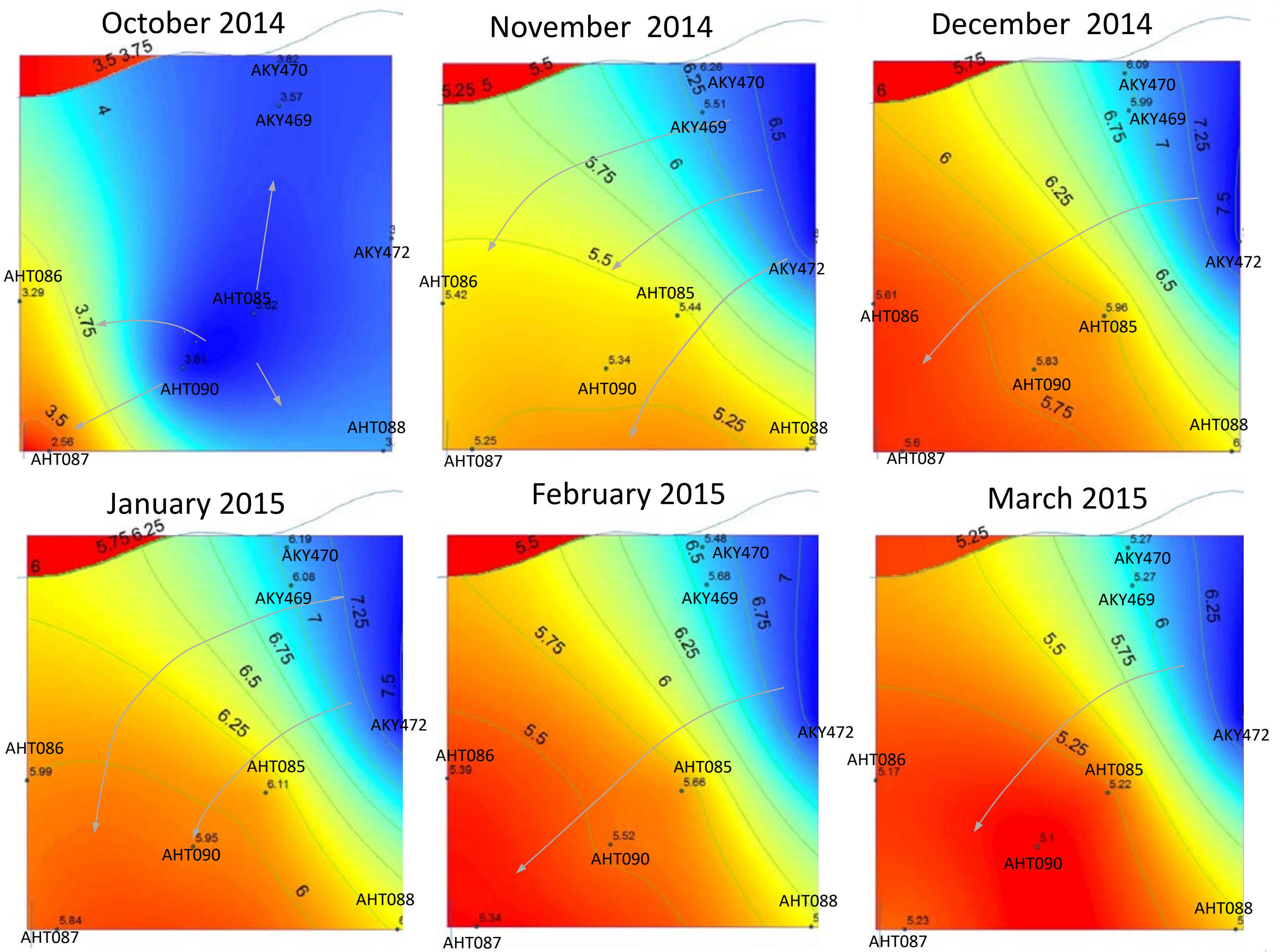

Figure 12. Average monthly elevation contours (feet above mean sea level) and flow directions (white arrows).

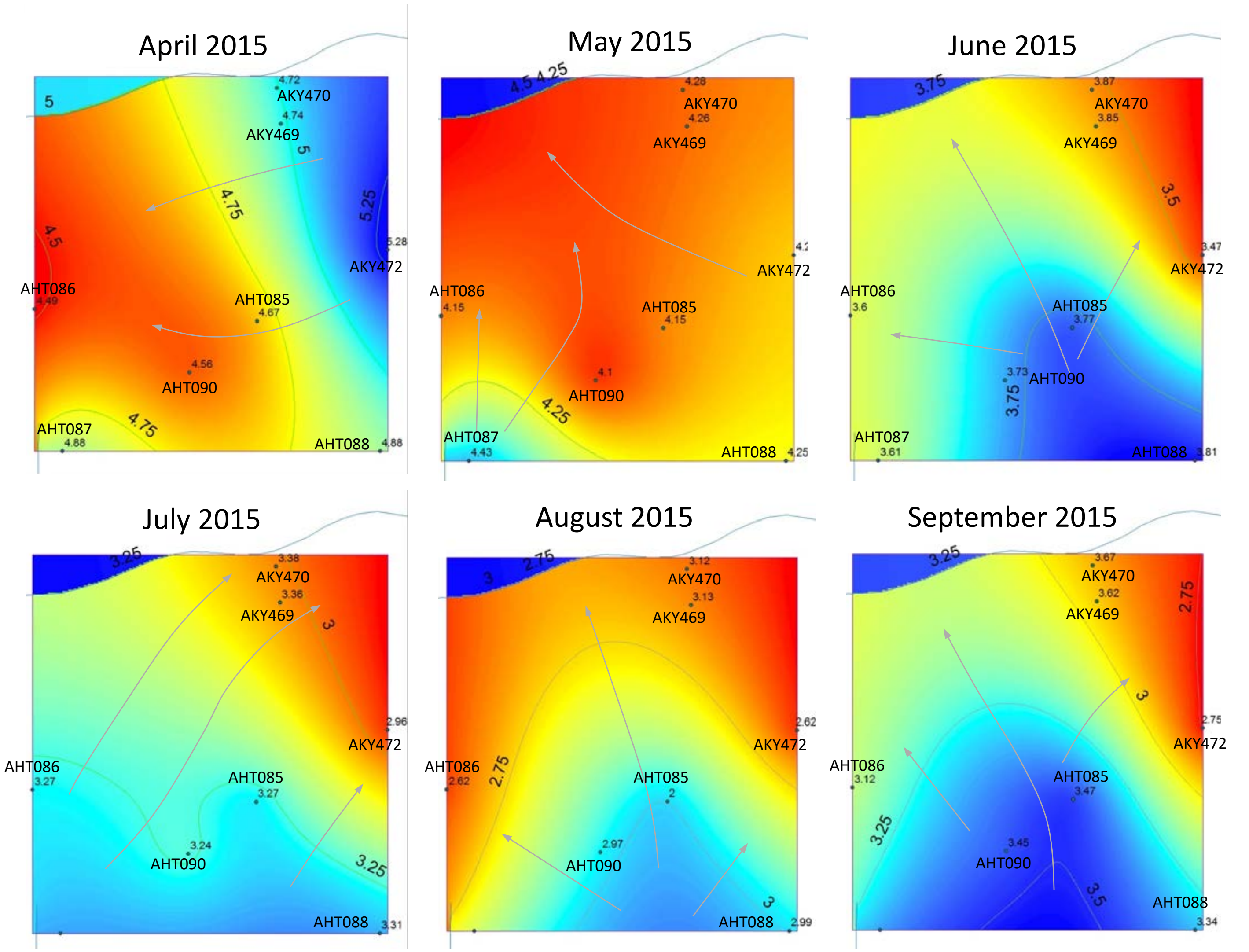

Figure 12 (continued). Average monthly elevation contours (feet above mean sea level) and flow directions (white arrows).

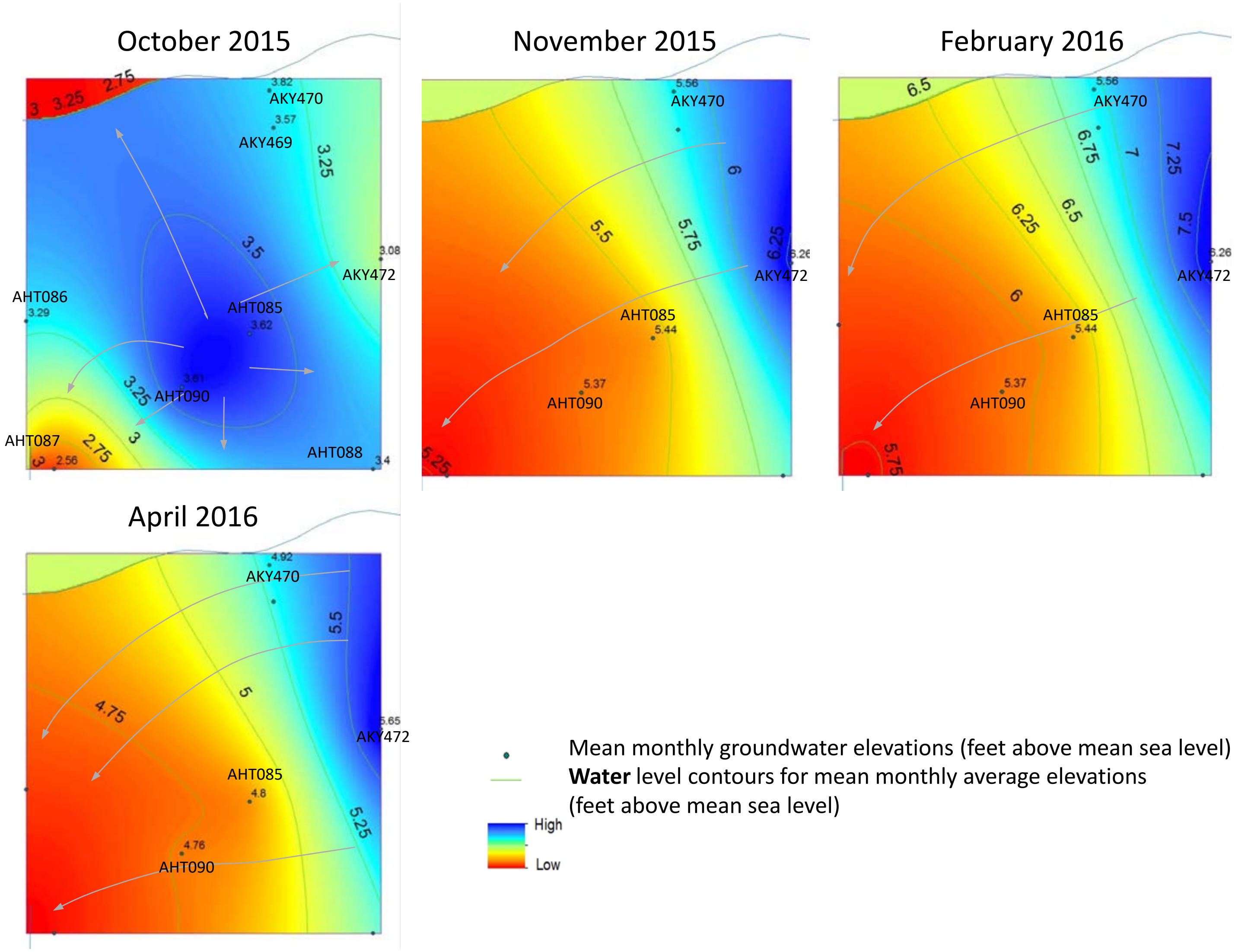

Figure 12 (continued). Average monthly elevation contours (feet above mean sea level) and flow directions (white arrows).

Horizontal hydraulic gradient

The magnitude of the horizontal hydraulic gradient, or slope of the water table, i_H, varied seasonally. The horizontal gradient between the wells was calculated as:

$$i_H = \frac{dh}{dl} \qquad \textit{(Equation 3)}$$

where

dh = difference in groundwater elevation between 2 wells at a given time (feet)
dl = distance between 2 wells (feet)

The gradient between Drainfield 1 and Edison Slough was calculated as the difference between the monthly water level elevations for AKY472 and AKY469 for months when the direction of flow from Zone 1 was toward Edison Slough, *dh*. The distance between the wells, *dl*, was 420 feet. The resulting i_H values are shown in Table 3.

The gradient between Drainfield 2 and the southwest agricultural drain was calculated using the monthly difference between the water level elevations for AHT085 and AHT087. The distance between these wells, *dl*, is 588 feet. The resulting i_H values are shown in Table 3.

Table 3. Horizontal gradient values based on elevations in wells.

Date	Horizontal gradient, i_H, between AKY472 and AKY469 (dimensionless)	Horizontal gradient, i_H, between AHT085 and AHT087 (dimensionless)
10/13/2014	NA	0.00301
11/18/2014	0.00110	0.00145
12/8/2014	0.00336	0.00224
1/12/2015	0.00362	0.00163
2/9/2015	0.00383	0.00301
3/10/2015	0.00124	0.00145
4/21/2015	0.00026	0.00134
5/13/2015	NA	0.00122
6/8/2015	NA	0.00192
7/7/2015	NA	0.00204
8/11/2015	NA	0.00196
9/17/2015	NA	0.00310
11/16/2015	NA	0.00395
1/11/2016	0.00193	0.00177
2/8/2016	0.00379	0.00179
3/16/2016	0.00300	0.00139
4/11/2016	0.00126	0.00075
7/27/2016	NA	0.00497

NA: The horizontal gradient was away from Edison Slough.

Groundwater velocity

Although monthly average groundwater contours indicated groundwater flow toward Edison Slough in May, June, August, September, and October of 2015, gradient estimates based on both manual and transducer-measured groundwater levels in wells AKY469 and AKY 470 for the weeks when manual measurements were made indicated flow away from the slough (Table 3). Therefore, no groundwater velocity estimates were made for Drainfield 1 to Edison Slough.

A variation of Darcy's Law was used to estimate the time of travel from Drainfield 2 to the southwest agricultural drain.

The average horizontal velocity of groundwater flow was estimated as:

$$v = \frac{-K_H(i_H)}{n_e} \qquad \textbf{(}\textit{Equation 4)}$$

where

v = Average linear groundwater velocity (feet/day)

K_H = Horizontal hydraulic conductivity (feet/day)

i_H = Horizontal hydraulic gradient (dimensionless)

n_e = Effective porosity (ratio of the volume of interconnected voids/volume of material that is capable of transmitting fluid)

For the Drainfield 2 discharge area, the K_H values derived from the slug tests at AHT090 and AHT085 (60 and 1.0 feet/day respectively from Table 3) were used in Equation 3 to represent the range of average linear velocity. Effective porosity was assumed to be 0.20 based on the particle size analysis (Appendix D) (Stephens et al., 1998). The i_H values for 6 dates were chosen from Table 3 to represent the range of horizontal gradients observed.

The velocity estimates ranged from 0.01 feet/day for several dates assuming a K_H of 1.0 feet/day to 1.92 feet/day on 11/16/15, as shown in Table 4.

Table 4. Average horizontal velocity estimates for groundwater in Drainfield 2.

Date	Velocity, *v,* if K_H=1.0 foot/day (feet/day)	Velocity, *v,* if K_H=60 feet/day (feet/day)
10/13/14	0.03	1.62
12/8/2014	0.02	1.32
3/10/2015	0.01	0.78
6/8/2015	0.01	1.02
11/16/15	0.02	1.92
4/11/2016	0.01	0.48

The estimated travel time for groundwater at the edge of Drainfield 2 to reach the southwest corner agricultural drain 70 feet away is 36-7,000 days based on the minimum and maximum estimated velocities. The estimated range for groundwater travel time from the middle of Drainfield 2 to the southwest corner drain, roughly 400 feet, would be 208-50,000 days.

These estimates assume that the K_H values represent the range of values for the drainfield area. It is likely that the actual range of K_H values along the flowpath is greater than that observed. In addition, preferential flow paths that short-circuit the matrix groundwater flow also probably affect movement of subsurface water. Surface water runoff in the winter may also divert water at the site to surface water drains.

Vertical hydraulic gradient

The direction of groundwater flow in the vertical direction was calculated as the difference between the groundwater elevations at side-by-side wells, AHT089 (15 feet) and BIP686 (38 feet), divided by the difference in altitude between the mid-points of the well screens according to Equation 4.

$$i_V = \frac{(Elevation\ of\ water\ in\ AHT089) - (Elevation\ of\ water\ in\ BIP686)}{(Screen\ midpoint\ elevation\ AHT089) - (Screen\ midpoint\ elevation\ BIP686)} \quad \textit{Equation 5}$$

Figure 13 shows that the vertical gradient was mostly positive, or downward, except in the fall following the dry summer period. Precipitation during the late fall through spring apparently maintained the downward gradient through most of the year as indicated by the mostly higher water table elevation in AHT089 than BIP686 (shown in Figure 13). Negative vertical gradients were observed in August, September, and November 2015 and July 2016.

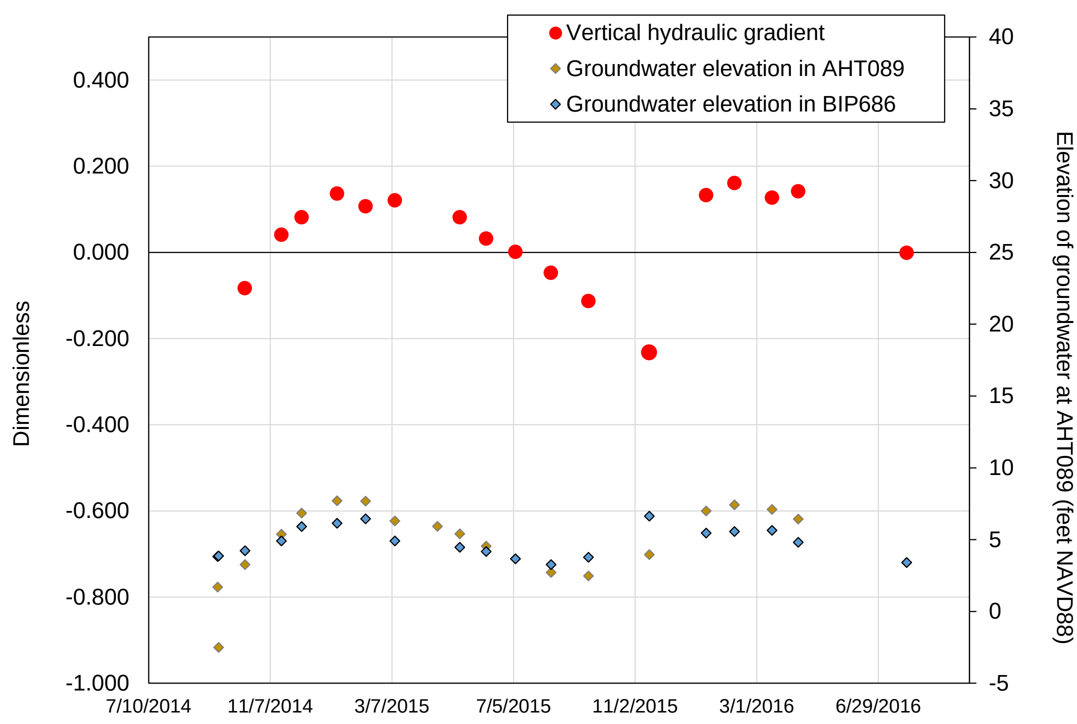

Figure 13. Water table elevations and vertical hydraulic gradients at side-by-side wells AHT089 (15 feet) and BIP686 (38 feet).

Red dots in the top graph with positive values indicate downward groundwater flow, and dots with negative values indicate upward flow.

Effluent and groundwater quality

Time series results for groundwater and effluent chemical quality are described in this section. Results are listed for pH, dissolved oxygen (DO), specific conductivity, total dissolved solids (TDS), ammonium-N, nitrate-N, total persulfate nitrogen (TPN), chloride, bromide, dissolved organic carbon (DOC), total coliform bacteria (TC), and fecal coliform bacteria (FC). *Nitrite+nitrate-N* laboratory results are referred to as *nitrate-N* in this report, because nitrite-N is typically negligible in surface water and groundwater (Sawyer and McCarty, 1978).

Effluent quality

Effluent water quality results are shown in Figures 14-15 and summarized in Appendix E, Table E-1. A statistical summary of the chemical effluent data is shown in Table 5. The effluent bacterial results are listed in Table 6. The effluent was not sampled for pH or DO. Discharge monitoring records submitted by the facility for the study period indicated that effluent pH ranged from 6.12 in September 2014 to 6.63 in July 2015.

A power outage to the computer system that regulates the amount of effluent discharging to Drainfield 2 occurred on February 7-11, 2015. Each zone in Drainfield 2 received a 200-gallon dosage by a manual rotation valve until power was restored. Normally the computer adjusts the dosage to each zone depending on the depth of water in the chamber surrounding the discharge pipe (Figure 3). Power to the rest of the WWTS was working during the computer power outage, including the UV disinfection system, the discharge to Drainfield 1, and the gravel filter rotation pumps (Mohns, 2017).

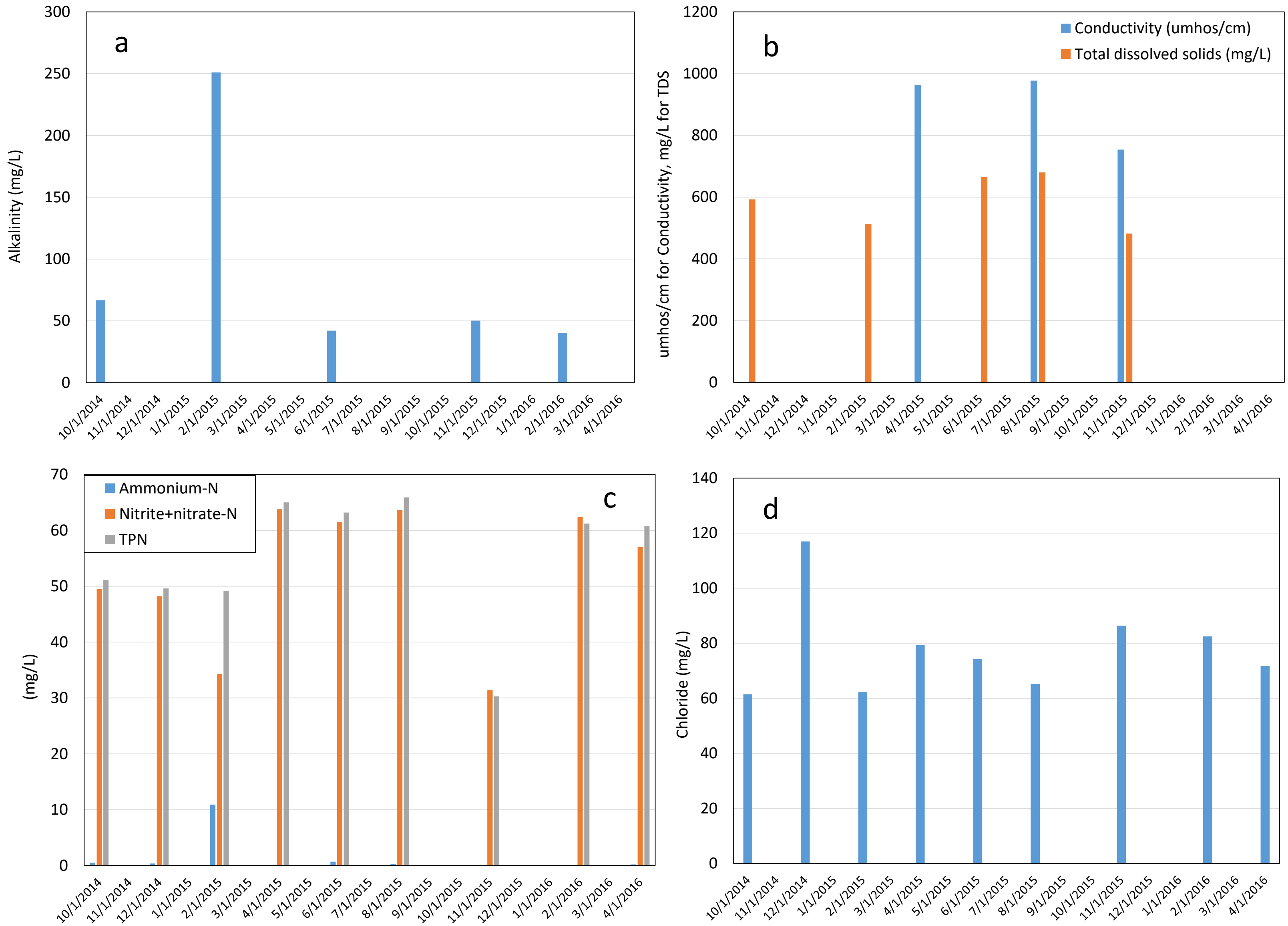

Figure 14. Effluent water quality results for (a) alkalinity, (b) conductivity, TDS, (c) ammonia-N, nitrite+nitrate-N, total persulfate nitrogen, and (d) chloride.

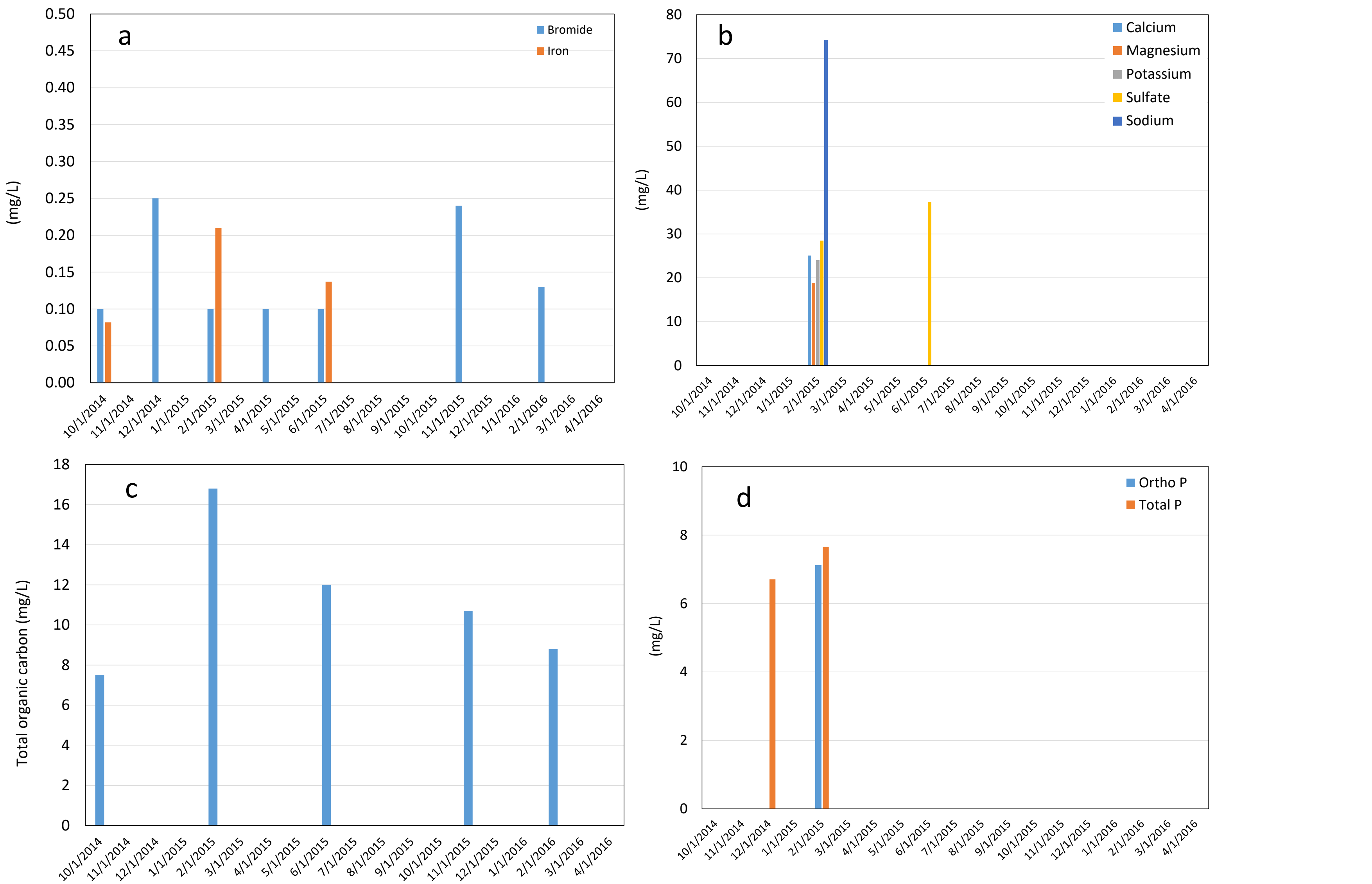

Figure 15. Effluent water quality results for (a) bromide, iron, (b) calcium, magnesium, potassium, sulfate, sodium, (c) total organic carbon, and (d) ortho and total phosphorous.

Table 5. Averages, standard deviations, medians, and number of samples for chemical effluent quality.

Parameter	Average	Standard Deviation	Median	Number of Samples
Specific Conductance	898	125	963	3
Alkalinity	90.1	90.6	50.2	5
Ammonium-N	1.48	3.54	0.274	9
Nitrite+nitrate-N	52.4	12.5	57.0	9
Total persulfate N	55.1	11.4	60.8	9
Chloride	77.8	17.1	74.2	9
Bromide[1]	0.15	0.07	0.1	7
Iron	0.14	0.06	0.137	3
Sulfate	32.9	6.22	32.9	2
Calcium	25.0	NA	NA	1
Magnesium	18.8	NA	NA	1
Potassium	24.0	NA	NA	1
Sodium	74.1	NA	NA	1
Ortho Phosphorus	7.12	NA	NA	1
Total phosphorus	7.19	0.67	7.19	2
Total dissolved solids	587	88.6	593	5
Total organic carbon	11.2	3.59	10.7	5

[1] For non-detects, half of the detection limit was used, 0.1 mg/L.

Table 6. Results for effluent bacterial quality (cfu/100 mL).

Fecal coliform bacteria (FC)		
10/14/2014	1	U
12/10/2014	**180**	
2/10/2015*	**3400**	J
4/22/2015	1	UJ
6/9/2015	1	UJ
8/12/2015	**36**	J
11/18/2015	**16**	J
2/9/2016	1	U
4/12/2016	1	U
Total coliform bacteria (TC)		
10/14/2014	1	UJ
12/10/2014	**560**	J
2/10/2015*	3	U
4/22/2015	1	UJ
6/9/2015	1	UJ
8/12/2015	**23**	J
11/18/2015	**6**	J
2/9/2016	**20**	
4/12/2016	**39**	J

*: The WWTS experienced a power failure February 7-11, 2016.
U: The organism was not detected at or above the reported result.
J: The organism was positively identified. The result is an estimate.

Alkalinity

Alkalinity results for the effluent ranged from 40 to 67 mg/L except for the sample collected on February 11, 2015, when alkalinity was 251 mg/L (Figure 14-a).

Specific conductance and total dissolved solids

Specific conductance and TDS values for the effluent samples were fairly consistent during the study (Figure 14-b) with somewhat higher levels in the summer, when precipitation was low. Conductivity ranged from 754-977 umhos/cm; TDS ranged from 482 to 680 mg/L.

Nitrogen

The total persulfate nitrogen (TPN) concentration in the effluent averaged 55 mg/L. TPN is the sum of ammonium-N, nitrate-N, and organic N. On average, 95% of the total nitrogen-N in the effluent was in the form of nitrate-N (Table 5) indicating that the effluent was well oxidized. Ammonia-N made up only 2.5% of the total nitrogen on average but was higher on February 11, 2015 (Figure 14-c). The lowest total nitrogen-N concentration occurred on November 18, 2015, when the concentration was roughly half of the average.

Chloride, bromide, and sodium

Chloride, bromide, and sodium are found not only in wastewater effluent but also at high concentrations in seawater. The average concentrations of these ions in the effluent were 77.8, 0.15, and 74.1 mg/L, respectively (Figures 14-d, 15-a, and 15-b).

Calcium, magnesium, potassium, sulfate, and iron

Results for calcium, magnesium, potassium, sulfate, and iron are shown in Figure 15-b. Except for iron and sulfate, samples were collected only in February 2015. Iron concentrations were somewhat higher on February 11, 2015 than on the other 2 dates. However, sulfate concentrations in effluent samples were lower in February 2015 than in June 2015.

