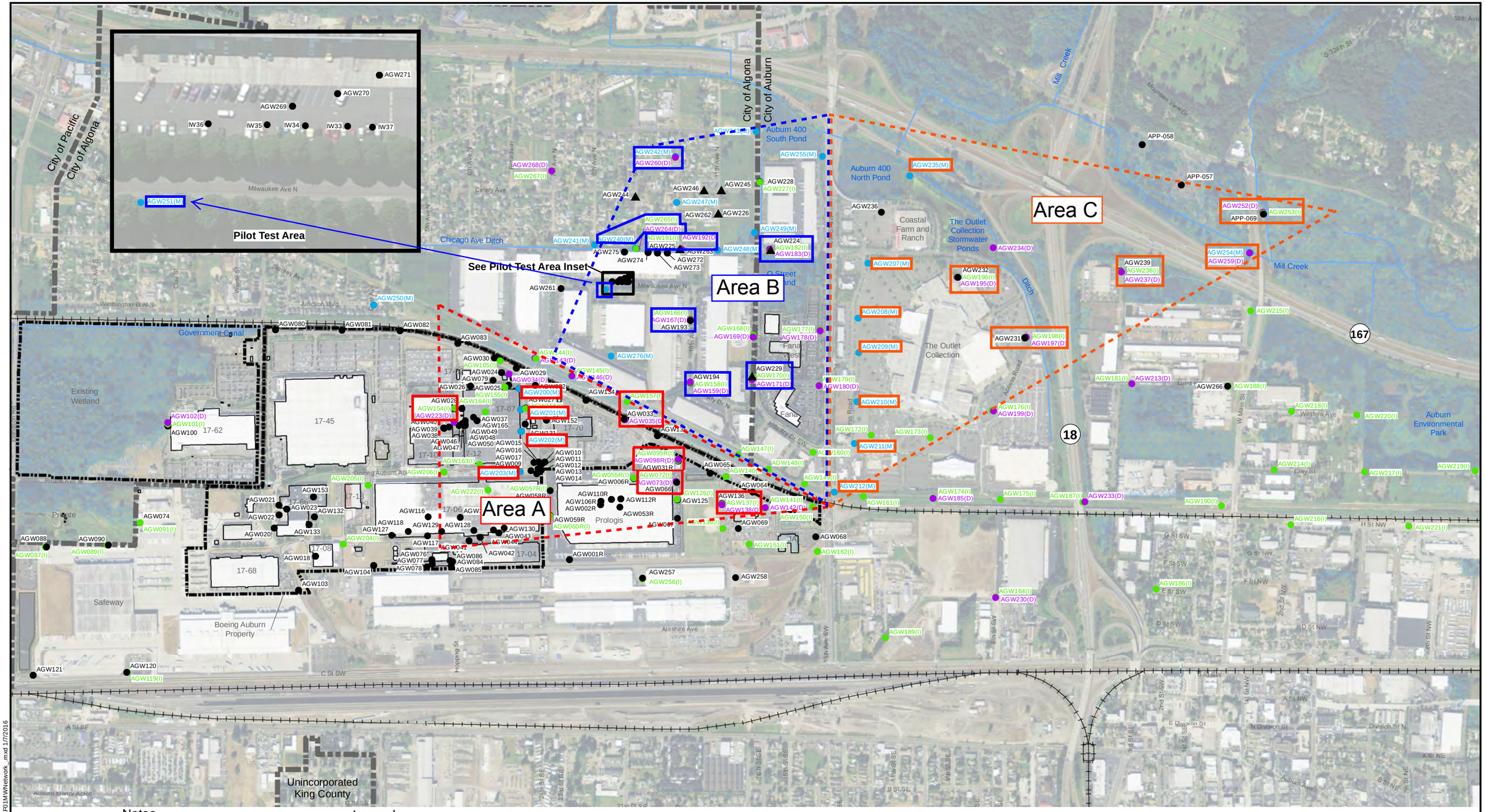
APPENDIX H

Hydraulic Gradient and Surface Water Capture Zones

Gradient Analysis



Notes

1. Well designations beginning with APP are installed and owned by WSDOT.
2. Black and white reproduction of this color original may reduce its effectiveness and lead to incorrect interpretation.

