PALL LIFE SCIENCES, EVERGREEN SYSTEM
AE-3 CAPTURE ANALYSIS
April 29, 2008

BACKGROUND

Pall Life Sciences (PLS) provides an analysis of the hydraulic capture zone of the PLS Evergreen System extraction well AE-3. PLS has been operating AE-3 with two other nearby extraction wells (LB-1 and LB-3) for the purpose of containing the Unit D_2 plume. The Evergreen System has been in operation for close to 15 years and has been the subject of several reports during this period. In addition, the capture zone for the Evergreen System under other flow conditions has been analyzed by PLS and the Michigan Department of Environmental Quality (MDEQ) on numerous occasions since this system was put into operation.

PLS has had to reduce the flow of AE-3 to 15 gallons per minute (gpm) as a result of lowered water levels in the area, and to some degree, well fouling. Historically, AE-3 has been operated at flow rates up to 32 gpm. This analysis examines whether AE-3 operating at 15 gpm in conjunction with the operation of LB-1 and LB-3 operating at a combined rate of approximately 185 gpm is containing the Unit D_2 plume (or 1,4-dioxane levels over 85 micrograms per liter [µg/L]).

APPROACH

PLS has used various models for previous capture zone analyses (MODFLOW, WINFLOW). For this analysis, the steady-state capture zone of AE-3 was analyzed using methods described by Grubb and others (Grubb 1993, Fetter 2001, Todd 1990).

The controlling equation for the one-half of the curve-shape for the capture zone is as follows:

$\mathbf{X = -Y / Tan (2\pi KbiY/Q)}$ where **X** and **Y** are the number of feet in the X or Y direction as defined on a Cartesian grid system; and

Q is the pumping rate (units = L^3/T; cubic feet per day (ft^3/day) or gallons per day (gpd)

K is the hydraulic conductivity (units = L/T; ft/day or gpd/ft^2)

B is the aquifer thickness (units = L; ft)

i is the hydraulic gradient of the flow field (units are dimensionless [ft/ft]) (remembering that the tangent or Tan (Y) must be in radians)

To calculate the two-dimensional shape of a capture zone requires three steps. First the distance from the pumping well downstream to the stagnation point is determined. The stagnation point (X_0) is the point marking the downgradient edge of the capture zone and is calculated as follows:

$$\mathbf{X_0 = -Q / (2\pi Kbi)}$$

Second, the maximum width of the capture zone is calculated. This is the maximum width of the capture zone as X approaches infinity and is given by:

$\mathbf{Y_{max} = \pm\ Q / (2Kbi)}$ where Y_{max} is the half-width of the capture zone as X approaches infinity (effectively, this is the line denoting the most upgradient edge or limit of the capture zone at steady-state conditions).

Once this maximum Y-value is known, smaller values of Y are substituted into the controlling equation that defines the overall curve shape of the capture zone.

Because the overall dimension of a capture zone is controlled by the time it takes for water to flow from an upgradient direction, each capture zone will require time to extend upgradient to the closest groundwater divide (Fetter, 2001). Additionally, we have simplified the shape of the capture zones by imposing their outlines on the map and extending the capture zone for each well in the upgradient direction for a limited distance.

INPUT

Aquifer Thickness

The hydrostratrigraphy of the AE-3 area has been presented multiple times in reports submitted to the MDEQ. Cross sections depicting the hydrostratigrapy of the Allison Street area are provided in Attachment 1. The total aquifer thickness shown on the cross section at AE-3 is approximately 90 feet. It is important to note that this aquifer fines downward at this location. As such, using a 90-foot-thick aquifer is considered conservative for this analysis.

Hydraulic Conductivity

AE-3 is completed in a portion of the Unit D_2 that is considerably less transmissive than the area around the LB-series wells. This is supported by a review of drilling logs, geophysical logs, and well capacity information.

An aquifer performance test at LB-1, west of AE-3, indicated the aquifer has a transmissivity of approximately 18,333 ft^2/day. The aquifer at this location was 76 feet thick, resulting in an average hydraulic conductivity of 241 ft/day.

The data collected from drilling near Allison Street (AE-1, AE-2, and AE-3) indicate that east of LB-1, the Unit D_2 has a higher percentage of finer-grained material; therefore, it is known that the hydraulic conductivity of the aquifer materials is lower in this area. Estimates from grain size analyses of samples collected during the installation/design of AE-3 suggest the hydraulic conductivity of materials in the screen zone at AE-3 is approximately 50 ft/day. Given some uncertainty in this value, for our analysis, we have used hydraulic conductivity values of 25, 50, and 75 ft/day.

Hydraulic Gradient/Flow Direction

The hydraulic gradient in the Allison Street area has changed with time as extraction has varied, but has consistently been very gentle. PLS has used a hydraulic gradient of 0.001 ft/ft for previous capture zone analyses and this analysis. The orientation of the capture zone is generally west-east based on available groundwater flow data.

RESULTS

The simulated capture zones for various hydraulic conductivity estimates are tabulated below and shown on Attachment 2, along with isoconcentration and potentiometric surface contours (October-March 2007/2008 and February 25, 2008 data, respectively). Supporting calculations are provided as Attachment 3.

Table No. 1

WELL NO.	Q Pumping Rate (gpm)	Q Pumping Rate (gpd)	i Hydraulic gradient (unitless)	K Hydraulic conductivity (gpd/ft^2)	b Aquifer thickness (ft)	Ymax (ft)	X_0 Stagnation point (ft)
AE-3	15	21,600	0.001	25	90	642	-204
AE-3	15	21,600	0.001	50	90	321	-102
AE-3	15	26,000	0.001	75	90	214	-63

gpm = gallons per minute
gpd = gallons per day
ft = feet or foot

COMPARISON OF RESULTS TO AVAILABLE DATA

PLS has compared the simulated capture zone to available water level and water quality data. The capture of the Evergreen System can be estimated from analyzing measured water level data. A comprehensive round of water level data were collected on February 25, 2008, from wells in the Evergreen area. A potentiometric surface map has been prepared using the February

25, 2008 data. The simulated capture zone compares well to the field data. The upgradient extent of the capture zone for AE-3 becomes difficult to interpret where there is overlap with the LB-1/3 capture. More advanced modeling, such as that used in prior simulations, is necessary to simulate the relationship between the LB-1/3 and AE-3 capture areas.

Water quality data along with isoconcentration contours for the Evergreen Allison Street area are shown on Attachment 2. Comparing these contours to the extent of the simulated capture zones, it is apparent that the simulated capture zones, depending on the given hydraulic conductivity, either fully encompass both the estimated width and downgradient extent of the plume (25 ft/day simulation), or capture the width, but show a minor area east of the capture area (50 and 75 ft/day simulations). Because there is no data point available between AE-3 and MW-47s/d, the exact location of the plume in this area can only be estimated. However, historic data from residential wells at 584 and 580 Allison have not exceeded 85 µg/L. As such, it should not be interpreted that the plume is in fact outside the capture.

As indicated in our recently submitted Valley Drive Area investigation, water quality data for key wells east of the Evergreen extraction demonstrate the Evergreen System has been effective in halting the migration of the plume at concentrations above 85 µg/L. These wells include, but are not limited to, MW-47s and MW-47d, MW-92, MW-107, MW-110, and residential wells at 545 Allison, and 2652 and 2643 Dexter Street.

CONCLUSION

This analysis indicates the Evergreen System operating at the current extraction rates is maintaining capture of the Unit D_2 plume.