Total organic carbon

The average TOC in the effluent was 11.2 mg/L and was highest, 16.8 mg/L, on February 11, 2015 (Figure 15-c).

Phosphorus

The average total phosphorus concentration in 2 samples was 7.19 mg/L. Orthophosphorus was analyzed only on February 11, 2015, when 93% of the total phosphorus was in the form of orthophosphorus (Figure 15-d).

Bacteria

Results for effluent samples were below detection in 56% of FC samples and 44% of TC samples (Table 6). The highest FC result was observed on February 11, 2015, 3,400 cfu/100 ml (J). Results for effluent samples collected on December 10, 2014 were 180 cfu/100 ml for FC and 560 cfu/100 ml (J) for TC. On other dates when detections occurred, effluent results were below 50 cfu/100 ml.

The geometric mean for the 9 FC effluent samples over 19 months was 9 cfu/100 mL. This is below the monthly permit limit of 200 cfu/100 mL.

Groundwater quality

Groundwater samples were collected semi-monthly on either the same day that the effluent samples were collected or the day before the effluent samples were collected. Results for most groundwater quality constituents varied widely across the site. Groundwater from wells AHT086, AHT087, and AHT088 was more saline than groundwater from the other wells, as indicated by specific conductivity, chloride, and bromide concentrations (Figure 16-a, -b, -c). Results for each constituent are described below and are listed in Appendix E, Table E-2.

pH

Values for pH in groundwater ranged from 5.71 to 7.29 (Figure 16-d). The mean groundwater pH was 6.42. Values for pH were somewhat lower in wells near the drainfields (AHT085, AHT090, AKY469, and AKY470) than wells further away.

Specific conductance, chloride, and bromide

Specific conductance, chloride, and bromide results followed similar patterns in the wells (Figures 16-a, -b, and -c). Well AHT086 had the highest value for all 3 analytes, 6,886 umhos/cm conductance, 2,450 mg/L chloride, and 9.7 mg/L bromide on October 14, 2014. Specific conductance, chloride, and bromide were also higher in the other 2 saline wells, AHT087 and AHT088, than in the non-saline wells.

Specific conductance, chloride, and bromide varied little over time in most wells except for AHT086. For example, chloride in AHT086 was lower in the winter and spring (923 mg/L on February 10, 2015) than in the summer and fall (2,350 mg/L on October 14, 2014).

Although a number of the groundwater specific conductance results exceeded the secondary maximum contaminant levels (MCLs) for drinking water of 700 umhos/cm, we could find no evidence of drinking water wells within one mile of the site.

Dissolved oxygen

DO concentrations were less than 1.5 mg/L in most wells (Figure 17-a). The DO concentration influences many chemical and biological processes including nitrification, denitrification, and bacterial viability. The maximum DO concentration was 3.89 mg/L at AHT089 on October 14, 2014. The mean DO concentration in all wells during the study was 0.44 mg/L. DO concentrations were not measured during the February 9-10, 2016 and April 12-13, 2016 sampling events due to equipment malfunctions.

Ammonium-N and total persulfate nitrogen

Ammonium-N and TPN results followed similar patterns in the wells (Figures 17-b -c). Ammonium is typically not found in high concentrations in groundwater. When DO is available, ammonium-N is rapidly converted to nitrate by soil bacteria. Ammonium-N concentrations over 2 mg/L were found in wells AHT086, AHT087, AHT088, AHT089, and AKY470. The highest ammonium-N concentration, 9.91 mg/L, was found at AHT086 on October 14, 2014. Typical ambient groundwater ammonium-N concentrations are less than 0.01 mg/L.

TPN concentrations in groundwater were typically about the same as ammonium-N, while nitrate-N values were almost all less than 0.5 mg/L.

Seasonal variability occurred in ammonium-N and TPN at some wells, especially AHT086, with higher concentrations in the summer/fall and lower concentrations in the winter/spring.

Nitrate-N

Nitrate-N concentrations were below 0.5 mg/L in all wells except AKY469 (Figure 17-d). Nitrate-N concentrations at AKY469 were above 2 mg/L on 2 dates, 12/8/14 and 2/10/15. The average nitrate-N concentration in the monitoring wells during the study was 0.16 mg/L. The median groundwater nitrate-N concentration was 0.026 mg/L.

Total dissolved solids, calcium, magnesium, potassium, sodium, and alkalinity

TDS, calcium, magnesium, potassium, and sodium concentrations were highest in the west and southwest wells, AHT086 and AHT087, and lowest in the wells near the wastewater discharges, AHT085, AHT090, and AKY469, as well as AKY472 (Figure 18-a -d).

TDS values ranged from 2,200 to 4,520 mg/L in wells AHT086 and ATH087, while concentrations in most wells and the effluent were in the 100-600 mg/L range (Figure 18-a). Magnesium was likewise higher in AHT086 and AHT087 (48.8-70.9 mg/L) than in other wells (2.09-33.4 mg/L; Figure 18-b). Potassium concentrations in AHT086 and AHT087 were higher than the other wells (26.5-27.3 mg/L compared to 3.08-11.1 mg/L), but the effluent concentration was in the same range as the higher wells, 24.0 mg/L (Figure 18-b). Sodium concentrations ranged from 4 to 930 mg/L, with the highest concentrations in southwest wells, AHT086, AHT087, and AHT088, and the lowest in the wells nearest the drainfields (AKY469, AHT085, and AHT090) (Figure 18-c). Calcium levels did not follow a clear spatial pattern and ranged from 9.07 to 30.6 mg/L (Figure 18-b).

Alkalinity values were highest in the west and southwest wells AHT086, AHT087, AHT088, AHT089, and BIP686 (228-511 mg/L; Figure 18-d). The effluent alkalinity was below 100 mg/L except for the February 11, 2015 sample, when it was 251 mg/L. Monitoring wells nearest the drainfields (AKY469, AHT085, and AHT090) had the lowest alkalinity values, 41-84 mg/L.

Iron and sulfate

Iron concentrations in the monitoring wells ranged from less than 0.050 to 24.3 mg/L (Figure 19-a). Anaerobic, or close to anaerobic, conditions in most groundwater samples favored conditions for dissolved ferrous iron. The highest iron concentrations occurred at AKY470 located on the banks of Edison Slough. The lowest iron concentrations were observed at AKY469, the well closest to AKY470. The effluent iron concentration in all 3 samples, which were fully aerated, was less than 0.50 mg/L.

Sulfate results in the monitoring wells ranged from 0.55 to 33.6 mg/L (Figure 19-b). The highest concentration occurred at AHT086 and the lowest at AHT089. The effluent sulfate results, 28.5 and 37.3 mg/L, were higher than almost all of the groundwater results.

Dissolved organic carbon

DOC concentrations were roughly 8-9 times higher in the southern and western wells, AHT086, AHT087, and AHT088 (35-48 mg/L) than in the wells closest to the wastewater discharges, AKY469, AHT085, and AHT090 (5-10 mg/L). See Figure 19-c. The well closest to Edison Slough, AKY470, had DOC concentrations in the higher range (32-42 mg/L). Effluent TOC concentrations, 7.5-16.8 mg/L, were relatively low compared with DOC concentrations in the southern, western, and near-slough wells.

Phosphorus

Total phosphorus in groundwater was mainly in the form of ortho-phosphate (Figure 20). Phosphorus concentrations were much higher in the southern wells (greater than 4 mg/L at AHT087 and AHT088) than in the other wells. Phosphorus concentrations were less than 0.2 mg/L in the wells closest to the wastewater discharges areas, AHT085, AHT085, and AKY469.

Effluent phosphorus, also entirely in the ortho-phosphate form, had the highest concentrations (greater than 7 mg/L).

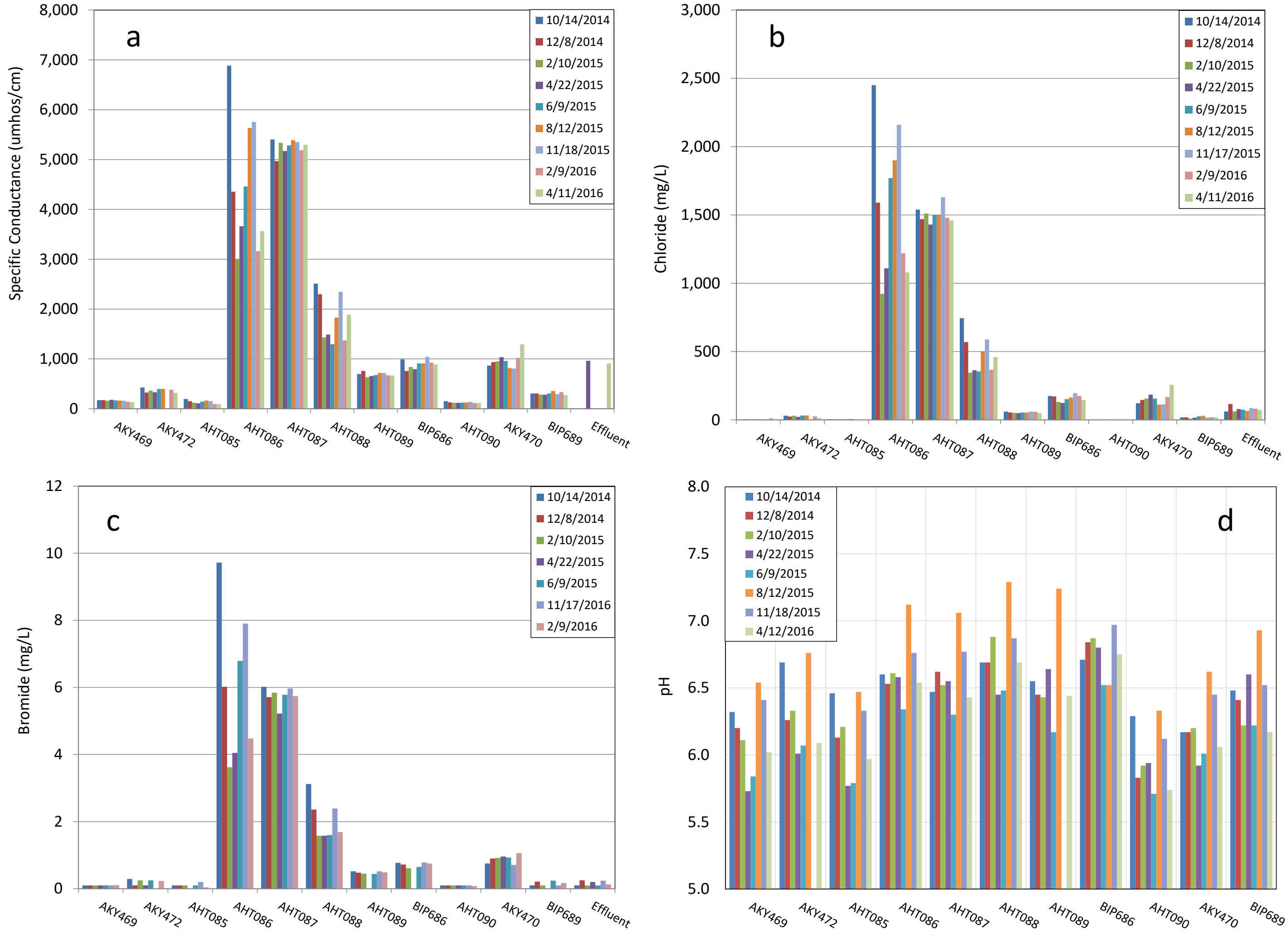

Figure 16. Groundwater quality results for (a) specific conductance, (b) chloride, (c) bromide, and (d) pH.

Effluent results are included in a-c for comparison.

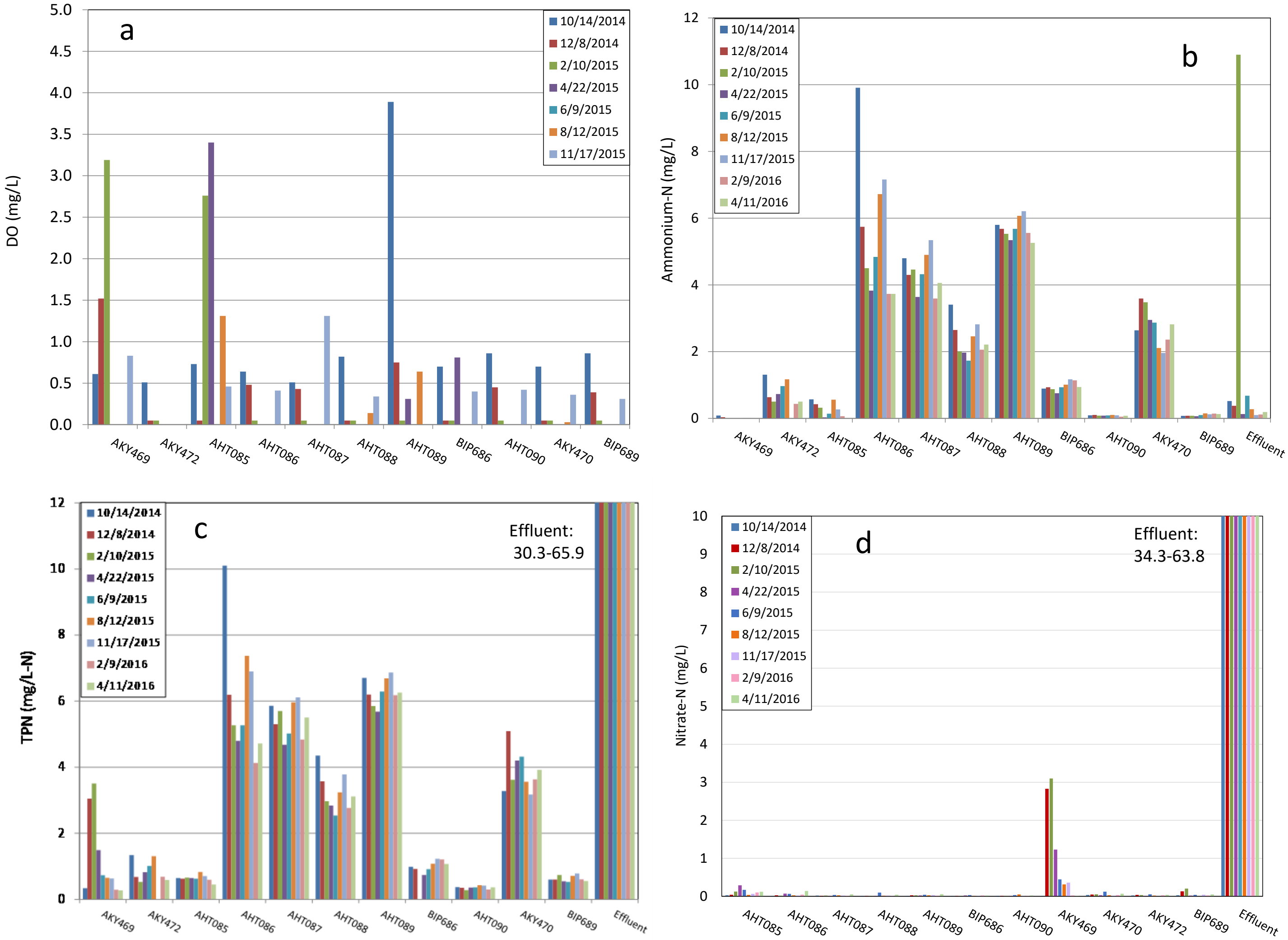

Figure 17. Groundwater quality results for (a) dissolved oxygen, (b) ammonium-N, (c) TPN, and (d) nitrate-N.

Effluent results are also included in b-d for comparison.

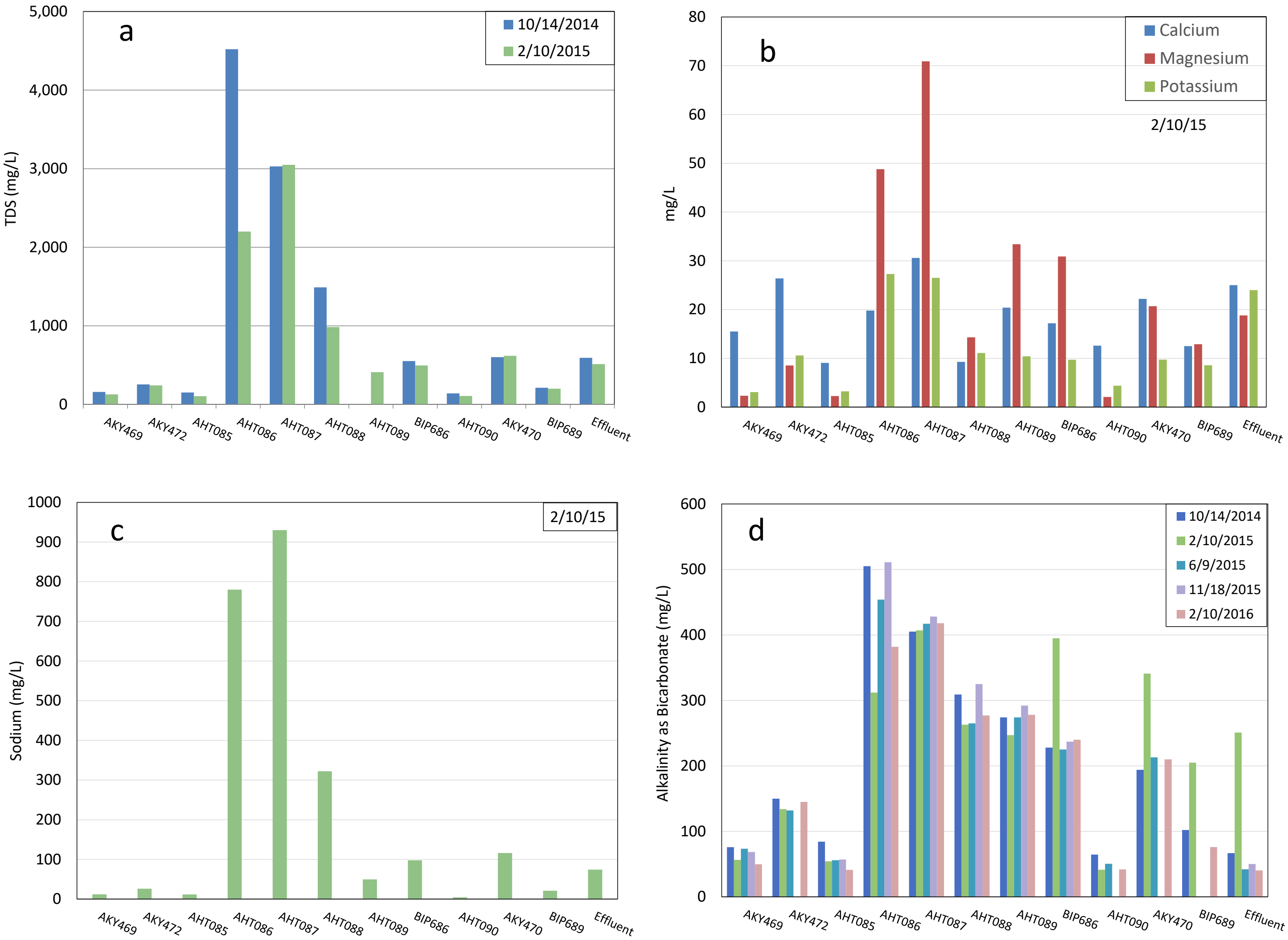

Figure 18. Groundwater quality results for (a) total dissolved solids, (b) calcium, magnesium, potassium, (c) sodium, and (d) alkalinity.

Effluent results are included for comparison.

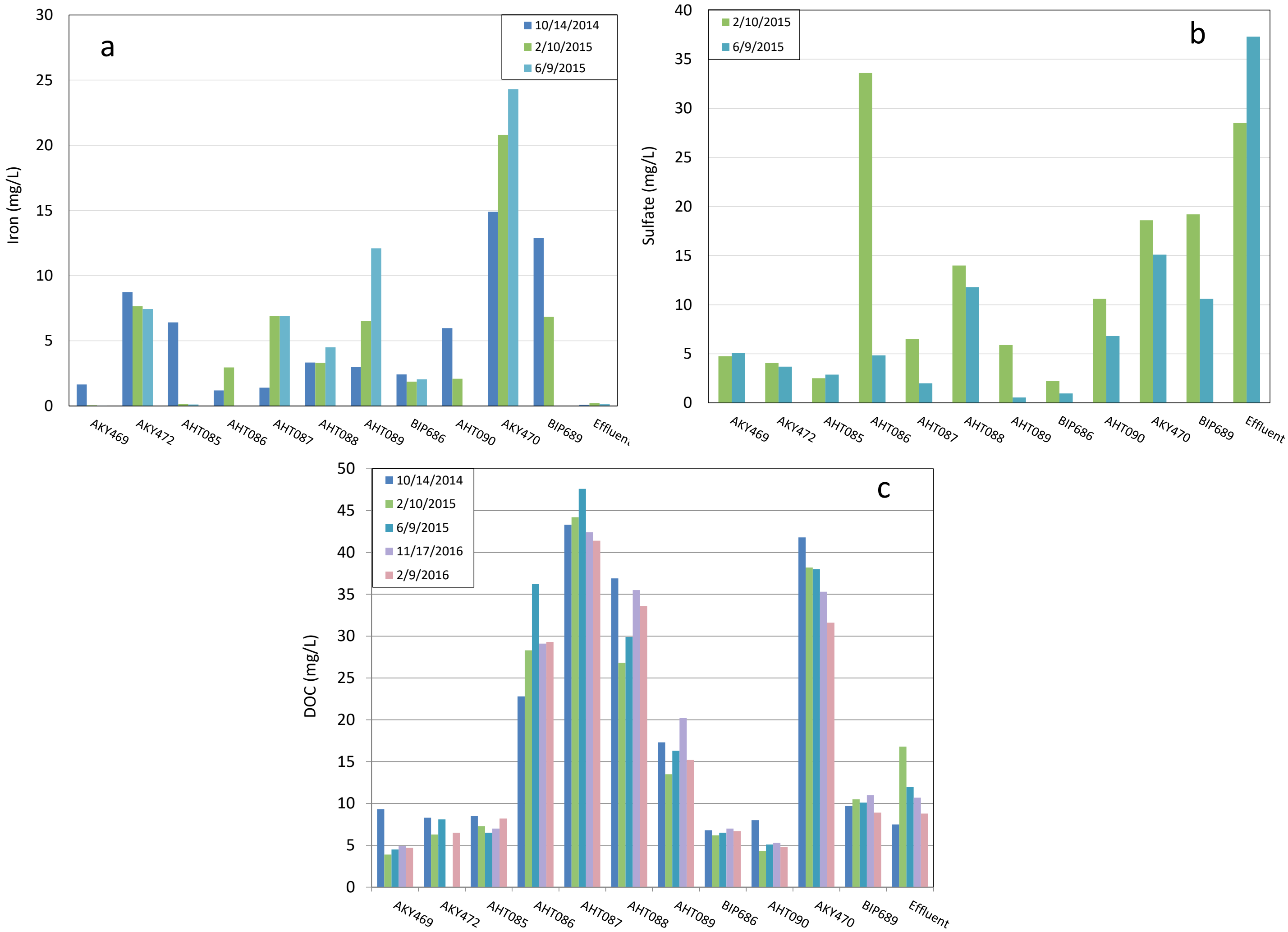

Figure 19. Groundwater quality results for (a) iron, (b) sulfate, and (c) dissolved organic carbon. *Effluent results are included for comparison.*

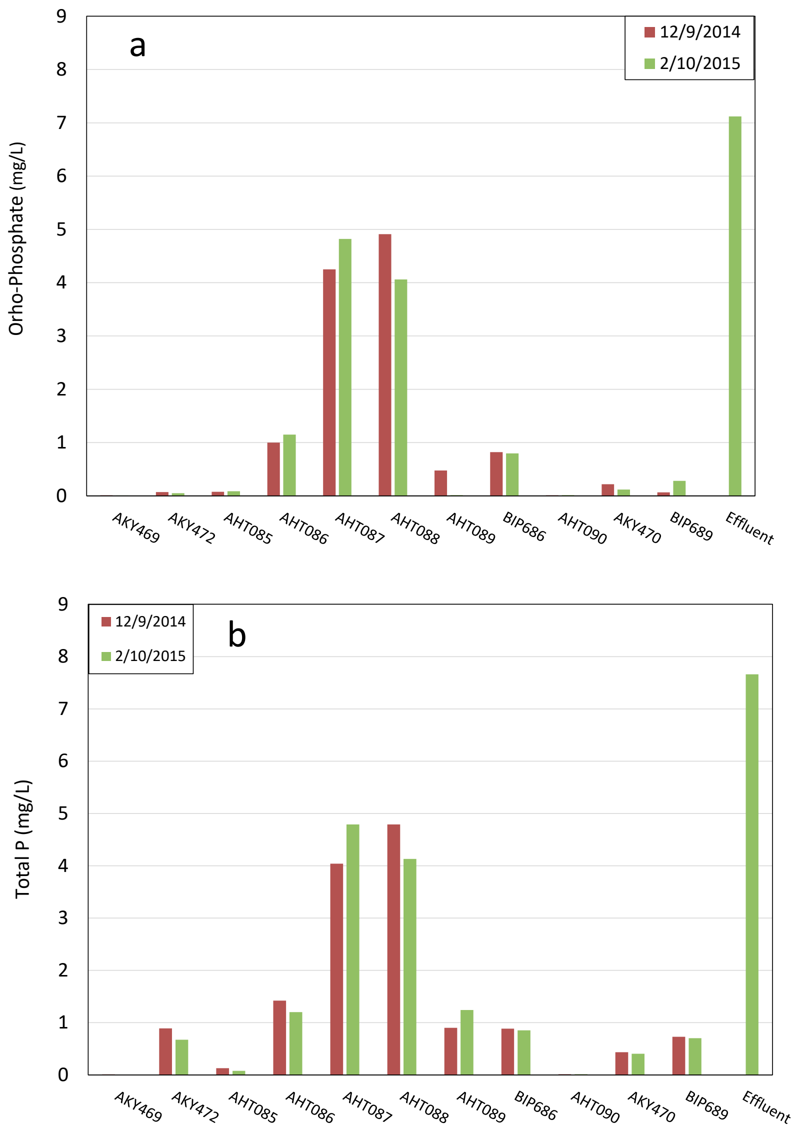

Figure 20. Concentrations in groundwater for (a) ortho-phosphate and (b) total phosphorus. *Effluent results are included for comparison.*

Fecal coliform bacteria (FC) and total coliform bacteria (TC)

FC were detected in 8 of 99 monitoring well samples (Table 7 and Appendix E, Table E-3). All other groundwater FC results were below detection limits.

Before February 2016, results from only 7 of 77 TC samples from the monitoring wells were above detection (Table E-3). The highest groundwater TC value before February 2016 was 20 cfu/100 ml. However, during the last 2 sampling events, TC were detected in all monitoring well samples, with values ranging from 5 to 1,600 cfu/100 ml (estimated) (Table 7 and Table E-3).

Table 7. Fecal coliform bacteria (FC) and total coliform bacteria (TC) detections in monitoring wells (cfu/100 ml).

Fecal coliform bacteria																						
	AKY469		AKY472		AHT085		AHT086		AHT087		AHT088		AHT089		BIP686		AHT090		AKY470		BIP689	
10/14/2014	**10**		ND		ND		**1**		ND		**40**	**J**	ND		ND		ND		ND		ND	
11/18/2015	ND		ND		ND		ND		ND		ND		ND		ND		ND		ND		**6**	
2/9/2016	**640**		ND		**3**		ND		ND		ND		ND		ND		ND		ND		ND	
4/12/2016	ND		ND		ND		ND		ND		ND		ND		**1**	**J**	**1**	**J**	ND		ND	
Total coliform bacteria																						
	AKY469		AKY472		AHT085		AHT086		AHT087		AHT088		AHT089		BIP686		AHT090		AKY470		BIP689	
10/14/2014	ND		**20**		ND		ND		ND		ND		ND		**5**		ND		ND		ND	
12/8/2014	ND		ND		ND		ND		ND		ND		ND		ND		**3**		ND		**7**	
2/10/2015*	ND		**1**	**J**	ND		**3**	**J**	ND		ND		**1**	**J**	ND		ND		**11**	**J**	ND	
11/18/2015	ND		ND		ND		ND		ND		ND		ND		ND		ND		ND		**8**	
2/9/2016	**840**		**510**		**240**		**860**		**290**		**16**		**230**	**J**	**97**	**J**	**12**		**43**		**3**	
4/12/2016	**120**	J	**1400**	**J**	**65**	**J**	**1600**	**J**	**5**	**J**	**160**	**J**	**540**	**J**	**44**	**J**	**15**	**J**	**16**	**J**	**9**	J

*Wastewater treatment system (WWTS) computer power outage, February 7-11, 2015. UV disinfection not affected.
Bold: Organism was present in the sample.
ND: Results were below detection. See Table E-2 for detection levels.

Discussion

Groundwater flow

Hydraulic conductivity estimates

Hydraulic conductivity values varied over 5 orders of magnitude based on slug test results (Table 2). The very low K_H values in wells AHT086 and AHT087 (2.5 x 10^{-6} to 3.5 x 10^{-7} cm/sec) are consistent with the slow recovery in these wells following low-flow purging and sampling as shown in Figure 11.

The highest K_H value was found at AHT090, 2 x 10^{-2} cm/sec, and is 5 orders of magnitude greater than the K_H values at AHT086 and AHT088. This suggests that horizontal velocity in the middle of the site is much higher than the velocity around the south and west downgradient boundaries of the site, assuming relatively uniform horizontal gradients. Fill added to the site during construction of Drainfield 2 should not have affected the slug test estimates for K_H at AHT090. According to engineering drawings of the fill location, less than one foot of fill was added near AHT090 (Gray and Osborne, 2003a). This should not have had an impact on the 5-10-foot deep open interval that the slug test represented.

Slug test estimates of K_H differed from the results found in 2001 at piezometers located near the newly installed monitoring wells (HWA GeoSciences, Inc., 2002). Table 8 shows that K_H values for the locations closest to Edison Slough and to Drainfield 1 (AKY469, AKY472, and AHT085) were 1-2 orders of magnitude higher than those reported in 2001. On the other hand, K_H results for the southern and western areas (wells AHT086, AHT087, and AHT088) were 3 orders of magnitude lower than K_H results found in 2001 in nearby piezometers.

Differences between the 2001 and 2016 results may be due to the different depths represented. The 2001 results represent the shallower, 6-foot piezometer depths, while 2016 results indicate conditions at 5-10 feet.

Table 8. K_H estimates from current and previous slug tests.

Well ID	Aquifer Test K_H Slug test 2016 (cm/sec)	HWA GeoSciences, 2001 Slug tests (cm/sec)	2016 compared to 2001
P4[1]		1.90E-04	1 order of magnitude higher
AKY469	7.06E-03		
P5[1]		2.40E-05	2 orders of magnitude higher
AKY472	1.76E-03		
AHT085	3.53E-04		1-2 orders of magnitude higher
P1[1]		2.73E-06	
P8[1]		5.64E-05	
AHT086	3.53E-07		3 orders of magnitude lower
P9[1]		2.95E-04	
AHT087	2.47E-06		3 orders of magnitude lower
P10[1]		*7.16E-03*	
AHT088	7.06E-07		3 orders of magnitude lower
P11[1]		4.17E-04	
P11[1]		3.16E-04	
AHT089	3.18E-04		
AHT090	2.12E-02		

[1] Piezometers from HWA GeoSciences, Inc., 2002.
Italic: Piezometer was loose, value suspect.
Green shading: Areas where K_H values were higher in 2016 than in 2001.
Orange shading: Areas where K_H values were lower in 2016 than in 2001.

Seasonal groundwater flow direction

The horizontal direction of groundwater flow in the 5-10-foot depth zone was from east to the southwest during November-May based on average monthly water table elevations (Figure 12). During the summer months of June-September, when discharge to the Edison WWTS is lowest, the average groundwater flow direction appeared to be from the south toward the north and also radiating out to the east and west.

In October, groundwater flowed outward in all directions from the middle of the site, indicating a mound. Lack of precipitation and lower discharge in the summer months and the resulting lower water table intensified the mound effect as the school year began in the fall.

The direction and magnitude of vertical groundwater flow varied seasonally with downward recharging conditions on 13 sampling dates and upward flow on 4 dates (Figure 13). The highest upward vertical gradient, -0.199, occurred on November 16, 2015, and the highest downward gradient, 0.194, on February 8, 2016.