Legend

- Offsite Water Table Well
- Shallow Monitoring Well (2 to 30 ft BGS)
- (I) Intermediate Monitoring Well (40 to 60 ft BGS)
- (D) Deep Monitoring Well (80 to 100 ft BGS)
- (M) Multi-Level Well
- Wetland Areas
- Water Bodies
- Waterways
- Area A Boundary
- Area B Boundary
- Area C Boundary

N

0 1,000 2,000

Scale in Feet

Base map source: Geometrix 2003; Aerial Photo Source: ESRI World Imagery; Parcel Data Source: King County GIS 2012

LANDAU ASSOCIATES

Boeing Auburn Auburn, Washington	Gradient Analysis Zones	Figure H-1

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Table H-1a
Area A Wells and Water Levels Hydraulic Gradient Analysis
Boeing Auburn Remediation Investigation
Auburn, Washington

Location	Aquifer Zone	Easting	Northing	Summer Water Level Elevation (ft) (6/11-6/16)	Winter Water Level Elevation (ft) (12/29-12/31)
AGW028	Shallow	1290566	107171	73.58	76.06
AGW031R	Shallow	1291125.2843	109488.5969	71.89	75.23
AGW033	Shallow	1290674.68249	108908.97218	72.02	75.18
AGW066	Shallow	1291356	109473	71.87	75.32
AGW136	Shallow	1291582.62	109957.69	71.57	75.12
AGW200-2	Shallow	1290349.87	107787.09	73.11	75.71
AGW201-2	Shallow	1290577.53	107804.13	73.13	75.96
AGW202-2	Shallow	1290809.29	107806.38	73.14	76.19
AGW203-2	Shallow	1291238.36	107796.15	73.19	76.57
AGW154	Intermediate	1290560	107098	73.48	76.21
AGW157	Intermediate	1290493	108939.9	72.07	75.30
AGW095R	Intermediate	1291121.1689	109485.6766	71.68	75.25
AGW072	Intermediate	1291345	109463	71.86	75.30
AGW137	Intermediate	1291588.92	109957.69	71.58	75.13
AGW200-4	Intermediate	1290349.87	107787.09	73.00	75.84
AGW201-4	Intermediate	1290577.53	107804.13	73.03	76.08
AGW202-4	Intermediate	1290809.29	107806.38	73.05	76.23
AGW203-4	Intermediate	1291238.36	107796.15	73.12	76.49
AGW223	Deep	1290710.5	107086.5	73.71	76.37
AGW035	Deep	1290684	108916	72.07	75.62
AGW073	Deep	1291345	109463	71.83	75.31
AGW098R	Deep	1291112.7	109488.5	71.83	75.18
AGW138	Deep	1291595.5839	109958.2472	71.46	75.11
AGW200-6	Deep	1290349.87	107787.09	72.84	75.92
AGW201-6	Deep	1290577.53	107804.13	72.95	76.06
AGW202-6	Deep	1290809.29	107806.38	73.01	76.23
AGW203-6	Deep	1291238.36	107796.15	73.09	76.50

Table H-1b
Area B Wells and Water Levels Hydraulic Gradient Analysis
Boeing Auburn Remedial Investigation
Auburn, Washington

