Appendix X

Documentation of Groundwater Monitoring System Design

Appendix X(a)

Documentation of Groundwater Monitoring System Design

Ameren Missouri Labadie Energy Center
Proposed Utility Waste Landfill
Franklin County, Missouri

Appendix X
Documentation of Groundwater Monitoring System Design

December 2012

INTRODUCTION

This document provides the methodology used to determine the number, location, spacing, and overall design of the proposed groundwater monitoring system for the proposed Ameren Missouri Labadie Utility Waste Landfill (UWL) at the Labadie Energy Center in Franklin County, Missouri. It is provided in support of the Solid Waste Disposal Area Construction Permit application submitted to MDNR-SWMP.

This evaluation is based on the results of the Detailed Site Investigation (DSI) undertaken in 2009-2010 and detailed in a report entitled, *Detailed Site Investigation Report for Ameren Missouri Labadie Power Plant Proposed Utility Waste Disposal Area, Franklin County, Missouri,* dated February 4, 2011 and revised March 30, 2011. Data from that report were utilized as baseline parameters for the development of a dispersion model that provided insight into the spacing of wells needed to provide a system of downgradient monitoring wells that would detect potential leakage from the UWL. The results of this analysis have been used to propose the number and location of the permanent groundwater monitoring wells for inclusion in the Solid Waste Disposal Area Construction Permit Application. Screen interval depths necessary to ensure full immersion during seasonal groundwater fluctuations were also assessed using the data from the DSI report. They are described at the end of this report.

BASELINE HYDROLOGIC DATA

Review of the hydrologic data contained in the DSI Report indicate that a notable feature concerning groundwater movement is the large temporal fluctuation in overall flow direction in response to the rise and fall of Missouri River elevation (refer also to Appendix W). Examination of the monthly groundwater maps contained in that report (December 2009 through November 2010) demonstrate that the prevailing direction of flow describes a wide arc approaching 180° as it moves roughly from north-northwest during periods of low river stage to east-southeast during periods of high river stage. These temporal changes can be quite rapid. For example, between May 11, 2010 and May 18, 2010, during which period of time the Missouri River rose 12 feet, the prevailing direction of groundwater movement shifted approximately 90 degrees from northeast to southeast. This shift was accompanied by site-wide increases in groundwater levels of between 1.5 and 7.25 feet and a corresponding increase in hydraulic gradient. As a result, much of the proposed disposal area perimeter exhibits both hydraulically upgradient and downgradient conditions with respect to waste disposal limits dependent on river stage. Further, areas of the proposed UWL closer to the Missouri River appear to exhibit a more vigorous response to changing river elevations than those areas more remote from the river proper.

For those reasons, it was determined that baseline hydrologic data used should be specific with respect to proposed landfill development nearest the river relative to proposed landfill development farther from the river. Consequently, for the proposed Cell 1 and Cell 2 construction areas, hydrologic data pertaining to piezometers installed during the DSI in the western and northwestern parts of the site were considered (reference Sheet 3 of Construction Permit Application Plans for site layout). Similarly, those data pertaining to the southern and southeastern parts of the site were considered for the Cell 3 and Cell 4 construction areas. This approach allows for the recognition of variations in hydrologic conditions across the site and accounts for them in the development of a model for long-term detection monitoring at the site.

The baseline data used for the proposed cell construction areas included an assessment of principal flow direction during each of the twelve successive months of water level monitoring, calculated hydraulic gradients, and hydraulic conductivity data as presented in the DSI report. These data are provided for review as Attachment 1 to this appendix. For both the Cell 1-2 and Cell 3-4 areas, average values for hydraulic gradient and hydraulic conductivity were obtained and those values were then used to calculate a range in groundwater velocity, as summarized in Table 1. Examination of Table 1 shows that subtle variations exist in the hydrologic data for each of these areas.

These baseline data were then input into the groundwater model to determine the direction and extent of plume dispersion over a given period of time in order to develop spacing criteria and the total number of long-term groundwater monitoring wells believed required along the perimeter of proposed waste disposal boundaries.

GROUNDWATER MODEL DESCRIPTION

The two-dimensional model chosen for use is called PLUME and is available in the Monitoring Network Design Package, MAP, authored by Golder Associates, Inc. (1992) and available through the International Ground Water Modeling Center at the Colorado School of Mines. This model was chosen because it provides a reasonable and readily available model for estimating groundwater plume dispersion independent of linear flow direction.

Mathematically stated it is:

$$C(x,y,t) = (C_o/4)\, e[(xv/2D_x)[1-(1+4kD_x/v^2)^{1/2}]]\ \mathrm{erfc}[[x-vt(1+4kD_x/v^2)^{1/2}]/2(D_xt)^{1/2}]$$
$$[\mathrm{erf}[(y+Y/2)/2(D_Yx/v)^{1/2}]-\mathrm{erf}[(y-Y/2)/2(D_Yx/v)^{1/2}]]$$

Where,

- $C(x,y,t)$ = target downgradient contaminant concentration. The value used was set at one-one thousandth (0.001) of the concentration at the point of release.

- C_o = the concentration of the contaminant at the point of release. This value is 1000x the downgradient contaminant concentration. For example, if an initial chloride concentration of 3,000 mg/l is used, then the target downgradient concentration is equal to 3 mg/l, which is within generally accepted laboratory PQLs.
- k = the first-order radioactive decay constant. A conservative value of zero was used in the analysis because no diminution of the source is assumed.
- erfc = complimentary error function
- x = distance downgradient from the release. This value is generated by the software to determine the shape and dimensions of the plume.
- v = average contaminant velocity. The contaminant velocity is calculated as the groundwater velocity divided by the retardation factor (R). Generally, mobile tracers like chloride will flow at the same rate as groundwater and will not be retarded. Therefore, a conservative value of one (1) was used for R and average contaminant velocity equals groundwater velocity. The averaged annual groundwater velocity is taken as the sum of the twelve monthly displacements, which then defines the major components of the resultant vector used to determine the dispersion coefficients. For Cells 1 and 2, an average yearly velocity of 14.54 feet (1.21 feet per month) was determined (Table 2a). For Cells 3 and 4, an average yearly velocity of 12.16 feet (1.0 foot per month) was determined (Table 2b).
- D_x = longitudinal dispersion coefficient. This is a constant used to model spreading of the wave front in the direction of flow. It is derived by using a coefficient times the average monthly velocity in the principal direction of flow for each of the twelve months of data collection. By projecting each monthly change in velocity and principal flow direction as a resultant vector, an estimate of the longitudinal dispersion is determined using one standard deviation divided by the average monthly velocity along the primary direction of flow. Tables 2a and 2b summarizes these calculations for both the Cell 1-2 and Cell 3-4 areas.
- t = time (in months) of continuous leakage from the defect. A value of 528 months or 44 years was used. This time period is roughly equivalent to the life expectancy of the UWL plus a 20-year closure-post closure time period.
- erf = error function
- y = transverse distance from the defect. This value is generated by the software to determine the shape and dimensions of the plume.
- Y = the width of the source. A value of one hundred feet was used because it anticipates a seam failure in the geomembrane liner.
- D_y = transverse dispersion coefficient. This is the constant used to model spreading of the wave front at right angles to the direction of flow for this two dimensional model. The model uses a coefficient times the average velocity in the primary direction of flow to provide a variation in the velocity. By projecting each monthly vector as the velocity at right angles to the resultant vector for the twelve months of data collection, an estimate of the transverse dispersion factor is calculated as the standard deviation of those twelve projections divided by

the average monthly velocity at right angles the direction of flow. Tables 2a and 2b summarizes these calculations for both the Cell 1-2 and Cell 3-4 areas.

The illustration provided below is intended as an aide to envision how leakages will fan out (disperse) from a discrete failure point. As the contaminants move with the groundwater downgradient (X-axis), the concentration at the leading edge of the plume gets broader (Y-axis).

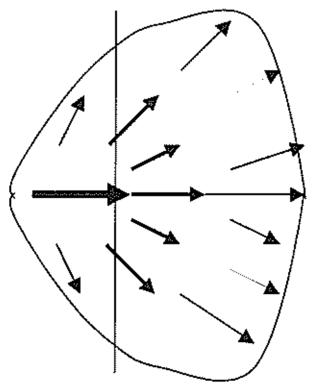


Illustration: Visualization of leak dispersion as it moves downgradient with groundwater flow.

Further documentation for the Plume model can be found in a paper authored by Wilson et al. (ref. Design of Ground-Water Monitoring Networks Using the Monitoring Efficiency Model (MEMO); GROUNDWATER, v.30, No. 6, Nov.-Dec. 1992). This reference provides a specific equation for modeling the longitudinal and transverse dispersion of a nonreactive constituent in a homogeneous medium. A copy of the reference is provided for review as Attachment 2 to this appendix.

CRITERIA FOR MODEL

As applied to the Labadie UWL, the model assumptions used were:

- Leakage from the UWL is through an imperfection in the geomembrane liner with a length of 100 feet.
- The liner failure allows leakage to move vertically until the contaminant encounters the top of the groundwater table.
- Each release is modeled as a set of particles that move within groundwater and the particles essentially serve as mathematical markers for estimating the extent of the plume.
- The contaminants stay suspended in the water column without creating density gradients, which could influence the direction of contaminant transport.

- Contaminants move by advective and dispersive components of flow, but will not diffuse due to chemical gradients.
- The vertical component of dispersion is not considered as significant as the horizontal component because contaminant concentrations are assumed to be preferentially moving parallel with groundwater flow direction. Moreover, the intended function of the well system is as a detection monitoring network and therefore the wells will be screened in the upper portion of the alluvial aquifer to ensure early detection in the event of a contaminant release, as described at the end of this report.
- The detection limit for the contaminant is sensitive enough to be reported as it moves near a given well point. This limit is set at one-one thousandth (0.001) of the actual concentration at the point of release.
- The prevailing direction of groundwater movement is equivalent to the average of the twelve monthly directional vectors noted for each area in Attachment 1.
- The model uses no loss or gain of the solute mass due to geochemical reactions following a release, including organic reactions. Therefore, both the first order decay constant and the chemical diffusion constant were set at zero.
- The modeling uses a period of diffusion of 528 months (44 years). This time period is roughly equivalent to the life expectancy of the UWL plus a 20-year closure-post closure time period.