Seasonal groundwater levels

Precipitation had a major influence on water table elevations in both drainfield areas (Figures 21 and 22). Figure 21 shows the water table depths in well AKY469 near Drainfield 1, where the shallowest water table depths occurred immediately following high precipitation events. Discharge to Drainfield 1 was limited to a set volume of 1,350 gallons/day until sometime between March 31 and June 1, 2015. The discharge limit to Drainfield 1 was then set at a maximum of 800-900 gallons/day. Discharge data were not available for April and May 2015 due to a power outage that disabled the computer data logging system.

Figure 22 shows that the depth to groundwater in wells near Drainfield 2 (AHT085, AHT086, AHT087, AHT088, and AHT090) corresponded with precipitation and discharges to the drainfield. During much of the winter, the vertical separation between the drainfields and the water table in nearby monitoring wells was in the 1-foot range. The transducer record, though incomplete, indicated water table depths of less than 1 foot from November 25-30, 2014 at AHT086 and January 5-6, 2015 at AKY469.

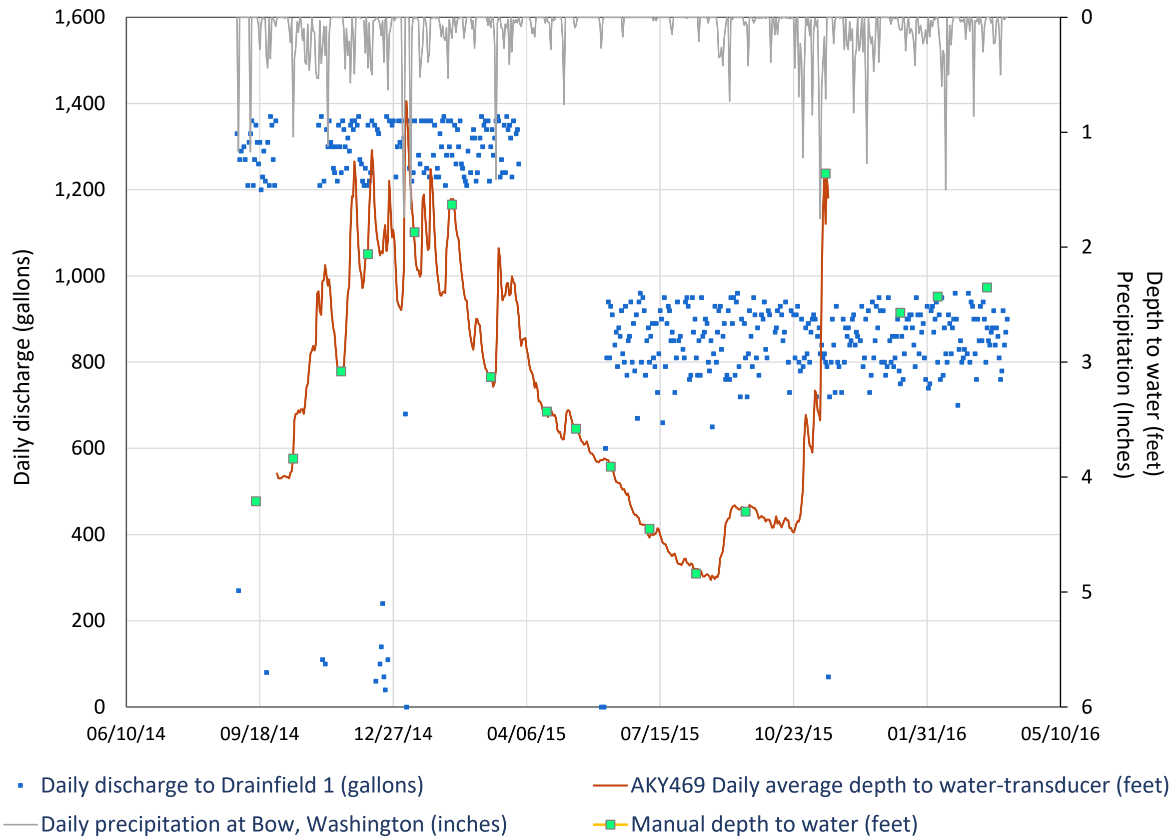

Figure 21. Precipitation at Bow, Washington, discharge to Drainfield 1, and depth to water measurements in nearby monitoring well AKY469.

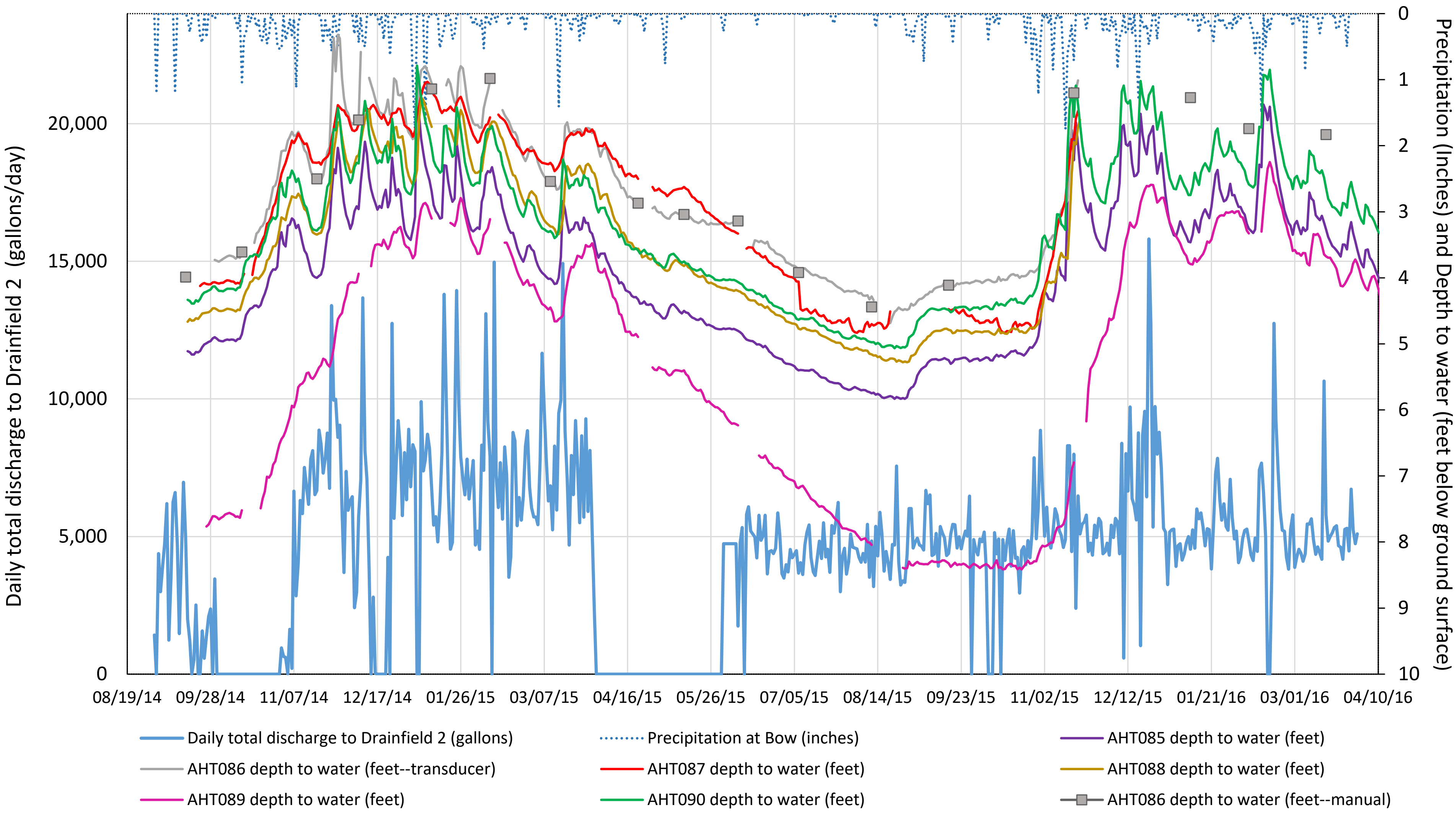

Figure 22. Precipitation at Bow, Washington, total daily discharge to Drainfield 2, transducer depth to water values in monitoring wells, and manual depth to water measurements in well AHT086.

Surface water influence on the groundwater flow direction was not analyzed in detail. Water table elevations were sometimes higher in the well nearest Edison Slough, AKY470, than in the next nearest well, AKY469. At other times, the elevations were reversed. It is probable that groundwater flow in the nearshore area changed direction seasonally and was influenced by tidal fluctuations.

Effluent water quality

Fecal coliform bacteria (FC) is the only effluent water quality parameter with a permit limit that was measured during the study. The geometric mean for 9 samples, 9 cfu/100 ml, was far below the monthly permit limit of 200 cfu/100 mL (Table 7). Only one of 9 FC effluent samples exceeded the weekly geometric mean limit on February 10, 2015 (3400 cfu/100 ml J).

Groundwater quality

Background and downgradient wells

Groundwater flow analysis based on interpolated monthly water level contours indicates the horizontal direction of shallow groundwater flow was from east to southwest during the highest precipitation months, November-May (Figure 12). Groundwater flow during June-September 2015, the time of year when Edison WWTS discharge and precipitation are lowest, was from south to north and also toward the east and west.

Monitoring well AKY472, the easternmost well, represents background conditions close to the property boundary during November-April (Figure 12). There was no monitoring well upgradient of the drainfield discharges for June-September, because groundwater was flowing radially.

During the November-May high precipitation period, wells AHT090 and AHT087 were downgradient of Drainfield 2. Two other wells were also likely downgradient of the WWTS discharges due to their proximity to the drainfields: AKY469, 50 feet north of Drainfield 1, and AHT085, 25 feet north of Zone 2 of Drainfield 2 (Figure 6). Well AKY469 was typically crossgradient relative to the upgradient well, AKY472.

Groundwater quality statistical summary

A statistical summary for each water quality constituent in each well is shown in Appendix F. The statistical summary includes average, standard deviation, and number of samples analyzed. These statistics are discussed below in relation to the *Groundwater Implementation Guidance* (Kimsey, 2005) *for the Ground Water Standards* (Chapter 173-200 WAC) concerning nitrate and 95% tolerance levels for additional constituents.

Groundwater quality data for AKY472 were used to develop statistical tolerance intervals to assess whether downgradient groundwater quality has been affected by the facility. Guidance in Chapter 13.6 of the *Implementation Guidance for the Ground Water Quality Standards* was used to calculate 95% tolerance intervals for parameters indicative of on-site sewage according to Equation 5 (Kimsey, 2005).

$$Tolerance\ interval = \ \ Mean +/-(K\ x\ S) \qquad\qquad Equation\ 5$$

where
Mean = Average of the population
K = Values for tolerance intervals based on sample size (n), Table 13.7 in Kimsey (2005) for 95% confidence
S = Standard deviation of the population

The fact sheet for the Edison WWTS wastewater discharge permit lists nitrate and TC as the pollutants of concern as well as the groundwater criteria as defined by Chapter 173-200 WAC and RCW 90.48.520. The tolerance intervals for nitrate-N and TC, as well as pH and DO, parameters of concern for Edison Slough, are shown in Table 9.

Table 9. Tolerance interval limits for pH, dissolved oxygen, nitrate-N, and total coliform bacteria (TC).

Parameter	Mean	Standard deviation (S)	Number of samples (n)	K (Table 13.7)[1]	Tolerance interval [2]
pH (S.U.)	6.3	0.30	7	3.401	5.28 - 7.34
DO (mg/L)	0.09	0.21	6	3.711	NA[3]
Nitrate-N (mg/L)	0.031	0.012	8	3.188	0.069
TC (cfu/100 mL)	240	500	8	3.188	1800

[1] Kimsey (2005)
[2] Tolerance interval = Mean +/- K x S (Kimsey, 2005) where S = Standard deviation of the background data and K is from Table 13.2 for 95% confidence, 95% coverage, and dependent on sample size.
[3] Equation yields a negative concentration, because the upgradient concentration is so low.

Comparison of downgradient groundwater quality with tolerance levels

Nitrate-N

All downgradient groundwater nitrate-N results are within the 95% tolerance limit, 0.069 mg/L, except at 1 of the 2 downgradient wells, AHT085 (5 exceedances of the tolerance limit), and the crossgradient well, AKY469 (6 exceedances of the tolerance limit), as shown in Table 10. The maximum nitrate-N concentration in AKY469 was 3.10 mg/L. The maximum nitrate-N in AHT085 was 0.292 mg/L. The 0.069 mg/L nitrate-N tolerance limit is very low compared with the groundwater standard for nitrate of 10 mg/L-N (Chapter 173-200 WAC).

Denitrification, which occurs under anoxic or very low DO concentrations, is probably a controlling factor for nitrate concentrations in groundwater at the site (Buss, 2005). DO concentrations at AKY469 and AHT085 were, at times, somewhat higher than concentrations at upgradient AKY472 and probably at least somewhat inhibitory of denitrification (Table 11). Nitrate in the groundwater at AKY469 and AHT085 that may otherwise have been converted to nitrogen gas therefore remained in the groundwater.

Table 10. Nitrate-N concentrations in downgradient well AHT085 and crossgradient well AKY469.

Highlighted values exceed 0.069 mg/L-N, the 95% tolerance limit from Table 9.

Well ID	10/14/14	12/8/14	2/10/15	4/22/15	6/9/15	8/12/15	11/17/15	2/9/16	4/11/16
AKY469	0.010	2.83	3.10	1.23	0.448	0.314	0.361	0.023	0.010
AHT085	0.029	0.041	0.125	0.292	0.172	0.039	0.065	0.101	0.118

Table 11. Dissolved oxygen concentrations in upgradient well AKY472, downgradient well AHT085, and crossgradient well AKY469.

Well ID	10/14/14	12/8/14	2/10/15	4/22/15	6/9/15	8/12/15	11/17/15	2/9/16	4/11/16
AKY472	0.51	0.05	0.05	0.0	0.0	0.0	NA	NA	NA
AKY469	0.61	1.52	3.19	0.0	0.0	0.0	0.83	NA	NA
AHT085	0.73	0.05	2.76	3.40	0.0	1.31	0.46	NA	NA

Six of 9 nitrate-N samples at AKY469 and 5 of 9 samples at AHT085 exceeded the 95% tolerance limit.

Total coliform bacteria (TC), pH, and DO

No results exceeded the 95% tolerance interval for pH or TC during the study (Table 9 and Appendix E, Table E-2). The DO values in upgradient well AKY472 were so low (0.0-0.51 mg/L, n=6) that a lower limit could not be established for downgradient wells.

Upgradient vs. downgradient groundwater quality

Table 12 shows mean concentrations during the study for the upgradient well AKY472; downgradient wells AHT085, AHT087, AHT090; and crossgradient well AKY469. Except for AHT087, the statistical means for most water quality parameters were lower in downgradient wells than the upgradient well.

Water quality at AHT087, as well as AHT086 and AHT088, is very different from water quality at the upgradient well and at the other downgradient wells and is probably more affected by adjacent seawater than by the Edison WWTS discharge. Therefore, AHT087 is not considered an appropriate downgradient well for evaluating effects of Edison WWTS on groundwater.

Table 12. Average concentrations of chemical water quality parameters for upgradient (AKY472), downgradient (AHT090, AHT085, AHT087), and crossgradient (AKY469) wells (mg/L unless specified).

Parameter	Upgradient AKY472	Downgradient AHT090	Downgradient AHT085	Downgradient AHT087	Crossgradient AKY469	Number of samples
Temperature (C°)	12.0	11.6	11.5	12.0	11.7	8
pH (S.U.)	6.3	6.0	6.1	6.6	6.1	7
Conductivity (umhos/cm)	368	126	137	5,277	161	8
Dissolved oxygen (DO)	0.09	0.25	1.44	0.16	0.88	6
Alkalinity	140	48	59	415	65	3
Ammonium-N	0.782	0.085	0.265	4.38	0.021	8
Nitrate-N	0.031	0.020	0.265	0.024	0.925	8
Total persulfate nitrogen (TPN)	0.870	0.359	0.641	5.44	1.21	8
Ortho-P	0.061	0.011	0.083	4.54	0.010	2
Total P	0.782	0.013	0.103	4.42	0.009	2
Chloride	26.4	1.54	4.05	1,502	4.80	8
Bromide[1]	0.24	NA[1]	NA[1]	5.75	NA[1]	6
Total dissolved solids (TDS)	246	122	119	3,072	131	4
Calcium	26.4	12.6	9.07	30.6	15.5	1
Iron	7.94	4.03	2.22	5.07	0.583	3
Magnesium	8.54	2.09	2.27	70.9	2.33	1
Potassium	10.6	4.38	3.23	26.5	3.08	1
Sodium	26.0	4.31	11.8	930	12.1	1
Sulfate	3.88	8.71	2.70	4.20	4.94	2
Dissolved organic carbon (DOC)	7.3	5.5	7.5	43.8	5.5	4

[1] The method reporting limit changed from 0.2 mg/L during the first 8 sample events to 0.03 mg/L for the last sample event in April 2016. There were no detections at 0.2 mg/L and one detection at 0.03 mg/L.

Fecal coliform bacteria (FC) and total coliform bacteria (TC)

More than half of the effluent FC results were below detection. Only one sample exceeded the effluent limit of 200 cfu/100 mL monthly geometric mean (Table 7).

The groundwater standard for TC is 1 cfu/100 mL. However, the Edison WWTS discharge permit does not require compliance with TC criteria at the property boundary due to the many TC sources other than the Edison WWTS facility in the vicinity (e.g., cattle, migrating birds). Instead, disinfection is evaluated by applying a FC limit at the point that treated flows leave the WWTS (the monitoring point after UV disinfection and before discharging to the drainfields). On February 9-10, 2016, TC were detected in all monitoring wells, including the upgradient well, and in the effluent (Table 8 and Appendix E, Table E-3). TC were also detected in well samples on April 12, 2016.

There is no groundwater standard for FC. Both FC and TC tend to be retained in soils by physical filtration and adsorption, especially in fined-grained soils like those at the Edison WWTS site (Gerba and Bitton, 1984). FC levels were below detection in all groundwater samples from both February and April 2016 with these exceptions: AKY469 with 640 cfu/100 mL and AHT085 with 3 cfu/100 mL on February 9, 2016 (Table 7 and Table E-3).

Water levels were higher in January 2016, and for a longer period of time, than water levels the previous winter, according to hydrographs in Figure 12. The high water levels also corresponded with heavy precipitation and resulting discharge to the drainfields (Figures 21-22). The higher water table elevations may have suspended TC that had built up in the soil and led to the elevated TC results on February 10, 2016, as seen at other locations (Brentlinger, 2016). Atherholt et al. (2016) found that elevated FC and TC concentrations were associated with seasonal effects, including higher precipitation, and not necessarily due to warm-blooded animal sources. Gerba and Bitton (1984) also cited evidence of rainfall increasing bacterial infiltration rates in soils. They associated heavy rainfall with bacterial contamination in Washington State studies.

The wells with TC detections may have continued to support bacteria after becoming contaminated. Therefore, samples collected from the wells on April 12, 2016 may have been representative of conditions in the wells but not necessarily of conditions in the aquifer. In addition to questions about well contamination, the April 12, 2016 TC samples are J-qualified as estimates because the field blank result was 120 cfu/100 ml.

TC results from the upgradient well, AKY472, were among the highest for February and April, 2016, when TC were detected in groundwater (Table 7). Therefore, it is unlikely that the Edison WWTS was a cause of the high TC results in groundwater.

Ultraviolet (UV) disinfection

During each sampling event, effluent samples were collected following cleaning of the UV disinfection light bulbs. In order to observe the effect of UV bulb cleaning on effluent bacteria concentrations, we collected FC and TC samples before and after cleaning on December 10, 2014. There was no significant difference between the pre-cleaning and post-cleaning samples (Table 13). Results for the test samples were higher than most other effluent samples during the study and may indicate that the bulbs may not have been functioning normally.

Table 13. FC and TC results for effluent samples before and after UV disinfection bulbs were cleaned on December 10, 2014 (cfu/100 ml).

Treatment	Fecal Coliform (FC)		Total Coliform (TC)
Pre-cleaning	200	G	350
Post-cleaning	180		560

G: Greater than

Seasonal contours for ammonium-N, chloride, bromide, and water level

The distribution of water quality constituent concentrations across an area can be an indicator of the influence of a drainfield system on groundwater. Chloride and bromide, often used as indicators of on-site sewage, are also found in high concentrations in seawater.

Nitrate concentrations, also commonly used as an indicator of sewage, were typically below detection in groundwater and therefore not useable for comparison. However, elevated ammonium concentrations can be indicative of coastal saline groundwater (Russak et al., 2015) as well as low concentrations in effluent and groundwater relative to other sources. Therefore, differences in ammonium concentration can be used to distinguish sources.

Figures 23-28 show contours for ammonium-N, chloride, and bromide from samples collected in four seasons as well as water table elevations for the month when water quality samples were collected. A common characteristic of the 3 constituents in most seasons is the appearance of 2 distinct areas of lower concentration. The low concentration areas are centered on Drainfield 1 (northern spot) and Drainfield 2 (southern spot). Seasonal variation in constituent concentrations across the site was not obvious from the contours. However, the areas of low groundwater ammonium and bromide concentrations centered on the drainfield areas appeared to be expanding over time.

Seasonal variation in groundwater flow directions based on monthly average water table contours appears to have had little influence on the concentrations of ammonium, chloride, and bromide across the site. The consistently high concentrations of ammonium, chloride, and bromide in wells around the edges of the site may indicate dispersion of these chemicals from subsurface water connected to seawater and from Edison Slough into groundwater at the site. A likely explanation for the contrast in concentration of these constituents over the drainfield areas is that the Edison WWTS effluent, which corresponds with the concentrations in the low concentration spots, is diluting the otherwise higher concentrations in groundwater.

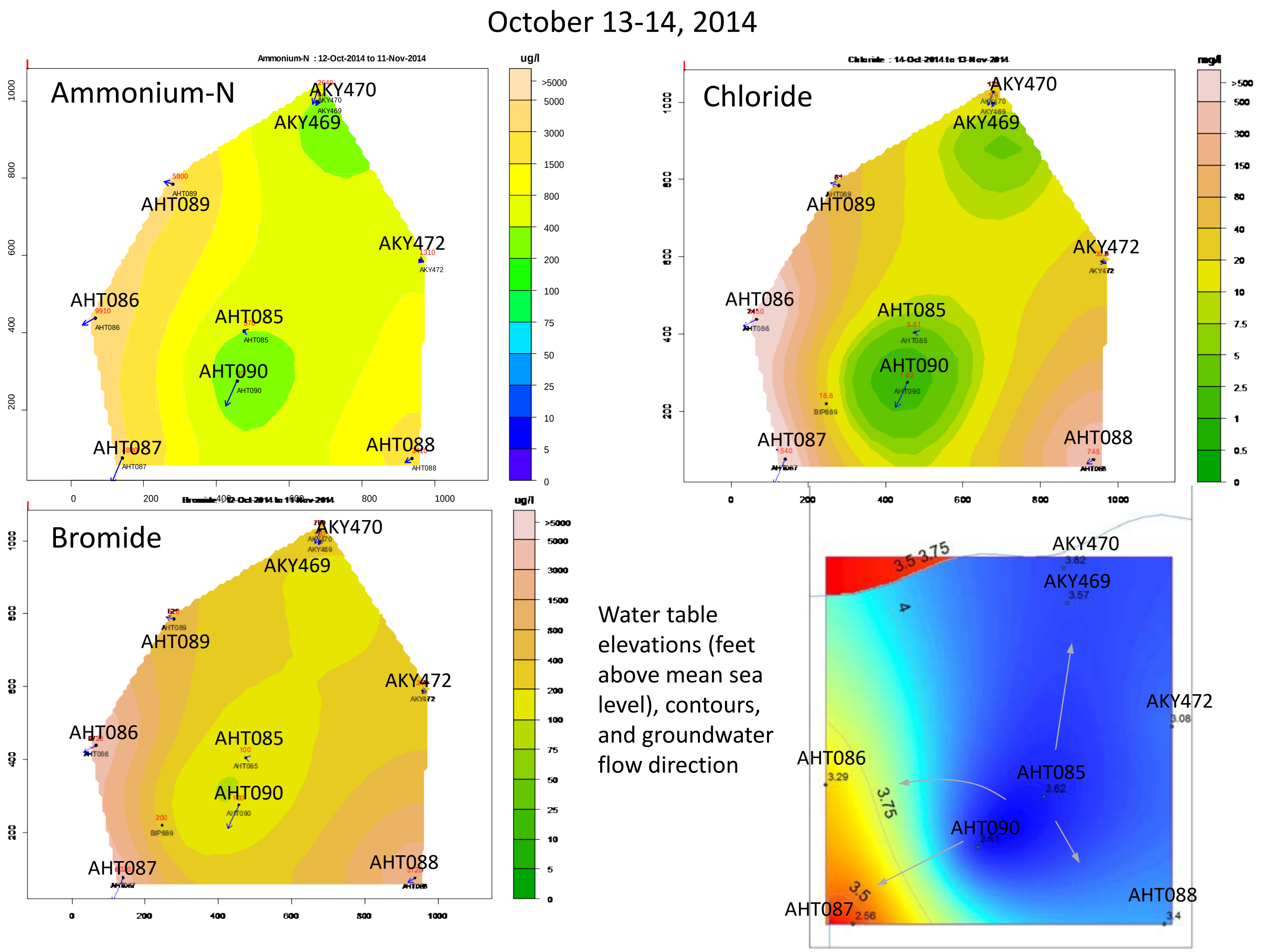

Figure 23. Contours of ammonium-N, chloride, and bromide concentrations and groundwater flow directions on October 13-14, 2014.

Water table elevations represent the mean for continuous measurements in October 2015.

December 9-10, 2014

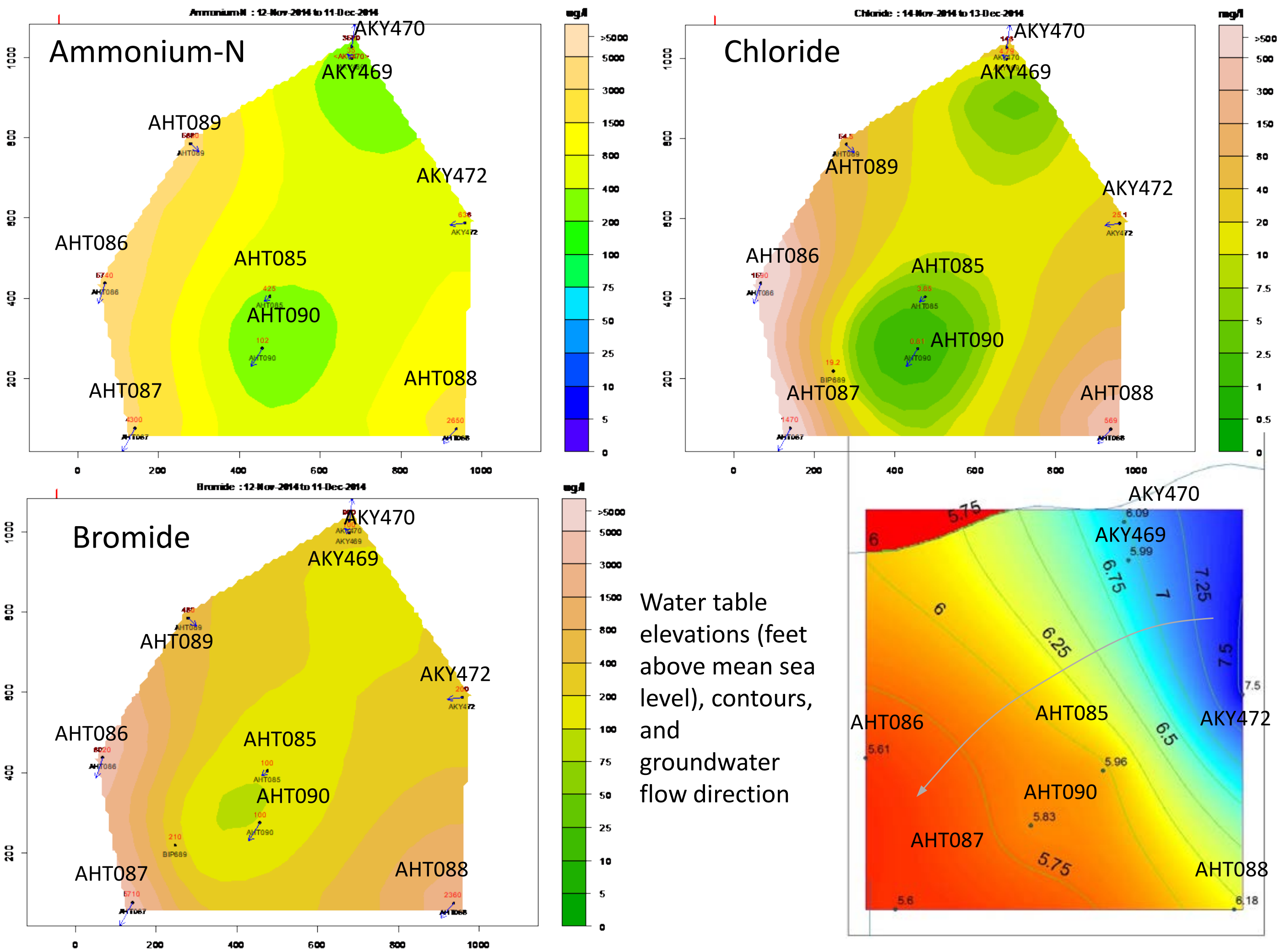

Figure 24. Contours of ammonium-N, chloride, and bromide concentrations and groundwater flow directions on December 9-10, 2014.

Water table elevations represent the mean for continuous measurements in December 2014.

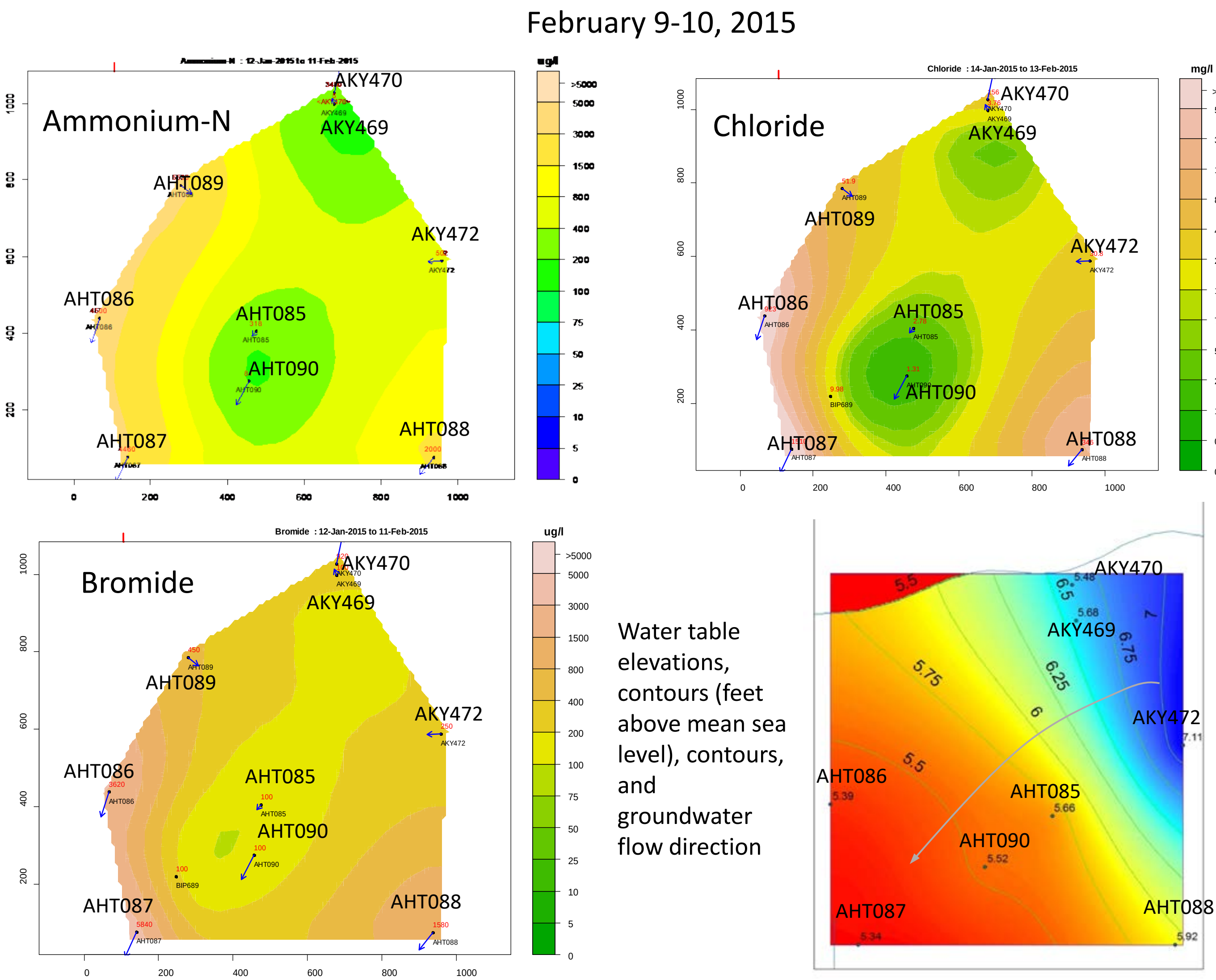

Figure 25. Contours of ammonium-N, chloride, and bromide concentrations and groundwater flow directions on February 9-10, 2015.