LIMITATIONS OF THIS ANALYSIS

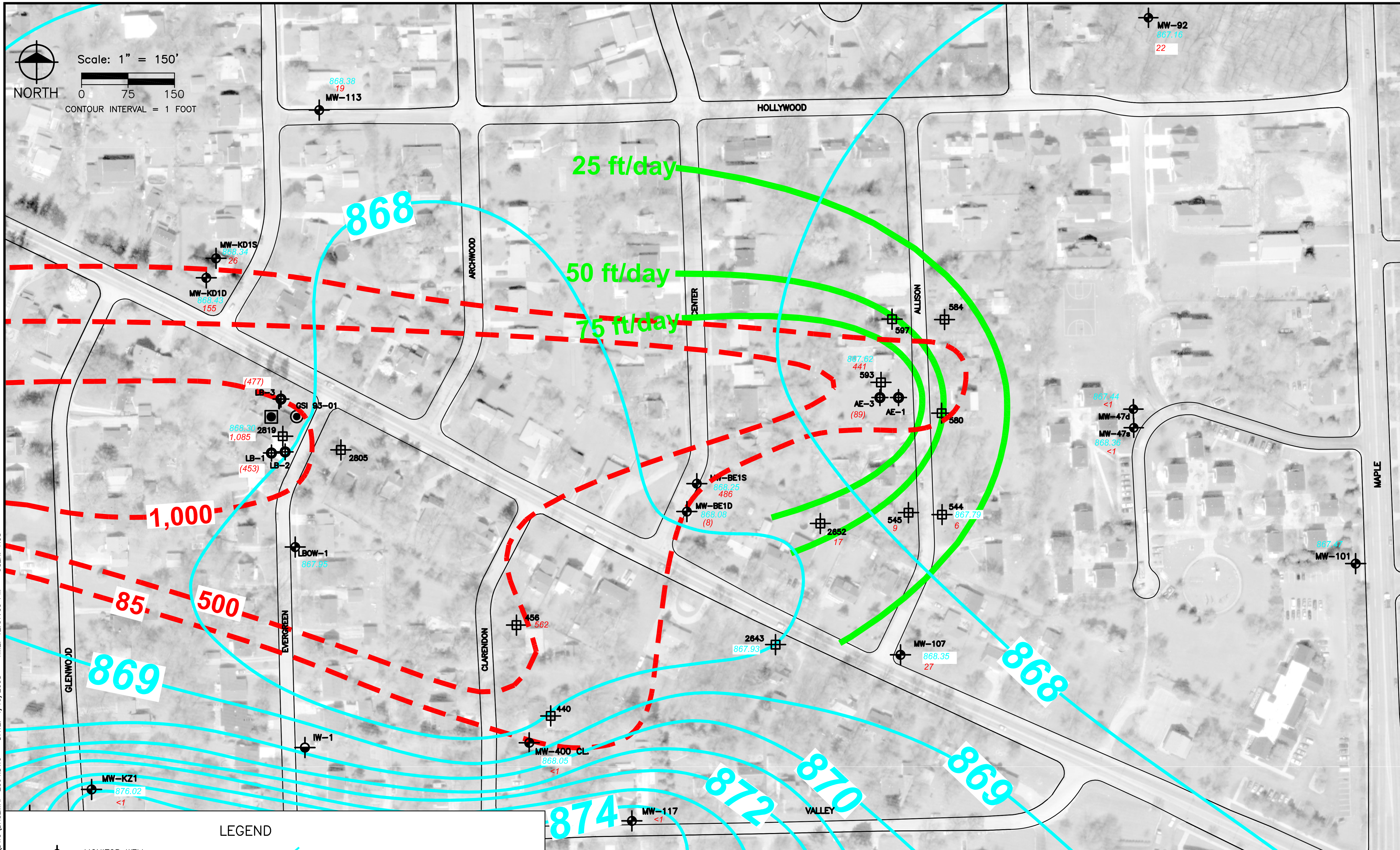
There are many assumptions regarding the use of the steady-state capture zone solution. It is also important to note that dispersion is neglected from the capture zone analysis. If dispersion were included in the analysis, there would not be a sharp capture zone boundary, instead there would be a wide boundary with width proportional to the dispersion coefficient. It should also be noted that this equation considers only advective flow and does not consider contaminant transport related effects.

REFERENCES

Grubb, Stuart, 1993, Analytical model for estimation of steady-state capture zones of pumping wells in confined and unconfined aquifers, *Ground Water*, 31, no. 1:27-32.

Fetter, C.W., 2001, Applied Hydrogeology, 4th ed., Upper Saddle River, New Jersey, Prentice Hall.

Todd, D.K., 1980, Groundwater hydrology, 2nd ed. New York: John Wiley.



LEGEND

- MONITOR WELL
- RESIDENTIAL WELL
- PURGE WELL
- HYDROGEOLOGIC TEST BORING
- UV/OX. TREATMENT SYSTEM
- TEMPORARY PURGE WELL
- SURFACE WATER ELEVATION POINT
- POTENTIOMETRIC SURFACE CONTOUR (ft. amsl)
- 867.95 POTENTIOMETRIC SURFACE ELEVATION (ft. amsl)
- 1,4-DIOXANE ISOCONCENTRATION CONTOUR (ug/L)
- 562 1,4-DIOXANE CONCENTRATION (ug/L)
- SIMULATED CAPTURE ZONE (FT./DAY)

EXTRACTION WELLS OPERATING DURING FEBRUARY 25, 2008 MONITORING EVENT

UNIT D_2 DOWNGRADIENT WELLS	
LB-1	95 gpm
LB-3	90 gpm
AE-3	15 gpm

INPUT FOR CAPTURE ZONE ANALYSIS

Hydraulic Gradient (i) = 0.0001 ft./ft.
Hydraulic Conductivity (K) = 25, 50, 75 ft./day
Aquifer Thickness (b) = 90 ft.
Flow (Q) = 15 gpm

SIMULATED CAPTURE ZONE AE-3

ftc&h

engineers
scientists
architects
constructors

fishbeck, thompson, carr & huber, inc.

Hard copy is intended to be 11"x17" when plotted. Scale(s) indicated and graphic quality may not be accurate for any other size.

Pall Life Sciences
Scio Twp., Washtenaw County, Michigan
AE-3 - Capture Zone Analysis

PROJECT NO.
F96502B

ATTACHMENT
2

PLOT INFO: F:\WORK\96502\DWG\BASEMAP 2004.DWG DATE: 4/10/2008 TIME: 12:57:03 PM USER: ACS
F:\WORK\96502\DWG\AERIAL2003 HIRES.DWG F:\WORK\96502\DWG\AATOPO.DWG M:\CUSTOM\ACAD2008\SYMBOLS\B-85X11.DWG F:\WORK\96502\REF\WASHTENAW CNTY PARCELS.DWG

AE-3

Q (gpm)	Q (ft^3/day)	gradient = i	T = bK (ft^2/day)	b (feet)	K (ft/day)
15	2887.5	0.001	2,250	90	25

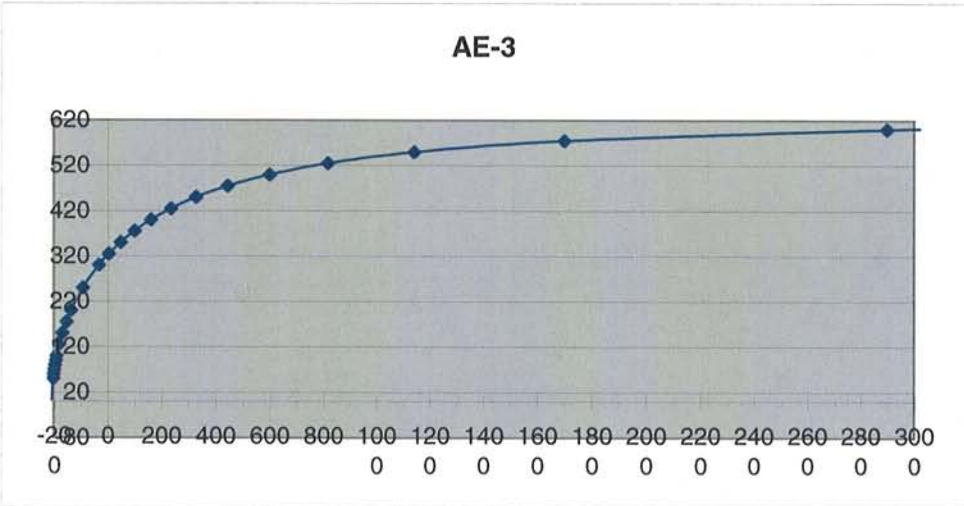
X (feet)	Y (feet)	**Ymax (ft)**	**stagnation pt**
-204.24	2	**641.67**	**-204.25**
-204.09	10		
-203.60	20		
-202.78	30		
-201.63	40		
-200.15	50		
-198.34	60		
-196.19	70		
-193.70	80		
-190.86	90		
-187.66	100		
-178.09	125		
-166.14	150		
-151.64	175		
-134.37	200		
-90.35	250		
-30.71	300		
6.63	325		
50.32	350		
101.85	375		
163.30	400		
237.73	425		
329.76	450		
446.78	475		
601.39	500		
816.91	525		
1142.08	550		
1698.62	575		
2900.23	600		
3333.78	605		
3902.84	610		
4683.60	615		
5822.58	620		