MODEL APPLICATION AND WELL SPACING

The application of the PLUME model to determine an appropriate spacing for the groundwater monitoring network required input values for velocity, transverse dispersivity, longitudinal dispersivity, and time (Tables 2a and 2b). The PLUME software then uses these data to generate a scaled, 2-dimensional plot for each of the four phases showing three contours representing concentrations of one-tenth (0.1), one-hundredth (0.01), and one-one thousandth (0.001) of the concentration at the point of entry into the groundwater (Attachment 3). The innermost contour around the source represents the highest concentration (10 percent of source concentration), the middle contour represents one percent of the source concentration, and the outermost contour represents one-tenth of a percent of the source concentration.

Once the plots were developed, a series of overlays were made and superimposed on a map of the site and oriented along the primary axis of flow as determined from the average of the monthly longitudinal flow vectors presented in Tables 2a and 2b. The origin of the plots (i.e. release point) was established as close to the edge of proposed waste boundaries as practicable. The overlays were then manipulated so that points of intersection were attained at the 0.001 contour interval. Those points of intersection along the downgradient sides of the proposed UWL were then considered the minimum spacing whereupon early detection of a release could be determined. The modeling effort resulted in the identification of 21 downgradient well locations (Figure 2). Beginning at the northwestern corner of the site, well spacing along the northern edge of Cell 2 is approximately

450 feet (well ID #'s MW-1 through MW-4). Well spacing between MW-5 and MW-7 is wider since these wells are farther from the waste disposal limits of Cell 2 due to the location of Pond 2. Well spacing along the eastern perimeter of Cell 3 is approximately 330 feet (well ID #'s MW-7 through MW-17). The spacing was increased along the southern edge of Cell 3 to avoid well placement impacting jurisdictional areas (well ID # MW-18). Well spacing along the eastern perimeter of Cell 4 is between approximately 330 and 500 feet (well ID #'s MW-19 through MW-21). Table 3 summarizes location information for the proposed downgradient wells. The table also describes a temporary monitoring well (TMW-1) that will serve as a "sentry" for the initial operations within Cell 1. It will be located immediately east (downgradient) of Cell 1 within the utility pipeline corridor (Figure 2) and used to supplement water quality data derived from the permanent downgradient wells located along the eastern perimeter of Cell 3. TMW-1 will be removed as soon as Cell 3 becomes operational.

For those areas considered hydraulically upgradient of proposed waste boundaries, which includes the western and southwestern perimeter of the site, seven additional wells are proposed to complete the groundwater monitoring network. These wells are identified as MW-22 through MW-28 on Figure 2. Spacing is greater for these wells than it is for the downgradient wells. It is widest along the west-central perimeter of the site (1,400 feet) but systematically decreases to less than 1,000 feet toward the northwestern and southeastern parts of the site (i.e. where downgradient conditions begin). Table 3 summarizes location information for the proposed upgradient wells.

WELL SCREEN PLACEMENT

A determination of well screen placement is primarily dependent upon two inter-related factors. One, the well screen should be placed at a level that ensures to the extent practicable that the entire screen interval remains fully saturated, even during periods of low river stage of the Missouri River. Two, the top of the well screen should be placed at a depth as shallow as practicable to provide early detection of contaminants that may disperse within the upper part of the water table. Lithologic composition and monitoring well construction constraints also have to be considered in the positioning of well screen depth.

As documented in the DSI Report for this facility, the chief control on water table elevations is the Missouri River. As the Missouri River stage increases, it is accompanied by a corresponding, progressive rise in groundwater levels in a northwest to southeast direction. Conversely, as the Missouri River stage decreases, it is accompanied by a progressive drop in groundwater levels that, if sustained, eventually reverses the overall direction of groundwater movement back to the northwest. While these fluctuations were apparent throughout the site, they become more pronounced to the northwest, as the Missouri River is approached. Piezometric data from that area document fluctuations in excess of eight feet whereas fluctuations in the southeastern part of the site are between three and four feet. In light of these data, a single elevation for the placement of well screens cannot be used. Rather, well screen elevations vary and become progressively deeper in a northwesterly direction.

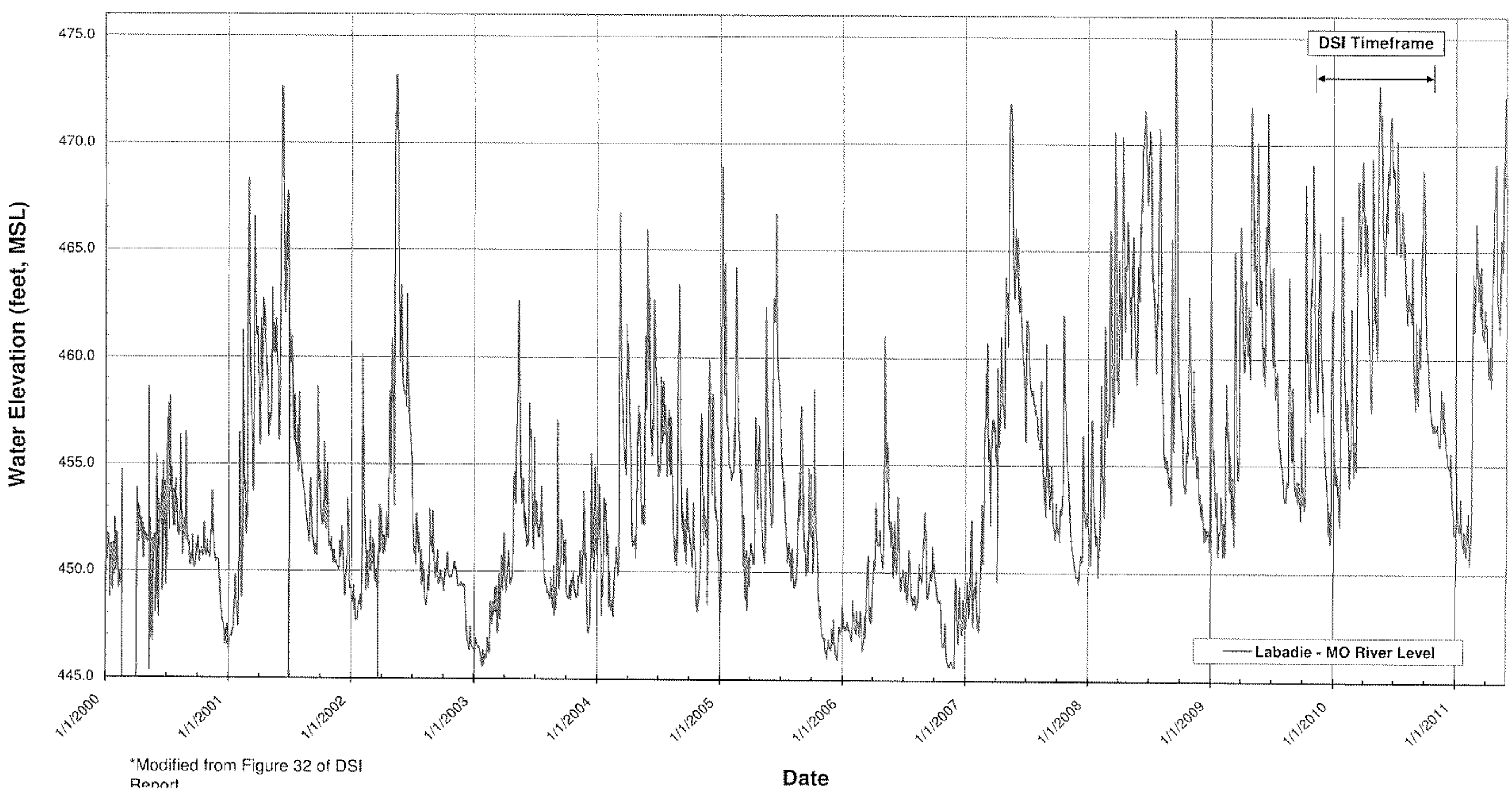
Review of the Missouri River data presented in the DSI report suggests that the 12-month timeframe during which piezometric monitoring was in effect at the site (December 2009 to November 2010) coincided with a period of relatively high Missouri River elevations (between 451 and 473 feet). Consequently, it was necessary to examine the historical data presented in that report to determine a low river elevation. Inspection of that data, which is included here for reference (Figure 1), indicates that 445 feet approximates the lowest recorded river elevation during the preceding ten-year timeframe.

Using this documented low river elevation as a point of intersection, linear regression plots were made showing the projected height of the water table surface at select points centered along the primary northwest-southeast axis of flow beneath the proposed UWL facility. Monthly water level data from a total of 14 piezometers installed during the DSI were used in the analysis (Attachment 4). The results show that the water table surface would be expected to drop to 454.5 feet in the extreme northwestern part of the facility near the location of former piezometer P-9 (Figure 2). Thus, a monitoring well in that area would need to have its well screen set at an elevation no higher than approximately 454 feet to ensure full saturation during low river stage. As the primary axis of flow is traced southeastward, the projected point of intersection of the water table surface with low river stage (445 feet) gradually increases and lines drawn perpendicular to the primary axis of flow in one-foot increments define the maximum well screen elevation throughout the remainder of the facility. Note that these incremental boundaries define regions where projected water table elevations remain approximately 0.5 feet above the maximum well screen height. Based on this analysis, anticipated well depths (assuming 10-ft well screens) for the proposed groundwater monitoring well system layout are summarized in Table 3.