Water table elevations represent the mean for continuous measurements in February 2015.

April 21-22, 2015

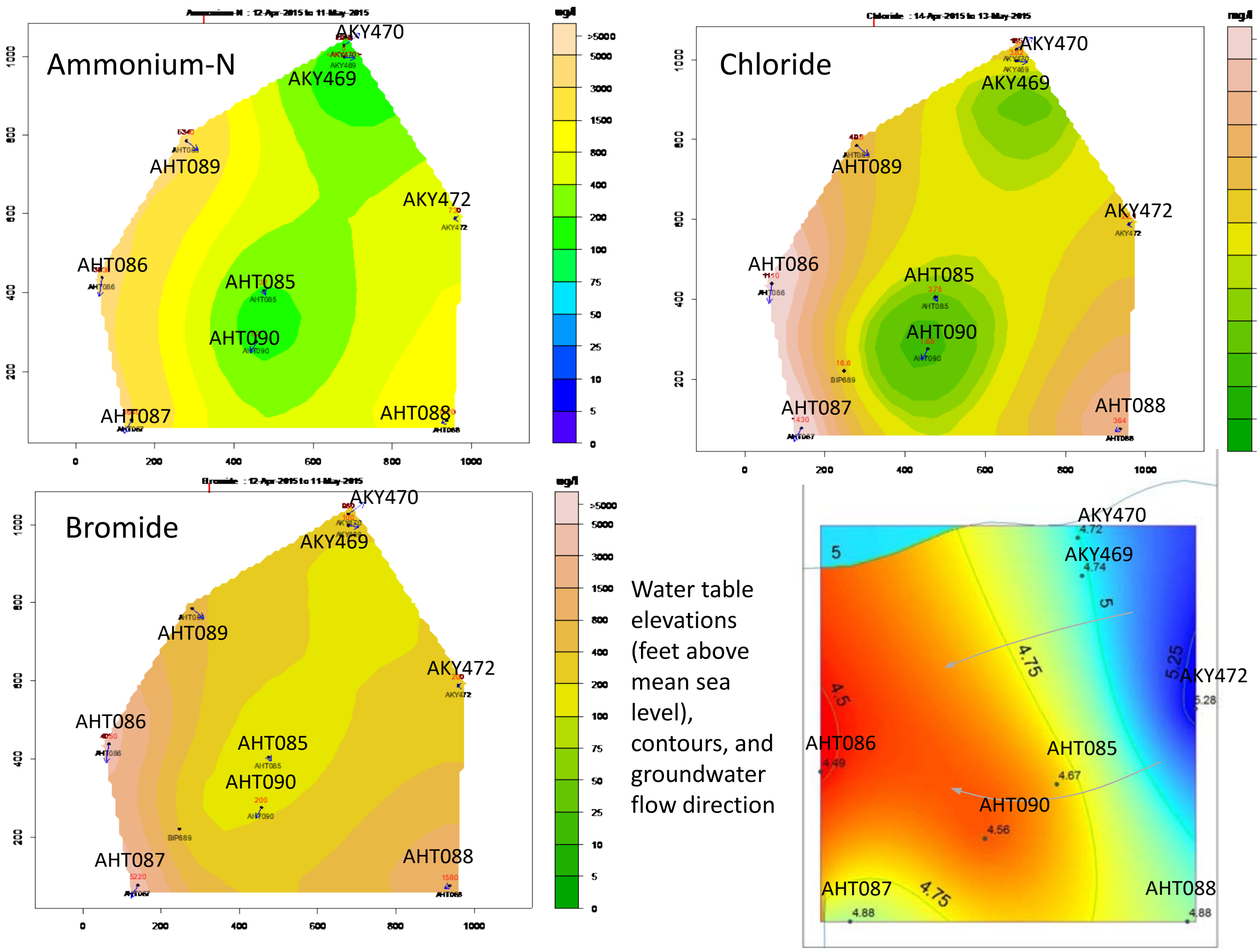

Figure 26. Contours of ammonium-N, chloride, and bromide concentrations and groundwater flow directions on April 21-22, 2015.

Water table elevations represent the mean for continuous measurements in April 2015.

August 11-12, 2015

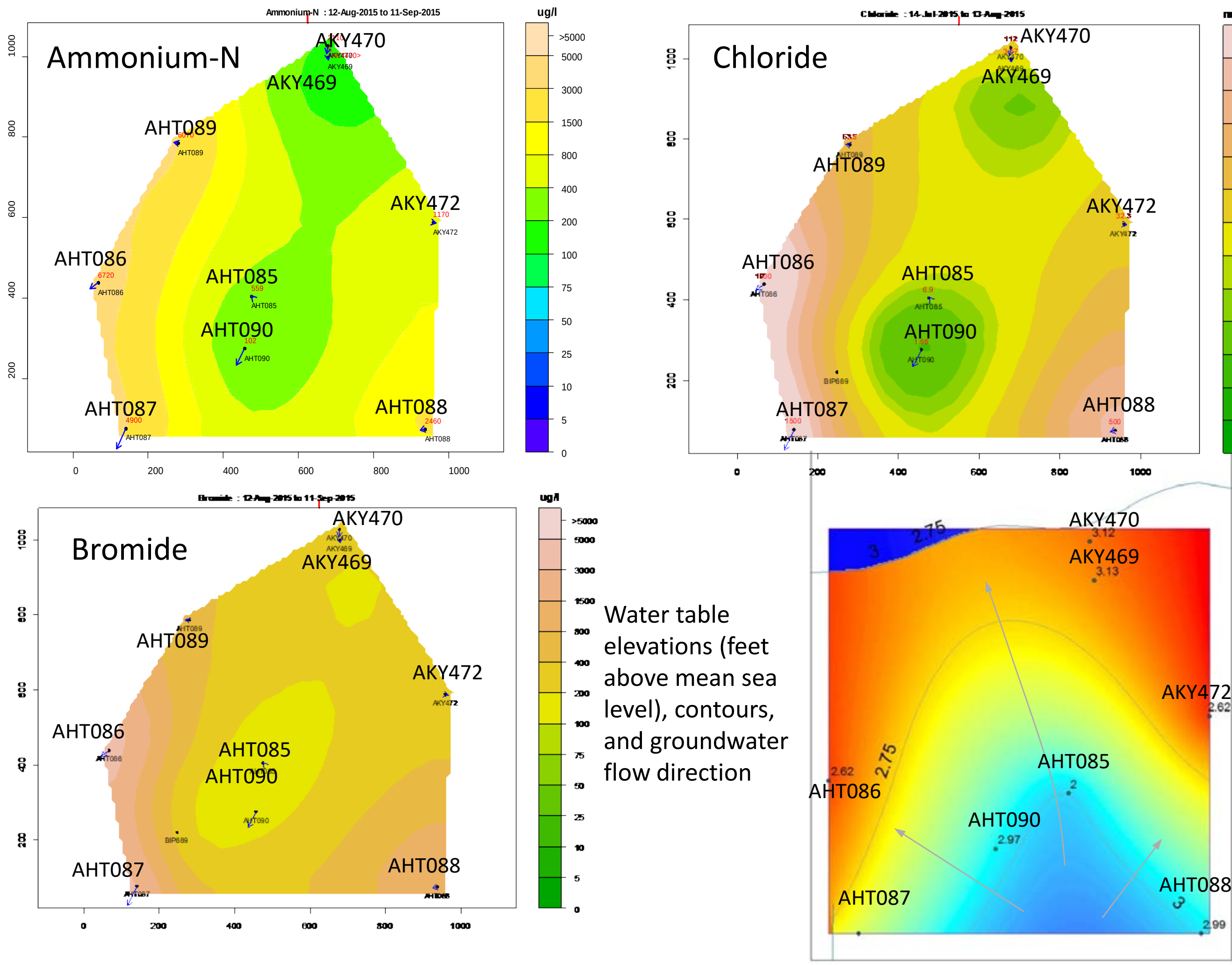

Figure 27. Contours of ammonium-N, chloride, and bromide concentrations and groundwater flow directions on August 11-12, 2015.

Water table elevations represent the mean for continuous measurements in August 2015.

February 8-10, 2016

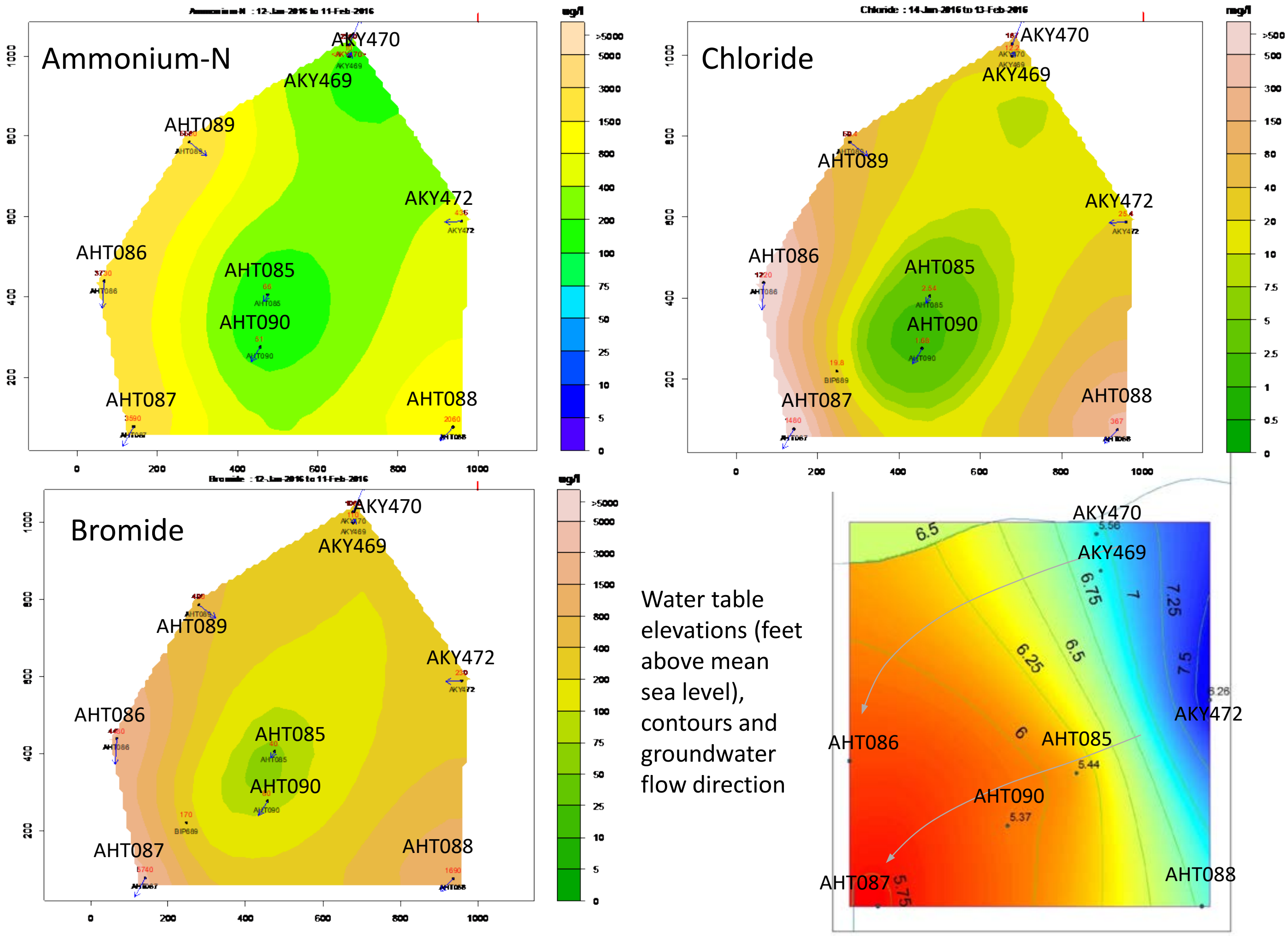

Figure 28. Contours of ammonium-N, chloride, and bromide concentrations and groundwater flow directions on February 8-10, 2016.

Water table elevations represent the mean for continuous measurements in February 2016.

Groundwater and effluent geochemical signature

The concentrations of cations and anions observed at each well are shown in Figure 29. The 3 wells in the southern and western portion of the site showed strong similarities and contained high ion concentrations, especially chloride, sodium, and potassium (AHT086, AHT087, and AHT088). This ionic pattern resembles a seawater influence.

The upgradient well (AKY72), as well as the wells in the middle and northern parts of the site (AKY469, AHT085, and AHT090), had an almost opposite pattern from wells in the southern and western portion of the site (Figure 29). Major ion concentrations in this group were very low, indicating little seawater influence.

A third ionic pattern was found in the effluent and wells AHT089, AKY470, and BIP686. Ion strength in this group was somewhat higher than the upgradient/middle/northern group but much lower than the southern/western wells. Wells AHT089 and BIP686 are deeper than the other monitoring wells and therefore perhaps more affected by seawater influence. The close proximity of AKY470 to Edison Slough probably explains an intermediate estuarine ionic signature in groundwater.

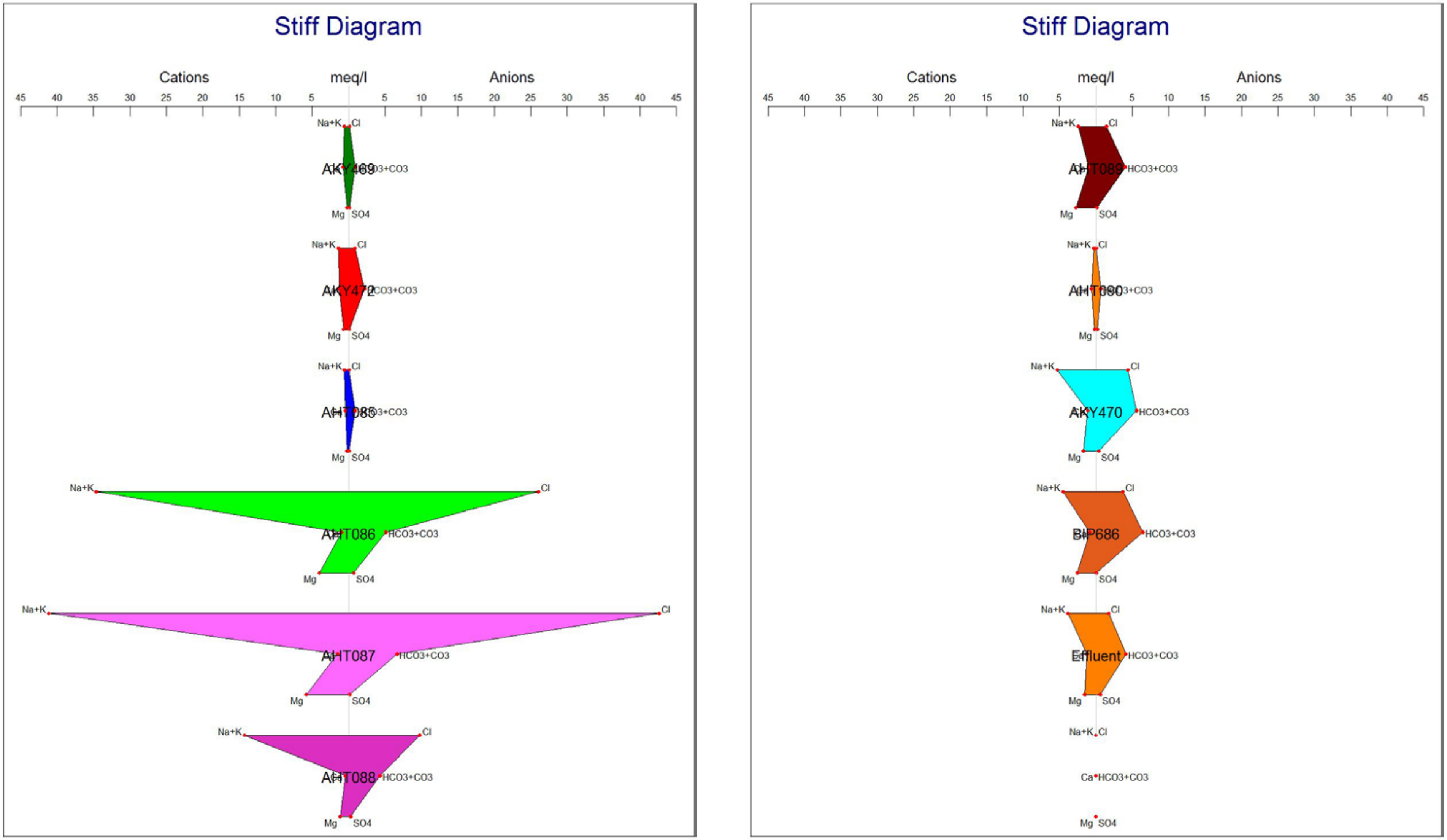

Figure 29. Stiff diagrams of relative groundwater ion concentrations in the monitoring wells on February 10-11, 2015.

Shallow vs. deeper groundwater quality

Samples from the 2 side-by-side wells, AHT089, 15 feet deep, and BIP686, 38 feet deep, had distinctly different concentrations of ammonium-N, chloride, and bromide as shown in Figure 30. Ammonium-N concentrations in the shallow well, AHT089, were more than 5 times higher than those in the deeper well. On the other hand, chloride in the shallow well was only about one-third of the concentration in the deeper well. Bromide followed the same pattern as chloride, indicating a larger seawater influence on the deeper than the shallower groundwater.

The vertical stratification between the more saline deeper water and the more dilute shallow groundwater occurred despite the mostly downward vertical gradient observed (Figure 13). Periods of upward vertical gradient in August, September, and October, 2015 apparently did not affect the stratification as indicated by the consistent differences in chloride, bromide, and ammonium concentration in the 2 wells (Figure 30).

Ammonium can be enriched in saline groundwater due to a cation exchange process (Russak et al., 2015). The enrichment can result in groundwater ammonium concentrations higher than total N in surrounding surface waters. Organic carbon can enhance the conversion of nitrogen to ammonium in saline groundwater. The average DOC was 16.5 mg/L at AHT089 and 6.64 mg/L at BIP686.

Nitrogen could also be entering the aquifer from surface water in the form of nitrate or ammonium. Nitrate could then be converted to ammonium as oxygenated surface water encounters reducing groundwater conditions. However, the total N concentration in a Salish Sea sample collected at Bayview State Park on February 10, 2016 contained only 0.433 mg/L total N. This indicates that oxygenated sea water is probably not a direct source of nitrogen to the local surface water/groundwater system.

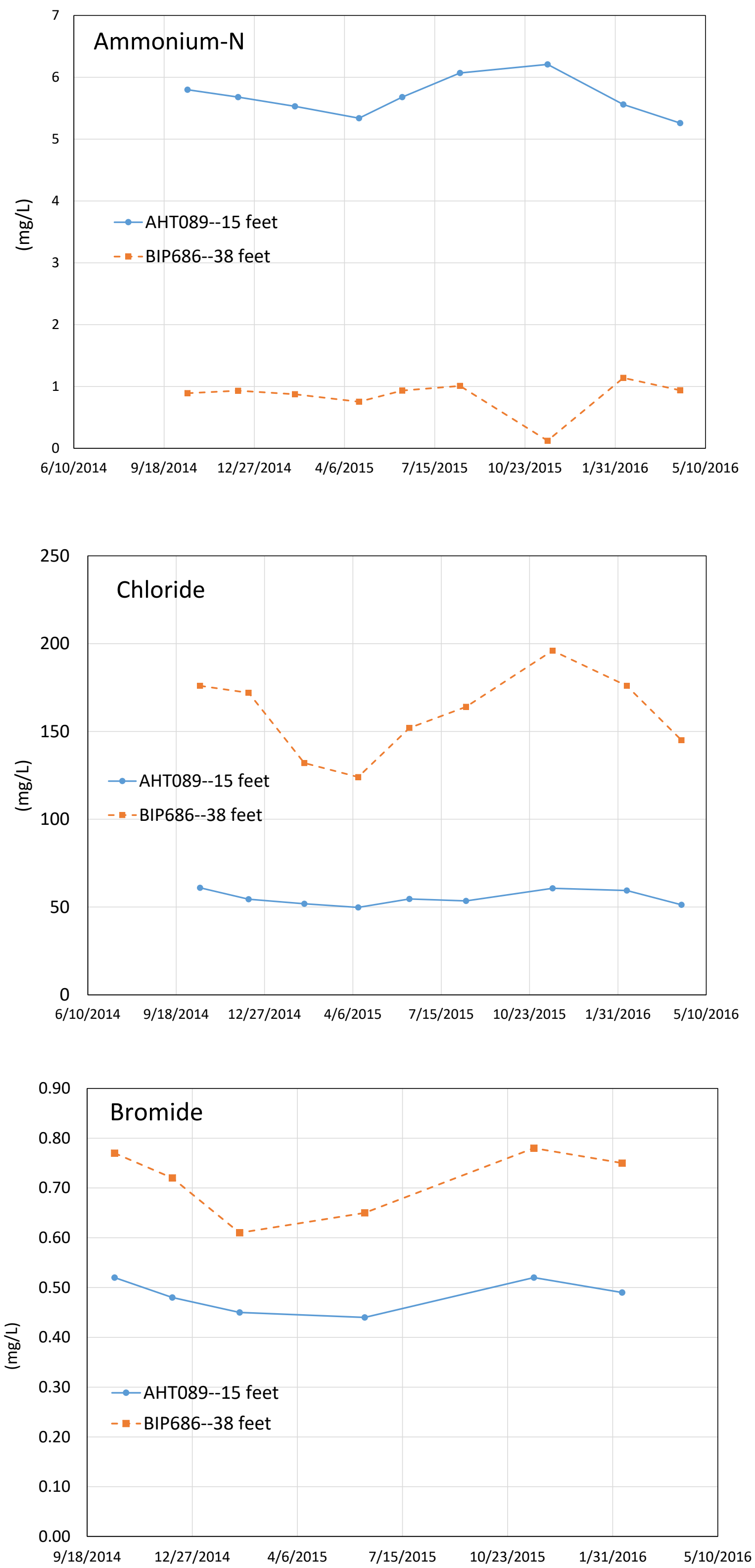

Figure 30. Ammonium-N, chloride, and bromide concentrations in wells AHT089 (15 feet) and BIP686 (38 feet).

Surface water quality

Groundwater and surface water are closely interconnected in the Edison WWTS area. Flow between Edison Slough, the agricultural drainage system, and the groundwater at the Edison WWTS study site are unrestricted.

The Skagit County Public Works Department routinely samples Edison Slough at the Edison School bridge station (SCMP36) and at the Edison pump station (SCMP37) as shown in Figure 31. Water quality sampling parameters include specific conductance, nitrite+nitrate-N, and total Kjeldahl nitrogen (TKN). Sample site SCMP36 is adjacent to the Edison WWTS study site. The agricultural drain in the southwest downgradient corner of the Edison WWTS site connects with Skagit County's SCMP37 sample site (Haley, 2017).

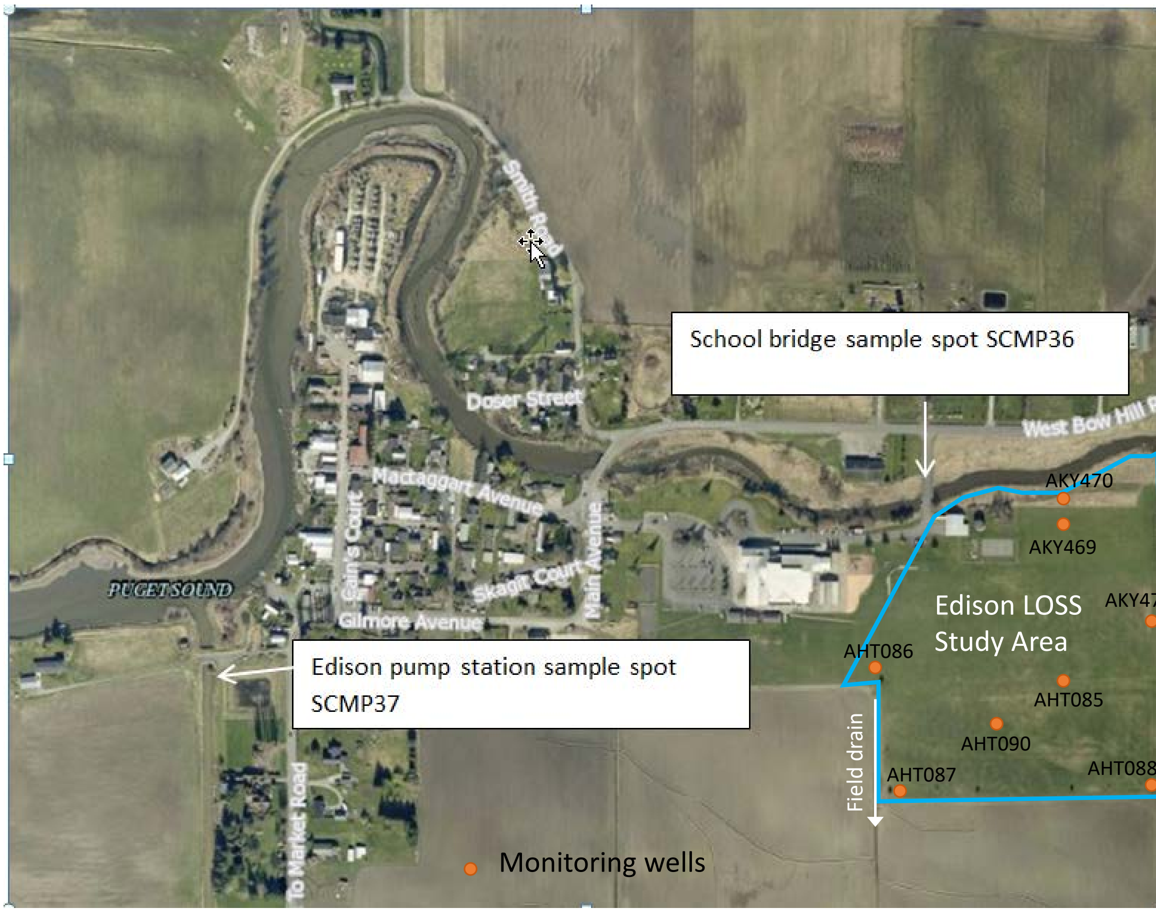

Figure 31. Skagit County Public Works Department water quality sampling sites and Edison Wastewater Treatment System (WWTS) study area.

Specific conductance

Specific conductance results at the 2 Skagit County surface water sites in Figure 32 varied dramatically over time compared with results in the Edison WWTS groundwater monitoring wells. Low tide conductivities in the surface water sites were similar to those in the non-saline monitoring wells (AHT085, AHT090, AKY469, AKY470, AKY472, and BIP686) as shown in Figure 33. However, high tide conductivities in Edison Slough were up to 8 times greater than even the highest conductivities found in monitoring wells.

Specific conductance results for the Pump 37 surface water site were similar to those in the monitoring wells near the agricultural drain (AHT086, AHT087, and AHT088) at the Edison WWTS site during two periods, November 4, 2014 to June 5, 2015 and September 22, 2015 to March 24, 2016. This similarity may be evidence of the connection between local surface water and groundwater.

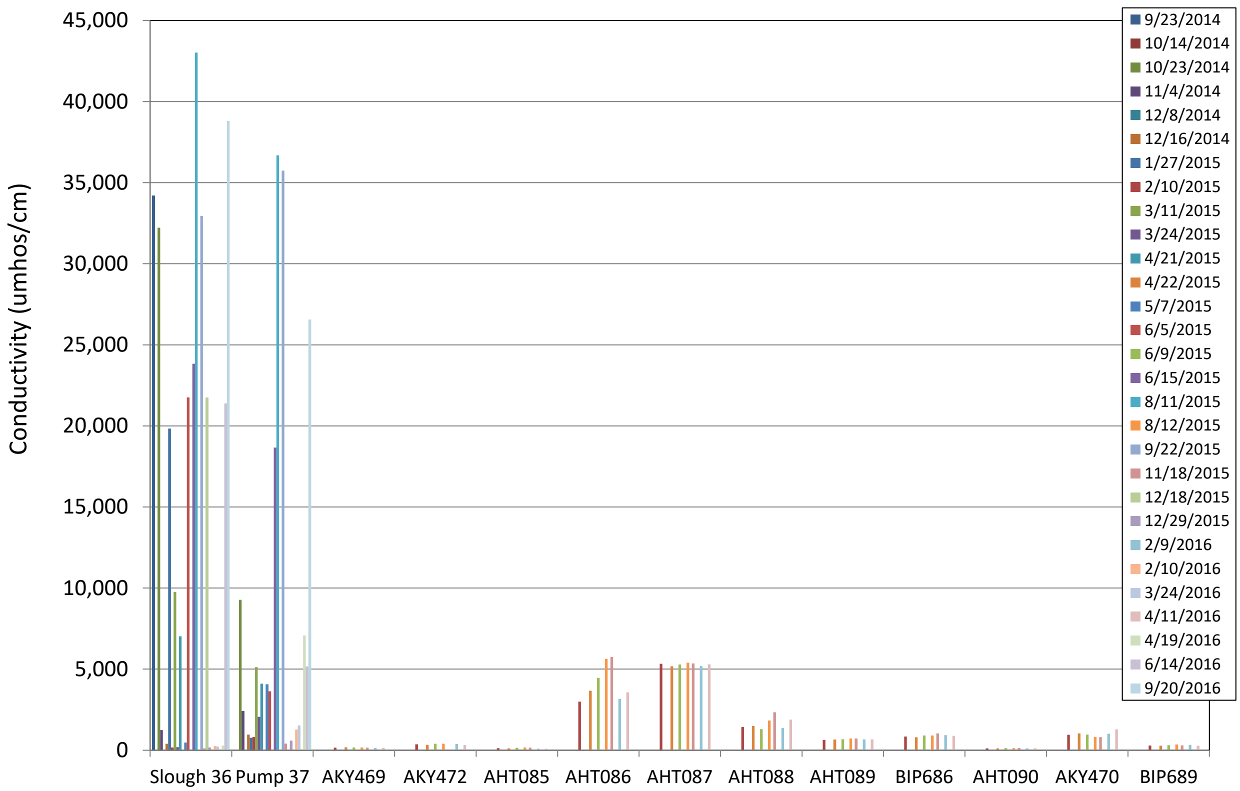

Figure 32. Specific conductance in surface water sites (Slough 36 and Pump 37) and Edison Wastewater Treatment System (WWTS) monitoring wells.

Nitrogen

Skagit County total nitrogen (total N) results for the surface water sites were similar to those in wells AKY470 (closest to Edison Slough) and AKY469 (180 feet south of the slough) (Figure 33). Total N concentrations in the downstream drainage ditch (SCMP37), which is connected with the Edison WWTS southwest corner field drain, were higher than Edison Slough at the school (SCMP36).

Groundwater total N concentrations in the saline wells (AHT086, AHT087, and AHT088) were higher than those at either Edison Slough surface water sites. Most of the total N in groundwater was in the form of ammonium-N (Figure 17-b, -c, and -d).

Although probably not associated with the Edison WWTS discharge, high total N in ambient local groundwater could be contributing, at least in part, to higher downstream total N in Edison Slough.