FORMULA

Y max = + or - Q / 2 b K i

stagnation pt = Xo = -(Q / 2 pi K b i)

shape of curve
X = - Y / Tan (2 pi K b i / Q)
tangent must be in radians



Note: The following general assumptions apply to the above equations.
Flow to well screen is horizontal and laminar
Aquifer is homogeneous and isotropic
Aquifer thickness is uniform
Aquifer is of infinite extent
Aquifer is confined
The well screen is fully penetrating

References

Todd, D.K., 1980, Groundwater hydrology, 2nd ed. New York: John Wiley.
Grubb, Stuart, 1993, Analytical model for estimation of steady-state capture zones of pumping wells
Fetter, C.W., 2001, Applied Hydrogeology, 4th ed., Upper Saddle River, New Jersey, Prentice Hall.

AE-3

Q (gpm)	Q (ft^3/day)	gradient = i	T = bK (ft^2/day)	b (feet)	K (ft/day)
15	2887.5	0.001	4,500	90	50

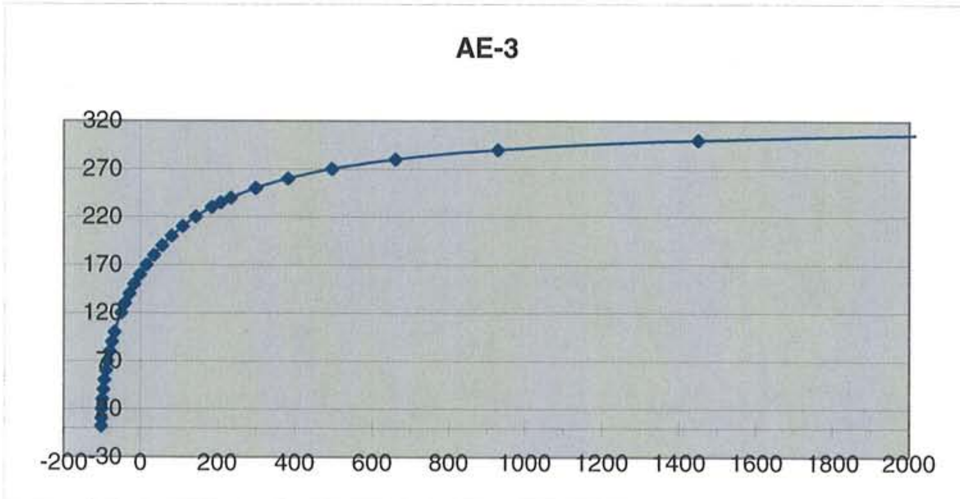
X (feet)	Y (feet)	**Ymax (ft)**	**stagnation pt**
-102.11	2	**320.83**	**-102.12**
-101.80	10		
-100.82	20		
-99.17	30		
-96.85	40		
-93.83	50		
-90.09	60		
-85.61	70		
-80.33	80		
-74.21	90		
-67.19	100		
-50.14	120		
-39.91	130		
-28.37	140		
-15.35	150		
-0.65	160		
16.00	170		
34.95	180		
56.63	190		
81.65	200		
110.81	210		
145.22	220		
186.51	230		
210.44	235		
237.08	240		
300.70	250		
383.59	260		
496.87	270		
662.56	280		
931.15	290		
1450.12	300		
2911.29	310		
39202.19	320		

FORMULA

Y max = + or - Q / 2 b K i

stagnation pt = Xo = -(Q / 2 pi K b i)

shape of curve
X = - Y / Tan (2 pi K b i / Q)
tangent must be in radians



Note: The following general assumptions apply to the above equations.
Flow to well screen is horizontal and laminar
Aquifer is homogeneous and isotropic
Aquifer thickness is uniform
Aquifer is of infinite extent
Aquifer is confined
The well screen is fully penetrating

References

Todd, D.K., 1980, Groundwater hydrology, 2nd ed. New York: John Wiley.
Grubb, Stuart, 1993, Analytical model for estimation of steady-state capture zones of pumping wells
Fetter, C.W., 2001, Applied Hydrogeology, 4th ed., Upper Saddle River, New Jersey, Prentice Hall.

AE-3

Q (gpm)	Q (ft^3/day)	gradient = i	T = bK (ft^2/day)	b (feet)	K (ft/day)
15	2887.5	0.001	6,750	90	**75**

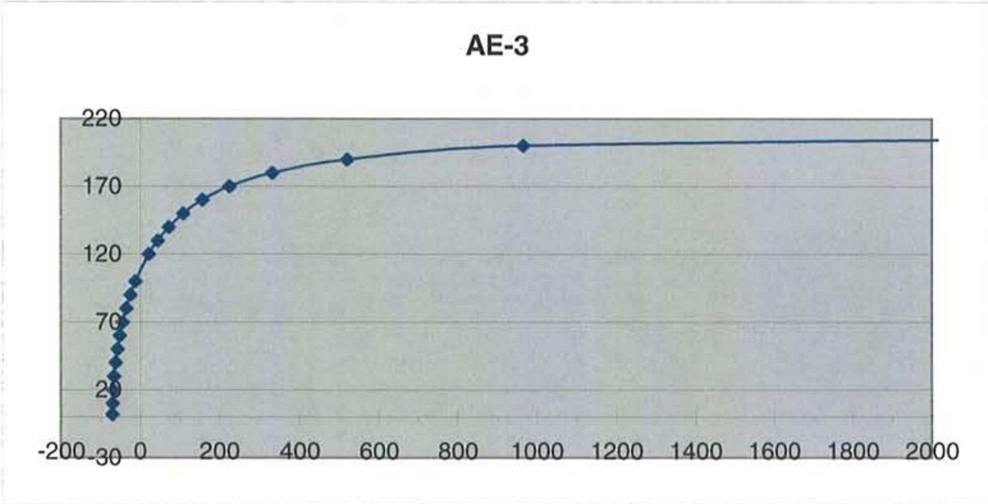
X (feet)	Y (feet)	**Ymax (ft)**	**stagnation pt**
-68.06	2	**213.89**	**-68.08**
-67.59	10		
-66.11	20		
-63.62	30		
-60.06	40		
-55.38	50		
-49.47	60		
-42.21	70		
-33.42	80		
-22.87	90		
-10.24	100		
23.30	120		
45.79	130		
73.87	140		
109.92	150		
158.05	160		
226.13	170		
331.25	180		
519.09	190		
966.74	200		
3672.31	210		

FORMULA

Y max = + or - Q / 2 b K i

stagnation pt = Xo = -(Q / 2 pi K b i)