Figures

Ameren Missouri Labadie Energy Center
Proposed Utility Waste Landfill
Construction Permit Application

Missouri River Historical Data (2000-2011)
Figure 1*



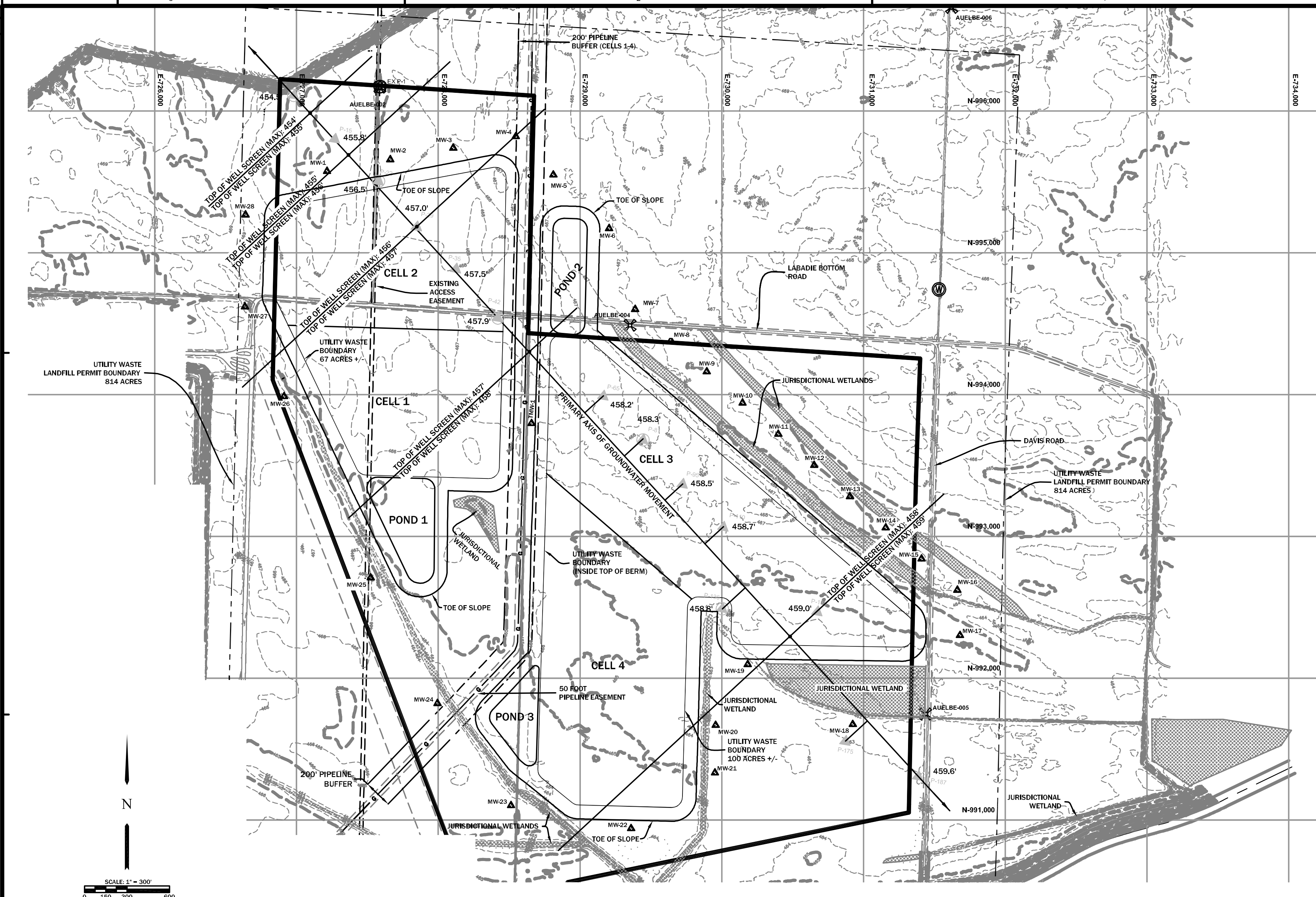
*Modified from Figure 32 of DSI Report

PRINT DIST.

REVISIONS

REV.	W.O.	SYM

M:\Share\CADDFiles\AMEREN UE\LABADIE\CONSTRUCTION PERMIT\2012 DRAWINGS\GROUNDWATER 06 2012\WELL LOCATIONS 10 12\APP X SIMAP 2012.dwg, SHEET 3, 1/7/2013 4:13:27 PM



SURVEY MONUMENTS

MONUMENT ID	NORTHING	EASTING	ELEVATION
AUELBE-001	990484.82	726569.81	467.19
AUELBE-002	996166.50	727588.30	470.70
AUELBE-003	989921.39	728508.32	467.59
AUELBE-004	994487.78	729353.29	467.02
AUELBE-005	991746.97	731438.29	462.78
AUELBE-006	996729.00	731621.70	467.67

Missouri State Plane Coordinate System Datum:
Horizontal Datum NAD 1983;
Vertical Datum NAVD 1988

CALL BEFORE YOU DIG - DRILL - BLAST
1-800-344-7483
(TOLL FREE)
MISSOURI ONE CALL SYSTEM, INC.

PERMIT DRAWINGS - NOT FOR CONSTRUCTION

THE GEOLOGIST WHOSE SIGNATURE AND PERSONAL SEAL APPEAR HEREON ASSUMES RESPONSIBILITY ONLY FOR WHAT APPEARS ON THIS PAGE AND DISCLAIMS PURSUANT TO SECTION 327.411 RSMO) ANY RESPONSIBILITY FOR ALL OTHER PLANS, SPECIFICATIONS, ESTIMATES, REPORTS OR OTHER DOCUMENTS OR INSTRUMENTS NOT SEALED BY THE UNDERSIGNED ENGINEER RELATING TO OR INTENDED TO BE USED FOR ANY PART OR PARTS OF THE PROJECT TO WHICH THIS PAGE REFERS.

REITZ & JENS, INC. CONSULTING ENGINEERS
1055 CORPORATE SQUARE DRIVE ST. LOUIS, MISSOURI 63132

GREDELL Engineering Resources, Inc. ENVIRONMENTAL ENGINEERING

PREPARED FOR Ameren MISSOURI

DRAWN W.J.A. (G.E.R.)	FIGURE 2, APPENDIX X PROPOSED UTILITY LANDFILL WELL SCREEN ELEVATION SUMMARY
CHKD. R.L.R. (G.E.R.)	
SUPV. T.R.G. (G.E.R.)	
APPD. T.R.G. (G.E.R.)	LOCATION 001009 — LABADIE ENERGY CENTER — CLASS 02010
Ameren MISSOURI — ST. LOUIS, MISSOURI	DECEMBER 18, 2012 — REV.

Tables

Construction Permit Application
Proposed Utility Waste Landfill
Ameren Missouri Labadie Energy Center
Franklin County, Missouri

Calculated Groundwater Velocities by Month
Table 1

Cells 1 and 2			
December 21, 2009			
Hydraulic Conductivity (K)	Cells 1 & 2 Site K_{avg} = 5.002 x 10^{-2} ft/min		
Hydraulic Gradient (*i*)	i = 0.0007 ft/ft		
Effective Porosity (n)	0.30	0.35	0.40
Velocity (=Ki/n) (ft/yr)	61	53	46
January 25, 2010			
Hydraulic Conductivity (K)	Cells 1 & 2 Site K_{avg} = 5.002 x 10^{-2} ft/min		
Hydraulic Gradient (*i*)	i = 0.0008 ft/ft		
Effective Porosity (n)	0.30	0.35	0.40
Velocity (=Ki/n) (ft/yr)	70	60	53
February 16, 2010			
Hydraulic Conductivity (K)	Cells 1 & 2 Site K_{avg} = 5.002 x 10^{-2} ft/min		
Hydraulic Gradient (*i*)	i = 0.0003 ft/ft		
Effective Porosity (n)	0.30	0.35	0.40
Velocity (=Ki/n) (ft/yr)	26	23	20
March 16, 2010			
Hydraulic Conductivity (K)	Cells 1 & 2 Site K_{avg} = 5.002 x 10^{-2} ft/min		
Hydraulic Gradient (*i*)	i = 0.0008 ft/ft		
Effective Porosity (n)	0.30	0.35	0.40
Velocity (=Ki/n) (ft/yr)	70	60	53
April 13, 2010			
Hydraulic Conductivity (K)	Cells 1 & 2 Site K_{avg} = 5.002 x 10^{-2} ft/min		
Hydraulic Gradient (*i*)	i = 0.0002 ft/ft		
Effective Porosity (n)	0.30	0.35	0.40
Velocity (=Ki/n) (ft/yr)	18	15	13
May 11, 2010			
Hydraulic Conductivity (K)	Cells 1 & 2 Site K_{avg} = 5.002 x 10^{-2} ft/min		
Hydraulic Gradient (*i*)	i = 0.0001 ft/ft		
Effective Porosity (n)	0.30	0.35	0.40
Velocity (=Ki/n) (ft/yr)	9	8	7
June 8, 2010			
Hydraulic Conductivity (K)	Cells 1 & 2 Site K_{avg} = 5.002 x 10^{-2} ft/min		
Hydraulic Gradient (*i*)	i = 0.0004 ft/ft		
Effective Porosity (n)	0.30	0.35	0.40
Velocity (=Ki/n) (ft/yr)	35	30	26
July 7, 2010			
Hydraulic Conductivity (K)	Cells 1 & 2 Site K_{avg} = 5.002 x 10^{-2} ft/min		
Hydraulic Gradient (*i*)	i = 0.0004 ft/ft		
Effective Porosity (n)	0.30	0.35	0.40
Velocity (=Ki/n) (ft/yr)	35	30	26
August 5, 2010			
Hydraulic Conductivity (K)	Cells 1 & 2 Site K_{avg} = 5.002 x 10^{-2} ft/min		
Hydraulic Gradient (*i*)	i = 0.0002 ft/ft		
Effective Porosity (n)	0.30	0.35	0.40
Velocity (=Ki/n) (ft/yr)	18	15	13
September 8, 2010			
Hydraulic Conductivity (K)	Cells 1 & 2 Site K_{avg} = 5.002 x 10^{-2} ft/min		
Hydraulic Gradient (*i*)	i = 0.0001 ft/ft		
Effective Porosity (n)	0.30	0.35	0.40
Velocity (=Ki/n) (ft/yr)	9	8	7
October 7, 2010			
Hydraulic Conductivity (K)	Cells 1 & 2 Site K_{avg} = 5.002 x 10^{-2} ft/min		
Hydraulic Gradient (*i*)	i = 0.0001 ft/ft		
Effective Porosity (n)	0.30	0.35	0.40
Velocity (=Ki/n) (ft/yr)	9	8	7
November 4, 2010			
Hydraulic Conductivity (K)	Cells 1 & 2 Site K_{avg} = 5.002 x 10^{-2} ft/min		
Hydraulic Gradient (*i*)	i = 0.0003 ft/ft		
Effective Porosity (n)	0.30	0.35	0.40
Velocity (=Ki/n) (ft/yr)	26	23	20