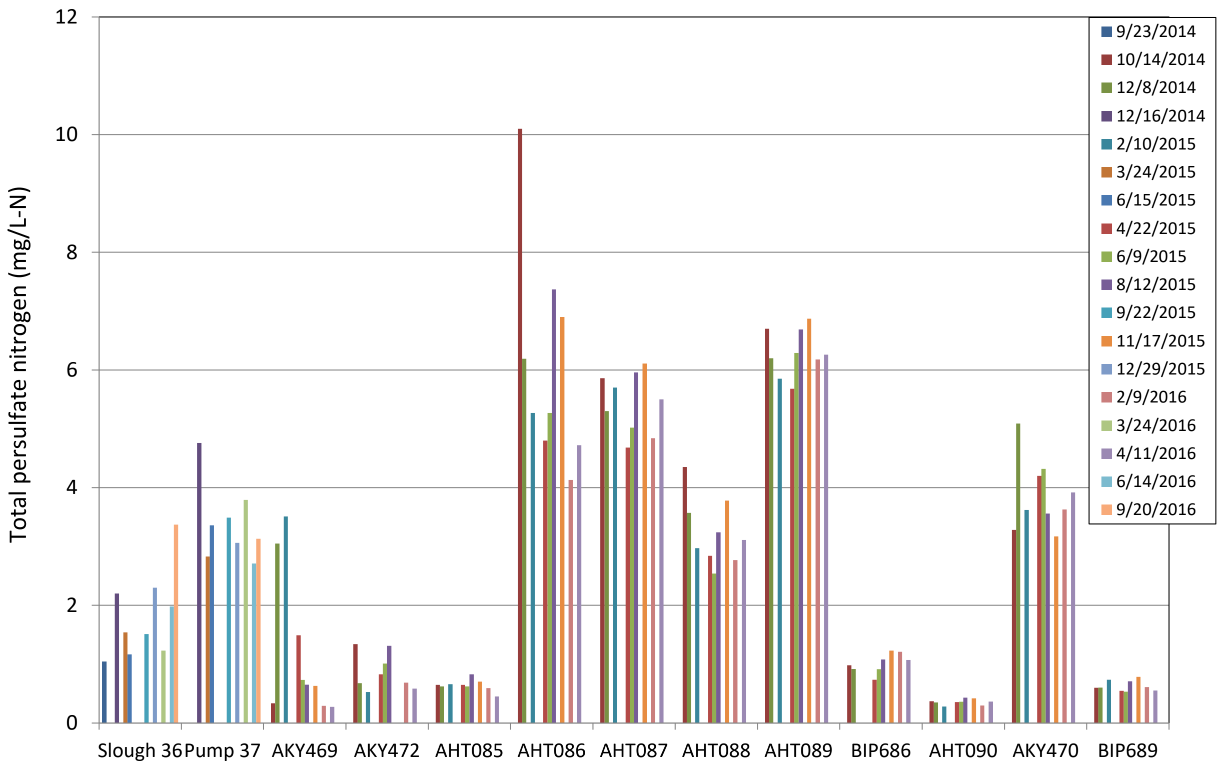

Figure 33. Total N concentrations in surface water sites (Slough 36 and Pump 37) and Edison Wastewater Treatment System (WWTS) monitoring wells.

Potential surface water/groundwater interactions

Overland flow to drains in the northeast and southwest corners of the Edison WWTS site was not monitored during the study but, at times, may impact Edison Slough. Surface water 303(d) category 5 listings in the Edison Slough are shown in Table 13. Although FC concentrations in effluent and groundwater were low or below detection during most of the study, ponding and overland flow to agricultural drains connecting with Edison Slough were observed in the winter and early spring. Samples of the ponded water were not collected; therefore, there is no evidence that bacteria or contaminants from ponded water were entering surface water.

Table 13. 303(d) listings near Edison Slough.

Location	2008 Category 5 listing
Edison Slough, upstream of the facility	DO, pH, FC
Unnamed creek (agricultural drainage ditch) along western edge of the drainfield, tributary to Samish River	DO, FC
Unnamed Creek (agricultural drainage ditch) along southwestern edge of the drainfield, tributary to Samish River	DO, pH, FC
Samish Bay, downstream of the facility at the mouth of Edison Slough	FC

DO: dissolved oxygen.
FC: fecal coliform bacteria.

Groundwater pH values in both upgradient and downgradient wells would meet surface water quality standards for Edison Slough (6.5-8.5 S.U.). Groundwater DO, however, was below the acceptable surface water standards in all wells, including the upgradient well, AKY472 (Figure 17-a). The low DO is likely due to natural conditions at and around the study site.

The complex and variable flow conditions at the Edison WWTS site make it difficult to estimate impacts on Edison Slough from groundwater/surface water interactions. Results from this study could be used to model groundwater flow and evaluate potential impacts on surface water under varying conditions. However, the data collected during this study do not indicate groundwater impacts on Edison Slough.

Conclusions

The following conclusions are based on the results of this 2014-2016 study:

- Water level measurements indicated the horizontal direction of groundwater flow in the 5-10-foot depth at the Edison Wastewater Treatment System (WWTS) site was generally from east toward the southwest during November-May. During June-September, the flow direction was from the south toward the north. In October, groundwater flow radiated outward from the middle of the site in all directions.
- Based on the observed groundwater flow direction, monitoring well AKY472, on the eastern boundary of the site, is suitable as an upgradient well during the November-May period. There was no upgradient well available during June-October. Two wells were designated to represent downgradient groundwater quality: AHT085 and AHT090. Well AKY469 was designated a crossgradient well. Although well AHT087 was downgradient during November-May, water quality in this well was apparently more affected by seawater than by the Edison Wastewater Treatment System (WWTS) and is not recommended for use as a downgradient well.
- Water levels in the drainfield area monitoring wells ranged from 0.35 feet above ground surface to 5.84 feet below ground surface based on manual measurements. Water levels were highest in the rainy winter months, November-February. The highest water table elevations were observed in monitoring wells AKY472 and AHT086.
- Hydraulic conductivity results based on slug tests varied by 5 orders of magnitude across the site. Results in the northern portion of the site were higher than previous estimates, but results were lower than previous results in the southern areas. Differences between results of this study and earlier study reports may be due to different sample depths and locations.
- Background groundwater quality was estimated for pH, DO, nitrate-N, and total coliform bacteria (TC) based on 6-8 samples collected at AKY472. Groundwater results for nitrate and TC were within the 95% tolerance interval recommended in the *Implementation Guidance for the Ground Water Quality* Standards except for nitrate at 2 wells. The calculated tolerance limit for nitrate-N at the site, 0.069 mg/L, is very low compared with the 10 mg/L criterion specified in the Washington State Ground Water Standards. The maximum nitrate-N concentration was 3.10 mg/L at one of the wells with tolerance limit exceedances (crossgradient AKY469) and 0.292 mg/L at the other well with exceedances (downgradient AHT085). Six exceedances of the tolerance limit for nitrate-N occurred at AKY469 and 5 exceedances at AHT085.
- Fecal coliform bacteria (FC) results were below detection in over half of the 9 effluent samples. The geometric mean of the effluent FC samples collected immediately after the UV bulbs were cleaned, 9 cfu/100 mL, was far below either the monthly or weekly permit limit for the facility (200 and 400 cfu/100 mL respectively).
- FC were detected in only 8 of the 99 monitoring well samples. The source of an elevated FC result at well AKY469, located between Drainfield 1 and Edison Slough, on February 9, 2016, is not known.

- TC results were mostly below detection in the effluent and groundwater samples. However, TC were detected in all wells, including the upgradient well, during the February 9, 2016 sampling. Theses detections may have resulted from higher than normal groundwater levels that released bacteria in the soil unrelated to the WWTS discharge. TC detections in April 12, 2016 samples may indicate well contamination from high water levels earlier in the year.
- Lower concentrations of most non-bacterial water quality constituents in the wells downgradient and closest to the drainfields, compared with wells further downgradient or crossgradient from the drainfields, indicate that the effluent is not degrading groundwater quality. Effluent may, in fact, be diluting ion concentrations in ambient groundwater such as chloride, bromide, and ammonium.
- Groundwater quality results indicated 3 main groundwater types at the site:
    - Wells in the north and east (AKY469, AHT085, AHT090, and AKY472) had the most dilute concentrations of ions and water quality parameters.
    - Wells in the south and west (AHT086, AHT087, and AHT088) had very high concentrations of ions, including chloride, bromide, potassium, and ammonium.
    - The deeper wells (AHT089 and BIP686), the well adjacent to Edison Slough (AKY470), and the effluent had a somewhat higher ionic strength than the northern/eastern group but far lower than the southern/western group.
- Vertical water quality stratification was evident in samples from side-by-side shallow (15-foot) and deep (38-foot) wells. Chloride and bromide concentrations were consistently higher in the deep well than in the shallow well. However, ammonium concentrations were higher in the shallow well than in the deep well. The vertical gradient, which was downward except during the late summer-early fall, did not seem to affect the water quality stratification.

Recommendations

The following recommendations are made based on the results of this 2014-2016 study:

- Use the following wells as monitoring wells for water level and water quality sampling:
  - Upgradient: AKY472
  - Downgradient: AHT090 and AHT085
  - Crossgradient: AKY469
- Renovate monitoring wells that will be sampled for water quality parameters so that they are completed above ground.
- Disinfect monitoring wells to ensure that total coliform bacteria (TC) and fecal coliform bacteria (FC) samples are representative of groundwater conditions.
- Monitor water levels at monitoring wells and piezometers to within 0.01 foot on a quarterly basis to determine groundwater flow direction.
- Monitor wells on a quarterly basis for pH, specific conductance, nitrate, ammonium-N, chloride, TC, and FC.
- Sample for FC effluent compliance before cleaning the UV bulbs to ensure that monthly bulb cleaning is sufficient to ensure consistent permit compliance.
- If further evaluation of water quality in Edison Slough occurs, include potential impacts of overland flow of surface water and contaminants from the Edison WWTS site as well as other nearby contaminant sources to the tributary agricultural drains and to the slough.
- Calibrate effluent flow meters at least annually to ensure accurate discharge estimates.

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Glossary, Acronyms, and Abbreviations

Glossary

Aquifer: Stratum or zone beneath the surface of the earth capable of producing water as from a well.

Denitrification: The bacterial or chemical process whereby nitrate is converted to nitrogen gas, usually in a reducing/low oxygen environment.

Dissolved oxygen (DO): A measure of the amount of oxygen dissolved in water.

Effluent: An outflowing of water from a natural body of water or from a man-made structure. For example, the treated outflow from a wastewater treatment plant (or system).

Groundwater: Subsurface water which is in the zone of saturation.

Hydraulic conductivity (K_H): The rate at which water moves through a material at a unit gradient and depends on the size and arrangement of the pores between the particles.

Ion: A positively or negatively charged atom or group of atoms formed by the gain or loss of one or more electrons.

Nonpoint source: Pollution that enters any waters of the state from any dispersed land-based or water-based activities, including but not limited to atmospheric deposition, surface-water runoff from agricultural lands, urban areas, or forest lands, subsurface or underground sources, or discharges from boats or marine vessels not otherwise regulated under the NPDES program. Generally, any unconfined and diffuse source of contamination. Legally, any source of water pollution that does not meet the legal definition of "point source" in section 502(14) of the Clean Water Act.

Parameter: Water quality constituent being measured (analyte). A physical, chemical, or biological property whose values determine environmental characteristics or behavior.

pH: A measure of the acidity or alkalinity of water. A low pH value (0 to 7) indicates that an acidic condition is present, while a high pH (7 to 14) indicates a basic or alkaline condition. A pH of 7 is considered to be neutral. Since the pH scale is logarithmic, a water sample with a pH of 8 is ten times more basic than one with a pH of 7.

Specific Conductivity: A measure of water's ability to conduct an electrical current. Conductivity is related to the concentration and charge of dissolved ions in water.

Upgradient: In hydrology, an *upgradient* location is one that exhibits a larger hydraulic head in comparison to a *downgradient* location. Water flows from areas of higher hydraulic gradient to areas of lower hydraulic gradient. Hydraulic head is the total pressure exerted by a water mass at a given point. Total hydraulic head is the sum of elevation head, pressure head, and velocity head.

Water table: The upper surface of a zone of saturation where the soil water pressure is equal to atmospheric pressure.

Zone of Saturation: A subsurface zone below which all pore space is filled with water.

303(d) list: Section 303(d) of the federal Clean Water Act requires Washington State to periodically prepare a list of all surface waters in the state for which beneficial uses of the water – such as for drinking, recreation, aquatic habitat, and industrial use – are impaired by pollutants. These are water quality-limited estuaries, lakes, and streams that fall short of state surface water quality standards and are not expected to improve within the next two years.

Acronyms and Abbreviations

DO	Dissolved oxygen
DOC	Dissolved organic carbon
Ecology	Washington State Department of Ecology
EIM	Environmental Information Management database
EPA	U.S. Environmental Protection Agency
FC	Fecal coliform bacteria
GWQSs	Ground Water Quality Standards
MEL	Manchester Environmental Laboratory
RPD	Relative percent difference
RSD	Relative standard deviation
SOP	Standard operating procedures
TC	Total coliform bacteria
TDS	Total dissolved solids
TPN	Total persulfate nitrogen
WAC	Washington Administrative Code
WWTS	Wastewater Treatment System

Units of Measurement

°C	degrees centigrade
cfu	colony-forming unit (bacteria)
cm	centimeter
ft	feet
gpd	gallons per day
L/s	liters per second (0.03531 cubic foot per second)
mg	milligram
mgd	million gallons per day
mg/L	milligrams per liter (parts per million)
mL	milliliters
mm	millimeters
S.U.	standard units
ug/L	micrograms per liter (parts per billion)
um	micrometer
umhos/cm	micromhos per centimeter

Appendices

Wastewater Treatment System Groundwater Assessment for Edison, Washington

Washington State Department of Ecology
Publication 18-03-007

https://fortress.wa.gov/ecy/publications/SummaryPages/1803007.html

Appendix A. Well information.

Table A-1. Well construction information.

Well Tag ID[1]	Latitude Decimal Degrees (NAD83HARN)	Longitude Decimal Degrees (NAD83HARN)	Land Surface Elevation NAVD88 (feet)	Well Completion Depth (feet)	Well Open Interval Upper Depth (feet)	Well Open Interval Lower Depth (feet)	Well Diameter (inches)	Well Construction Method Description	Water level measuring point (feet above ground surface)	Water level measuring point ID
AHT085	48.560618	-122.434647	8.75	9.7	4.7	9.7	2	Bored/Augured	-0.57	MP1
AHT086	48.560661	-122.43695	7.26	9.5	4.5	9.5	2	Bored/Augured	-0.56	MP1
									-0.14	MP2
AHT087	48.559685	-122.436633	6.15	10.1	5.1	10.1	2	Bored/Augured	-0.24	MP1
AHT088	48.559721	-122.433355	8.18	10.3	5.3	10.3	2	Bored/Augured	-0.42	MP1
									-0.09	MP2
AHT089	48.561631	-122.436113	10.79	15	10	15	2	Bored/Augured	-0.29	MP1
AHT090	48.560231	-122.435354	7.95	9.6	4.6	9.6	2	Bored/Augured	-0.29	MP1
AKY469	48.561968	-122.434455	7.93	9.8	4.8	9.8	2	Bored/Augured	-0.4	MP1
AKY470	48.56224	-122.43452	6.78	5.5	4	5.5	1.5	Driven	3.95	MP1
AKY472	48.56111	-122.433307	7.91	10.7	5.7	10.7	2	Bored/Augured	0.55	MP1
									-0.23	MP2
BIP686	48.56164907	-122.4361601	10.79	38	28	38	2	Bored/Augured	1.55	MP1

[1] See Table A-2 for links to Ecology's EIM database, including drilling logs and construction information. Also see Figure A-1.

Table A-2. Links to photographs of split-spoon samples and particle size distribution graphs for monitoring wells.

The links connect with the EIM database http://ecyeim/search/

Well Tag ID	Well logs	Photographs of split-spoon samples	Particle size distribution graphs
AKY469	AKY469.pdf	AKY469_2_5ft.jpg AKY469_5_0ft.jpg AKY469_7_5_ft.jpg AKY469_10_0_ft.jpg	AKY469_grain_size_distribution.jpg
AKY472	AKY472.pdf	AKY472_2_5_ft.jpg AKY472_5_0_ft.jpg AKY472_7_5_ft.jpg AKY472_7_5_ft_split.jpg AKY472_10_ft.jpg AKY472_10_ft_split.jpg AKY472_15 ft.jpg AKY472_15 ft_split.jpg AKY472_17_5 ft.jpg AKY472_17_5 ft_split.jpg AKY472_20_ft.jpg	AKY472_grain_size_distribution.jpg
AHT085	AHT085.pdf	AHT085_2_5.jpg AHT085_2_5_split.jpg AHT085_5_0.jpg AHT085_7_5.jpg AHT085_7_5_split.jpg AHT085_10_ft_split.jpg	AHT085_grain_size_distribution.jpg
AHT086	AHT086.pdf	AHT086_2_5.jpg AHT086_5_0.jpg AHT086_7_5.jpg	AHT086_grain_size_distribution.jpg
AHT087	AHT087.pdf	AHT087_2_5.jpg AHT087_5_0.jpg AHT087_7_5_split.jpg AHT087_10_ft_split.jpg	AHT087_grain_size_distribution.jpg
AHT088	AHT088.pdf	AHT088_2_5 ft.jpg AHT088_5_0_ft.jpg AHT088_7_5_split.jpg AHT088_10_ft.jpg AHT088_10_split_a.jpg	AHT088_grain_size_distribution.jpg
AHT089	AHT089.pdf	AHT089_5_ft_a.jpg AHT089_7_5_a.jpg AHT089_10ft.jpg AHT089_12_5ft.jpg AHT089_15ft.jpg	AHT089_grain_size_distribution.jpg
AHT090	AHT090.pdf	AHT090_2_5_split.jpg AHT090_5_0.jpg AHT090_7_5.jpg AHT090_10_0.jpg	AHT090_grain_size_distribution.jpg

Figure A-1. Well report for BIP686.

The Department of Ecology does NOT Warranty the Data and/or the Information on this Well Report.

ENTERED

Whatcom

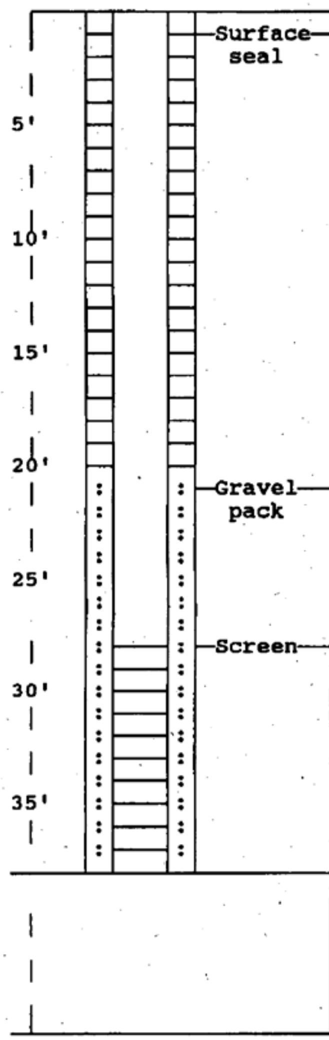
ENVIRONMENTAL WELL REPORT

283666

START CARD NO: R036359

PROJECT NAME: 577 MAIN AVE/EDISON
WELL IDENTIFICATION NO: A1640 MW1
DRILLING METHOD: HOLLOW STEM AUGER
DRILLER: JOHN AUMILLER #2244
FIRM: HAYES DRILLING, INC.
SIGNATURE: [signature]
CONSULTING FIRM: BE SCHOOL DISTRICT
REPRESENTATIVE: RON JOHNSON

LOCATION: T 36 R 3E SEC 33
DISTANCE: SE ¼
SW ¼
DATUM: MONITORING WELL
WATER LEVEL LEVATION:
INSTALLED: 05/27/97
DEVELOPED: 05/27/97
DEPTH DRILLED: 38' COMPLETED: 38'

AS BUILT	WELL DATA	FORMATION DESCRIPTION
	+2'-28' 2" PVC Casing 28'-38' 2" PVC Screen monoflex 20 slot 0'-20' Surface seal w/bentonite chips & concrete 20'-38' Gravel pack 8/12 sand	0'-1' Topsoil 1'-7' Tan silty clay 7'-20' Gray silty sand 20'-25' Sand gravel & water 25' Med sand & water

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Appendix B. Hydraulic testing

Methods and results

Slug tests were performed on the 8 monitoring wells installed for this project to estimate the horizontal hydraulic conductivity of the shallow aquifer. We used Teflon bailers for slugs in a "slug-out" test (U.S. Geological Survey, 2011).

On the day before the tests, July 26, 2016, we manually measured and recorded the depth to water in each well before installing a pre-programmed pressure transducer. The measurement intervals for the pressure transducers were pre-set at frequencies designed to capture the rising curve of the water in the well after the slug was removed. The transducers were positioned a few inches above the bottom of the well. A Teflon slug/bailer was then lowered into each well to a depth where the bailer was completely submerged. The slugs and transducers were secured to the top of the casing using non-stretch fishing line. The wells were then allowed to recover overnight.

The next day, July 27, 2016, the slugs were rapidly removed from the wells at the pre-assigned time to correspond with the start time on the pressure transducers. The transducers were allowed to log for one day and were then removed from the wells. The transducer data were downloaded in the office.

Data from the transducers was analyzed using the Bouwer and Rice (1976) method as presented in the U.S. Geological Survey spreadsheet (Halford and Kuniansky, 2002). Spreadsheet summaries of input and output data for each well are provided in Ecology's EIM database http://www.ecology.wa.gov/eim/ (Look up the Well Tag ID under Groundwater data. Then click Well details). Summary sheets for slug-test results for each well are also shown in Figures B-1 through B-8.

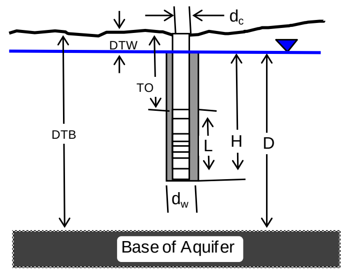
Figure B-1. Summary of slug-test data analysis for well AHT085.

WELL ID: AHT085

Local ID: AHT085
Date: 7/27/2016
Time: 0:00

INPUT

Construction:	
Casing dia. (d_c)	2 Inch
Annulus dia. (d_w)	8.25 Inch
Screen Length (L)	5 Feet
Depths to:	
water level (DTW)	4.58 Feet
top of screen (TOS)	5 Feet
Base of Aquifer (DTB)	30 Feet
Annular Fill:	
across screen -- Fine Sand	
above screen -- Bentonite	
Aquifer Material -- Silt, Loess	



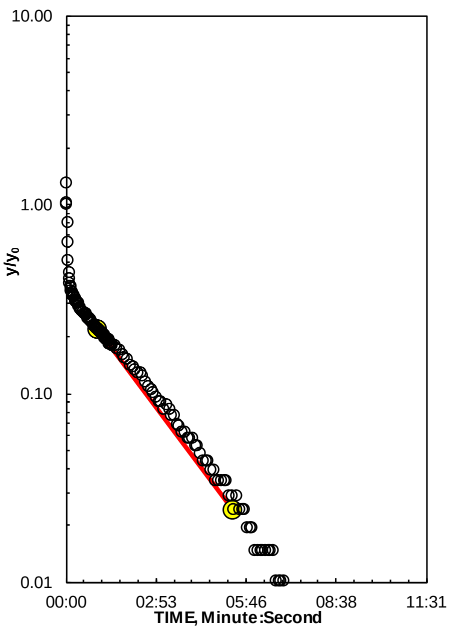
COMPUTED

L_{wetted}	5 Feet
D =	25.42 Feet
H =	5.42 Feet
L/r_w =	14.55
$y_{0\text{-DISPLACEMENT}}$ =	1.27 Feet
$y_{0\text{-SLUG}}$ =	1.17 Feet
From look-up table using L/r_w	
Partial penetrate A =	2.049
B =	0.308
ln(Re/rw) =	1.598
Re =	1.70 Feet
Slope =	0.003656 $\log_{10}$/sec
$t_{90\%}$ recovery =	274 sec

Input is consistent.

K =	0.8 Feet/Day

Adjust slope of line to estimate K



Water level above top of screen, can evaluate rising and falling head tests

K= 0.8 is greater than likely maximum of 0.1 for Silt, Loess

slope points	0:01:02	0.216
	0:05:23	0.024

REMARKS:

Bouwer and Rice analysis of slug test, WRR 1976

Reduced Data

Entry	Time, Hr:Min:Sec	Water Level
1	0:00:01.0	5.85
2	0:00:04.0	5.60
3	0:00:07.0	5.13
4	0:00:10.0	5.05
5	0:00:13.0	5.01
6	0:00:16.0	4.99
7	0:00:19.0	4.98
8	0:00:22.0	4.96
9	0:00:25.0	4.95
10	0:00:28.0	4.94
11	0:00:31.0	4.93
12	0:00:34.0	4.92
13	0:00:37.0	4.91
14	0:00:40.0	4.90
15	0:00:43.0	4.89
16	0:00:46.0	4.89
17	0:00:49.0	4.88
18	0:00:52.0	4.87
19	0:00:55.0	4.87
20	0:00:58.0	4.86
21	0:01:01.0	4.86
22	0:01:04.0	4.85
23	0:01:07.0	4.85
24	0:01:10.0	4.84
25	0:01:13.0	4.83
26	0:01:16.0	4.83
27	0:01:19.0	4.82
28	0:01:22.0	4.82
29	0:01:25.0	4.81
30	0:01:28.0	4.80
31	0:01:39.0	4.80
32	0:01:54.0	4.77
33	0:02:09.0	4.75
34	0:02:24.0	4.74
35	0:02:39.0	4.72
36	0:02:54.0	4.70
37	0:03:09.0	4.68
38	0:03:24.0	4.67
39	0:03:39.0	4.66
40	0:03:54.0	4.65
41	0:04:09.0	4.64
42	0:04:24.0	4.63
43	0:04:39.0	4.63
44	0:04:54.0	4.62
45	0:05:09.0	4.62

Figure B-2. Summary of slug test data analysis for well AHT086.

WELL ID: AHT086

Local ID: AHT086
Date: 7/27/2016
Time: 0:00

INPUT

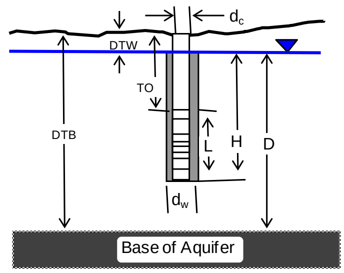
Construction:	
Casing dia. (d_c)	2 Inch
Annulus dia. (d_w)	8.25 Inch
Screen Length (L)	5 Feet
Depths to:	
water level (DTW)	3.53 Feet
top of screen (TOS)	5 Feet
Base of Aquifer (DTB)	30 Feet
Annular Fill:	
across screen --	Fine Sand
above screen --	Bentonite
Aquifer Material --	Silt, Loess

COMPUTED

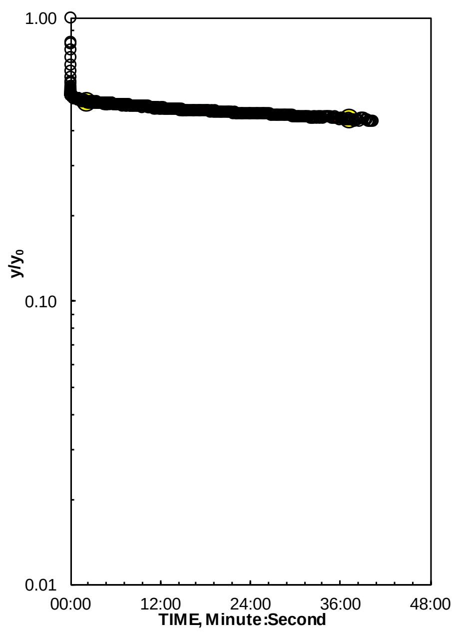
L_{wetted}	5 Feet
D =	26.47 Feet
H =	6.47 Feet
L/r_w =	14.55
$y_{0\text{-DISPLACEMENT}}$ =	2.16 Feet
$y_{0\text{-SLUG}}$ =	1.17 Feet
From look-up table using L/r_w	
Partial penetrate A =	2.049
B =	0.308
ln(Re/rw) =	1.662
Re =	1.81 Feet
Slope =	4.61E-06 $\log_{10}$/sec
$t_{90\%}$ recovery =	217036 sec

Input is consistent.

K = 0.001 Feet/Day



Adjust slope of line to estimate K



Water level above top of screen, can evaluate rising and falling head tests
K within reasonable range for aquifer material selected

slope points	0:13:48	0.502
	3:44:28	0.439

REMARKS:

Bouwer and Rice analysis of slug test, WRR 1976

Reduced Data

Entry	Time, Hr:Min:Sec	Water Level
1	0:00:01.0	5.69
2	0:00:14.0	4.74
3	0:00:27.0	4.70
4	0:00:40.0	4.69
5	0:00:53.0	4.68
6	0:01:06.0	4.67
7	0:01:19.0	4.67
8	0:01:44.0	4.66
9	0:02:49.0	4.65
10	0:03:54.0	4.65
11	0:04:59.0	4.64
12	0:06:04.0	4.64
13	0:07:09.0	4.64
14	0:08:14.0	4.64
15	0:09:19.0	4.63
16	0:10:24.0	4.62
17	0:11:29.0	4.62
18	0:13:39.0	4.62
19	0:15:49.0	4.61
20	0:17:59.0	4.61
21	0:20:09.0	4.61
22	0:22:19.0	4.61
23	0:24:29.0	4.60
24	0:26:39.0	4.60
25	0:28:49.0	4.61
26	0:30:59.0	4.60
27	0:36:29.0	4.59
28	0:42:59.0	4.59
29	0:49:29.0	4.58
30	0:55:59.0	4.58
31	1:02:29.0	4.57
32	1:08:59.0	4.56
33	1:15:29.0	4.56
34	1:21:59.0	4.55
35	1:28:29.0	4.55
36	1:38:29.0	4.54
37	1:51:29.0	4.54
38	2:04:29.0	4.53
39	2:17:29.0	4.51
40	2:30:29.0	4.52
41	2:43:29.0	4.51
42	2:56:29.0	4.50
43	3:09:29.0	4.49
44	3:22:29.0	4.48
45	3:35:29.0	4.47

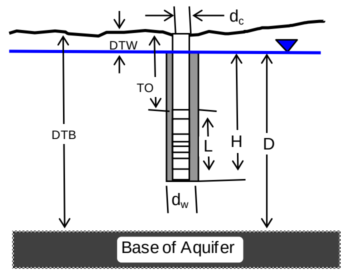
Figure B-3. Summary of slug test data analysis for well AHT087.

WELL ID: AHT087

Local ID: AHT087
Date: 7/27/2016
Time: 0:00

INPUT

Construction:	
Casing dia. (d_c)	2 Inch
Annulus dia. (d_w)	8.25 Inch
Screen Length (L)	5 Feet
Depths to:	
water level (DTW)	5.2 Feet
top of screen (TOS)	5 Feet
Base of Aquifer (DTB)	30 Feet
Annular Fill:	
across screen -- Fine Sand	
above screen -- Bentonite	
Aquifer Material -- Silt, Loess	



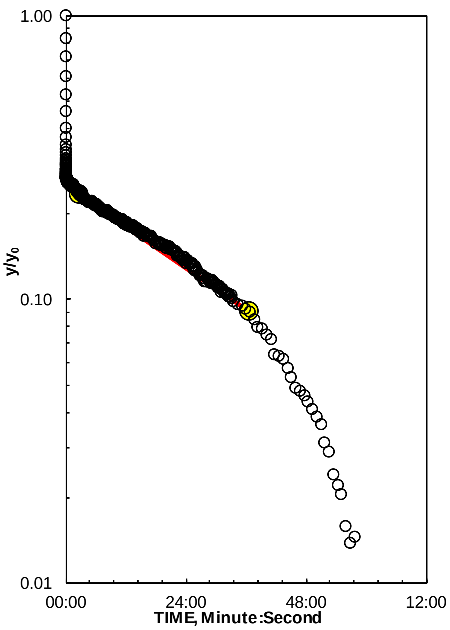
COMPUTED

L_{wetted}	4.8 Feet
D =	24.8 Feet
H =	4.8 Feet
L/r_w =	13.96
$y_{0\text{-DISPLACEMENT}}$ =	1.91 Feet
$y_{0\text{-SLUG}}$ =	1.17 Feet
From look-up table using L/r_w	
Partial penetrate A =	2.031
B =	0.304
ln(Re/rw) =	1.536
Re =	1.60 Feet
Slope =	3.38E-05 $\log_{10}$/sec
$t_{90\%}$ recovery =	29604 sec

Input is consistent.