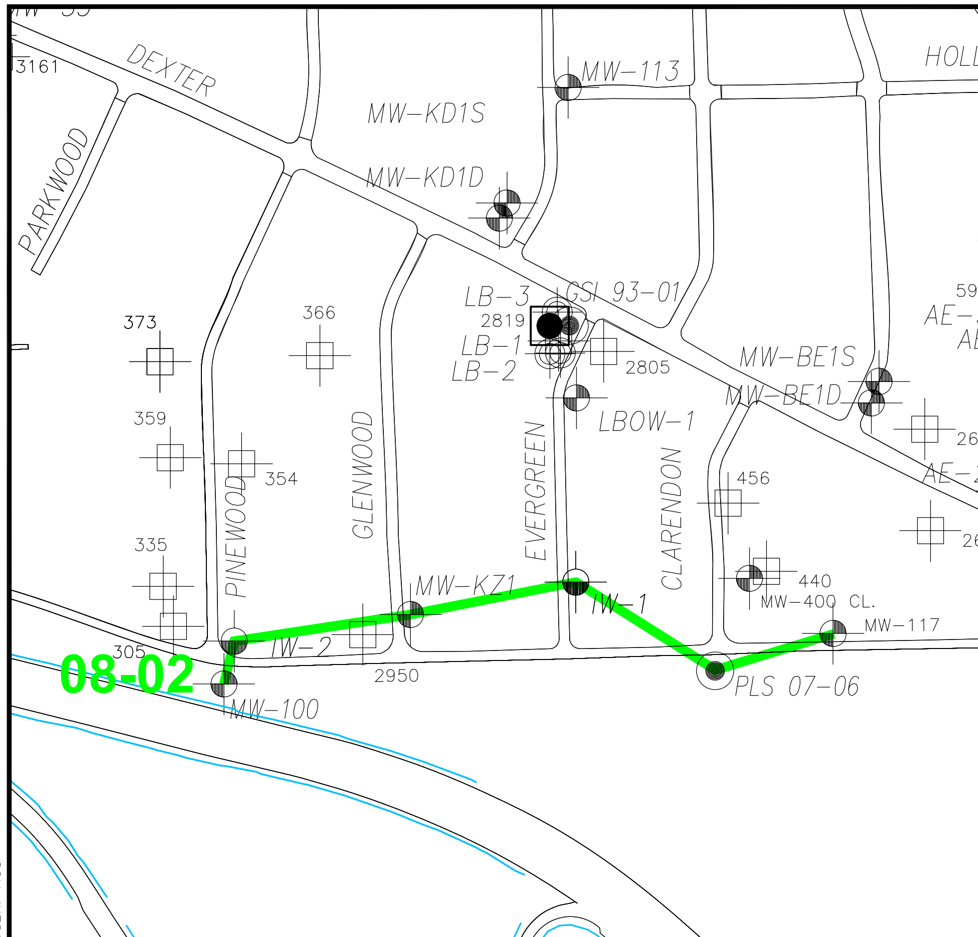
shape of curve
X = - Y / Tan (2 pi K b i / Q)
tangent must be in radians



Note: The following general assumptions apply to the above equations.
Flow to well screen is horizontal and laminar
Aquifer is homogeneous and isotropic
Aquifer thickness is uniform
Aquifer is of infinite extent
Aquifer is confined
The well screen is fully penetrating

References

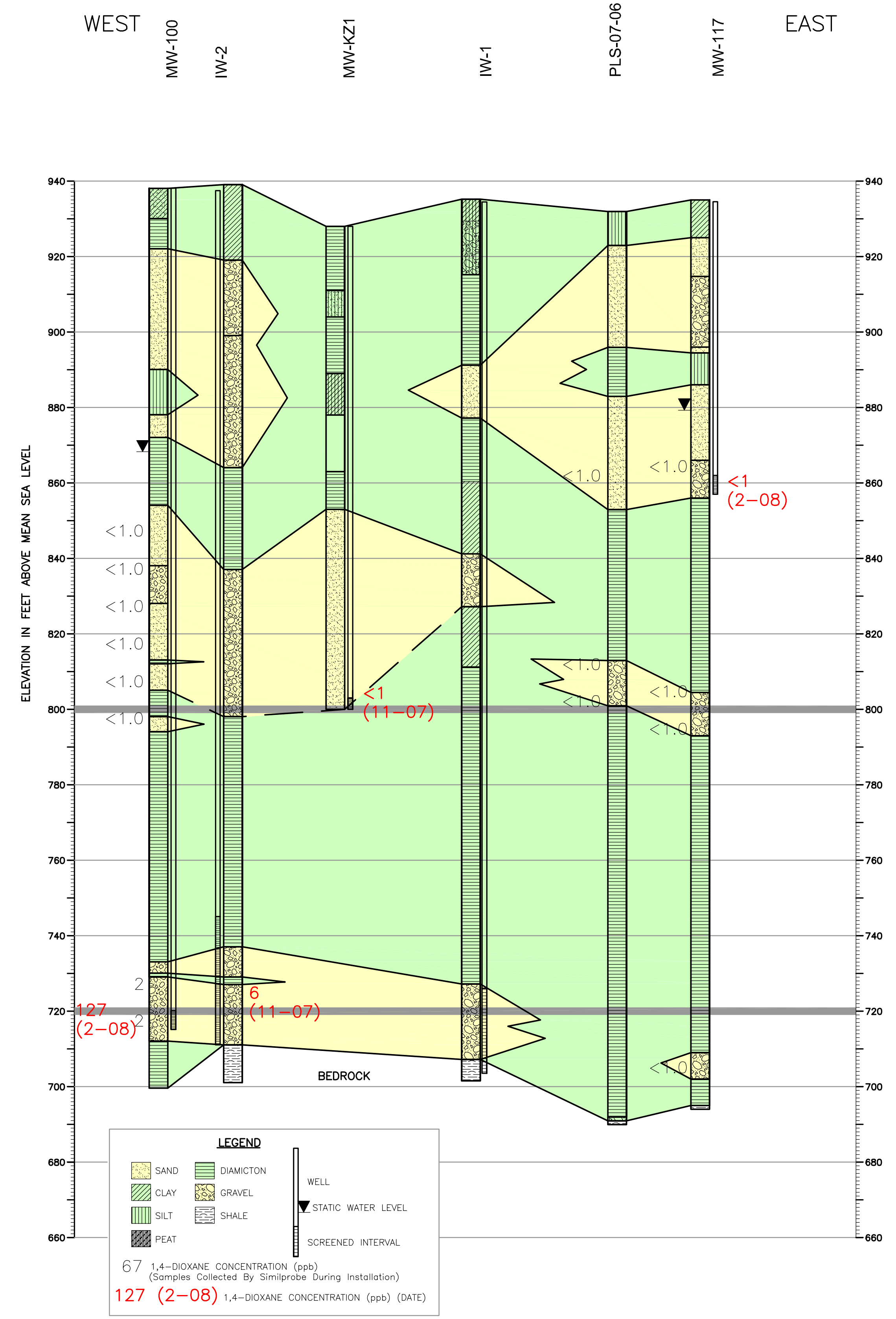
Todd, D.K., 1980, Groundwater hydrology, 2nd ed. New York: John Wiley.
Grubb, Stuart, 1993, Analytical model for estimation of steady-state capture zones of pumping wells in
Fetter, C.W., 2001, Applied Hydrogeology, 4th ed., Upper Saddle River, New Jersey, Prentice Hall.



NORTH

Scale: 1" = 400'

0 200 400



Scale: 1" = 400'

0 200 400

VERTICAL EXAGGERATION = 10X

CROSS SECTION 08-02

ftc&h

engineers

scientists

architects

constructors

fishbeck, thompson, carr & huber, inc.

Hard copy is intended to be 11"x17" when plotted. Scale(s) indicated and graphic quality may not be accurate for any other size.

Pall Life Sciences

Scio Twp., Washtenaw County, Michigan

AE-3 - Capture Zone Analysis

PROJECT NO.