Cells 3 and 4			
December 21, 2009			
Hydraulic Conductivity (K)	Cells 3 & 4 Site K_{avg} = 5.567 x 10^{-2} ft/min		
Hydraulic Gradient (*i*)	i = 0.0003 ft/ft		
Effective Porosity (n)	0.30	0.35	0.40
Velocity (=Ki/n) (ft/yr)	29	25	22
January 25, 2010			
Hydraulic Conductivity (K)	Cells 3 & 4 Site K_{avg} = 5.567 x 10^{-2} ft/min		
Hydraulic Gradient (*i*)	i = 0.0004 ft/ft		
Effective Porosity (n)	0.30	0.35	0.40
Velocity (=Ki/n) (ft/yr)	39	33	29
February 16, 2010			
Hydraulic Conductivity (K)	Cells 3 & 4 Site K_{avg} = 5.567 x 10^{-2} ft/min		
Hydraulic Gradient (*i*)	i = 0.0001 ft/ft		
Effective Porosity (n)	0.30	0.35	0.40
Velocity (=Ki/n) (ft/yr)	10	8	7
March 16, 2010			
Hydraulic Conductivity (K)	Cells 3 & 4 Site K_{avg} = 5.567 x 10^{-2} ft/min		
Hydraulic Gradient (*i*)	i = 0.0005 ft/ft		
Effective Porosity (n)	0.30	0.35	0.40
Velocity (=Ki/n) (ft/yr)	49	42	37
April 13, 2010			
Hydraulic Conductivity (K)	Cells 3 & 4 Site K_{avg} = 5.567 x 10^{-2} ft/min		
Hydraulic Gradient (*i*)	i = 0.0003 ft/ft		
Effective Porosity (n)	0.30	0.35	0.40
Velocity (=Ki/n) (ft/yr)	29	25	22
May 11, 2010			
Hydraulic Conductivity (K)	Cells 3 & 4 Site K_{avg} = 5.567 x 10^{-2} ft/min		
Hydraulic Gradient (*i*)	i = 0.0002 ft/ft		
Effective Porosity (n)	0.30	0.35	0.40
Velocity (=Ki/n) (ft/yr)	20	17	15
June 8, 2010			
Hydraulic Conductivity (K)	Cells 3 & 4 Site K_{avg} = 5.567 x 10^{-2} ft/min		
Hydraulic Gradient (*i*)	i = 0.0004 ft/ft		
Effective Porosity (n)	0.30	0.35	0.40
Velocity (=Ki/n) (ft/yr)	39	33	29
July 7, 2010			
Hydraulic Conductivity (K)	Cells 3 & 4 Site K_{avg} = 5.567 x 10^{-2} ft/min		
Hydraulic Gradient (*i*)	i = 0.0004 ft/ft		
Effective Porosity (n)	0.30	0.35	0.40
Velocity (=Ki/n) (ft/yr)	39	33	29
August 5, 2010			
Hydraulic Conductivity (K)	Cells 3 & 4 Site K_{avg} = 5.567 x 10^{-2} ft/min		
Hydraulic Gradient (*i*)	i = 0.0003 ft/ft		
Effective Porosity (n)	0.30	0.35	0.40
Velocity (=Ki/n) (ft/yr)	29	25	22
September 8, 2010			
Hydraulic Conductivity (K)	Cells 3 & 4 Site K_{avg} = 5.567 x 10^{-2} ft/min		
Hydraulic Gradient (*i*)	i = 0.0001 ft/ft		
Effective Porosity (n)	0.30	0.35	0.40
Velocity (=Ki/n) (ft/yr)	10	8	7
October 7, 2010			
Hydraulic Conductivity (K)	Cells 3 & 4 Site K_{avg} = 5.567 x 10^{-2} ft/min		
Hydraulic Gradient (*i*)	i = 0.0002 ft/ft		
Effective Porosity (n)	0.30	0.35	0.40
Velocity (=Ki/n) (ft/yr)	20	17	15
November 4, 2010			
Hydraulic Conductivity (K)	Cells 3 & 4 Site K_{avg} = 5.567 x 10^{-2} ft/min		
Hydraulic Gradient (*i*)	i = 0.0001 ft/ft		
Effective Porosity (n)	0.30	0.35	0.40
Velocity (=Ki/n) (ft/yr)	10	8	7

Notes

1. Hydraulic gradient values derived using 3-point methods for 12 month monitoring period 12/09-11/10.

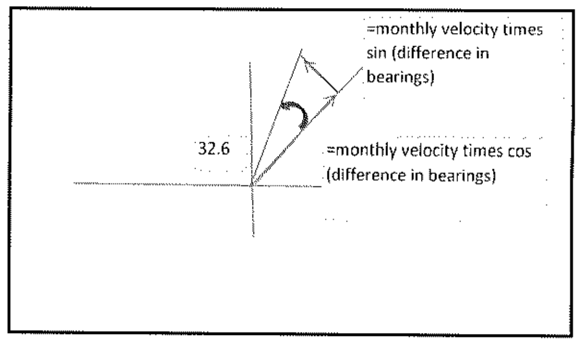
Construction Permit Application
Proposed Utility Waste Landfill
Ameren Missouri Labadie Energy Center
Franklin County, Missouri

Plume Definition for Cells 1 and 2
Table 2a

Cells 1 & 2	Month/Year	Azimuth	Hydraulic Gradient	Velocity (ft/yr)	Velocity (ft/month)	East Component =x	North Component= y	Resultant East Vector	Resultant North Vector		Hydraulic Conductivity, *.01 ft/yr		delta angle	Cos (delta angle)	Sin (delta angle)	Monthly Velocity *Cos(delta angle)	Monthly Velocity *Sin(delta angle)
	Dec-09	-74	0.0007	53	4.38	-4.21	1.21	-4.21	1.21		4.642		-106.65	-0.286	-0.958	-1.255	-4.198
	January-10	20	0.0008	60	5.01	1.71	4.71	-2.50	5.91		6.324		-12.65	0.976	-0.219	4.886	-1.097
	February-10	-51	0.0003	23	1.88	-1.46	1.18	-3.96	7.10		4.482		-83.65	0.111	-0.994	0.208	-1.866
	March-10	63	0.0008	60	5.01	4.46	2.27	0.50	9.37		4.561		30.35	0.863	0.505	4.322	2.531
	April-10	94	0.0002	15	1.25	1.25	-0.09	1.75	9.28		5.00225	Average	61.35	0.479	0.878	0.600	1.099
	May-10	17	0.0001	8	0.63	0.18	0.60	1.94	9.88		Effective		-15.65	0.963	-0.270	0.603	-0.169
	June-10	102	0.0004	30	2.50	2.45	-0.52	4.38	9.36		Porosity (n) =	0.35	69.35	0.353	0.936	0.883	2.343
	July-10	115	0.0004	30	2.50	2.27	-1.06	6.65	8.30				82.35	0.133	0.991	0.333	2.482
	August-10	94	0.0002	15	1.25	1.25	-0.09	7.90	8.21				61.35	0.479	0.878	0.600	1.099
	September-10	-22	0.0001	8	0.63	-0.23	0.58	7.67	8.79				-54.65	0.579	-0.816	0.362	-0.511
	October-10	48	0.0001	8	0.63	0.47	0.42	8.13	9.21				15.35	0.964	0.265	0.604	0.166
	November-10	-57	0.0003	23	1.88	-1.58	1.02	6.56	10.24				-89.65	0.006	-1.000	0.012	-1.878
						Average velocity, ft/yr =		12.16	57.35								
						Bearing, Northeast=			32.65								

Average	38.5	0.00037	
Standard Deviation	61.9	0.00026	
Error in Mean	17.9	0.00008	0.1572432

Average monthly velocity	1.013	0.000
Standard Deviation in monthly velocity	1.767	2.059
Average yearly velocity	12.157	0.000
Alpha	1.744	2.032
	Longitudinal	Transverse



Construction Permit Application
Proposed Utility Waste Landfill
Ameren Missouri Labadie Energy Center
Franklin County, Missouri

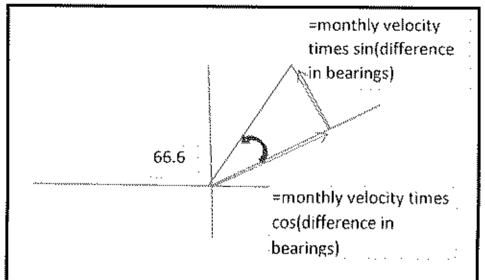
Plume Definition for Cells 3 and 4
Table 2b