K =	0.007 Feet/Day

Adjust slope of line to estimate K



Water level is below top of screen, evaluate rising head tests only
K within reasonable range for aquifer material selected

slope points	0:16:44	0.234
	3:41:29	0.09

REMARKS:

Bouwer and Rice analysis of slug test, WRR 1976

Reduced Data

Entry	Time, Hr:Min:Sec	Water Level
1	0:00:01.0	7.11
2	0:00:14.0	5.79
3	0:00:27.0	5.75
4	0:00:40.0	5.73
5	0:00:53.0	5.72
6	0:01:06.0	5.71
7	0:01:19.0	5.71
8	0:01:40.0	5.71
9	0:02:45.0	5.70
10	0:03:50.0	5.69
11	0:04:55.0	5.69
12	0:06:00.0	5.68
13	0:07:05.0	5.68
14	0:08:10.0	5.68
15	0:09:15.0	5.68
16	0:10:20.0	5.67
17	0:11:25.0	5.67
18	0:12:30.0	5.66
19	0:13:35.0	5.66
20	0:14:40.0	5.66
21	0:15:45.0	5.66
22	0:16:50.0	5.65
23	0:17:55.0	5.65
24	0:19:00.0	5.65
25	0:20:05.0	5.64
26	0:21:10.0	5.64
27	0:26:00.0	5.62
28	0:32:30.0	5.62
29	0:39:00.0	5.60
30	0:45:30.0	5.59
31	0:52:00.0	5.58
32	0:58:30.0	5.57
33	1:05:00.0	5.56
34	1:11:30.0	5.55
35	1:18:00.0	5.54
36	1:27:30.0	5.54
37	1:40:30.0	5.52
38	1:53:30.0	5.50
39	2:06:30.0	5.49
40	2:19:30.0	5.47
41	2:32:30.0	5.45
42	2:45:30.0	5.43
43	2:58:30.0	5.42
44	3:11:30.0	5.40
45	3:36:30.0	5.38

Figure B-4. Summary of slug test data analysis for well AHT088.

WELL ID: AHT088

Local ID: AHT088
Date: 7/27/2016
Time: 0:00

INPUT

Construction:

Casing dia. (d_c)	2 Inch
Annulus dia. (d_w)	8.25 Inch
Screen Length (L)	5 Feet

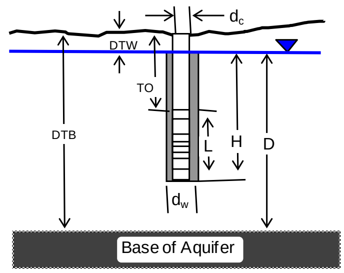
Depths to:

water level (DTW)	4.89 Feet
top of screen (TOS)	5 Feet
Base of Aquifer (DTB)	30 Feet

Annular Fill:

across screen -- Fine Sand
above screen -- Bentonite

Aquifer Material -- Silt, Loess



COMPUTED

L_{wetted}	5 Feet
D =	25.11 Feet
H =	5.11 Feet
L/r_w =	14.55
$y_{0\text{-DISPLACEMENT}}$ =	2.45 Feet
$y_{0\text{-SLUG}}$ =	1.17 Feet

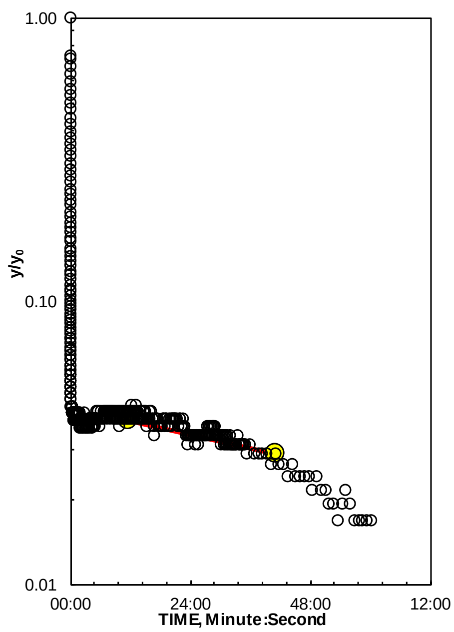
From look-up table using L/r_w

Partial penetrate A =	2.049
B =	0.308
ln(Re/rw) =	1.576
Re =	1.66 Feet
Slope =	1.11E-05 log_{10}/sec
$t_{90\%}$ recovery =	90215 sec

Input is consistent.

K = 0.002 Feet/Day

Adjust slope of line to estimate K



Water level above top of screen, can evaluate rising and falling head tests
K within reasonable range for aquifer material selected

slope points		
	1:09:59	0.038
	4:06:29	0.029

REMARKS:

Bouwer and Rice analysis of slug test, WRR 1976

Reduced Data

Entry	Time, Hr:Min:Sec	Water Level
1	0:00:01.0	7.24
2	0:00:14.0	5.72
3	0:00:27.0	5.28
4	0:00:40.0	5.09
5	0:00:53.0	4.99
6	0:01:06.0	4.95
7	0:01:19.0	4.92
8	0:01:40.0	4.90
9	0:02:45.0	4.89
10	0:03:50.0	4.89
11	0:04:55.0	4.89
12	0:06:00.0	4.89
13	0:07:05.0	4.89
14	0:08:10.0	4.89
15	0:09:15.0	4.89
16	0:10:20.0	4.89
17	0:11:25.0	4.89
18	0:13:30.0	4.89
19	0:15:40.0	4.89
20	0:17:50.0	4.89
21	0:20:00.0	4.89
22	0:22:10.0	4.89
23	0:24:20.0	4.89
24	0:26:30.0	4.89
25	0:28:40.0	4.89
26	0:30:50.0	4.89
27	0:36:00.0	4.88
28	0:42:30.0	4.89
29	0:49:00.0	4.89
30	0:55:30.0	4.89
31	1:02:00.0	4.89
32	1:08:30.0	4.89
33	1:15:00.0	4.89
34	1:21:30.0	4.89
35	1:28:00.0	4.89
36	1:37:30.0	4.89
37	1:50:30.0	4.88
38	2:03:30.0	4.89
39	2:16:30.0	4.88
40	2:29:30.0	4.87
41	2:42:30.0	4.88
42	2:55:30.0	4.88
43	3:08:30.0	4.88
44	3:21:30.0	4.88
45	3:46:30.0	4.86

Figure B-5. Summary of slug test data analysis for well AHT089.

WELL ID: AHT089

Local ID: AHT089
Date: 7/27/2016
Time: 0:00

INPUT

Construction:

Casing dia. (d_c)	2 Inch
Annulus dia. (d_w)	8.25 Inch
Screen Length (L)	10 Feet

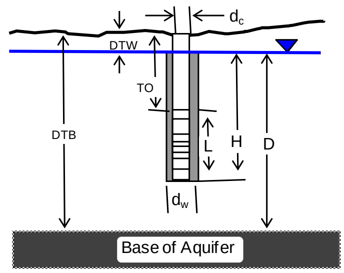
Depths to:

water level (DTW)	7.13 Feet
top of screen (TOS)	5 Feet
Base of Aquifer (DTB)	30 Feet

Annular Fill:

across screen -- Fine Sand
above screen -- Bentonite

Aquifer Material -- Fine Sand



COMPUTED

L_{wetted}	7.87 Feet
D =	22.87 Feet
H =	7.87 Feet
L/r_w =	22.89
$y_{0\text{-DISPLACEMENT}}$ =	0.50 Feet
$y_{0\text{-SLUG}}$ =	0.98 Feet

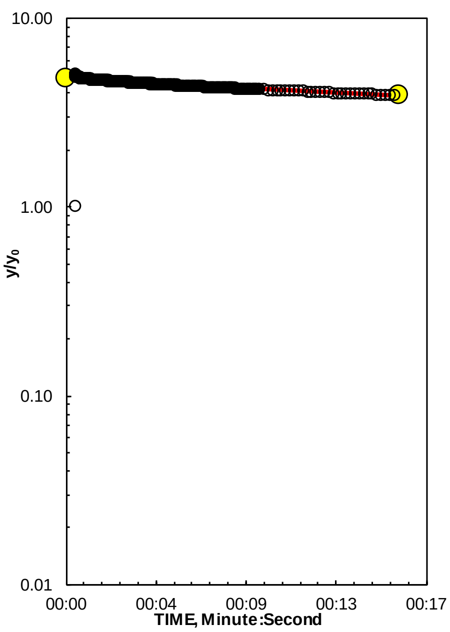
From look-up table using L/r_w

Partial penetrate A =	2.300
B =	0.368
ln(Re/rw) =	1.951
Re =	2.42 Feet
Slope =	0.005488 $\log_{10}$/sec
$t_{90\%}$ recovery =	182 sec

Input is consistent.

K = 0.9 Feet/Day

Adjust slope of line to estimate K



Water level is below top of screen, evaluate rising head tests only

K= 0.9 is less than likely minimum of 3 for Fine Sand

slope points	0:00:00	4.736
	0:00:16	3.869

REMARKS:

Bouwer and Rice analysis of slug test, WRR 1976

Reduced Data

Entry	Time, Hr:Min:Sec	Water Level
1	0:00:00.0	7.63
2	0:00:00.0	9.57
3	0:00:00.0	9.56
4	0:00:00.0	9.56
5	0:00:00.0	9.55
6	0:00:00.0	9.54
7	0:00:00.1	9.54
8	0:00:00.1	9.54
9	0:00:00.1	9.53
10	0:00:00.2	9.51
11	0:00:00.2	9.51
12	0:00:00.3	9.50
13	0:00:00.3	9.50
14	0:00:00.3	9.50
15	0:00:00.4	9.49
16	0:00:00.4	9.48
17	0:00:00.5	9.48
18	0:00:00.6	9.48
19	0:00:00.7	9.47
20	0:00:00.7	9.47
21	0:00:00.8	9.46
22	0:00:00.9	9.45
23	0:00:01.0	9.45
24	0:00:01.1	9.44
25	0:00:01.2	9.44
26	0:00:01.3	9.43
27	0:00:01.5	9.43
28	0:00:01.8	9.41
29	0:00:02.1	9.41
30	0:00:02.3	9.39
31	0:00:02.6	9.38
32	0:00:02.9	9.37
33	0:00:03.1	9.36
34	0:00:03.4	9.34
35	0:00:03.7	9.34
36	0:00:04.1	9.32
37	0:00:04.6	9.30
38	0:00:05.2	9.28
39	0:00:05.7	9.27
40	0:00:06.3	9.26
41	0:00:06.8	9.25
42	0:00:07.4	9.23
43	0:00:07.9	9.21
44	0:00:08.4	9.20
45	0:00:09.6	9.17

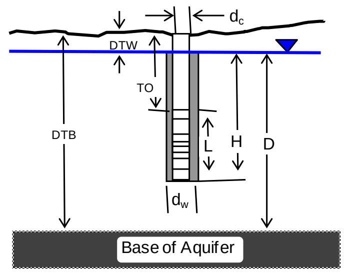
Figure B-6. Summary of slug test data analysis for well AHT090.

WELL ID: AHT090

Local ID: AHT090
Date: 8/14/1997
Time: 0:00

INPUT

Construction:	
Casing dia. (d_c)	2 Inch
Annulus dia. (d_w)	8.25 Inch
Screen Length (L)	5 Feet
Depths to:	
water level (DTW)	4.55 Feet
top of screen (TOS)	5 Feet
Base of Aquifer (DTB)	30 Feet
Annular Fill:	
across screen --	Coarse Sand
above screen --	Bentonite
Aquifer Material --	Medium Sand



Reduced Data

Entry	Time, Hr:Min:Sec	Water Level
1	0:00:01.0	5.74
2	0:00:02.0	5.34
3	0:00:03.0	4.92
4	0:00:04.0	4.73
5	0:00:05.0	4.64
6	0:00:06.0	4.59
7	0:00:07.0	4.57
8	0:00:08.0	4.56
9	0:00:09.0	4.55
10	0:00:10.0	4.55
11	0:00:11.0	4.55

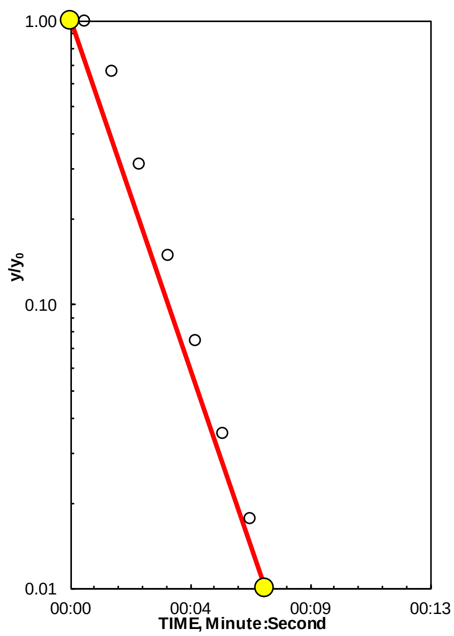
COMPUTED

L_{wetted}	5 Feet
D =	25.45 Feet
H =	5.45 Feet
L/r_w =	14.55
$y_{0\text{-DISPLACEMENT}}$ =	1.19 Feet
$y_{0\text{-SLUG}}$ =	1.17 Feet
From look-up table using L/r_w	
Partial penetrate A =	2.049
B =	0.308
ln(Re/rw) =	1.600
Re =	1.70 Feet
Slope =	0.285714 $\log_{10}$/sec
$t_{90\%}$ recovery =	4 sec

Input is consistent.

K = 60 Feet/Day

Adjust slope of line to estimate K



Water level above top of screen, can evaluate rising and falling head tests
K within reasonable range for aquifer material selected

slope points	0:00:00	1
	0:00:07	0.01

REMARKS:

Bouwer and Rice analysis of slug test, WRR 1976

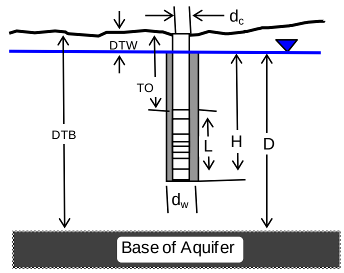
Figure B-7. Summary of slug test data analysis for well AKY469.

WELL ID: AKY469

Local ID: AKY469
Date: 7/27/2016
Time: 0:00

INPUT

Construction:		
Casing dia. (d_c)	2	Inch
Annulus dia. (d_w)	8.25	Inch
Screen Length (L)	5	Feet
Depths to:		
water level (DTW)	4.26	Feet
top of screen (TOS)	5	Feet
Base of Aquifer (DTB)	30	Feet
Annular Fill:		
across screen -- Fine Sand		
above screen -- Bentonite		
Aquifer Material -- Medium Sand		



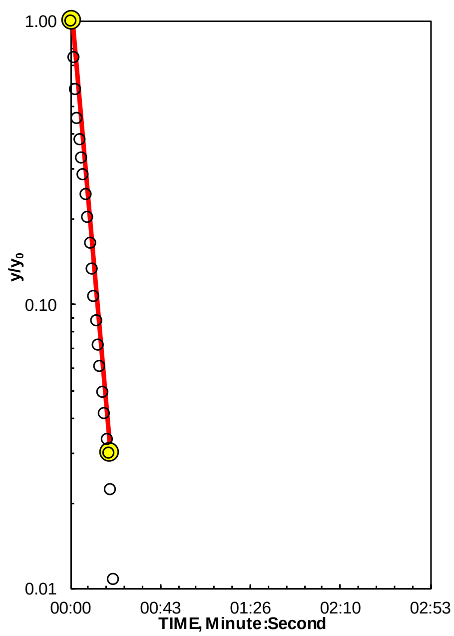
COMPUTED

L_{wetted}	5	Feet
D =	25.74	Feet
H =	5.74	Feet
L/r_w =	14.55	
$y_{0\text{-DISPLACEMENT}}$ =	1.45	Feet
$y_{0\text{-SLUG}}$ =	1.17	Feet
From look-up table using L/r_w		
Partial penetrate A =	2.049	
B =	0.308	
ln(Re/rw) =	1.619	
Re =	1.73	Feet
Slope =	0.084604	$\log_{10}$/sec
$t_{90\%}$ recovery =	12	sec

Input is consistent.

K = 20 Feet/Day

Adjust slope of line to estimate K



Water level above top of screen, can evaluate rising and falling head tests

K within reasonable range for aquifer material selected

slope points		
	0:00:01	1
	0:00:19	0.03

Bouwer and Rice analysis of slug test, WRR 1976

REMARKS:

Reduced Data

Entry	Time, Hr:Min:Sec	Water Level
1	0:00:01.0	5.71
2	0:00:03.0	5.09
3	0:00:05.0	4.81
4	0:00:07.0	4.68
5	0:00:09.0	4.55
6	0:00:11.0	4.45
7	0:00:13.0	4.39
8	0:00:15.0	4.35
9	0:00:17.0	4.32
10	0:00:19.0	4.30
11	0:00:21.0	4.28
12	0:00:23.0	4.26
13	0:00:25.0	4.24
14	0:00:27.0	4.23
15	0:00:29.0	4.22
16	0:00:31.0	4.21
17	0:00:33.0	4.21
18	0:00:35.0	4.20
19	0:00:37.0	4.20
20	0:00:39.0	4.20
21	0:00:41.0	4.20
22	0:00:43.0	4.19
23	0:00:45.0	4.19
24	0:00:47.0	4.19
25	0:00:49.0	4.18
26	0:00:51.0	4.19
27	0:00:53.0	4.18
28	0:00:55.0	4.19
29	0:00:57.0	4.19
30	0:00:59.0	4.18
31	0:01:01.0	4.18
32	0:01:03.0	4.19
33	0:01:05.0	4.18
34	0:01:07.0	4.18
35	0:01:09.0	4.18
36	0:01:11.0	4.18
37	0:01:13.0	4.18
38	0:01:15.0	4.18
39	0:01:17.0	4.18
40	0:01:19.0	4.18
41	0:01:21.0	4.18
42	0:01:23.0	4.18
43	0:01:25.0	4.18
44	0:01:27.0	4.18
45	0:01:29.0	4.18

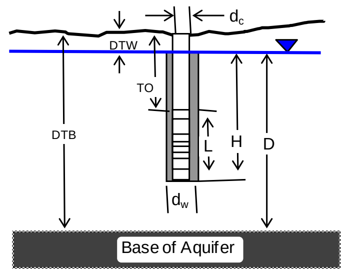
Figure B-8. Summary of slug test data analysis for well AKY472.

WELL ID: AKY472

Local ID: AKY472
Date: 7/27/2016
Time: 0:00

INPUT

Construction:		
Casing dia. (d_c)	2	Inch
Annulus dia. (d_w)	8.25	Inch
Screen Length (L)	5	Feet
Depths to:		
water level (DTW)	4.64	Feet
top of screen (TOS)	5	Feet
Base of Aquifer (DTB)	30	Feet
Annular Fill:		
across screen -- Fine Sand		
above screen -- Bentonite		
Aquifer Material -- Fine Sand		



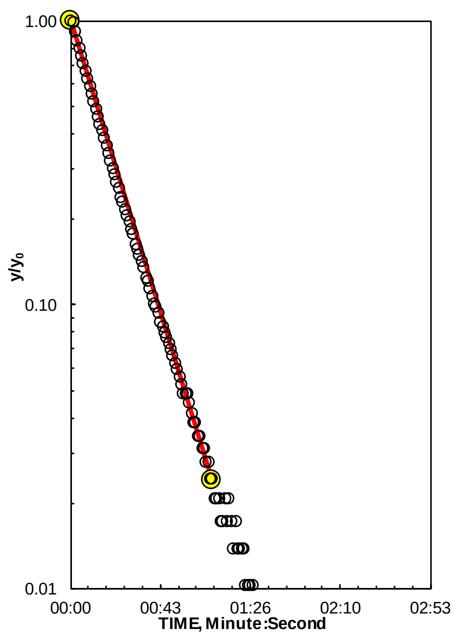
COMPUTED

L_{wetted}	5	Feet
D =	25.36	Feet
H =	5.36	Feet
L/r_w =	14.55	
$y_{0\text{-DISPLACEMENT}}$ =	1.69	Feet
$y_{0\text{-SLUG}}$ =	1.17	Feet
From look-up table using L/r_w		
Partial penetrate A =	2.049	
B =	0.308	
ln(Re/rw) =	1.594	
Re =	1.69	Feet
Slope =	0.02382	log_{10}/sec
$t_{90\%}$ recovery =	42	sec

Input is consistent.

K =	5	Feet/Day

Adjust slope of line to estimate K



Water level above top of screen, can evaluate rising and falling head tests
K within reasonable range for aquifer material selected

slope points	0:00:00	1
	0:01:08	0.024

REMARKS:

Bouwer and Rice analysis of slug test, WRR 1976

Reduced Data

Entry	Time, Hr:Min:Sec	Water Level
1	0:00:01.0	6.33
2	0:00:03.0	6.19
3	0:00:05.0	6.00
4	0:00:07.0	5.84
5	0:00:09.0	5.70
6	0:00:11.0	5.57
7	0:00:13.0	5.47
8	0:00:15.0	5.37
9	0:00:17.0	5.29
10	0:00:19.0	5.21
11	0:00:21.0	5.15
12	0:00:23.0	5.10
13	0:00:25.0	5.04
14	0:00:27.0	5.00
15	0:00:29.0	4.97
16	0:00:31.0	4.94
17	0:00:33.0	4.90
18	0:00:35.0	4.88
19	0:00:37.0	4.85
20	0:00:39.0	4.83
21	0:00:41.0	4.81
22	0:00:43.0	4.80
23	0:00:45.0	4.78
24	0:00:47.0	4.77
25	0:00:49.0	4.76
26	0:00:51.0	4.74
27	0:00:53.0	4.73
28	0:00:55.0	4.72
29	0:00:57.0	4.72
30	0:00:59.0	4.71
31	0:01:01.0	4.70
32	0:01:03.0	4.70
33	0:01:05.0	4.69
34	0:01:07.0	4.69
35	0:01:09.0	4.68
36	0:01:11.0	4.67
37	0:01:13.0	4.67
38	0:01:15.0	4.67
39	0:01:17.0	4.67
40	0:01:19.0	4.66
41	0:01:21.0	4.66
42	0:01:23.0	4.66
43	0:01:25.0	4.66
44	0:01:27.0	4.66
45	0:01:29.0	4.65

Appendix C. Quality assurance results

Grain size samples

Relative standard deviations (RSDs) for 4 samples on which triplicate analyses were run are shown in Table C-1. RSDs for each size class ranged from 3.6-101%. The RSD for the AHT089-7.5 sample was generally the lowest.

No measurement quality objectives were specified in the project QAPP for grain size analysis. However the high variation among results for the triplicate analyses should be taken into account when using the grain size data for estimating hydraulic properties.

Field meter calibration and verification

A Hydrolab MS-5 mini-sonde was used during this project to measure temperature, pH, conductivity, and dissolved oxygen. The meter was calibrated before each field event and post-calibrated at the end of the event per SOP EAP033 (Swanson, 2007).

Fresh commercially-prepared buffer solutions and reference standards were used to calibrate the mini-sonde for pH and specific conductance. The dissolved oxygen sensor was calibrated against theoretical water-saturated air using the manufacturer-supplied calibration chamber. The initial pH and specific conductance calibrations were checked by placing the probes in pH buffer solutions and reference standards, respectively, and evaluating the difference between the standard and the meter values (Table C-2). The pH calibration was accepted if the metered values differed by less than ± 0.05 pH units from the buffer value. The specific conductance calibration was accepted if the meter values deviated by no more than ± 5% from the specific conductance check standards.

After each sampling event, the mini-sonde was rechecked against reference standards to confirm it had not drifted unacceptably since the initial calibration. Results were either accepted, qualified as estimates, or rejected as unusable based on the post-use acceptance criteria listed in Table C-2.

Calibration acceptance standards were met for pH, conductivity, and dissolved oxygen for all dates except April 2016. pH and dissolved oxygen did not calibrate even before sampling, therefore results for those parameters were rejected for that date. All other results were accepted without qualification.

Table C-1. Relative standard deviation results of triplicate grain size analyses for size classes (%).

Sample IDs represent the well tag ID and the depth below ground surface where the sample was taken.

Sample ID	4.75 mm	4.00 mm	2.00 mm	1.00 mm	0.50 mm	0.25 mm	0.125 mm	0.063 mm	0.032 mm	.016 mm	0.008 mm	0.004 mm	0.002 mm	0.001 mm	<0.001 mm
AKY472-7.5	0.30	0.30	1.80	3.10	3.40	4.70	9.60	4.10	33.7	7.80	10.2	7.10	2.90	1.50	9.70
	0.40	0.10	1.40	3.50	5.10	7.10	11.8	2.50	30.7	10.8	14.4	6.80	3.20	1.80	9.60
	1.80	0.10	2.60	5.10	4.40	6.40	8.30	3.20	21.9	10.4	9.40	3.80	2.60	1.50	9.60
RSD	101	69.3	31.6	27.1	19.9	20.3	17.9	24.6	21.3	16.9	23.7	30.9	10.3	10.8	0.6
AKY472-17.5	0.60	0.20	3.10	3.50	3.10	2.40	2.50	1.30	11.9	16.2	13.5	14.1	6.80	3.30	17.60
	ND	ND	2.00	3.00	3.30	2.30	3.00	1.70	24.4	14.7	12.2	10.4	4.90	2.30	15.80
	1.00	0.60	4.60	6.10	3.30	2.10	2.40	1.40	24.3	12.7	10.8	8.70	3.40	1.60	16.90
RSD	35.4	70.7	40.4	39.6	3.6	6.7	12.2	14.2	35.6	12.1	11.1	24.9	33.9	35.6	5.4
AHT087-2.5	ND	0.10	1.40	1.50	2.00	4.50	10.10	6.70	35.6	5.60	6.50	10.2	4.80	2.20	8.60
	ND	0.30	1.00	2.70	2.60	7.00	18.90	2.20	30.1	5.50	6.50	9.40	3.60	1.60	8.90
	0.1	ND	0.90	0.40	2.10	11.7	15.40	7.30	24.4	6.40	7.80	8.40	3.40	1.60	9.70
RSD	NA	70.7	24.1	75.0	14.4	47.3	29.9	51.6	18.6	8.5	10.8	9.7	19.3	19.2	6.3
AHT089-7.5	ND	ND	1.10	1.40	1.40	3.00	4.50	7.50	22.3	11.8	12.3	10.9	5.00	2.50	16.3
	ND	ND	1.90	1.70	1.60	3.00	8.50	1.90	20.9	11.8	12.8	11.0	5.90	2.90	14.6
	ND	ND	2.00	1.70	1.70	2.80	8.00	8.60	18.7	13.0	14.4	10.1	4.00	1.60	14.8
RSD	NA	NA	29.6	10.8	9.8	3.9	31.1	59.9	8.8	5.7	8.3	4.6	19.1	28.5	6.1

mm: millimeters
RSD: Relative Standard Deviation = Standard deviation/mean of the values.

Table C-2. Hydrolab mini-sonde calibration records.

Date	Status	pH				Specific conductance				Dissolved oxygen			
		Reference standard (pH)	Meter reading (pH)	Deviation from standard (pH units)	Accept or reject calibration/ result[1,2]	Reference standard (uS cm^{-1})	Meter reading (uS cm^{-1})	Deviation from standard (%)	Accept or reject calibration/ result[1,2]	Meter reading (mg L^{-1})	Saturation (%)	Deviation from saturation (%)	Accept or reject calibration/ result[1,2]
10/10/2014	Pre-sampling	4.01	4.04	0.03	Accept	99.9	100.4	0.50	Accept	8.76	100.1	0.1	Accept
		7.00	7.00	0.00	Accept	1412	--	--	--				
10/16/2014	Post-sampling	7.00	7.04	0.04	Accept	0.0	0.0	0.0	Accept	8.62	99.4	0.6	Accept
		4.01	4.07	0.06	Accept	99.9	103.5	3.60	Accept				
						1412	1408	0.28	Accept				
12/5/2014	Pre-sampling	7.00	7.02	0.02	Accept	1412	--	--	--		100	0	Accept
		4.01	4.01	0.00	Accept	100.0	101.0		Accept				
12/11/2014	Post-sampling	7.00	6.99	0.01	Accept	0.0	0.0	0.0	Accept	8.44	96.8	3.2	Accept
		4.01	3.99	0.02	Accept	99.9	99.0	0.90	Accept				
						1412	1410	0.14	Accept				
2/6/2015	Pre-sampling	7.00	6.99	0.01	Accept	1412	--	--	--	8.55	100.1	0.1	Accept
		4.01	4.02	0.01	Accept	100.0	100.1	0.10	Accept				
2/12/2015	Post-sampling	7.00	7.04	0.04	Accept	0.0	0.0	0.0	Accept	8.78	103.7	3.7	Accept
		4.01	4.03	0.02	Accept	100.2	102.2	2.00	Accept				
						1412	1410	0.14	Accept				
4/20/2015	Pre-sampling	7.00	--	--	--	100.2	100.5	0.30	Accept		99.5	0.5	Accept
		4.01	--	--	--	1412	--	--	--				
4/23/2015	Post-sampling	7.00	6.98	0.02	Accept	100.2	104.90	4.69	Accept		99.0	1.0	Accept
		4.01	4.03	0.02	Accept	1412	1408.0	0.28	Accept				
6/5/2015	Pre-sampling	7.00	7.01	0.01	Accept	100.2	101.6	1.40	Accept		100.0	0	Accept
		4.01	3.99	0.02	Accept	1411	1413	0.14	Accept				
6/10/2015	Post-sampling	7.00	6.97	0.03	Accept	0.0	0.0	0.0	Accept		100.1	0.1	Accept
		4.01	3.97	0.04	Accept	100.2	99.4	0.80	Accept				
						1411	1416	0.35	Accept				
8/10/2015	Pre-sampling	7.00	7.03	0.03	Accept	100.2	100.2	0.0	Accept		100.3	0.3	Accept
		4.01	4.01	0.00	Accept	1411	1412	0.07	Accept				

Date	Status	pH				Specific conductance				Dissolved oxygen			
		Reference standard (pH)	Meter reading (pH)	Deviation from standard (pH units)	Accept or reject calibration/ result[1,2]	Reference standard ($uS\ cm^{-1}$)	Meter reading ($uS\ cm^{-1}$)	Deviation from standard (%)	Accept or reject calibration/ result[1,2]	Meter reading ($mg\ L^{-1}$)	Saturation (%)	Deviation from saturation (%)	Accept or reject calibration/ result[1,2]
8/13/2015	Post-sampling	7.00	7.03	0.03	Accept	0.0	0.0	0.0	Accept		100.6	0.6	Accept
		4.01	4.01	0.00	Accept	100.2	101.5	1.30	Accept				
						1411	1417	0.43	Accept				
11/13/2015	Pre-sampling	7.00	7.00	0.00	Accept	100.3	99.5	0.80	Accept	8.75	100.0	0	Accept
		4.01	4.01	0.00	Accept	1413	1413	0.0	Accept				
11/19/2015	Post-sampling	7.00	7.26	0.04	Accept	0.0	0.0	0.0	Accept		102.7	2.7	Accept
		4.01	4.26	0.04	Accept	100.3	100.5	0.20	Accept				
						1413	1390	1.63	Accept	8.64	100.0	0	Accept
2/5/2016	Pre-sampling	7.00	drifting		Reject	100.0	102.0	2.00	Accept				
		4.01	drifting		Reject								
2/11/2016	Post-sampling	7.00	7.61	0.61	Reject	0.0	0.0	0.0	Accept	NA	NA		Reject
		4.01	4.01	0.00	Accept	100.3	98.1	2.19	Accept				
						1413	1378	2.48	Accept				
4/11/2016	Pre-sampling	7.00	7.02	0.02	Accept	100.0	101.0	1.00	Accept		100.0	0	Accept
		4.01	4.06	0.05	Accept								
4/13/2016	Post-sampling	7.00	7.06	0.06	Accept	100.0	102.3	2.30	Accept		100.9	0.9	Accept
		4.01	4.11	0.10	Accept								

[1] Pre-sampling calibration acceptance criteria.
[2] Post-sampling acceptance criteria-deviation from check standards

pH
Deviation from check standards following initial calibration:
≤± 0.05 pH deviation from all standards = Accept calibration
>± 0.05 pH deviation from any standard = Reject calibration

Specific conductance
≤± 5% deviation from all standards = Accept calibration
>± 5% deviation from any standard = Reject calibration

Dissolved oxygen
≥ 99.5% saturation and ≤ 100.5% = Accept calibration
< 99.5% saturation or > 100.5% = Reject calibration

Continued notes for Table C-2:

pH

Deviation from check standards following post-calibration:

≤± 0.15 pH deviation from all standards = Accept results

>± 0.15 pH and ≤± 0.5 pH deviation from any standard = Reject results

± 0.5 pH deviation from any standard = Reject results

Specific conductance

≤± 5% deviation from all standards = Accept results

>± 5% and ≤± 10% deviation from any standard = Qualify results as estimates ("J" code)

> 10% deviation from any standard = Reject results

Dissolved oxygen

≤ ±5% saturation = Accept results

≥ ± 5% saturation and ≤ ± 10% = Qualify results as estimates ("J" code)

≥ ± 10% = Reject results

Review of water quality data

All wells were sampled using properly calibrated field meters, dedicated sample tubing, and new in-line-cartridge filters. Samples were collected in pre-cleaned bottles supplied by the Manchester Environmental Laboratory (MEL) Pre-acidified bottles were used for preserved samples. Filled sample bottles were labeled, bagged, and then stored in clean, ice-filled coolers pending their arrival at the laboratory. Sample chain-of-custody procedures were followed throughout the project.