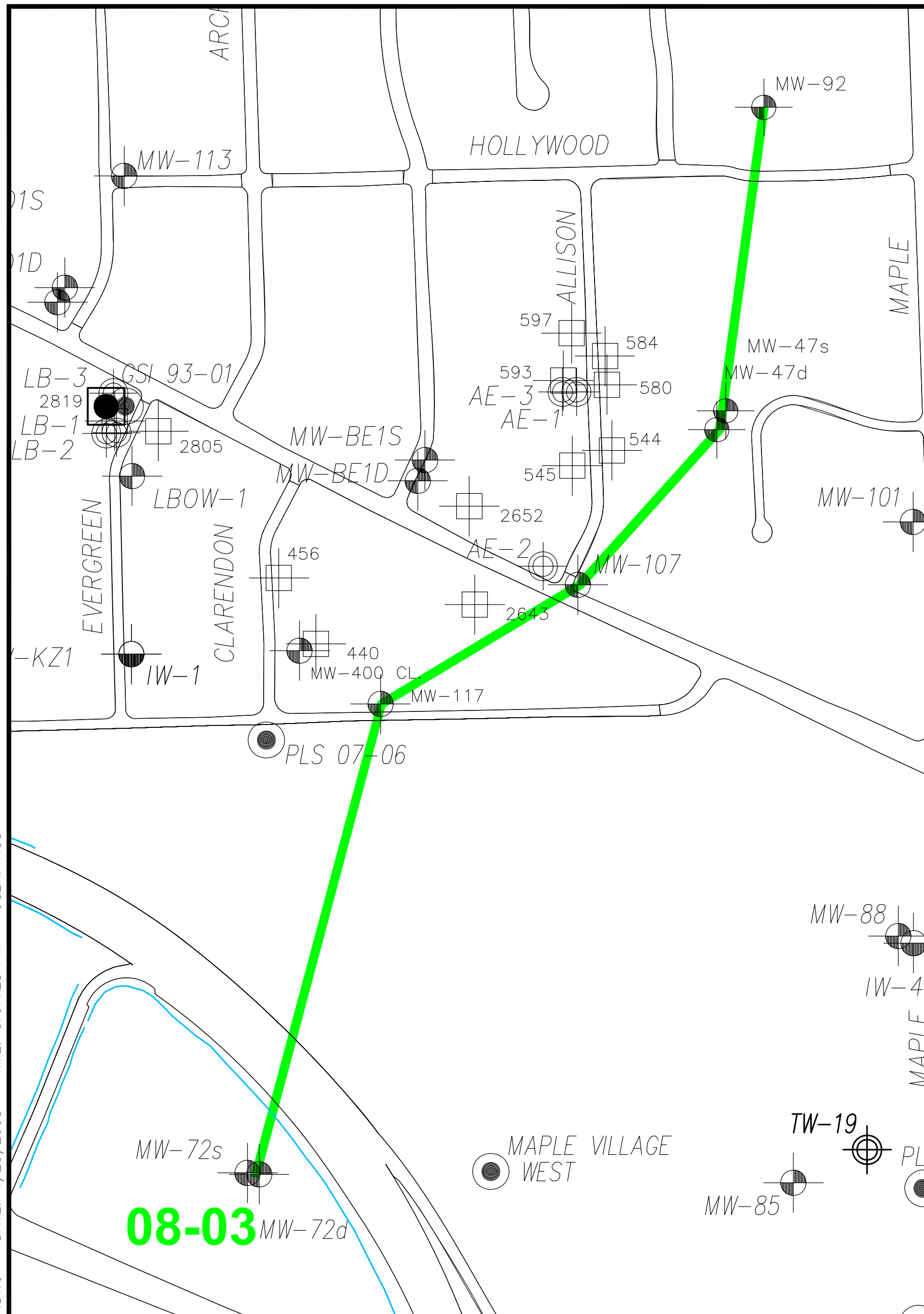
F96502B

ATTACHMENT

1

PLOT INFO: F:\WORK\96502\DWG\EVERGREEN 2007\XSEC EVERGREEN MDEQ 2007.DWG DATE: 4/25/2008 TIME: 5:00:27 PM USER: ACS

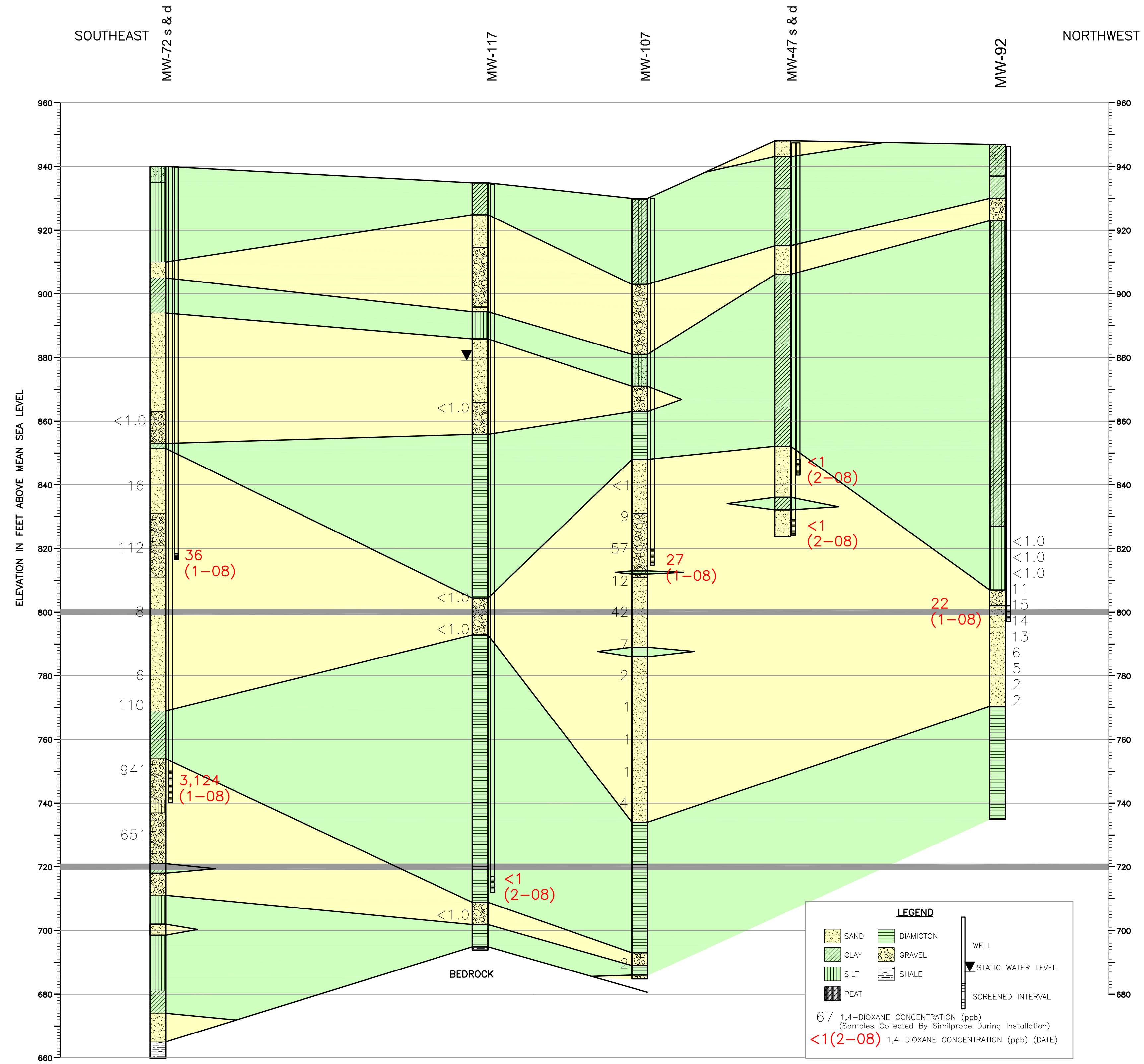
N:\96502B\RASTER\460ROSE.TIF N:\96502\RASTER\MW-72GAMMA.TIF N:\96502\RASTER\MW82GAMMA.TIF N:\96502\RASTER\MW86GAMMA.TIF



NORTH

Scale: 1" = 400'

0 200 400



Scale: 1" = 400'

0 200 400

VERTICAL EXAGGERATION = 10X

CROSS SECTION 08-03

ftc&h

engineers

scientists

architects

constructors

fishbeck, thompson, carr & huber, inc.

Hard copy is intended to be 11"x17" when plotted. Scale(s) indicated and graphic quality may not be accurate for any other size.