Cells 3 & 4	Month/Year	Azimuth	Hydaulic Gradient	Velocity (ft/yr)	Velocity (ft/month)	East Component= x	North Component= y	Resultant East Vector	Resultant North Vector		Hydraulic Conductivity, *.01 ft/yr		delta angle	Cos (delta angle)	Sin (della angle)	Monthly Velocity *Cos(delta angle)	Monthly Velocity *Sin(delta angle)
	Dec-09	-70	0.0003	25	2.08	-1.96	0.71	-1.96	0.71		4.642		-136.58	-0.726	-0.687	-1.513	-1.432
	January-10	3	0.0004	33	2.75	0.14	2.75	-1.81	3.46		6.324		-63.58	0.445	-0 896	1.224	-2.463
	February-10	-11	0.0001	8	0.67	-0.13	0.65	-1.94	4.11		4.482		-77.58	0.215	-0 977	0.143	-0.651
	March-10	63	0.0005	42	3.50	3.12	1.59	1.18	5.70		4.561		-3.58	0.998	-0.062	3.493	-0.219
	April-10	84	0.0003	25	2.08	2.07	0.22	3.25	5.92		5.00225	Average	17.42	0.954	0.299	1.988	0.624
	May-10	70	0.0002	17	1.42	1.33	0.48	4.58	6.40				3.42	0.998	0.060	1.414	0.084
	June-10	105	0.0004	33	2.75	2.66	-0.71	7.24	5.69		Effective		38.42	0.784	0.621	2.155	1.709
	July-10	109	0.0004	33	2.75	2.60	-0.90	9.84	4.80		Porosity (n)=	0.35	42.42	0.738	0.675	2.030	1.855
	August-10	95	0.0003	25	2.08	2.08	-0.18	11.91	4.62				28.42	0.880	0.476	1.832	0.991
	September-10	47	0.0001	8	0.67	0.49	0.45	12.40	5.07				-19.58	0.942	-0.335	0.628	-0.223
	October-10	81	0.0002	17	1.42	1.40	0.22	13.80	5.29				14.42	0.969	0.249	1.372	0.353
	November-10	-43	0.0001	8	0.67	-0.45	0.49	13.34	5.78				-109.58	-0.335	-0.942	-0.223	-0.628

Average velocity, ft/yr =	14.54	23.42			
Bearing, Northeast=	66.58				

Average	54.8	0.00028	
Standard Deviation	50.5	0.00014	
Error in Mean	14.6	0.00004	0.1280281

Average monthly velocity	1.212	0.000
Standard Deviation in monthly velocity	1.307	1.239
Average yearly velocity	14.543	0.000
Alpha	1.078	1.023
	Longitudinal	Transverse



Construction Permit Application
Proposed Utility Waste Landfill
Ameren Missouri Labadie Energy Center
Franklin County, Missouri

Groundwater Monitoring Well Summary
Table 3

Monitoring Well Designation	Upgradient or Downgradient	Northing	Easting	Ground Surface Elevation (approx.)	Well Depth (feet, bgs)	Screen Length (feet)	Top of Screen Interval Elevation (approx.)
MW-1	DG	995574	727216	470	25	10	455
MW-2	DG	995656	727662	469	23	10	456
MW-3	DG	995738	728106	468	22	10	456
MW-4	DG	995819	728547	468	21	10	457
MW-5	DG	995548	728812	468	21	10	457
MW-6	DG	995171	729206	467	20	10	457
MW-7	DG	994600	729389	467	19	10	458
MW-8	DG	994380	729642	466	18	10	458
MW-9	DG	994160	729895	465	17	10	458
MW-10	DG	993940	730147	466	18	10	458
MW-11	DG	993720	730400	466	18	10	458
MW-12	DG	993500	730653	465	17	10	458
MW-13	DG	993280	730905	465	17	10	458
MW-14	DG	993060	731158	464	16	10	458
MW-15	DG	992840	731410	464	15	10	459
MW-16	DG	992620	731663	464	15	10	459
MW-17	DG	992302	731681	465	16	10	459
MW-18	DG	991674	730925	462	13	10	459
MW-19	DG	992096	730184	463	15	10	458
MW-20	DG	991668	729958	463	14	10	459
MW-21	DG	991332	729953	463	14	10	459
MW-22	UG	990940	729361	464	15	10	459
MW-23	UG	991102	728514	465	17	10	458
MW-24	UG	991822	727995	465	17	10	458
MW-25	UG	992708	727524	466	18	10	458
MW-26	UG	993986	726913	467	20	10	457
MW-27	UG	994619	726637	468	22	10	456
MW-28	UG	995267	726640	469	24	10	455
TMW-1	DG	993795	728659	467	19	10	458

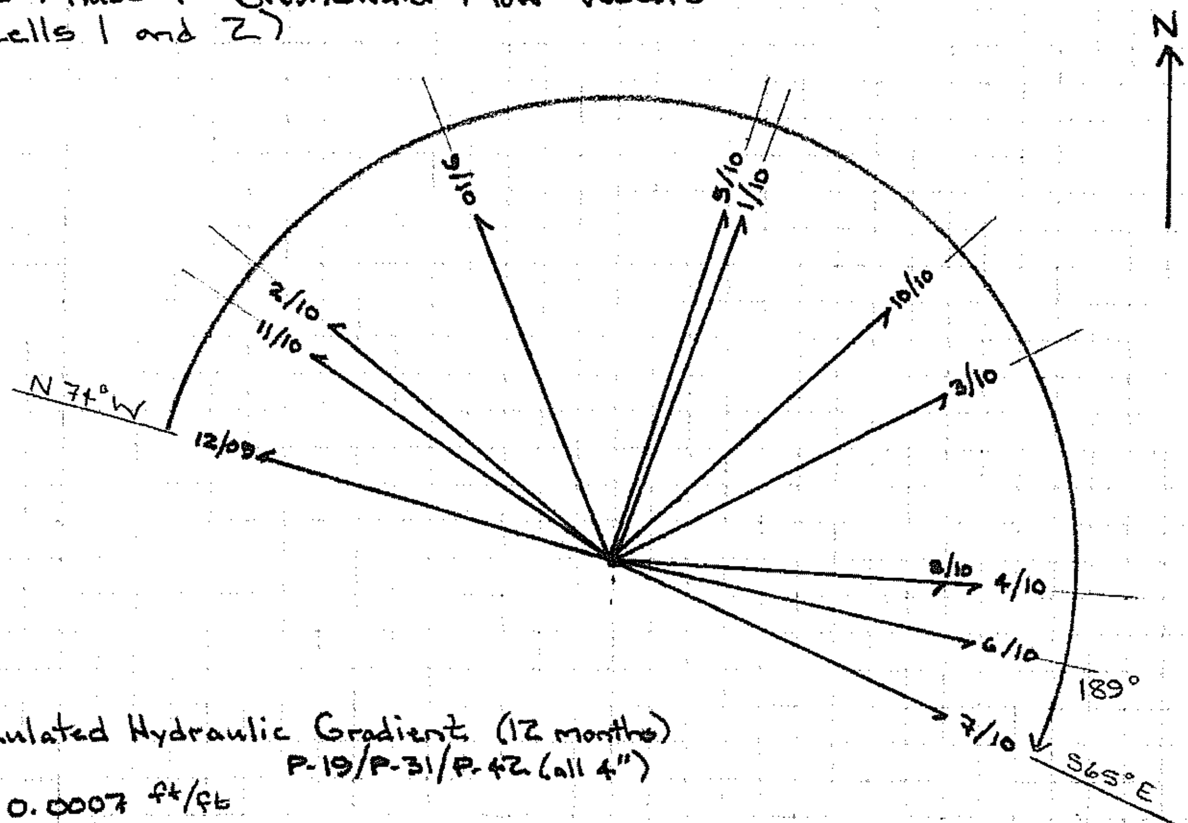
Attachment 1

Baseline Hydrologic Data Notes

GREDELL Engineering Resources, Inc.
ENVIRONMENTAL ENGINEERING — LAND - AIR - WATER
Telephone (573) 659-9078

Date: 5-25-12	Page No: 1 of 1
Client: Reitz & Jens	
Prepared By: M.C. Carlson	Checked By: MCC
Project: Labadie Construction Permit	
Subject: Groundwater Monitoring System	

1. "Old Phase 4" Groundwater Flow Vectors (Cells 1 and 2)



2. Calculated Hydraulic Gradient (12 months)
P-19/P-31/P-42 (all 4")

12/09	1.	0.0007 ft/ft
1/10	2.	0.0008
2/10	3.	0.0003
3/10	4.	0.0008
4/10	5.	0.0002
5/10	6.	0.0001
6/10	7.	0.0004
7/10	8.	0.0004
8/10	9.	0.0002
9/10	10.	0.0001
10/10	11.	0.0001
11/10	12.	0.0003