Laboratory quality assurance

MEL follows strict protocols to ensure and evaluate the quality of analytical results (Ecology, 2008). Instrument calibration was performed by laboratory staff before each analytical run and checked against verification standards and blank samples. Calibration standards and blanks were analyzed at a frequency of 10% during the analysis and at the end of the analytical run. The laboratory also evaluates procedural blanks, spiked samples, and laboratory control samples (LCS) as additional quality checks. Results of these analyses were summarized in a case narrative and submitted to the client along with each result package.

The laboratory quality assurance (QA) narrative and supporting data indicate that all samples arrived at the laboratory in good condition. All samples were processed and analyzed within acceptable holding times. Table C-3 lists the laboratory quality assurance results. Table C-4 specifies the acceptance criteria for results specified in the QAPP (Carey, 2014). The following samples did not meet the applicable acceptance criteria:

- Ammonium-N on 4/12/16. The RPD was outside the acceptance limits, however concentrations were less than 5 times the detection limit. Therefore no qualifications are needed for associated data.
- Total dissolved solids on 2/9/16. The RPD was outside the acceptance limits, however concentrations were less than 5 times the detection limit. Therefore no qualifications are needed for associated data.
- Calcium on 2/10/16. Matrix spike results were outside the acceptance limits and results for that date are qualified as estimates (J) in Appendix E, Tables E-1 and E-2.
- Dissolved organic carbon on 6/9/15. Matrix spike results were outside the acceptance limits and results for that date are qualified as estimates (J) in Tables E-1 and E-2.
- Fecal coliform bacteria on 11/17/15. The RPD was outside the acceptance limits. However concentrations in duplicate samples, 2 and 6 cfu/100 ml, were less than 20 cfu/100 ml, a threshold for higher variability in bacteria samples. Mathieu (2006) recommends that the project manager review the data at low concentrations for usability. These data are considered usable without qualification.
- Total coliform bacteria on 10/14/14, 12/9/14, and 11/17/15. RPD's was outside the acceptance limits. Results for 10/14/14 and 11/17/15 were below 20 cfu/100 ml, and should also be acceptable without qualification for use. Results for 12/9/14 include one value greater than 20 cfu/100 ml, however both duplicate values are qualified as "J" estimates by the laboratory. Therefore, no further qualification is needed.

Table C-3. Laboratory quality assurance results.

Date	Constituent	Duplicate Results					Laboratory Control Samples (LCS)	Matrix Spike	Blank	
		mg/L		mg/L		RPD +/- 10%	90-110%	80-120%	mg/L	
10/14/2014	Alkalinity	75.7		75.8		0.13			5.0	
2/10/2015		56.5		56.5		0.00			5.0	U
6/9/2015									5.0	U
6/9/2015		73.5		73.5		0.00			5.0	U
11/18/2015		68.1		68.4		0.44	96		5.0	U
2/9/2016		49.5		49.7		0.40			5.0	U
10/14/2014	Ammonium-N	0.899		0.893		0.67	98	90	0.010	
12/9/2015		0.424		0.425			100	97	0.010	U
12/9/2015		0.033		0.032			102	93	0.010	U
2/10/2015		0.010	U	0.010	U	NA	102	94	0.010	U
4/22/2015		0.010	U	0.010	U	NA	101	99	0.010	U
4/22/2015		0.010	U	0.010	U	NA	101	96	0.010	U
6/9/2015		0.010	U	0.010	U	NA	99	100	0.010	U
8/12/2015		0.013		0.013		0.00	106	97	0.010	U
11/17/2015		1.12		1.13		0.89	100	95	0.010	U
11/17/2015		0.010	U	0.010	U	NA	103	93	0.010	U
2/9/2016		0.010	U	0.010	U	NA	101	94	0.010	U
4/12/2016		0.013		0.015		14.3	101	97	0.010	U
10/14/2014	Nitrite+Nitrate-N	0.010		0.010	U	NA	103	103	0.010	
12/9/2015		2.80		2.83		1.07	99	93	0.010	U
2/10/2015		3.09		3.10		0.32	100	99	0.010	U
2/10/2015		0.418		0.419		0.24	97	84	0.010	U
4/22/2015		1.24		1.23		0.81	105	97	0.010	U
6/9/2015		0.448		0.448		0.00	103	94	0.010	U
8/12/2015		0.315		0.314		0.32	104	97	0.010	U
11/17/2015		0.358		0.361		0.83	104	117	0.010	U
2/9/2016		0.192		0.193		0.52	101	97	0.010	U
2/9/2016		0.022		0.023		4.44	102	87	0.010	U
4/12/2016		0.010	U	0.010	U	NA	106	95	0.010	U

Table C-3 is continued on the next 4 pages

Date	Constituent	Duplicate Results				Laboratory Control Samples (LCS)	Matrix Spike	Blank	
		mg/L		mg/L		RPD +/- 10%	90-110%	80-120%	mg/L	
10/14/2014	Total Persulfate N	0.348		0.335		3.81	100	81	0.025	
12/9/2015		0.620		0.621		0.16	96	82	0.025	U
12/9/2015		1.090		1.09		0.00	95	95	0.025	U
2/10/2015		3.50		3.51		0.29	103	98	0.025	U
4/22/2015		1.48		1.49		0.67	101	87	0.025	U
6/9/2015		0.740		0.733		0.95	99	84	0.025	U
8/12/2015		0.573		0.605		5.43	102	81	0.025	U
11/17/2015		0.657		0.631		4.04	94	90	0.025	U
2/9/2016		0.298		0.290		2.72	99	85	0.025	U
4/12/2016		0.025	U	0.025	U	NA	107	105		
12/9/2014	Ortho-P	0.0785		0.0776		1.15	99	91	0.0030	U
12/9/2014		0.0087		0.0087		0.00	96	94	0.0030	U
2/10/2015		0.0043		0.0044		2.30	96	95	0.0030	U
2/10/2015		0.0342		0.0340		0.59	93	99	0.0030	U
12/9/2014	Total P	0.433		0.435		0.46	93	95	0.0050	U
2/10/2015		0.077		0.077		0.00	95	94	0.0050	U
10/14/2014	Chloride	1.91		1.90		0.52	98	100	0.10	
10/14/2014								102		
10/14/2014		11.6		11.4		1.74	99	97	0.10	
12/9/2015		4.86		4.79		1.45	102	92	0.10	U
12/9/2015								93		
2/10/2015		3.78		3.76		0.53	98	97	0.10	U
2/10/2015								98		
4/22/2015		3.80		3.82		0.52	102	99	0.10	U
4/22/2015								96		
4/22/2015		3.20		3.15		1.57	99	96	0.10	U
4/22/2015								98		
6/9/2015		3.61		3.58		0.83	98	101	0.10	U
6/9/2015								91		
8/12/2015		3.56		3.57		0.28	100	100	0.10	U
8/12/2015								100		
11/17/2015		3.09		3.13		1.29	101	97	0.10	U
11/17/2015								99		
2/9/2016		12.2		12.2		0.00	107	109	0.10	U
2/9/2016								106		
4/12/2016		6.63		6.58		0.76	99	100	0.10	U
4/12/2016								103		

Date	Constituent	Duplicate Results					Laboratory Control Samples (LCS)	Matrix Spike	Blank	
		mg/L		mg/L		RPD +/- 10%	90-110%	80-120%	mg/L	
10/14/2014	Bromide[1]	0.20		0.20	U	NA	100	101	0.20	
10/14/2014								103		
12/9/2015		0.20	U	0.20	U	NA	101	102	0.20	U
2/10/2015		0.20	U	0.20	U	NA	100	100	0.20	U
2/10/2015								100		
4/22/2015		0.20	U	0.20	U	NA	101	99	0.20	U
6/9/2015		0.20	U	0.20	U	NA	98	100	0.20	U
6/9/2015								99		
11/17/2015		0.20	U	0.20	U	NA	101	104	0.20	U
11/17/2015								97		
2/9/2016		0.108		0.107		0.93	104	110	0.03	U
2/9/2016								107		
10/14/2014	Total Dissolved Solids	256		254		0.78	102		5	
10/14/2014		141		140		0.71			5	
2/10/2015		235		242		2.94	102		5	U
2/10/2015		404		410		1.47			5	U
6/9/2015		240		237		1.26	100		6	U
6/9/2015		627		622		0.80			6	U
11/18/2015		458		458		0.00	106		5	U
11/18/2015		218		218		0.00			5	U
2/9/2016		554		560		1.08	101		13	U
2/9/2016		102		118		14.5				
2/10/2015	Calcium						99	77	0.050	U
2/10/2015								79		
2/10/2015	Magnesium						100	96	0.050	U
2/10/2015								95		
2/10/2015	Potassium						98	93	0.50	U
2/10/2015								98		
2/10/2015	Sodium						103	84	0.050	U
2/10/2015								92		
2/10/2015	Sulfate	4.78		4.77		0.21	98	99	0.30	U
2/10/2015								101		
6/9/2015		5.07		5.10		0.59	95	98	0.30	U
6/9/2015								95		

Date	Constituent	Duplicate Results					Laboratory Control Samples (LCS)	Matrix Spike	Blank	
		mg/L		mg/L		RPD +/- 10%	90-110%	80-120%	mg/L	
10/14/2014	Iron						102	96	0.050	U
10/14/2014								97		
2/10/2015							101	99	0.050	U
2/10/2015								95		
6/9/2015							100	99	0.050	U
6/9/2015								97		
10/14/2014	Dissolved Organic Carbon	7.36		7.46		1.35	100	101	1.0	
2/10/2015							95		1.0	U
6/9/2015		4.51		4.54		0.66	94	124	1.0	U
11/18/2015		18.0		16.9		6.30	99	83	1.0	U
11/18/2015		1.0	U	1.0	U	NA	99	99	1.0	U
2/9/2016		4.75		4.69		1.27	101	98	1.0	U
10/14/2014	Fecal coliform bacteria (cfu/100 ml)	1	U	1	U	NA			1	U
10/14/2014									1	U
12/9/2014		1	U	1	U	NA			1	U
12/9/2014		1	U	1	U	NA			1	U
12/9/2014									1	U
12/9/2014									1	U
2/10/2015		1	U	1	U	NA			1	U
2/10/2015		4200	J	3400	J	21.1			1	U
2/10/2015									1	U
2/10/2015									1	U
4/22/2015		1	U	1	U	NA			1	U
4/22/2015									1	U
6/9/2015		1	U	1	U	NA			1	U
6/9/2015									1	U
8/12/2015		1	U	1	U	NA			1	U
8/12/2015									1	U
11/17/2015		2		6		100			1	U
11/17/2015		22		16		31.6			1	U
11/17/2015									1	U
11/17/2015									1	U
2/9/2016		1	U	1	U	NA			1	U
2/9/2016		57		43		28.0			1	U
2/9/2016									1	U
2/9/2016									1	U
4/12/2016		1	U	1	U	NA			1	U
4/12/2016		1	U	1	U	NA			1	U

Date	Constituent	Duplicate Results					Laboratory Control Samples (LCS)	Matrix Spike	Blank	
		mg/L		mg/L		RPD +/- 10%	90-110%	80-120%	mg/L	
4/12/2016									1	U
4/12/2016									1	U
10/14/2014	Total coliform bacteria (cfu/100 ml)	2		5		85.7			1	U
12/9/2014		1	U	1	U	NA			1	U
12/9/2014		29	J	1	UJ	187			1	U
12/9/2014									1	U
12/9/2014									1	U
2/10/2015		1	U	1	U	NA			1	U
2/10/2015		3	U	3	U	NA			1	U
2/10/2015									1	U
2/10/2015									1	U
4/22/2015		1	U	1	U	NA			1	U
4/22/2015									1	U
6/9/2015		1	U	1	U	NA			1	U
6/9/2015									1	U
8/12/2015		1	U	1	U	NA			1	U
8/12/2015									1	U
11/17/2015		3		8		90.9			1	U
11/17/2015		10		6		50.0			1	U
11/17/2015									1	U
11/17/2015									1	U
2/9/2016		1	U	1	U	NA			1	U
2/9/2016		1	U	1	U	NA			1	U
2/9/2016									1	U
2/9/2016									1	U
4/12/2016		570		540	J	5.4			1	U
4/12/2016		1600	J	1600	J	0.0			1	U
4/12/2016									1	U
4/12/2016									1	U

Highlighted values are outside the acceptance limits set for the study.

[1] The detection limit for bromide was 0.2 mg/L for all dates except February 2016, when the detection limit was 0.03 mg/L.

U: The analyte was detected at or above the reported result.

J: The analyte was positively identified; the associated value is the approximate concentration in the sample

Table C-4. Measurement quality objectives.

Parameter	Matrix[1]	Duplicate samples	Matrix spikes	Lowest concentration/ level of interest
		Relative % difference (RPD)	% Recovery limits	Units
Field measurements				
Temperature	W	NA	NA	3 C°
pH	W, ME	NA	NA	NA
Specific conductivity	W, ME	NA	NA	10 umhos/cm
Dissolved oxygen	W, ME GW, ME	NA	NA	0.1 mg/L
Water level	W	0.2	NA	0.01 ft
Laboratory analyses				
Alkalinity	FW, ME	10	20	5.0 mg/L
Ammonia-N	FW, ME	10	20	0.010 mg/L
Nitrite+nitrate-N	FW, ME	10	20	0.010 mg/L
Total persulfate N	FW, ME	10	20	0.025 mg/L
Ortho Phosphate	FW, ME	10	20	0.0050 mg/L
Total Phosphate	FW, ME	10	20	0.0050 mg/L
Cations/anions (Na, K, Ca, Mg, SO_4)	FW, ME	10	20	0.10 mg/L
Chloride	FW, ME	10	20	0.10 mg/L
Bromide	FW, ME	10	20	0.10 mg/L
Iron	FW, ME	10	20	0.10 mg/L
DOC	FW, ME	10	20	1.0 mg/L
Fecal coliform- MF[2]	W, ME	40	NA	1 cfu/100 ml
Total coliform--MF[2]	W, ME	40	NA	1 cfu/100 ml
Grain size (drilling samples)	S	NA	NA	NA

[1] W= Water, FW= Groundwater filtered in the field, S= Soil, ME= Municipal effluent.
[2] MF= Membrane filter.

Field quality assurance

To assess sampling bias and overall analytical precision, field equipment blanks and replicate samples were collected and submitted to the laboratory during each sample event. Equipment blanks were prepared using laboratory-grade de-ionized water and were handled and filtered in the same manner as actual samples. Results for the field blanks listed in Table C-5 were below detection for all parameters with the following exceptions:

- Ammonium-N on 4/22/15
- TPN on 4/22/15, 6/9/15, 8/12/15, and 11/17/15
- Chloride on 10/14/14
- TDS on 11/18/15

Analyte concentrations were less than 10 times the blank concentrations in duplicate samples collected on the same dates as the above blank detections. Therefore data for these dates were considered useable without qualification.

Results for the total coliform bacteria field blank on 4/12/16 was 110 cfu/100 ml. Therefore data for that date are qualified as an estimate (J) in Tables F-1 and F-2.

Most of the field duplicates met the project measurement quality objective of +/-10% relative percent difference (RPD) established for precision (Carey, 2014) (Table C-3). The RPD for nitrate-N on 12/9/14 and 2/9/16 did not meet the RPD acceptance criteria, however the concentrations were less than 5 times the method detection limit of 0.010 mg/L. This level of difference is acceptable at such low concentrations (MEL 2008).

The nitrite+nitrate-N, TPN, and DOC results for 6/9/15 also did not meet the +/-10% RPD acceptance criteria and had concentrations greater than 5 times the respective method detection limits. Therefore nitrite+nitrate-N and TPN data for 6/9/15 are qualified as estimates (J) in Tables F-1 and F-2.

The RPD for the DOC duplicate sample results for 6/9/15 was 10.5% and duplicate sample concentrations close to 5 times the method detection limit. This level of difference was considered acceptable, and DOC data for this date are not qualified.

The RPD for duplicate total coliform bacteria samples did not meet the +/-40% criteria for study precision on 2 dates:

- 10/14/14 with sample results of 5 and 2 cfu/100 ml.
- 4/12/16 with sample results of 120 and 39 cfu/100 ml.

Although these RPDs did not meet the acceptance criteria, the 10/14/14 results are below 20 cfu/100 ml that typically indicate high variability (Mathieu, 2006). Although the 4/12/16 results are above the 20 cfu/100 ml threshold for especially high variability, Mathieu (2006) indicates that such variability in only 2 replicates may be acceptable. Therefore data for these dates are not qualified.

Table C-5. Field quality assurance results.

Date	Constituent	Field Duplicate Results					Blank	
		mg/L		mg/L		RPD +/- 10%	mg/L	
10/14/2014	Alkalinity	228		229		0.44	5.0	U
2/10/2015		41.3		39.1		5.47	5.0	U
6/9/2015		74		74		1.08	5.0	U
11/18/2015		237		238		0.42	5.0	U
2/9/2016		145		143		1.39	5.0	U
10/14/2014	Ammonium-N	0.893		0.920		2.98	0.010	U
12/9/2014		4.30		4.45		3.43	0.010	U
2/10/2015		0.081		0.080		1.24	0.010	U
4/22/2015		0.082		0.080		2.47	0.013	
6/9/2015		0.010	U	0.010	U	NA	0.010	U
8/12/2015		0.559		0.563		0.71	0.010	U
11/17/2015		1.17		1.13		3.48	0.010	U
2/9/2016		0.435		0.447		2.72	0.010	U
4/12/2016		0.010	U	0.010	U	NA	0.010	U
10/14/2014	Nitrite+Nitrate-N	0.010	U	0.010	U	NA	0.010	U
12/9/2014		0.014		0.010	U	33.3	0.010	U
2/10/2015		0.014		0.012		15.4	0.010	U
4/22/2015		0.010	U	0.010	U	NA	0.010	U
6/9/2015		0.448		0.355		23.2	0.010	U
8/12/2015		0.039		0.037		5.26	0.010	U
11/17/2015		0.010	U	0.010	U	NA	0.010	U
2/9/2016		0.028		0.033		16.4	0.010	U
4/12/2016		0.010	U	0.010	U	NA	0.010	U
10/14/2014	Total Persulfate N	0.981		1.02		3.90	0.025	U
12/9/2014		5.30		5.32		0.38	0.025	U
2/10/2015		0.281		0.270		3.99	0.025	U
4/22/2015		0.354		0.377		6.29	0.057	
6/9/2015		0.733		0.612		18.0	0.031	
8/12/2015		0.827		0.831		0.48	0.056	
11/17/2015		1.23		1.21		1.64	0.032	
2/9/2016		0.684		0.718		4.85	0.025	U
4/12/2016		0.273		0.258		5.65	0.025	U
12/9/2014	Ortho-P	4.25		4.30		1.17	0.0030	U
2/10/2015		0.0126		0.0123		2.41	0.0030	U
12/9/2014	Total P	4.04		4.02		0.50	0.0050	U
2/10/2015		0.0129		0.0133		3.05	0.0050	U

Table C-5 is continued on the next 2 pages.

Date	Constituent	Field Duplicate Results					Blank	
		mg/L		mg/L		RPD +/- 10%	mg/L	
10/14/2014	Chloride	176		175		0.57	0.77	
12/9/2014		1470		1490		1.35	0.10	U
2/10/2015		1.31		1.37		4.48	0.10	U
4/22/2015		1.68		1.76		4.65	0.10	U
6/9/2015		3.58		3.62		1.11	0.10	U
8/12/2015		6.90		6.96		0.87	0.10	U
11/17/2015		196		198		1.02	0.10	U
2/9/2016		25.4		25.4		0.00	0.10	U
4/12/2016		6.58		6.76		2.70	0.10	U
10/14/2014	Bromide	0.77		0.78		1.29	0.20	U
12/9/2014		5.71		5.59		2.12	0.20	U
2/10/2015		0.20	U	0.20	U	NA	0.20	U
4/22/2015		0.20	U	0.20	U	NA	0.20	U
6/9/2015		0.20	U	0.20	U	NA	0.20	U
11/17/2015		0.78		0.78		0.00	0.20	U
2/9/2016		0.23		0.23		0.00	0.03	U
10/14/2014	Total Dissolved Solids	551		550		0.18	6	U
2/10/2015		107		105		1.89	6	U
6/9/2015		123		131		6.30	6	U
11/18/2015		610		617		1.14	8	
2/9/2016		252		250		0.80	19	U
2/10/2015	Calcium	12.6		12.7		0.79	0.050	U
2/10/2015	Magnesium	2.09		2.07		0.96	0.050	U
2/10/2015	Potassium	4.38		4.36		0.46	0.050	U
2/10/2015	Sodium	4.31		4.26		1.17	0.281	
2/10/2015	Sulfate	10.6		10.8		1.87	0.30	U
6/9/2015		5.10		5.13		0.59	0.30	U
10/14/2014	Iron	2.42		2.36		2.51	0.050	U
2/10/2015		2.09		1.97		5.91	0.050	U
6/9/2015		0.050	U	0.050	U	NA	0.050	U
10/14/2014	Dissolved Organic Carbon	6.8		6.7		1.48	1.0	U
2/10/2015		4.3		4.2		2.35	1.0	U
6/9/2015		4.5		5.0		10.5	1.0	U
11/18/2015		7.0		6.7		4.4	1.0	U
2/9/2016		6.5		6.1		6.3	1.0	U

Date	Constituent	Field Duplicate Results					Blank	
		mg/L		mg/L		RPD +/- 10%	mg/L	
10/14/2014	Fecal coliform bacteria (cfu/100 ml)	1	U	1	U	NA	1	U
12/9/2014		1	U	1	U	NA	1	U
2/10/2015		1	U	1	U	NA	1	U
4/22/2015		1	U	1	U	NA	1	U
6/9/2015		1	UJ	1	UJ	NA	1	U
8/12/2015		1	U	1	U	NA	1	U
11/17/2015		1	U	1	U	NA	1	U
2/9/2016		1	U	1	U	NA	1	U
4/12/2016		1	U	1	U	NA	1	U
10/14/2014	Total coliform bacteria (cfu/100 ml)	5		2		86	1	U
12/9/2014		1	U	1	U	NA	1	UJ
2/10/2015		1	U	1	U	NA	1	U
4/22/2015		1	U	1	U	NA	1	U
6/9/2015		1	UJ	1	UJ	NA	1	U
8/12/2015		1	U	1	U	NA	1	U
11/17/2015		1	U	1	U	NA	1	U
2/9/2016		510		550		7.5	1	U
4/12/2016		120		39		102	110	

Highlighted values did not meet measurement quality objectives (MQOs).

Appendix D. Particle size distributions and soil classifications for split-spoon soil samples.

Well Tag ID	Depth (feet BGS[1])	Soil Class[2]	Description	% Sand & Gravel[3]	% Silt[3]	% Clay[3]	Soil texture[4]	D_{10} (mm)[5]	D_{60} (mm)[6]	D_{30} (mm)[7]	D_{10} (mm)	C_u[8]	C_c[9]
AKY469	2.5	Silt or clay (>50% passing 75 um)		39	42	17	Sandy silt	0.0009	0.072	0.014	0.0009	80	3.0
AKY469	5.0	Can be classified as sand		88	4.1	8.0	Silty sand	0.011	0.420	0.300	0.011	38	19
AKY469	7.5	Can be classified as sand	Coarser below 2.5'	81	10	9.4	Silty sand	0.004	0.340	0.190	0.004	85	27
AKY469	10.0	Can be classified as sand		79	15	6.4	Silty sand	0.032	0.370	0.210	0.032	12	4
AKY472	2.5	Can be classified as sand	Coarser at top than	68	17	15	Silty sand	0.0025	0.240	0.040	0.003	96	3
AKY472	5.0	Can be classified as sand	deeper	78	13	8.5	Silty sand	0.007	0.380	0.200	0.007	54	15
AKY472	7.5	Silt or clay (>50% passing 75 um)		24	60	16	Silt with sand	0.0015	0.49	0.016	0.002	327	0.3
AKY472	10.0	Silt or clay (>50% passing 75 um)		13	64	23	Silt						
AKY472	12.5	Silt or clay (>50% passing 75 um)		15	59	26	Silt/Clay						
AKY472	15.0	Silt or clay (>50% passing 75 um)		18	59	23	Silt/Clay						
AKY472	17.5	Silt or clay (>50% passing 75 um)		15	53	32	Silt/Clay						
AKY472	20.0	Silt or clay (>50% passing 75 um)		18	54	28	Silt/Clay						
AHT085	2.5	Silt or clay (>50% passing 75 um)	Coarser at 5' than	28	62	10	Silt with sand	0.0045	0.05	0.025	0.0045	11	2.8
AHT085	5.0	Can be classified as sand	deeper	83	9.0	8.0	Sand with silt	0.007	0.51	0.200	0.007	73	11
AHT085	7.5	Silt or clay (>50% passing 75 um)		27	58	15	Silt	0.0019	0.51	0.029	0.0019	268	0.9
AHT085	10.0	Silt or clay (>50% passing 75 um)		15	65	20	Silt						
AHT086	2.5	Can be classified as sand	Coarser at top than	84	9.0	7.0	Sand with silt	0.017	0.48	0.270	0.017	28	9
AHT086	5.0	Silt or clay (>50% passing 75 um)	deeper	16	67	17	Silt	0.001	0.045	0.016	0.001	45	5.7
AHT086	7.5	Silt or clay (>50% passing 75 um)		28	51	21	Silt	0.0009	0.05	0.014	0.0009	56	4.4
AHT086	10.0	Silt or clay (>50% passing 75 um)		37	48	15	Silt						
AHT087	2.5	Silt or clay (>50% passing 75 um)	Homogeneous	23	59	18	Silt	0.0018	0.490	0.013	0.0018	272	0.2
AHT087	5.0	Silt or clay (>50% passing 75 um)	over depth	19	68	13	Silt	0.002	0.039	0.015	0.002	20	2.9
AHT087	7.5	Silt or clay (>50% passing 75 um)		24	56	20	Silt						
AHT087	10.0	Silt or clay (>50% passing 75 um)		21	54	25	Silt						
AHT088	2.5	Silt or clay (>50% passing 75 um)	Fairly homogenous	19	54	27	Silt	0.001	0.039	0.006	0.001	39	1.0
AHT088	5.0	Silt or clay (>50% passing 75 um)	over depth, coarser	16	57	27	Silt	0.0009	0.027	0.006	0.0009	30	1.4
AHT088	7.5	Silt or clay (>50% passing 75 um)	at 10'	18	65	17	Silt	0.002	0.039	0.011	0.002	20	1.6
AHT088	10.0	Silt or clay (>50% passing 75 um)		46	40	14	Silt	0.0028	0.130	0.022	0.0028	46	1.3
AHT089	2.5	Can be classified as sand	Coarser at top 2.5'	62	30	8.0	Silty sand	0.008	0.170	0.045	0.008	21.3	1.5
AHT089	5.0	Silt or clay (>50% passing 75 um)	than deeper	10	72	18	Silt	0.002	0.037	0.013	0.002	18.5	2.3
AHT089	7.5	Silt or clay (>50% passing 75 um)		16	58	26	Silt						
AHT089	10.0	Silt or clay (>50% passing 75 um)		16	63.0	21	Silt						

Well Tag ID	Depth (feet BGS[1])	Soil Class[2]	Description	% Sand & Gravel[3]	% Silt[3]	% Clay[3]	Soil texture[4]	D_{10} (mm)[5]	D_{60} (mm)[6]	D_{30} (mm)[7]	D_{10} (mm)	C_u[8]	C_c[9]
AHT090	2.5	Can be classified as sand		77	10	13	Sand with silt	0.003	0.230	0.150	0.003	77	33
AHT090	5.0	Can be classified as sand		84	7	9.0	Sand with silt	0.004	0.460	0.270	0.004	115	40
AHT090	7.5	Can be classified as sand		86	11	3.0	SW-SM-Well graded sand w/ silt	0.046	0.550	0.270	0.046	12	3
AHT090	10.0	Can be classified as sand		92	2.0	6.0	SP-SM-Poorly graded sand w/ silt	0.180	0.620	0.390	0.18	3	1

Shaded areas indicate silty sands.

[1]: Below ground surface

[2]: Plasticity index and liquid limit were not determined, therefore silt and clay could not be distinguished.

[3]: From grain size distribution curves in Table A-2.

[4]: Based on ASTM D2487-92 (Classification of Soils for Engineering Purposes (Unified Soil Classification System)) and ASTM D 2488-90 (Standard Practice for Description of Soils (Visual-Manual Procedure) and grain size curves (Table A-2).

[5]: Effective grain size: Particle size diameter through which 10% of sample particles pass on cumulative particle size distribution curve.

[6]: Particle size diameter through which 60% of sample particles pass on cumulative particle size distribution curve.

[7]: Particle size diameter through which 30% of sample particles pass on cumulative particle size distribution curve.

[8]: C_u: D_{60}/D_{10} (Coefficient of Uniformity--if 1-3, then well graded, greater than 3 poorly graded))

[9]: C_C: $(D_{30})^2/(D_{10} \times D_{60})$ (Coefficient of curvature measures the shape of the particle size curve indicating gradation--if less than 5 very uniform; if greater than 5 non-uniform)

Appendix E. Water quality results.

Table E-1. Edison Wastewater Treatment System (WWTS) effluent water quality results.