Pall Life Sciences

Scio Twp., Washtenaw County, Michigan

AE-3 - Capture Zone Analysis

PROJECT NO.

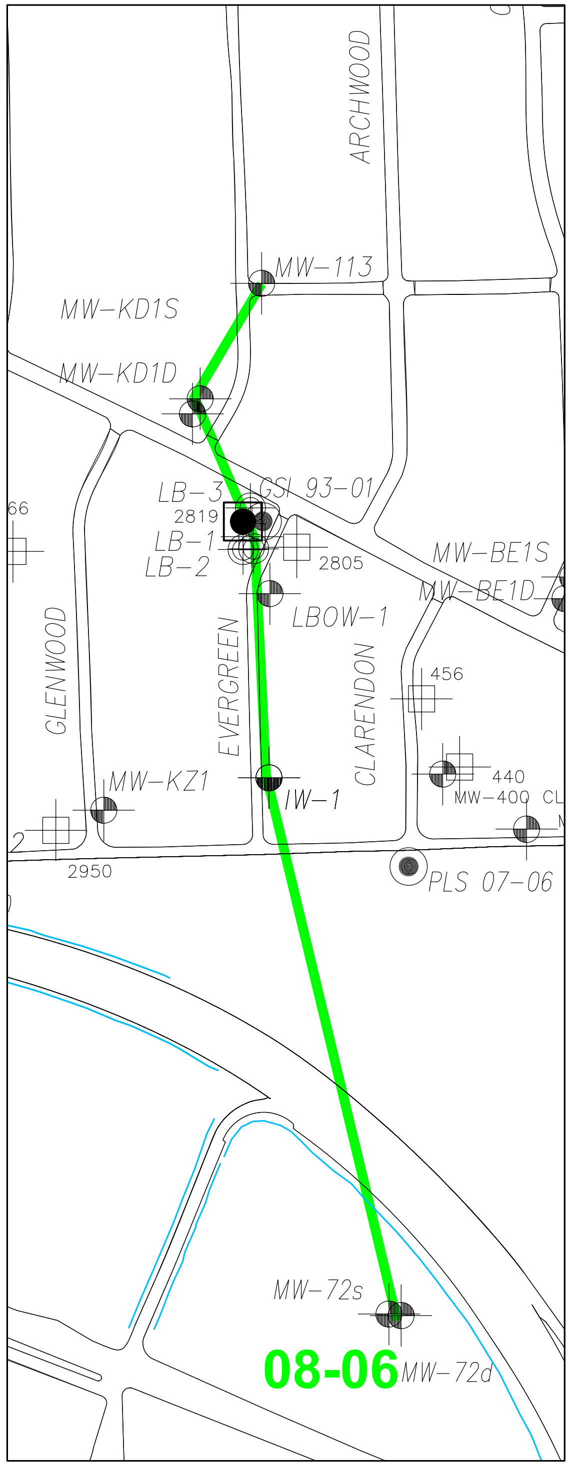
F96502B

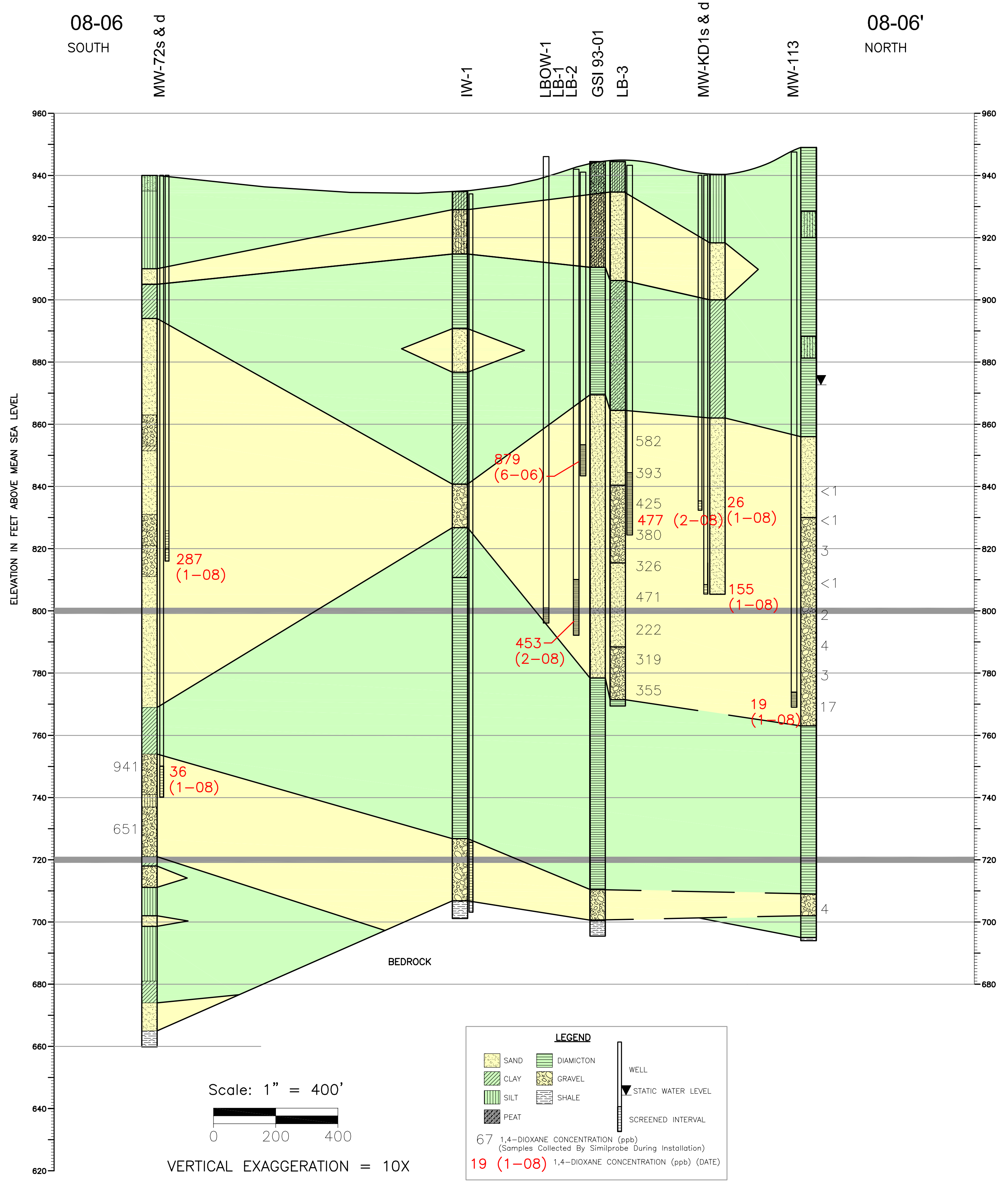
ATTACHMENT

1

PLOT INFO: F:\WORK\96502\DWG\EVERGREEN 2007\XSEC EVERGREEN MDEQ 2007.DWG DATE: 4/25/2008 TIME: 5:07:28 PM USER: ACS

N:\96502B\RASTER\460ROSE.TIF
N:\96502\RASTER\MW-72GAMMA.TIF
N:\96502\RASTER\MW82GAMMA.TIF
N:\96502\RASTER\MW86GAMMA.TIF





CROSS SECTION 08-06

ftc&h

engineers

scientists

architects

constructors

fishbeck, thompson, carr & huber, inc.

Hard copy is intended to be 11"x17" when plotted. Scale(s) indicated and graphic quality may not be accurate for any other size.