Avg: 0.00037 ft/ft

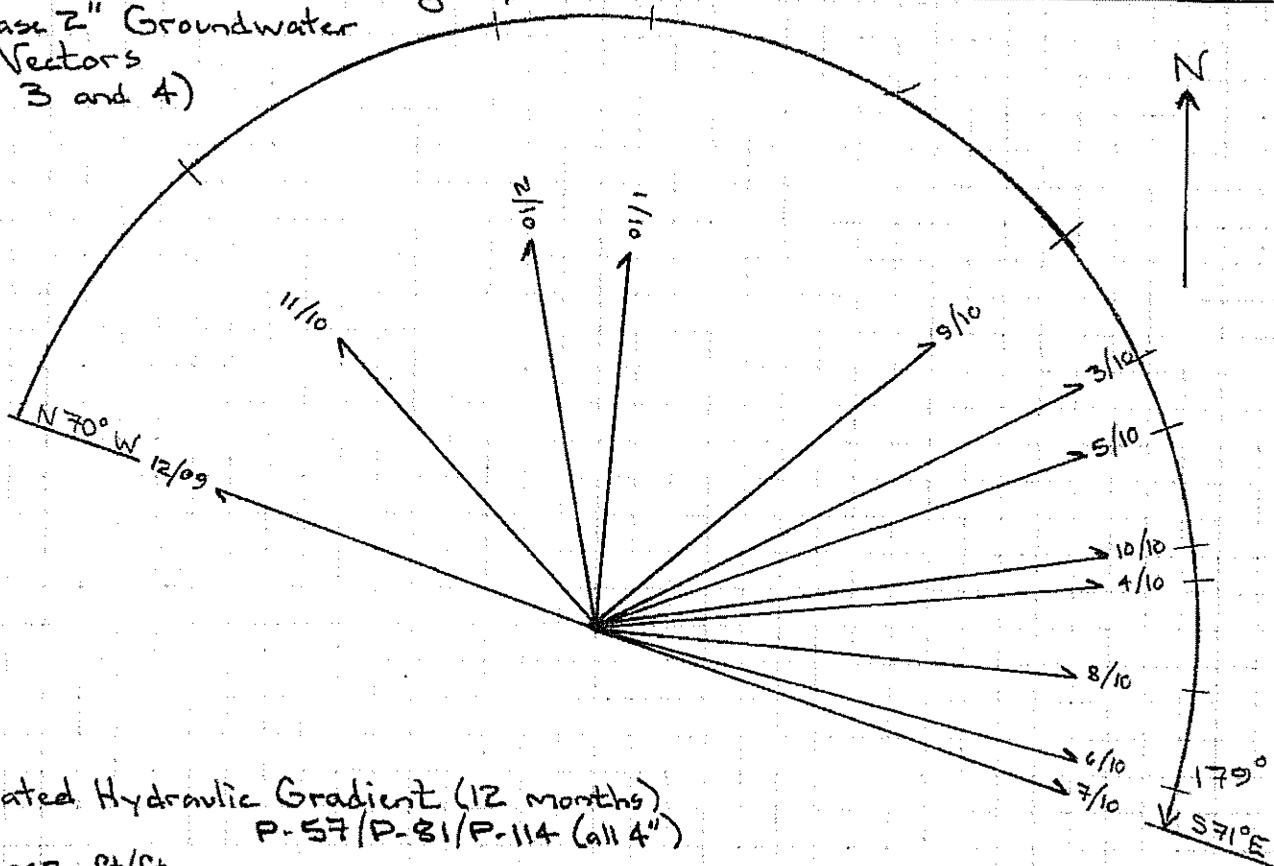
3. Calculated K values from w/in Old Phase 4 realignment area (from DSI)

1. P-19 : 4.642×10^{-2} ft/min
2. P-22 : 6.324×10^{-2} "
3. P-31 : 4.482×10^{-2} "
4. P-42 : 4.561×10^{-2} "

Avg: 5.002×10^{-2} ft/min

GREDELL Engineering Resources, Inc. ENVIRONMENTAL ENGINEERING — LAND - AIR - WATER — Telephone (573) 659-9078	Date: 5-25-12	Page No: 1 of 1
	Client: Reitz + Jens	
Prepared By: M.C. Carlson / Checked By: MCC	Project: Labadie Construction Permit	
Subject: Groundwater Monitoring System		

1. "Old Phase 2" Groundwater Flow Vectors (Cells 3 and 4)



2. Calculated Hydraulic Gradient (12 months) P-57/P-81/P-114 (all 4")

1. 0.0003 ft/ft
2. 0.0004
3. 0.0001
4. 0.0005
5. 0.0003
6. 0.0002
7. 0.0004
8. 0.0004
9. 0.0003
10. 0.0001
11. 0.0002
12. 0.0001

Avg: 0.00028 ft/ft

3. Calculated K values from w/in Old Phase 2 (Cells 3 and 4) Area (from DSI):

1. P-53: 2.444×10^{-2} ft/min
2. P-57: 4.737×10^{-2} ft/min
3. P-81: 7.184×10^{-2} ft/min
4. P-85: 7.744×10^{-2} ft/min
5. P-114: 5.724×10^{-2} ft/min

Avg: 5.567×10^{-2} ft/min

Attachment 2

Wilson, C.R., Einberger, C.M., Jackson, R.L., and Mercer, R.B. (1992) "*Design of Ground-Water Monitoring Networks Using the Monitoring Efficiency Model (MEMO)*"; *GROUNDWATER*, V. 30, No. 6, Nov.-Dec.

Computer Notes

Design of Ground-Water Monitoring Networks Using the Monitoring Efficiency Model (MEMO)

by Charles R. Wilson[a], Carl M. Einberger[a], Ronald L. Jackson[b], and Richard B. Mercer[b]

Abstract

An analytical Monitoring Efficiency Model (MEMO) has been developed to assist in the design of monitoring well networks. The method simulates the migration of hypothetical contaminant plumes from a site and quantifies the efficiency of alternative well network designs in detecting the plumes. The computed detection efficiency provides a basis for optimizing the design. Maps of the site showing areas from which releases would or would not be detected by a given well network are produced, providing insight into the benefits of adding, deleting, or moving specific wells.

Introduction

Ground-water monitoring is generally required by regulatory agencies at hazardous waste sites, solid waste landfills, and other sites where the potential release of chemicals to the sursurface is a concern. The goals of ground-water monitoring include verifying regulatory compliance and providing early warning of a chemical release. Although the intent of such monitoring is to protect human health and the environment, a clear approach for measuring the degree of protection offered by a monitoring system has not been well established. A Monitoring Efficiency Model (MEMO) presented in this paper provides a method for quantifying the efficiency of a given monitoring well network in detecting a potential chemical release, and graphically depicting areas where releases would not be detected. The method is an extension and refinement of a physical design approach suggested by Massmann, Freeze and others (Massmann and Freeze, 1987; Freeze et al., 1990) and Meyer and Brill (1988). It provides an easily understood way to adjust and optimize the network design to site and waste conditions, and to quantify the degree of protection for public and regulatory review.

[a]Golder Associates Inc., Redmond, Washington 98052.

[b]Westinghouse Hanford Company, Richland, Washington 99352.

Received June 1991, revised March 1992, accepted April 1992.

Discussion open until May 1, 1993.

General Approach

The technique developed in this paper quantifies the monitoring efficiency of a given monitoring well network by determining areas within a potential chemical source area where a chemical release would or would not be detected by the monitoring well network. Monitoring efficiency is defined as the ratio of the area of detection to the total area of the site. For example, a determined efficiency of 90 percent predicts that releases occurring over 90 percent of the site would be detected by the monitoring wells, and releases occurring over 10 percent of the site would not be detected.

The monitoring efficiency solution is determined in the following manner. A grid of potential chemical source points is defined within the potential source area. At each potential source point, a contaminant plume is generated using an analytical contaminant transport solution. If the plume is intersected by a monitoring well before it migrates beyond a specified boundary, the source point is considered to be detected. After checking each grid point to determine whether the plume released from that point is detected or not detected, the monitoring efficiency is calculated, and a map showing areas from which chemical releases would not be detected is produced.

An illustration of the application of MEMO is shown in Figure 1. Critical geometric elements are the potential source area(s), a grid of potential source points, the buffer zone boundary, and monitoring well locations. The buffer zone boundary is defined as the limit to which a plume can migrate before it should be detected, and serves as the plume migration limit for "early warning" detection of a contami-

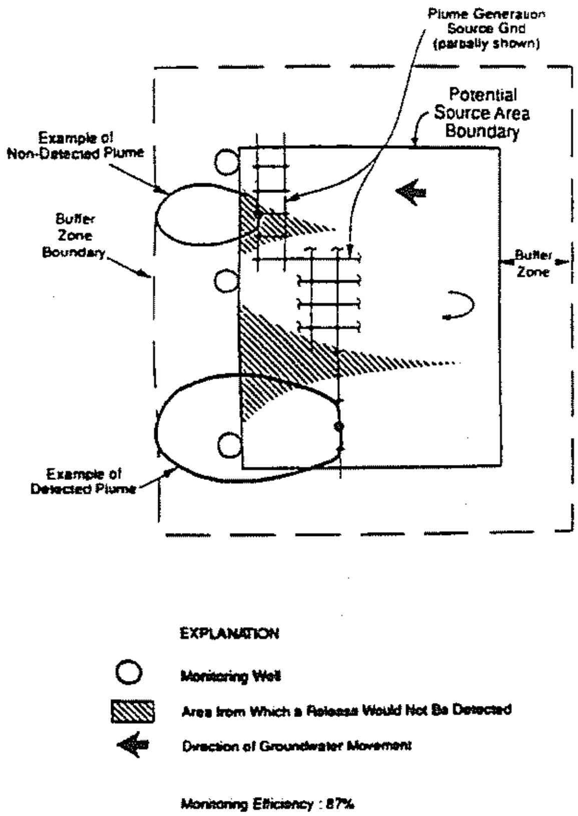


Fig. 1. Illustration of MEMO results.

nant release. A plume that moves beyond this limit without detection by a monitoring well is considered to be undetected. Figure 1 shows examples of detected and nondetected plumes and two distinct nondetected regions defined by source grid points from which generated plumes were not detected by monitoring wells prior to passing the buffer zone boundary.

Ground-water flow and contaminant transport parameters are required to determine the plume dimensions and configuration. Specific flow and transport input requirements will depend upon the plume generation routine used in the analysis. MEMO currently uses a two-dimensional plume generation routine based on the two-dimensional analytical solution of Domenico and Robbins (1985), but the methodology incorporated into MEMO can be applied with other analytical contaminant transport solutions.

MEMO is applied using available site-specific and/or literature-based information. Multiple simulations can be performed to analyze the sensitivity of a specific problem domain to input parameters. Because MEMO is based upon a simulation of physical processes, evaluations of the adequacy of the design are determined from the physical parameters and processes governing contaminant migration, rather than upon qualitative judgments of how many wells are enough.

Plume Generation

MEMO uses a plume generation routine to compute the sizes and shapes of the plumes from each grid point. The plume generation routine currently incorporated into MEMO is based upon the two-dimensional analytical transport model presented in Domenico and Robbins (1985) and modified in Domenico (1987). This model assumes that solute is released along a continuous line source in a uniform aquifer, and predicts the concentrations that would be observed at points downstream of that source. The governing equation is:

$$C(x, y, t) = (C_o/4) \exp\{(xv/2D_x)[1 - (1 + 4kD_x/v^2)^{1/2}]\}$$
$$\text{erfc}\{[x - vt(1 + 4kD_x/v^2)^{1/2}]/2(D_x t)^{1/2}\}$$
$$\{\text{erf}[(y + Y/2)/2(D_y x/v)^{1/2}] - \text{erf}[(y - Y/2)/2(D_y x/v)^{1/2}]\}$$

where $C(x, y, t)$ = concentration at x, y, t; C_o = source concentration; x = distance downstream from the source; y = transverse distance from the source; k = first-order radioactive decay constant; Y = width of the source in the ground water; v = average contaminant velocity; D_x = longitudinal dispersion coefficient; D_y = transverse dispersion coefficient; and t = time.