Sample date	Parameter	Result	Units
4/22/2015	Specific Conductivity (at 25 deg C)	963	umhos/cm
8/12/2015	Specific Conductivity (at 25 deg C)	977	umhos/cm
11/18/2015	Specific Conductivity (at 25 deg C)	754	umhos/cm
10/15/2014	Alkalinity as Bicarbonate	66.7	mg/L
2/11/2015	Alkalinity as Bicarbonate	251	mg/L
6/8/2015	Alkalinity as Bicarbonate	42.1	mg/L
11/18/2015	Alkalinity as Bicarbonate	50.2	mg/L
2/10/2016	Alkalinity as Bicarbonate	40.3	mg/L
10/15/2014	Ammonium--N	0.520	mg/L
12/10/2014	Ammonium--N	0.378	mg/L
2/11/2015	Ammonium--N	10.9	mg/L
4/22/2015	Ammonium--N	0.128	mg/L
6/8/2015	Ammonium--N	0.680	mg/L
8/12/2015	Ammonium--N	0.274	mg/L
11/18/2015	Ammonium--N	0.099	mg/L
2/10/2016	Ammonium--N	0.116	mg/L
4/12/2016	Ammonium--N	0.190	mg/L
10/15/2014	Nitrate-Nitrite as N	49.5	mg/L
12/10/2014	Nitrate-Nitrite as N	48.2	mg/L
2/11/2015	Nitrate-Nitrite as N	34.3	mg/L
4/22/2015	Nitrate-Nitrite as N	63.8	mg/L
6/8/2015	Nitrate-Nitrite as N	61.5	mg/L
8/12/2015	Nitrate-Nitrite as N	63.6	mg/L
11/18/2015	Nitrate-Nitrite as N	31.4	mg/L
2/10/2016	Nitrate-Nitrite as N	62.4	mg/L
4/12/2016	Nitrate-Nitrite as N	57.0	mg/L
10/15/2014	Total Persulfate Nitrogen	51.1	mg/L
12/10/2014	Total Persulfate Nitrogen	49.6	mg/L
2/11/2015	Total Persulfate Nitrogen	49.2	mg/L
4/22/2015	Total Persulfate Nitrogen	65	mg/L
6/8/2015	Total Persulfate Nitrogen	63.2	mg/L
8/12/2015	Total Persulfate Nitrogen	65.9	mg/L
11/18/2015	Total Persulfate Nitrogen	30.3	mg/L
2/10/2016	Total Persulfate Nitrogen	61.2	mg/L
4/12/2016	Total Persulfate Nitrogen	60.8	mg/L
12/10/2014	Total Phosphorus	6.71	mg/L
2/11/2015	Total Phosphorus	7.66	mg/L
2/11/2015	Orthophosphate	7.12	mg/L

Sample date	Parameter	Result		Units
10/15/2014	Chloride	61.5		mg/L
12/10/2014	Chloride	117		mg/L
2/11/2015	Chloride	62.4		mg/L
4/22/2015	Chloride	79.3		mg/L
6/8/2015	Chloride	74.2		mg/L
8/12/2015	Chloride	65.3		mg/L
11/18/2015	Chloride	86.4		mg/L
2/10/2016	Chloride	82.5		mg/L
4/12/2016	Chloride	71.8		mg/L
10/15/2014	Bromide	0.2	U	mg/L
12/10/2014	Bromide	0.25		mg/L
2/11/2015	Bromide	0.2	U	mg/L
4/22/2015	Bromide	0.2	U	mg/L
6/8/2015	Bromide	0.2	U	mg/L
11/18/2015	Bromide	0.24		mg/L
2/10/2016	Bromide	0.13		mg/L
10/15/2014	Total Dissolved Solids	593		mg/L
2/11/2015	Total Dissolved Solids	513		mg/L
6/8/2015	Total Dissolved Solids	666		mg/L
8/12/2015	Total Dissolved Solids	680		mg/L
11/18/2015	Total Dissolved Solids	482		mg/L
2/11/2015	Calcium	25.0	J	mg/L
10/15/2014	Iron	0.082		mg/L
2/11/2015	Iron	0.210		mg/L
6/8/2015	Iron	0.137		mg/L
2/11/2015	Magnesium	18.8		mg/L
2/11/2015	Potassium	24.0		mg/L
2/11/2015	Sodium	74.1		mg/L
2/11/2015	Sulfate	28.5		mg/L
6/8/2015	Sulfate	37.3		mg/L
2/11/2015	Dissolved Organic Carbon	16.8		mg/L
6/8/2015	Dissolved Organic Carbon	12.0	J	mg/L
10/15/2014	Total Organic Carbon	7.5		mg/L
11/18/2015	Total Organic Carbon	10.7		mg/L
2/10/2016	Total Organic Carbon	8.8		mg/L
10/14/2014	Total Coliform	1	UJ	cfu/100 mL
12/10/2014	Total Coliform	560	J	cfu/100 mL
2/11/2015	Total Coliform	3	U	cfu/100 mL
4/22/2015	Total Coliform	1	UJ	cfu/100 mL
6/8/2015	Total Coliform	1	UJ	cfu/100 mL
8/12/2015	Total Coliform	23	J	cfu/100 mL
11/17/2015	Total Coliform	6	J	cfu/100 mL
2/10/2016	Total Coliform	20		cfu/100 mL
4/12/2016	Total Coliform	39	J	cfu/100 mL

Sample date	Parameter	Result		Units
10/15/2014	Fecal Coliform	1	U	cfu/100 mL
12/10/2014	Fecal Coliform	180		cfu/100 mL
2/11/2015	Fecal Coliform	3400	J	cfu/100 mL
4/22/2015	Fecal Coliform	1	UJ	cfu/100 mL
6/8/2015	Fecal Coliform	1	UJ	cfu/100 mL
8/12/2015	Fecal Coliform	36	J	cfu/100 mL
11/18/2015	Fecal Coliform	16	J	cfu/100 mL
2/10/2016	Fecal Coliform	1	U	cfu/100 mL
4/12/2016	Fecal Coliform	1	U	cfu/100 mL

U: The analyte was detected at or above the reported result.
J: The analyte was positively identified; the associated value is the approximate concentration in the sample

Table E-2. Groundwater quality results.

Well tag ID	Sample Date	Temperature (C°)	pH (S.U.)	Spec. cond. (umhos/cm)	DO (mg/L)	Alkalinity (mg/L)	Ammonium-N (mg/L)		Nitrite+ nitrate-N (mg/L)		Total Persulfate N (mg/L)	Ortho-P (mg/L)	Total P (mg/L)	Chloride (mg/L)	Bromide (mg/L)[1]		TDS (mg/L)	Calcium (mg/L)	Iron (mg/L)		Magnesium (mg/L)	Potassium (mg/L)	Sodium (mg/L)	Sulfate (mg/L)	DOC (mg/L)	FC (#/100 ml)		TC (#/100 ml)	
AHT085	10/15/2014	13.6	6.46	196	0.73	84.3	0.570		0.029		0.648			5.51	0.20	U	151		6.41						8.5	1	U	1	U
AHT085	12/9/2014	11.7	6.13	151	0.00		0.425		0.041		0.621	0.078	0.129	3.85	0.20	U										1	U	1	U
AHT085	2/10/2015	9.41	6.21	123	2.76	54.3	0.318		0.125		0.659	0.088	0.077	2.78	0.20	U	105	9.07 J	0.144		2.27	3.23	11.8	2.52	7.3	8	U	3	J
AHT085	4/22/2015	10.6	5.77	110	3.40		0.032		0.292		0.648			3.75												1	U	1	U
AHT085	6/9/2015	12.3	5.79	143	0.00	55.9	0.140		0.172	J	0.621			5.18	0.20	U	104		0.116					2.88	6.5 J	1	U	1	U
AHT085	8/12/2015	14.5	6.47	165	1.31		0.559		0.039		0.827			6.9												1	U	1	U
AHT085	11/18/2015	12.1	6.33	153	0.46	57.0	0.269		0.065		0.703			3.83	0.20	U	144								7.0	1	U	1	U
AHT085	2/10/2016	8.93		96.1		41.2	0.066		0.101		0.593			2.54	0.04		90								8.2	3		240	
AHT085	4/12/2016	10.0	5.97	93.1			0.010	U	0.118		0.450			2.09												1	U	65	J
AHT086	10/14/2014	13.7	6.60	3,163	0.64	505	9.91		0.010	U	10.1			2,450	9.72		4,520		1.19						22.8	1		1	U
AHT086	12/9/2014	12.0	6.53	2,995	0.48		5.74		0.026		6.19	1.00	1.42	1,590	6.02											1	U	1	U
AHT086	2/10/2015	9.76	6.61	3,566	0.00	312	4.50		0.016		5.27	1.15	1.20	923	3.62		2,200	19.8 J	2.96		48.8	27.3	780	33.6	28.3	1	U	3	J
AHT086	4/22/2015	10.8	6.58	3,662	0.00		3.83		0.070		4.80			1,110	4.05											1	UJ	1	UJ
AHT086	6/9/2015	12.8	6.34	4,460	0.00	454	4.84		0.065	J	5.27			1,770	6.79		3,070							4.85	36.2 J	1	U	1	U
AHT086	8/12/2015	15.6	7.12	5,633	0.00		6.72		0.025		7.37			1,900												1	UJ	1	UJ
AHT086	11/17/2015	12.7	6.76	6,886		511	7.16		0.019		6.90			2,160	7.9		4,210								29.1	1	U	1	U
AHT086	2/10/2016	9.57		5,754		382	3.73		0.045		4.13			1,220	4.48		2,090								29.3	1	U	860	
AHT086	4/13/2016	10.3	6.54	4,356			3.73		0.139		4.72			1,080												1	U	1600	J
AHT087	10/15/2014	14.0	6.47	5,403	0.51	405	4.80		0.021		5.86			1,540	6.02		3,030		1.40						43.3	1	U	1	U
AHT087	12/9/2014	12.3	6.62	4,970	0.43		4.30		0.014		5.30	4.25	4.04	1,470	5.71											1	U	1	U
AHT087	2/10/2015	10.2	6.52	5,335	0.00	407	4.46		0.019		5.70	4.82	4.79	1,510	5.84		3,050	30.6 J	6.90		70.9	26.5	930	6.49	44.2	1	U	1	U
AHT087	4/22/2015	10.7	6.55	5,273	0.00		3.64		0.012		4.68			1,430	5.22											1	U	1	U
AHT087	6/9/2015	13.0	6.30	5,286	0.00	417	4.32		0.035	J	5.02			1,500	5.78		3,070		6.91					2.00	47.6 J	1	U	1	U
AHT087	8/12/2015	14.9	7.06	5,390	0.00		4.90		0.026		5.96			1,500												1	U	1	U
AHT087	11/17/2015	12.3	6.77	5,351		428	5.34		0.021		6.11			1,630	5.97		3,220									1	UJ	1	UJ
AHT087	2/10/2016	10.2		5,187		418	3.59		0.014		4.84			1,480	5.74		2,990								42.4	1	U	290	
AHT087	4/13/2016	10.2	6.43	5,294			4.06		0.052		5.50			1,460											41.4	1	U	5	J
AHT088	10/15/2014	13.6	6.88	2,511	0.82	309	3.41		0.011		4.35			745	3.12		1,490		3.33						36.9	40	J	1	UJ
AHT088	12/9/2014	12.6	6.69	2,299	0.00		2.65		0.011		3.57	4.91	4.13	569	2.36											1	U	1	U
AHT088	2/11/2015	10.3	6.45	1,433	0.00	263	2.00		0.015		2.97	4.06	4.79	346	1.58		984	9.29 J	3.31		14.3	11.1	322	14.0	26.8	1	UJ	1	UJ
AHT088	4/22/2015	11.2	6.48	1,490	0.00		1.97		0.010	U	2.84			364	1.58											1	U	1	U
AHT088	6/9/2015	12.7	7.29	1,297	0.00	265	1.73		0.098	J	2.54			355	1.60		1,020		4.50					11.8	29.9 J	1	U	1	U
AHT088	8/12/2015	14.1	6.69	1,830	0.14		2.46		0.018		3.24			500												1	U	1	U
AHT088	11/17/2015	12.7	6.87	2,346	0.34	325	2.82		0.019		3.78			589	2.39		1,420								35.5	1	U	1	U
AHT088	2/10/2016	10.5		1,370		277	2.06		0.012		2.77			367	1.69		1,100								33.6	1	U	16	
AHT088	4/12/2016	10.5	6.69	1,886			2.21		0.040		3.11			460												1	U	160	J
AHT089	10/14/2014	12.8	6.55	697	3.89	274	5.80		0.010	U	6.70			61.0	0.52		439		2.99						17.3	1	UJ	1	UJ
AHT089	12/9/2014	13.6	6.45	760	0.75		5.68		0.026		6.20	0.477	0.901	54.5	0.48											1	U	1	UJ
AHT089	2/10/2015	11.4	6.43	633	0.00	247	5.53		0.025		5.85	0.492	1.24	51.9	0.45		410	20.4 J	6.51		33.4	10.4	49.5	5.89	13.5	1	UJ	1	J
AHT089	4/22/2015	11.0	6.64	656	0.31		5.34		0.022		5.68			49.8												1	UJ	1	UJ
AHT089	6/9/2015	12.5	6.17	677	0.00	274	5.68		0.041	J	6.29			54.6	0.44		418		12.1					0.55	16.3 J	1	UJ	1	UJ
AHT089	8/12/2015	13.2	7.24	718	0.64		6.07		0.025		6.69			53.5												1	UJ	1	UJ

Well tag ID	Sample Date	Temper-ature (C°)	pH (S.U.)	Spec. cond. (umhos/cm)	DO (mg/L)	Alka-linity (mg/L)	Ammo-nium-N (mg/L)		Nitrite+ nitrate-N (mg/L)		Total Persulfate N (mg/L)	Ortho-P (mg/L)	Total P (mg/L)	Chloride (mg/L)	Bromide (mg/L)[1]		TDS (mg/L)	Calcium (mg/L)	Iron (mg/L)		Magne-sium (mg/L)	Potas-sium (mg/L)	Sodium (mg/L)	Sulfate (mg/L)	DOC (mg/L)	FC (#/100 ml)		TC (#/100 ml)	
AHT089	11/17/2015	12.8		718		292	6.21		0.031		6.87			60.7	0.52		458								20.2	1	U	1	U
AHT089	2/10/2016	11.1		673		278	5.56		0.018		6.18			59.4	0.49		408								15.2	1	UJ	230	J
AHT089	4/12/2016	11.2	6.44	667			5.26		0.055		6.26			51.3												1	U	540	J
AHT090	10/15/2014	13.4	6.29	153	0.86	64.5	0.092		0.015		0.370			1.62	0.20	U	140		5.97						8.0	1	U	1	U
AHT090	12/10/2014	11.7	5.83	129	0.45		0.102		0.015		0.350	0.0098	0.0138	0.81	0.20	U										1	U	3	
AHT090	2/10/2015	9.63	5.92	118	0.00	41.3	0.081		0.014		0.281	0.0126	0.0129	1.31	0.20	U	107	12.6 J	2.09		2.09	4.38	4.31	10.6	4.3	1	U	1	U
AHT090	4/22/2015	10.7	5.94	118	0.00		0.082		0.010	U	0.354			1.68	0.20	U										1	U	1	U
AHT090	6/9/2015	12.7	5.71	123	0.00	50.5	0.088		0.031	J	0.362			1.64	0.20	U	106							6.81	5.1 J	1	U	1	U
AHT090	8/12/2015	14.5	6.33	124	0.00		0.102		0.050		0.431			1.56												1	U	1	U
AHT090	11/18/2015	12.2	6.12	138	0.42	39.5	0.091		0.010	U	0.418			1.50	0.20	U	137								5.3	1	U	1	U
AHT090	2/10/2016	9.46		113		41.9	0.051		0.010	U	0.297			1.68	0.08		118								4.8	1	U	12	
AHT090	4/13/2016	10.0	5.74	115			0.078		0.024		0.364			2.08												1	J	15	J
AKY469	10/15/2014	14.3	6.32	172	0.61	75.8	0.084		0.010		0.335			1.90	0.20	U	158		1.65						9.3	10		1	U
AKY469	12/10/2014	11.9	6.20	172	1.52		0.035		2.83		3.05	0.0105	0.0098	4.79	0.20	U										1	U	1	U
AKY469	2/10/2015	9.3	6.11	160	3.19	56.5	0.010	U	3.10		3.51	0.0089	0.0091	3.76	0.20	U	127	15.5 J	0.05	U	2.33	3.08	12.1	4.77	3.9	1	U	1	UJ
AKY469	4/22/2015	10.7	5.73	179	0.00		0.010	U	1.23		1.49			3.82	0.20	U										1	U	1	U
AKY469	6/9/2015	12.6	5.84	169	0.00	73.5	0.010	U	0.448	J	0.733			3.58	0.20	U	123		0.05	U				5.10	4.5 J	1	UJ	1	UJ
AKY469	8/12/2015	15.6	6.54	164	0.00		0.010	U	0.314		0.605			3.47												1	U	1	U
AKY469	11/18/2015	12.2	6.41	160	0.83	68.4	0.010	U	0.361		0.631			3.13	0.20	U	140								4.9	1	U	1	U
AKY469	2/10/2016	8.5		140		49.7	0.010	U	0.023		0.290			12.2	0.11		108								4.7	640		840	
AKY469	4/12/2016	10.1	6.02	132			0.010	U	0.010	U	0.273			6.58												1	U	120	J
AKY470	10/14/2014	14.5	6.17	866	0.70	194	2.64		0.035		3.28			123	0.75		601		14.9						41.8	1	U	1	U
AKY470	12/10/2014	11.1	6.17	936	0.00		3.59		0.048		5.09	0.218	0.435	146	0.90											1	U	1	U
AKY470	2/11/2015	9.16	6.20	950	0.00	341	3.48		0.053		3.62	0.120	0.404	156	0.92		618	22.2 J	20.8		20.7	9.74	116	18.6	38.2	1	U	11	
AKY470	4/22/2015	10.7	5.92	1034	0.00		2.95		0.028		4.20			185	0.96											1	U	1	U
AKY470	6/9/2015	12.7	6.01	959	0.00	213	2.87		0.121	J	4.32			156	0.93		622		24.3					15.1	38.0 J	1	U	1	U
AKY470	8/12/2015	15.1	6.62	816	0.03		2.11		0.028		3.56			112												1	U	1	U
AKY470	11/18/2015	11.6	6.45	805	0.36	206	1.96		0.018		3.17			113	0.71		546								35.3	1	U	1	U
AKY470	2/10/2016	8.3		1021		210	2.36		0.031		3.63			167	1.06		632								31.6	1	U	43	
AKY470	4/12/2016	9.8	6.06	1293			2.82		0.067		3.92			257												1	U	16	J
AKY472	10/15/2014	14.9	6.69	427	0.00	150	1.31		0.023		1.34			30.8	0.29		254		8.74						8.3	1	U	20	
AKY472	12/10/2014	11.7	6.26	324	0.00		0.636		0.038		0.677	0.0706	0.889	25.1	0.20											1	U	1	UJ
AKY472	2/11/2015	9.6	6.33	366	0.00	134	0.502		0.031		0.526	0.0514	0.674	30.8	0.25		242	26.4 J	7.65		8.54	10.6	26.0	4.06	6.3	1	U	1	UJ
AKY472	4/22/2015	11.0	6.01	332	0.00		0.730		0.014		0.826			22.1	0.20											1	U	1	U
AKY472	6/9/2015	13.2	6.07	397	0.51	132	0.967		0.052	J	1.01			32.0	0.25		237		7.65					3.70	8.1 J	1	UJ	1	UJ
AKY472	8/12/2015	16.3	6.76	400	0.00		1.17		0.020		1.31			32.3												1	U	1	U
AKY472	11/18/2015																												
AKY472	2/9/2016	9.4		382		145	0.435		0.028		0.684			25.4	0.23		252								6.5	1	U	510	
AKY472	4/12/2016	10.4	6.09	320			0.503		0.038		0.585			13.0												1	U	1400	J
BIP686	10/14/2014	13.4	6.71	989	0.70	228	0.893		0.010	U	0.981			176	0.77		551		2.42						6.8	1	U	5	
BIP686	12/9/2014	12.5	6.84	758	0.0		0.932		0.010	U	0.916	0.821	0.885	172	0.72											1	UJ	1	UJ
BIP686	2/9/2015	11.5	6.87	838	0.0	395	0.875		0.010	U	0.990	0.797	0.853	132	0.61		496	17.2 J	1.87		30.9	9.72	97.8	2.25	6.2	1	UJ	1	UJ
BIP686	4/22/2015	11.9	6.80	795	0.81		0.754		0.023		0.736			124												1	UJ	1	UJ

Well tag ID	Sample Date	Temper-ature (C°)	pH (S.U.)	Spec. cond. (umhos/cm)	DO (mg/L)	Alka-linity (mg/L)	Ammo-nium-N (mg/L)		Nitrite+ nitrate-N (mg/L)		Total Persulfate N (mg/L)	Ortho-P (mg/L)	Total P (mg/L)	Chloride (mg/L)	Bromide (mg/L)[1]		TDS (mg/L)	Calcium (mg/L)	Iron (mg/L)		Magne-sium (mg/L)	Potas-sium (mg/L)	Sodium (mg/L)	Sulfate (mg/L)	DOC (mg/L)	FC (#/100 ml)		TC (#/100 ml)	
BIP686	6/9/2015	12.4	6.52	911	0.0	225	0.934		0.031	J	0.913			152	0.65		511		2.04					0.97	6.5 J	1	UJ	1	UJ
BIP686	8/12/2015	13.6	7.31	968	0.17		1.01		0.010	U	1.08			164												1	UJ	1	UJ
BIP686	11/17/2015	12.15	6.97	1,042		237	1.17		0.010	U	1.23			196	0.78		610								7.0	1	U	1	U
BIP686	2/9/2016	11.57		927		240	1.14		0.023		1.21			176	0.75		560								6.7	1	U	97	J
BIP686	4/12/2016	11.65	6.75	889			0.939		0.020		1.07			145												1	J	44	J
BIP689	10/15/2014					102	0.075		0.030		0.597			18.6	0.20	U	212								9.7	1	U	1	U
BIP689	12/9/2014						0.080		0.132		0.600	0.0656	0.728	19.2	0.21											1	U	7.0	J
BIP689	2/10/2015					205	0.078		0.205		0.735	0.281	0.703	9.98	0.20	U	200	12.5 J	6.84		12.9	8.58	21.1	19.2	10.5	1	U	1	U
BIP689	4/22/2015						0.066		0.019	J	0.546			16.6												1	U	1	U
BIP689	6/9/2015						0.099		0.037		0.531			26.8	0.24									10.6	10.1 J	1	U	1	U
BIP689	8/12/2015																									1	U	1	U
BIP689	11/17/2015					72.4	0.124		0.042		0.785			17.2	0.20	U	218								11.0	6	J	8	
BIP689	2/10/2016					76.0	0.144		0.022		0.610			19.8	0.17		228								8.9	1	U	3	
BIP689	4/13/2016						0.130		0.049		0.553			19.6												1	U	9	J

[1] The reporting limit was 0.2 mg/L for all samples except those collected in February 2016, when the reporting limit was 0.03 mg/L.
U: Analyte was not detected at or above the reported result.
J: Analyte was positively identified, and the reported result is an estimate.
B: Analyte was detected in the field blank.
Spec cond.: Specific conductivity
DO: Dissolved oxygen
DOC: Dissolved organic carbon
FC: Fecal coliform bacteria
TC: Total coliform bacteria

Table E-3. Fecal and total coliform bacteria results in groundwater.

Fecal coliform bacteria	AKY469	AKY472	AHT085	AHT086	AHT087	AHT088	AHT089	BIP686	AHT090	AKY470	BIP689
10/14/2014	**10**	1 U	1 U	**1**	1 U	**40 J**	1 UJ	1 U	1 U	1 U	1 U
12/8/2014	1 U	1 U	1 U	1 U	1 U	1 U	1 UJ	1 UJ	1 U	1 U	1 U
2/10/2015*	1 U	1 U	8 U	1 U	1 U	1 UJ	1 UJ	1 UJ	1 U	1 U	1 U
4/22/2015	1 U	1 U	1 U	1 UJ	1 U	1 U	1 UJ	1 UJ	1 U	1 U	1 U
6/9/2015	1 UJ	1 UJ	1 U	1 U	1 U	1 U	1 UJ	1 UJ	1 U	1 U	1 U
8/12/2015	1 U	1 U	1 U	1 UJ	1 U	1 U	1 UJ	1 UJ	1 U	1 U	1 U
11/18/2015	1 U	NA	1 U	1 U	1 UJ	1 U	1 U	1 U	1 U	1 U	**6**
2/9/2016	**640**	1 U	**3**	1 U	1 U	1 U	1 UJ	1 U	1 U	1 U	1 U
4/12/2016	1 U	1 U	1 U	1 U	1 U	1 U	1 U	**1 J**	**1 J**	1 U	1 U

Total coliform bacteria	AKY469	AKY472	AHT085	AHT086	AHT087	AHT088	AHT089	BIP686	AHT090	AKY470	BIP689
10/14/2014	1 U	**20**	1 U	1 U	1 U	1 UJ	1 UJ	**5**	1 U	1 U	1 U
12/8/2014	1 U	1 UJ	1 U	1 U	1 U	1 U	1 UJ	1 UJ	**3**	1 U	**7**
2/10/2015*	1 U	**1 J**	3 U	**3 J**	1 U	1 UJ	1 U	1 UJ	1 U	**11 J**	1 U
4/22/2015	1 U	1 U	1 U	1 UJ	1 U	1 U	1 UJ	1 UJ	1 U	1 U	1 U
6/9/2015	1 UJ	1 UJ	1 U	1 U	1 U	1 U	1 UJ	1 UJ	1 U	1 U	1 U
8/12/2015	1 U	1 U	1 U	1 UJ	1 U	1 U	1 UJ	1 UJ	1 U	1 U	1 U
11/18/2015	1 U	NA	1 U	1 U	1 UJ	1 U	1 U	1 U	1 U	1 U	**8**
2/9/2016	**840**	**510**	**240**	**860**	**290**	**16**	**230** J	**97** J	**12**	**43**	**3**
4/12/2016	**120** J	**1400** J	**65**	**1600** J	**5** J	**160** J	**540** J	**44** J	**15** J	**16** J	**9** J

*Wastewater treatment plant computer power outage February 7-11, 2015.
Bold: Organism was present in the sample.
U: Analyte was not detected at or above the reported result.
J: Analyte was positively identified, and the reported result is an estimate.

Appendix F. Summary statistics for groundwater data

(In mg/L unless otherwise specified)

AKY472			
Parameter	Average	Standard deviation	Number of samples
Temperature (C°)	12.0	2.5	8
pH (s.u.)	6.3	0.30	7
Conductivity (umhos/cm)	368	39.8	8
DO	0.09	0.21	6
Alkalinity	140	8.7	3
Ammonium-N	0.782	0.330	8
Nitrate-N	0.031	0.012	8
TPN	0.870	0.318	8
Ortho-P	0.061	0.014	2
Total P	0.782	0.152	2
Chloride	26.4	6.61	8
Bromide	0.24	0.03	6
TDS	246	8.10	4
Calcium	26.4	NA	1
Iron	7.94	0.70	3
Magnesium	8.54	NA	1
Potassium	10.6	NA	1
Sodium	26.0	NA	1
Sulfate	3.88	0.25	2
DOC	7.3	1.0	4

AKY470			
Parameter	Average	Standard deviatior	Number of samples
Temperature (C°)	11.4	2.3	9
pH (s.u.)	6.2	0.23	8
Conductivity (umhos/cm	964	148	9
DO	0.16	0.27	7
Alkalinity	233	60.9	5
Ammonium-N	2.75	0.559	9
Nitrate-N	0.048	0.031	9
TPN	3.87	0.598	9
Ortho-P	0.169	0.069	2
Total P	0.420	0.022	2
Chloride	157	44.9	9
Bromide	0.89	0.12	7
TDS	604	34.19	5
Calcium	22.2	NA	1
Iron	20.0	4.75	3
Magnesium	20.7	NA	1
Potassium	9.74	NA	1
Sodium	116	NA	1
Sulfate	16.9	2.47	2
DOC	37.0	3.8	5

AKY469 (mg/L)			
Parameter	Average	Standard deviation	Number of samples
Temperature (C°)	11.7	2.3	9
pH (s.u.)	6.1	0.28	8
Conductivity (umhos/cm)	161	15	9
DO	0.88	1.17	7
Alkalinity	65	11.3	5
Ammonium-N	0.02	0.03	9
Nitrate-N	0.925	1.22	9
TPN	1.21	1.23	9
Ortho-P	0.010	0.001	2
Total P	0.009	0.0005	2
Chloride	4.80	3.2	9
Bromide	NA[1]	NA[1]	7
TDS	131	18.8	5
Calcium	15.5	NA	1
Iron	0.583	0.92	3
Magnesium	2.33	NA	1
Potassium	3.08	NA	1
Sodium	12.1	NA	1
Sulfate	4.94	0.23	2
DOC	5.5	2.2	5

[1] No detections at 0.2 mg/L detection limit. One result 0.11 mg/L.

AHT090			
Parameter	Average	Standard deviation	Number of samples
Temperature (C°)	11.6	1.8	9
pH (s.u.)	6.0	0.24	8
Conductivity (umhos/cm)	126	13	9
DO	0.25	0.34	7
Alkalinity	48	10.4	5
Ammonium-N	0.085	0.02	9
Nitrate-N	0.020	0.01	9
TPN	0.36	0.05	9
Ortho-P	0.011	0.002	2
Total P	0.013	0.0006	2
Chloride	1.54	0.34	9
Bromide	NA[1]	NA[1]	7
TDS	122	16.2	5
Calcium	12.6	NA	1
Iron	4.03	2.74	2
Magnesium	2.09	NA	1
Potassium	4.38	NA	1
Sodium	4.31	NA	1
Sulfate	8.71	2.68	2
DOC	5.5	1.4	5

[1] No detections at 0.2 mg/L detection limit. One result 0.08 mg/L.

AHT085			
Parameter	Average	Standard deviation	Number of samples
Temperature (C°)	11.5	1.9	9
pH (s.u.)	6.1	0.28	8
Conductivity (umhos/cm)	137	34	9
DO	1.44	1.35	7
Alkalinity	59	15.7	5
Ammonium-N	0.265	0.22	9
Nitrate-N	0.265	0.22	9
TPN	0.641	0.10	9
Ortho-P	0.083	0.007	2
Total P	0.103	0.037	2
Chloride	4.05	1.56	9
Bromide	NA[1]	NA[1]	6
TDS	119	27.0	5
Calcium	9.07	NA	1
Iron	2.22	3.63	3
Magnesium	2.27	NA	1
Potassium	3.23	NA	1
Sodium	11.8	NA	1
Sulfate	2.70	0.25	2
DOC	7.5	0.8	5

[1] No detections at 0.2 mg/L detection limit. One result 0.04 mg/L.

AHT086			
Parameter	Average	Standard deviation	Number of samples
Temperature (C°)	11.9	2.0	9
pH (s.u.)	6.6	0.23	8
Conductivity (umhos/cm)	4497	1332	9
DO	0.19	0.29	6
Alkalinity	433	85.1	5
Ammonium-N	5.57	2.07	9
Nitrate-N	0.046	0.04	9
TPN	6.08	1.84	9
Ortho-P	1.08	0.106	2
Total P	1.31	0.156	2
Chloride	1578	532	9
Bromide	6.08	2.23	7
TDS	3218	1119	5
Calcium	19.8	NA	1
Iron	2.08	1.25	2
Magnesium	48.8	NA	1
Potassium	27.3	NA	1
Sodium	780	NA	1
Sulfate	19.2	20.3	2
DOC	29.1	4.76	5

[1] No detections at 0.2 mg/L detection limit. One result 0.04 mg/L.

For non-detections, one-half of the detection limit was used.

AHT087			
Parameter	Average	Standard deviation	Number of samples
Temperature (C°)	12.0	1.8	9
pH (s.u.)	6.6	0.23	8
Conductivity (umhos/cm)	5277	132	9
DO	0.16	0.24	6
Alkalinity	415	9.3	5
Ammonium-N	4.38	0.58	9
Nitrate-N	0.024	0.01	9
TPN	5.44	0.51	9
Ortho-P	4.54	0.403	2
Total P	4.42	0.530	2
Chloride	1502	57	9
Bromide	5.75	0.26	7
TDS	3072	88	5
Calcium	30.6	NA	1
Iron	5.07	3.18	3
Magnesium	70.9	NA	1
Potassium	26.5	NA	1
Sodium	930	NA	1
Sulfate	4.2	3.2	2
DOC	43.8	2.38	5

AHT088			
Parameter	Average	Standard deviation	Number of samples
Temperature (C°)	12.0	1.5	9
pH (s.u.)	6.8	0.27	8
Conductivity (umhos/cm)	1829	464	9
DO	0.19	0.32	7
Alkalinity	288	27.8	5
Ammonium-N	2.37	0.52	9
Nitrate-N	0.026	0.03	9
TPN	3.24	0.57	9
Ortho-P	4.49	0.601	2
Total P	4.46	0.467	2
Chloride	477	137	9
Bromide	2.05	0.60	7
TDS	1203	235	5
Calcium	9.29	NA	1
Iron	3.71	0.68	3
Magnesium	14.3	NA	1
Potassium	11.1	NA	1
Sodium	322	NA	1
Sulfate	12.9	1.6	2
DOC	32.5	4.15	5

AHT089			
Parameter	Average	Standard deviation	Number of samples
Temperature (C°)	12.2	1.0	9
pH (s.u.)	6.6	0.33	7
Conductivity (umhos/cm)	689	39	9
DO	0.93	1.48	6
Alkalinity	273	16.3	5
Ammonium-N	5.68	0.31	9
Nitrate-N	0.028	0.01	9
TPN	6.30	0.40	9
Ortho-P	0.48	0.011	2
Total P	1.07	0.240	2
Chloride	55.2	4.19	9
Bromide	0.48	0.03	6
TDS	427	21	5
Calcium	20.4	NA	1
Iron	7.20	4.59	3
Magnesium	33.4	NA	1
Potassium	10.4	NA	1
Sodium	49.5	NA	1
Sulfate	3.2	3.8	2
DOC	16.5	2.50	5