Location	Aquifer Zone	Easting	Northing	Summer Water Level Elevation (ft) (6/11-6/16)	Winter Water Level Elevation (ft) (12/29-12/31)
AGW194	Shallow	1290288	109617	71.40	74.40
AGW229	Shallow	1290211.5000	110281.7000	71.08	73.86
AGW193	Shallow	1289619.50000	109619.80000	70.74	73.00
AGW251-2	Shallow	1289287	108709	70.60	72.17
AGW225	Shallow	1288848.10	109507.70	69.00	70.15
AGW224	Shallow	1288858.20	110475.90	68.98	70.50
AGW240-3	Shallow	1288847.28	109028.68	69.40	70.48
AGW242-2	Shallow	1287860.95	109460.66	67.78	69.01
AGW158	Intermediate	1290284.00	109617.40	71.46	74.40
AGW170	Intermediate	1290219	110282	71.11	73.96
AGW166	Intermediate	1289600	109620.7	70.82	73.16
AGW251-4	Intermediate	1289286.7271	108708.6497	71.30	73.52
AGW191	Intermediate	1288848	109514	69.41	70.85
AGW265	Intermediate	1288848.18	109041.09	69.84	71.51
AGW182	Intermediate	1288855.9	110464.1	68.78	70.23
AGW242-5	Intermediate	1287860.946	109460.658	67.99	69.26
AGW159	Deep	1290278.30	109616.60	71.53	74.63
AGW171	Deep	1290255.90	110281.40	71.08	73.93
AGW183	Deep	1288856.3	110470.5	68.94	69.44
AGW192	Deep	1288848	109521	69.50	70.97
AGW264 (a)	Deep	1288848	109047	70.06	68.43
AGW183	Deep	1288856.3	110470.5	68.94	69.44
AGW260	Deep	1287868.2210	109460.2360	67.96	69.27
AGW167	Deep	1289612.43	109619.91	71.26	73.91

a. Well excluded from the analysis due to anomalous winter water elevation.

Table H-1c
Area C Wells and Water Levels Hydraulic Gradient Analysis
Boeing Auburn Remedial Investigation
Auburn, Washington

Location	Aquifer Zone	Easting	Northing	Summer Water Level Elevation (ft) (6/11-6/16)	Winter Water Level Elevation (ft) (12/29-12/31)
AGW235-2	Shallow	1288071	111971	66.40	67.63
AGW207-2	Shallow	1289007.6200	111524.9290	68.47	70.08
AGW208-2	Shallow	1289593.51000	111417.86000	69.25	71.24
AGW209-2	Shallow	1289965	111423	69.62	72.01
AGW210-2	Shallow	1290493.07	111402.14	69.92	72.84
AGW211-2	Shallow	1290939.95	111375.49	70.25	73.24
AGW212-2	Shallow	1291458.78	111161.74	70.89	74.53
AGW232	Shallow	1289159.75	112487.98	67.77	69.29
AGW231	Shallow	1289807.50	113205.17	66.56	69.00
AGW239	Shallow	1289089	114227	64.77	65.56
AGW254-2	Shallow	1288892	115618.6	61.59	63.07
APP-069	Shallow	1288478.3727	115759.8247	61.96	63.16
AGW235-5	Intermediate	1288071	111971	67.07	68.50
AGW207-4	Intermediate	1289007.62	111524.93	68.47	70.12
AGW208-4	Intermediate	1289593.51	111417.86	69.29	71.29
AGW209-4	Intermediate	1289965.11	111423.1	69.62	72.13
AGW210-4	Intermediate	1290493.07	111402.14	69.93	72.86
AGW211-4	Intermediate	1290939.95	111375.49	70.22	73.53
AGW212-3	Intermediate	1291458.8	111161.7	70.34	74.07
AGW196	Intermediate	1289154	112470	67.73	69.27
AGW198	Intermediate	1289803	113212	67.60	69.01
AGW238	Intermediate	1289095.3	114232.1	64.56	65.86
AGW254-5	Intermediate	1288892.4127	115618.5647	61.64	63.09
AGW253	Intermediate	1288469.14	115757.54	61.99	63.18
AGW235-7	Deep	1288070.60	111970.80	67.02	68.50
AGW207-7	Deep	1289007.62	111524.93	68.59	70.30
AGW208-7	Deep	1289593.51	111417.86	69.49	71.78
AGW209-7	Deep	1289965.11	111423.1	69.64	72.16
AGW210-7	Deep	1290493.07	111402.14	69.65	72.64
AGW211-7	Deep	1290939.95	111375.49	70.04	73.46
AGW212-7	Deep	1291458.78	111161.74	70.33	74.06
AGW195	Deep	1289154.96	112478.17	67.94	69.61
AGW197	Deep	1289798.1	113219.38	67.57	69.14
AGW237	Deep	1289103.2	114236.6	65.67	66.99
AGW259	Deep	1288899.354	115611.856	61.63	63.09
AGW252	Deep	1288459.703	115756.0447	62.06	63.23