The average contaminant velocity is computed as:

$$v = Ki/Rn$$

where K = hydraulic conductivity; i = hydraulic gradient; R = retardation factor; and n = effective porosity.

The dispersion coefficients are functions of the contaminant velocity, the dispersivities, the retardation factor, and the diffusion coefficient for the contaminant of interest.

$$D_x = \alpha_x v + D_m/R$$
$$D_y = \alpha_y v + D_m/R$$

where α_x = longitudinal dispersivity; α_y = transverse dispersivity; and D_m = effective molecular diffusion coefficient for the contaminant of interest.

MEMO is solved using a specified dilution contour, defined as:

$$C_{dil} = C_{ds}/C_o$$

where C_{ds} is the detection standard selected as the limiting concentration to be detected by a monitoring well, and C_o, as defined above, is the source concentration.

Assumptions of the plume generation routine include negligible vertical ground-water flow and vertical chemical transport, a uniform ground-water flow field, and a continuous line source. The assumption of a uniform flow field implies constant hydrologic and transport properties and a uniform hydraulic gradient over the length of the plume.

Significant judgment is required prior to performing MEMO simulations for a site. An evaluation of the suitability of the model assumptions presented in the previous section must be performed on a case-by-case basis. For example, it should be recognized that the plume shape predicted by the model is idealized for uniform aquifer conditions, and the heterogeneities present at field sites may cause plumes to assume irregular shapes. As with any model, care must be taken that erroneous conclusions are not made based on inadequate assumptions about the problem domain.

Required Input Parameters

The principal input parameters required for MEMO are the geometry and discretization of the problem domain, potential source width, the contaminant transport parameters, and the dilution contour to be measured in the monitoring wells. Parameters that are not known from site-specific field data must be conservatively estimated. Sensitivity analyses may be performed to identify critical parameters affecting monitoring efficiency predictions.

Geometry of Problem Domain

Key geometric elements of the problem domain are the potential source area(s), monitoring wells to be investigated, and the location of the buffer zone boundary. Geometric data are input using a standard coordinate system, and a uniform source grid spacing must also be specified. The sensitivity of an efficiency analysis to the source grid spacing should be evaluated, since grid spacing can influence the accuracy of the solution.

Monitoring wells are located between the potential source area(s) and the buffer zone boundary. Plumes that are not detected by a monitoring well prior to contacting the buffer zone boundary are considered to be "not detected" in the monitoring efficiency estimate. However, it should not be inferred that plumes considered "not detected" for purposes of network design will never be detected. Plumes will continue to expand until steady state is reached, and may eventually be detected prior to reaching steady state. Identification of a buffer zone is necessary because unless the center line of a plume directly contacts a monitoring well, the leading edge of the plume will migrate beyond the monitoring well prior to plume detection.

Although a smaller buffer zone width is more conservative because it will generate a lower apparent monitoring efficiency, our sensitivity analyses have indicated that MEMO efficiency predictions are not particularly sensitive to buffer zone widths greater than several hundred feet. The appropriate width for the buffer zone will depend on site-specific and regulatory conditions. General criteria for establishing buffer zone widths include distances to property boundaries and neighboring dwellings, distances to ground-water supply wells or surface-water bodies, the velocity of ground-water movement, and the relative costs and benefits of providing early detection of a release. Buffer zone widths established for hazardous waste facilities in current regulations vary, but are on the order of hundreds to thousands of feet. We have used a conservative width of 500 feet for remote sites.

Potential Source Width

Vertical migration of contaminants through the unsaturated zone to the water table is assumed to create a source of contamination in the ground water that generates the contaminant plume. The width of the source in the ground water will depend upon the dimensions of the release at the waste site and the subsequent dispersion in the unsaturated zone. The size and strength of this source may be estimated from field measurements if releases have occurred at the site, or from the size, type of contaminants, and transport mechanisms of a hypothetical release from the site.

The data needed to support a rigorous analysis of the potential source width are often lacking, requiring that this parameter be conservatively estimated. Smaller source widths are more conservative because they are more difficult to detect. The source width estimate should take into account the dimensions of the release at the waste site and the effects of migration through the unsaturated zone. The dimensions of the release at the waste site may be, for example, the dimensions of a typical waste container at an unlined site, or may be the dimensions of a potential liner leak at a lined site. Migration through the unsaturated zone is usually accompanied by lateral spreading. The source width may be increased for larger release dimensions and larger unsaturated zone thicknesses, but the estimated mass flux of contaminants entering the ground water should be held constant by adjusting the source concentration used to calculate the dilution contour.

Contaminant Transport Parameters

Contaminant transport parameters required for plume generation are the direction of ground-water movement, the average contaminant velocity, and the longitudinal and transverse dispersivities. Optional contaminant transport parameters are the molecular diffusion coefficient and the first-order radioactive decay constant.

If ground-water level data are available for a site, they can be used to estimate the direction of ground-water movement. If no water-level data are available, the direction of ground-water movement may be estimated from regional hydrogeologic data or from site topography. The sensitivity of the monitoring efficiency estimate to variations in ground-water flow direction should be considered, particularly when no field data are available. The efficiency of a particular monitoring well network can be significantly changed by a change in the ground-water flow direction.

The average contaminant velocity can be approximated from estimates of the average hydraulic conductivity, hydraulic gradient, retardation factor, and effective porosity at the site. With the Domenico and Robbins plume generation routine, for a plume of a given length the shape of the generated plume is independent of the time required to develop the plume, if decay and molecular diffusion are negligible. For example, a plume that traveled 500 feet in five years would be predicted to have the same shape as one that traveled 500 feet in 50 years. Because of this independence, for cases where decay and diffusion are negligible, the monitoring efficiency solution is not dependent on the hydraulic parameters governing the average contaminant velocity, and is not sensitive to the choice of average contaminant velocity.

Site-specific dispersivities are rarely available, and must usually be estimated from available literature values for similar geologic media. Gelhar et al. (1985) provide a source for such information. Dispersivity values have been reported to increase as the length of the plume increases, although the most reliable measured values are the lower estimates. The selection of values is complicated by the fact that considerably more data are available for longitudinal than transverse dispersivities; thus the uncertainty is higher for the transverse dispersivity. If the data base for transverse dispersivity cannot support a direct estimate, it can be estimated as a fraction of the longitudinal value ($\alpha_y/\alpha_x = 0.1$ is commonly used). The width of the plume is quite sensitive to the transverse dispersivity (α_y) and is relatively insensitive to the longitudinal dispersivity (α_x). Longer, thinner plumes are harder to detect, and therefore larger values of longitudinal and smaller values of transverse dispersivity are more conservative. For application to a site with unconsolidated silts, sands, and gravels, the best direct estimate values for transverse and longitudinal dispersivities were 8 and 28 feet, respectively, using a scale of interest of about 1,000 feet. The relatively high transverse to longitudinal ratio of about 0.3 was supported by limited site-specific data. For conservatism, the monitoring network design was based upon a transverse dispersivity of 5 feet and a longitudinal dispersivity of 35 feet.

For most field situations, the diffusion coefficient is quite small compared to the adjective velocity and can be neglected. For sites with very low adjective velocities, the effect of molecular diffusion can be evaluated in a sensitivity analysis. Radioactive or chemical decay can be incorporated into the monitoring efficiency study by specifying a first-order decay constant.

Dilution Contour

The dilution contour (C_{dil}), defined as the ratio of the detection standard (C_{ds}) to the concentration at the source of the plume in the ground water (C_o), identifies the boundary of the plume used in the monitoring efficiency determination. The monitoring efficiency is affected by the dilution contour, because plumes of a given length are slightly wider for a lower dilution contour than for a higher dilution contour. The wider plumes would be easier to detect and fewer monitoring wells would be required to achieve a target monitoring efficiency. To provide adequate early warning of a release, the design should be based upon a dilution contour for the more mobile potential contaminants at the site.

To determine an appropriate dilution contour, the source strength and detection standard must be estimated. The source strength is the contaminant concentration at the plume source within the aquifer. The potential source strength may be estimated through analysis of ground-water samples from an identified source area where a release has already occurred, through analysis of the physical conditions of the waste and the site, or through identifying a threshold source strength that would be of regulatory concern. The first of these approaches is not typically possible, because monitoring well network designs are generally prepared for sites where releases have not yet occurred or have not been established. In estimating source strength using the other approaches, release of contaminants from the potential source area(s) is considered to be continuous and governed by long-term average hydrologic conditions.

If the mass flux rate of contaminants released from the site is assumed to be constant, the strength and width of the source in the ground water become inversely related. If the width of the source increases, such as from a higher estimated dispersion in the unsaturated zone, the strength of the source must decrease, because the total mass flux of contaminant entering the ground water remains constant. Although the network design is sensitive to changes in either source strength or source width when taken independently, it becomes relatively insensitive when the inverse relationship between these parameters is considered.

Estimates of source strength based upon the physical conditions of the waste and the site may be made considering the amounts and physical states of potential contaminants in the waste, the probable mobilization and release mechanisms into the unsaturated zone, the dispersive effects occurring in the unsaturated zone, and the rate of ground-water movement in the underlying aquifer. Factors which should be considered are whether the waste is in solid or liquid form, and its potential mobility given the conditions of release or disposal. The data necessary to rigorously address the processes of release and subsequent migration to the ground water are often unavailable, and conservative estimates must be made.