Pall Life Sciences

Scio Twp., Washtenaw County, Michigan

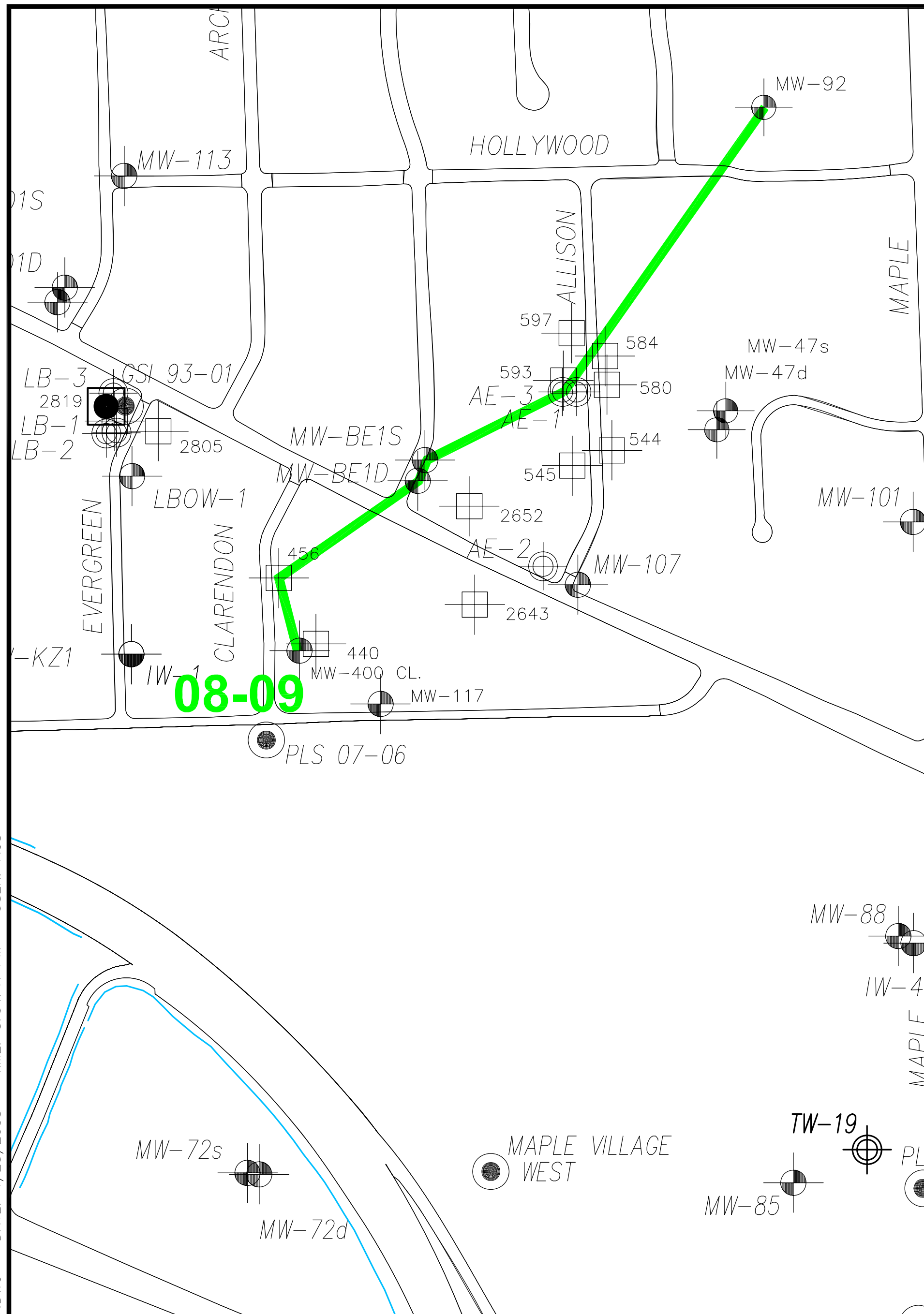
AE-3 - Capture Zone Analysis

PROJECT NO. F96502B

ATTACHMENT 1

PLOT INFO: F:\WORK\96502\DWG\EVERGREEN 2007\XSEC EVERGREEN MDEQ 2007.DWG DATE: 4/25/2008 TIME: 5:08:50 PM USER: ACS

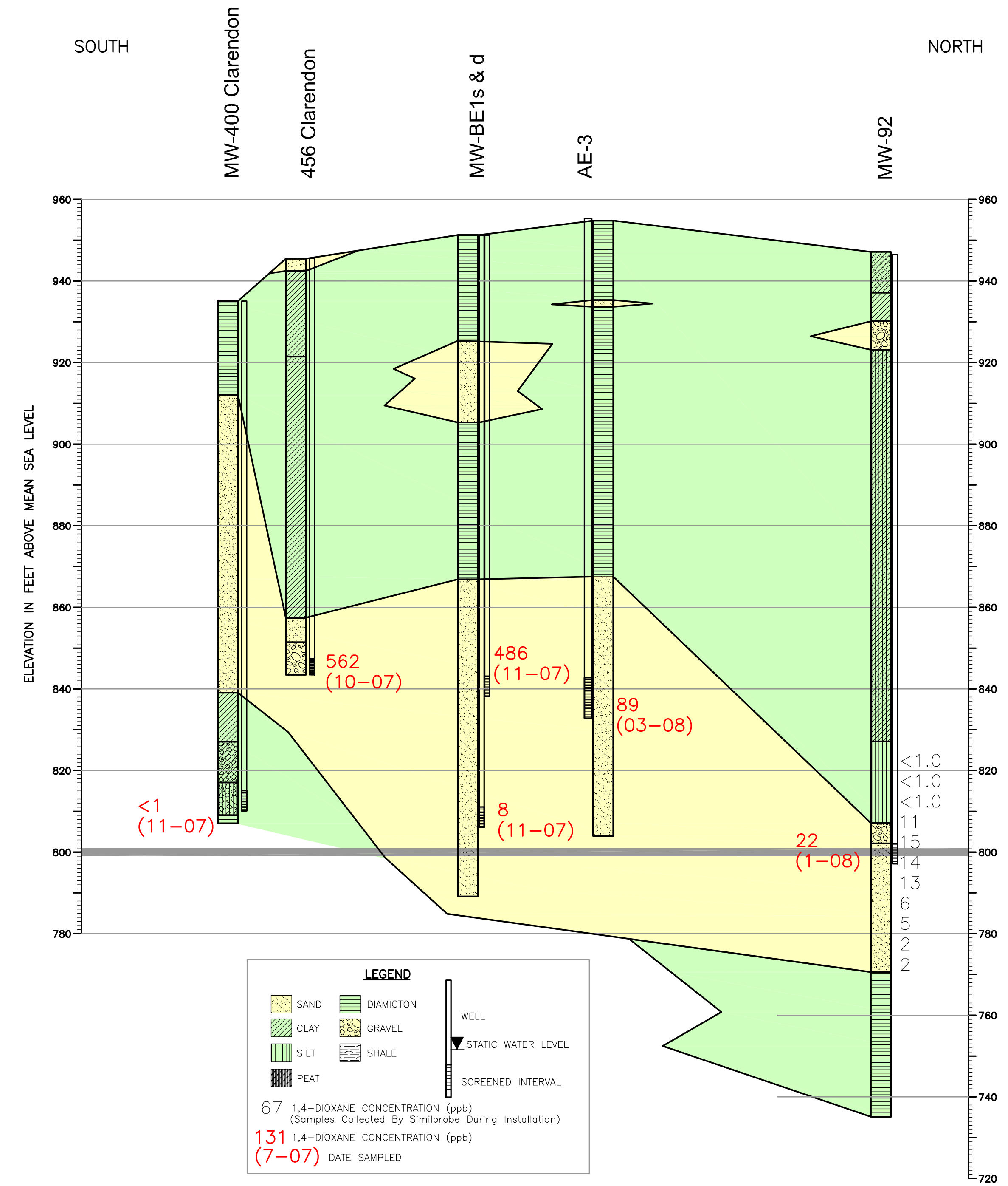
N:\96502B\RASTER\460ROSE.TIF N:\96502\RASTER\MW-72GAMMA.TIF N:\96502\RASTER\MW82GAMMA.TIF N:\96502\RASTER\MW86GAMMA.TIF



NORTH

Scale: 1" = 400'

0 200 400



Scale: 1" = 400'

0 200 400

VERTICAL EXAGGERATION = 10X

CROSS SECTION 08-09

ftc&h

engineers

scientists

architects

constructors

fishbeck, thompson, carr & huber, inc.