Capture Zone

CAPTURE ZONE DEPTH CALCULATION
CHICAGO AVENUE DITCH
BOEING AUBURN

DOWNGRADIENT EXTENT OF GROUNDWATER CAPTURE

Estimated downgradient extent of groundwater captured by the ditch is calculated by determining the x value for the stagnation point (x_{sp}, y_{sp} ; Zheng et al. 1988). The x value is calculated using Equation 1 as follows:

Equation 1:

$$x_{sp} = -\left[\frac{a(h_O - h_d)}{\pi I}\right]^{1/2}$$

Where:

x_{sp}	Downgradient extent of stagnation point, feet downgradient of the ditch (ft)
a	Half the width of the ditch (ft). The width of the ditch was measured on January 21, 2015 at the staff gauge SWSG-2. The width of the ditch was approximately 6 ft wide. The ditch width varies throughout the year; however, a width of 6 ft is used for the purposes of these calculations. Therefore, a = 3 ft.
h_o	Head in aquifer underlying the ditch (ft, MSL). Average monthly water levels at AGW225 were calculated to determine the average monthly head in the aquifer underlying the ditch.
h_d	Head of the ditch (ft, MSL). Average monthly water levels at SWSG-2 were calculated to determine the average monthly head of the ditch.
I	Uniform water table gradient$\left(\frac{\partial h}{\partial x}\right)$, unitless. The regional gradient was calculated from shallow zone groundwater elevations collected in July 2014 from AGW083 to AGW243-3. I = 0.0019.

The smallest difference in average monthly head between the aquifer and the ditch occurred in September 2014 [0.52 feet (ft)]. The largest difference in average monthly head between the aquifer and the ditch occurred in April 2014 (2.35 ft). The downgradient extent of ditch capture (x_{sp}) was calculated for the months of September and April to determine the approximate minimum and maximum downgradient capture of the ditch. The minimum calculated extent of downgradient ditch capture was approximately 16 ft. The maximum calculated extent of downgradient ditch capture was approximately 34 ft.

DEPTH OF GROUNDWATER CAPTURE

Estimated effective depth of capture is calculated by using Equation 2 as follows (Chambers and Bahr 1992):

Equation 2:

$$D = \left(\frac{2wH}{\pi IR}\right)^{-1/2}$$

Where:

D	Effective depth of capture zone, ft
w	width of ditch, ft
H	Difference in head in the aquifer and stage in the ditch, ft
I	Regional gradient (both upgradient and downgradient of the ditch), unitless
R	Ratio of horizontal to vertical hydraulic conductivity, unitless, value is assumed to be 5 for these calculations.

The smallest difference in average monthly head between the aquifer and the ditch occurred in September 2014 (0.52 ft). The largest difference in average monthly head between the aquifer and the ditch occurred in April 2014 (2.35 ft). The depth of capture was calculated for the months of September and April to determine the approximate minimum and maximum depth capture of the ditch. The minimum depth capture was approximately 14 ft and the maximum extent of downgradient ditch capture was approximately 31 ft.

REFERENCES

Chambers, L. W. and J.M. Bahr. 1992. "Tracer Test Evaluation of a Drainage Ditch Capture Zone." *Ground Water*. 30(5): 667-675.

Zheng, C., H.F. Wang, M.P. Anderson, and K.R. Bradbury. 1988. "Analysis of Interceptor Ditches for Control of Groundwater Pollution." *Journal of Hydrology*. 98: 67-81.