Hard copy is intended to be 11"x17" when plotted. Scale(s) indicated and graphic quality may not be accurate for any other size.

Pall Life Sciences

Scio Twp., Washtenaw County, Michigan

AE-3 - Capture Zone Analysis

PROJECT NO.

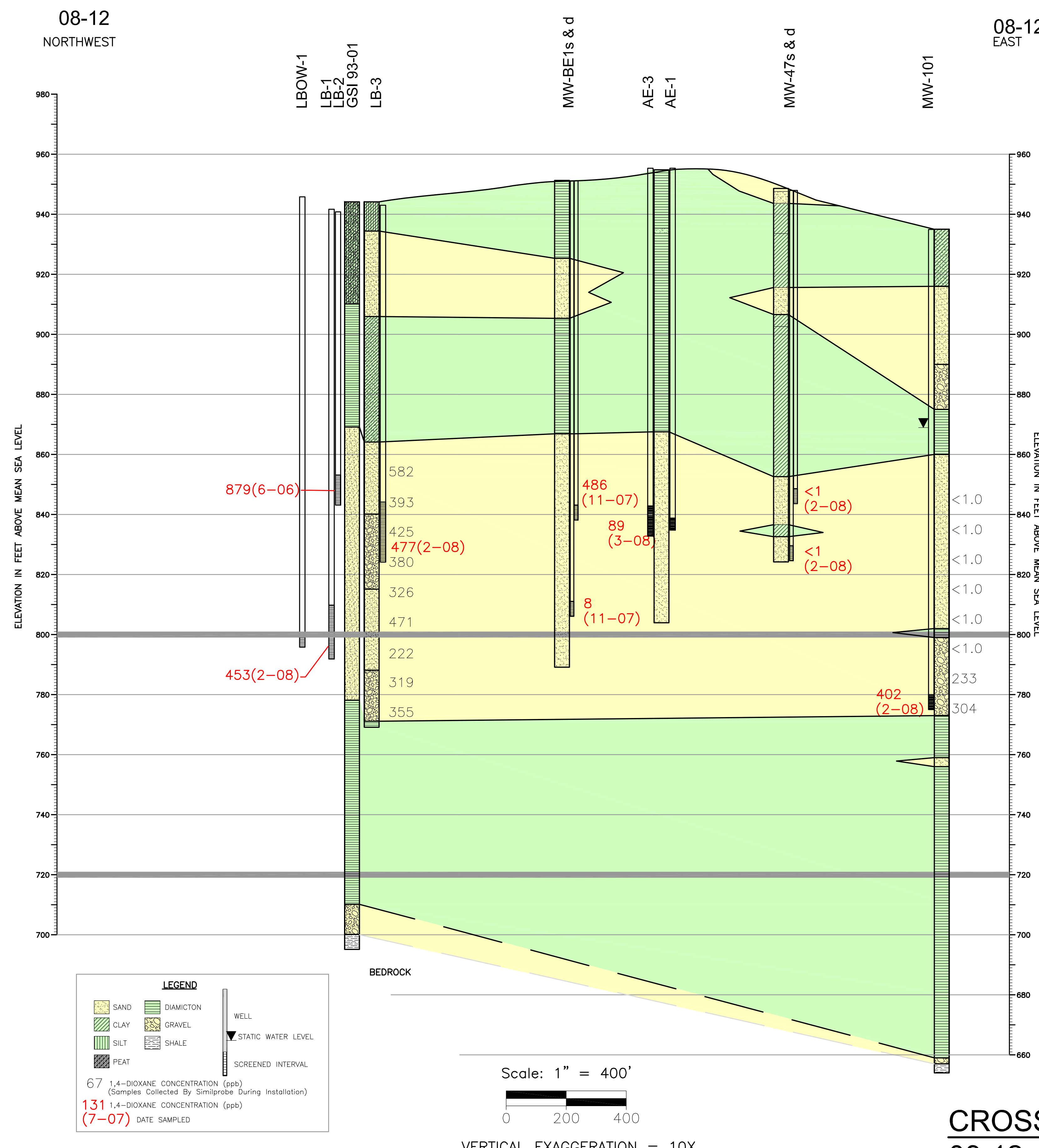
F96502B

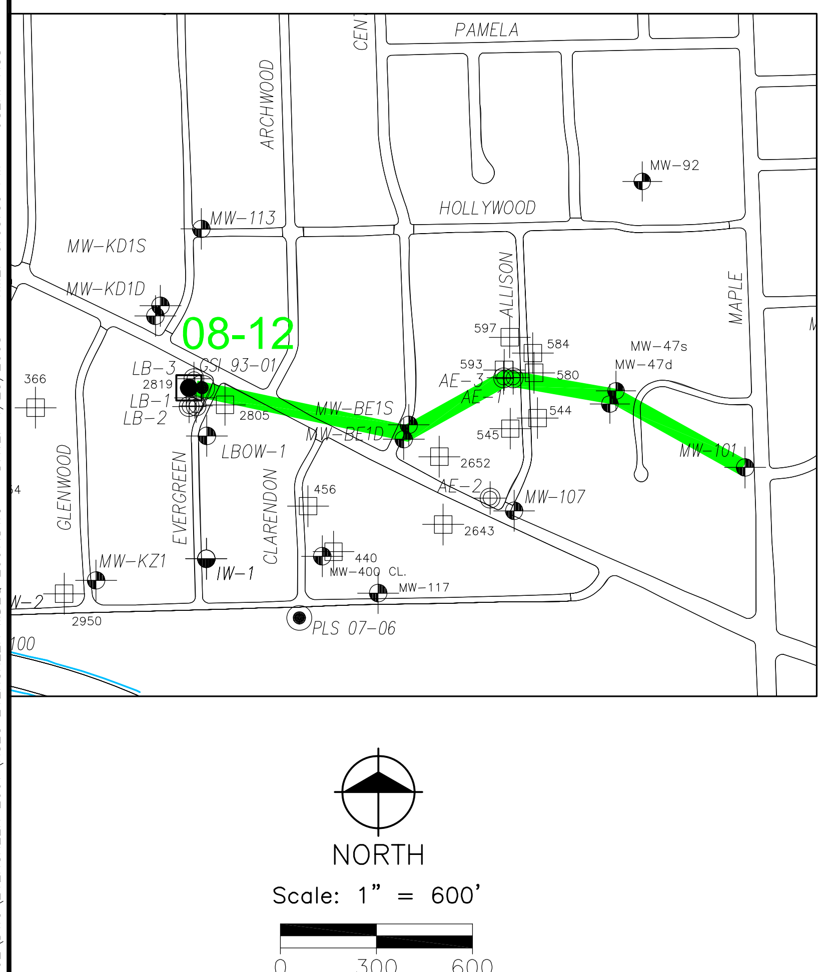
ATTACHMENT

1

PLOT INFO: F:\WORK\96502\DWG\EVERGREEN 2007\XSEC EVERGREEN MDEQ 2007.DWG DATE: 4/25/2008 TIME: 5:04:41 PM USER: ACS

N:\96502B\RASTER\460ROSE.TIF
N:\96502\RASTER\MW-72GAMMA.TIF
N:\96502\RASTER\MW82GAMMA.TIF
N:\96502\RASTER\MW86GAMMA.TIF





fishbeck, thompson, carr & huber, inc.

engineers
scientists
architects
constructors

Hard copy is intended to be 11"x17" when plotted. Scale(s) indicated and graphic quality may not be accurate for any other size.

Pall Life Sciences
Scio Twp., Washtenaw County, Michigan

AE-3 - Capture Zone Analysis

CROSS SECTION 08-12

PROJECT NO. F96502B

ATTACHMENT 1

PLOT INFO: F:\WORK\96502\DWG\EVERGREEN 2007\XSEC EVERGREEN MDEQ 2007.DWG DATE: 4/25/2008 TIME: 5:05:39 PM USER: ACS