Estimates of source strength may also be based upon threshold values that would be of regulatory concern. This approach is useful when the contaminant of concern has an assigned regulatory standard such as a maximum contaminant level (MCL), but its concentration at the point of release at the waste site is difficult to estimate, for example, because of a lack of solubility information. This approach has been particularly useful for metals and radionuclides. The threshold strength of concern is generally considered to be the regulatory standard, and the contaminant concentration at the source in the ground water would be set to approximately equal that standard. This would be more conservative than estimates based on solubility limits if the regulatory standard is less than the estimated source concentration. However, if the estimated source concentration is less than the regulatory standard, it is recommended that the regulatory standard be used as the source concentration to avoid an overly conservative design.

Example Application

MEMO has been employed to design monitoring networks for eight waste management areas on the U.S. Department of Energy's Hanford Site in eastern Washington. Before applying MEMO at a location, the relevant hydrogeologic data and information on waste characteristics are assembled and reviewed to develop alternative conceptual models of the directions and stability of ground-water movement and the unsaturated zone transport conditions associated with alternative release scenarios. Uncertainties in parameter values are analyzed in MEMO sensitivity studies, and uncertainties in the validity of the assumptions used in MEMO are identified. Higher design monitoring efficiencies may be used at sites with greater parameter uncertainties.

The data base parameters for MEMO were developed

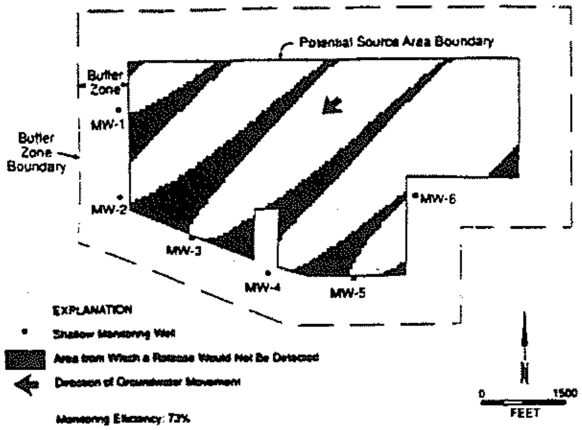


Fig. 2. Example MEMO results for a network of six wells.

by applying the logic described above. The results of example applications are shown in Figures 2 and 3 for a waste site of irregular geometry. The direction of ground-water flow was assumed to be the same throughout the site. The following data base was used in this example:

Source Width	20 feet
Buffer Zone Width	500 feet
Longitudinal Dispersivity	35 feet
Transverse Dispersivity	5 feet
C_{dil}	0.001

Contaminant decay and molecular diffusion were considered negligible in this example.

Figure 2 shows the MEMO results for a relatively sparse downgradient network of six wells. The shaded areas on the figure indicate locations where a release is not predicted to be detected. The influence of the approximately 1,500-foot gaps between the monitoring wells can be seen in the sizes of the shaded areas. The efficiency of this network is about 73 percent, and is less the minimum target of 90

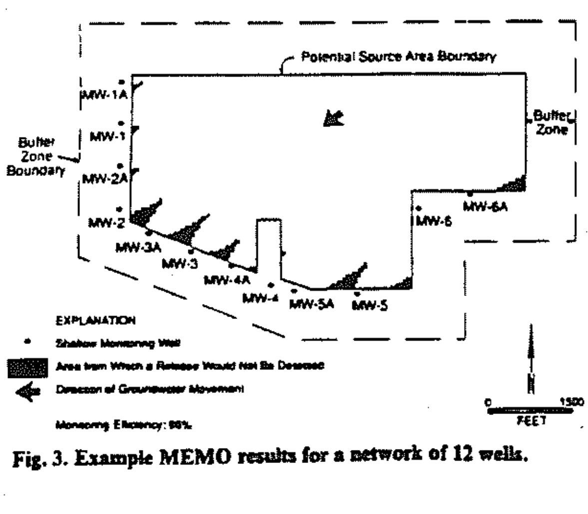


Fig. 3. Example MEMO results for a network of 12 wells.

percent adopted for this example. Efficiencies may be improved by adding or adjusting locations of monitoring wells in the vicinity of the larger shaded areas.

Figure 3 shows the MEMO results for the site shown in Figure 2, but with a network of 12 wells. This network greatly reduces the shaded areas and increases the monitoring efficiency to 96 percent. This efficiency may be unnecessarily high for the site, particularly if the direction of ground-water flow is stable. Monitoring wells can be moved, added, or deleted until a satisfactory network is achieved. The sensitivity of the final network to uncertainties in ground-water flow directions or in any of the other input parameters can also be evaluated.

Future Model Development

The monitoring efficiency concept of MEMO can be developed with other assumptions and applications. Some examples of areas for future model development are discussed in this section.

MEMO currently provides a deterministic solution for the monitoring efficiency. A probabilistic model incorporating a Monte Carlo approach has been considered, with user-specified probabilistic functions for each of the field or literature-derived input parameters. Rather than producing a single monitoring efficiency, a range of values would be produced. Graphical output could present contours of the frequency of detection of each potential source point, rather than shading nondetected potential source points.

A three-dimensional analytical solution can be incorporated into MEMO to allow evaluations of nested monitoring well networks. The user would specify well locations and screen intervals for each well. Plume migration would be limited by a planar buffer zone limit. MEMO can also be developed with a two-dimensional or three-dimensional finite-difference or finite-element contaminant transport module, to allow application to sites where available data and site complexity suggest that the simplifying assumptions of the current analytical solution are inappropriate.

As an alternative to using the buffer zone concept, plumes can be limited by migration time or allowed to reach steady state, prior to checking for detection in a monitoring well. However, if this approach is used, the downgradient limit of each generated plume will vary with the geometry of the source area. At sites where ground-water contamination is of concern, early warning of contamination is typically desired to allow corrective action to be taken. The buffer zone boundary serves as the limit for plume migration before early warning should occur. For this reason, the buffer zone concept is our preferred configuration for the model.

Conclusions

MEMO is a method for monitoring well network design that is quantitative and produces easily understood graphical output. The computed detection efficiency provides data for optimization of a monitoring network design based upon physical processes. The model requires significant judgment because of the need to obtain or estimate the input parameters. The benefits obtained from adding, deleting, or moving wells can be readily demonstrated using multiple simulations. The model has been found to be of significant value in justifying a network design to both regulatory agencies and site owners. The approach can be readily adapted or enhanced to address alternative problems. For example, the model can be modified for use with three-dimensional plume generation techniques if required for a particular site. It also can be developed on a probabilistic basis, to quantify the uncertainty in the design, as an alternative to the deterministic and conservative approach described here. The expanded use of MEMO and other similar design approaches is expected to promote reduction in the uncertainties inherent in monitoring well network design.

Availability of Model

MEMO software and a User's Manual can be obtained from the authors.

Acknowledgments

MEMO was developed at the request of Westinghouse Hanford Company, Richland, Washington, for the U.S. Department of Energy. The authors would like to acknowledge the support and insightful comments received on the MEMO concept from many colleagues. Particular thanks go to Ian Miller, Rick Kossik, and George Evans for their valuable insights into the basic modeling concepts, and to Scott Kindred, John Velimesis, and Scott Warner for their help in brainstorming ideas, verifying the code, polishing the text, and working through many manual applications.

References

Domenico, P. A. 1987. An analytical model for multidimensional transport of a decaying contaminant species. Journal of Hydrology. no. 91, pp. 49-58.

Domenico, P. A. and G. A. Robbins. 1985. A new method of contaminant plume analysis. Ground Water. v. 23, no. 4, pp. 476-485.

Freeze, R. A., J. Massmann, L. Smith, T. Sperling, and B. James. 1990. Hydrogeological decision analysis: 1. A framework. Ground Water. v. 28, pp. 738-766.

Gelhar, L. W., A. Mantoglou, C. Welty, and K. R. Rohfelt. 1985. A review of field scale physical solute transport processes in saturated and unsaturated porous media. Electrical Power Research Institute, Palo Alto, CA. RP-2485-05.

Massman, J. and R. A. Freeze. 1987. Ground water contamination from waste management sites: The interaction between risk-based engineering design and regulatory policy. Water Resources Res. v. 23, pp. 351-380.

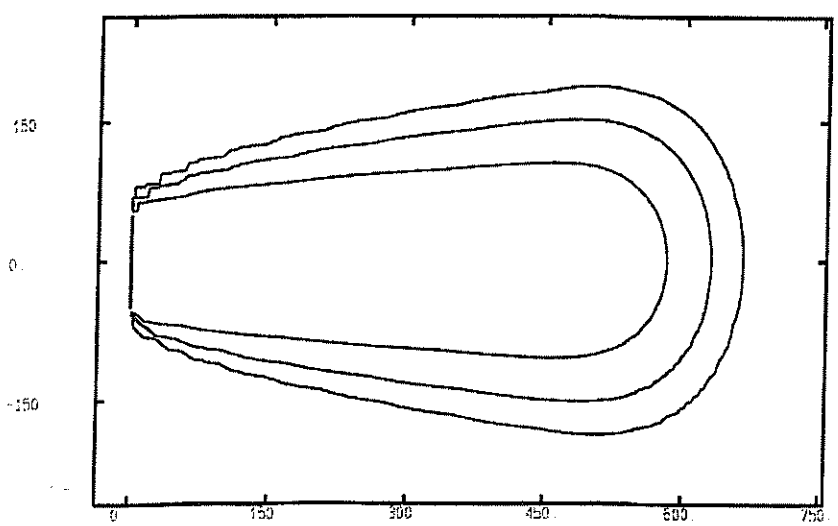
Meyer, P. D. and E. D. Brill, Jr. 1988. A method for locating wells in a ground water monitoring network under conditions of uncertainty. Water Resources Res. v. 24, pp. 1277-1282.

Attachment 3

PLUME Model Outputs

Construction Permit Application
Proposed Utility Waste Landfill
Ameren Missouri Labadie Energy Center
Cells 1 and 2
Plume Model Output for 44 Years

MAP ver 1.1 PLUME Simulation Golder Associates Inc.

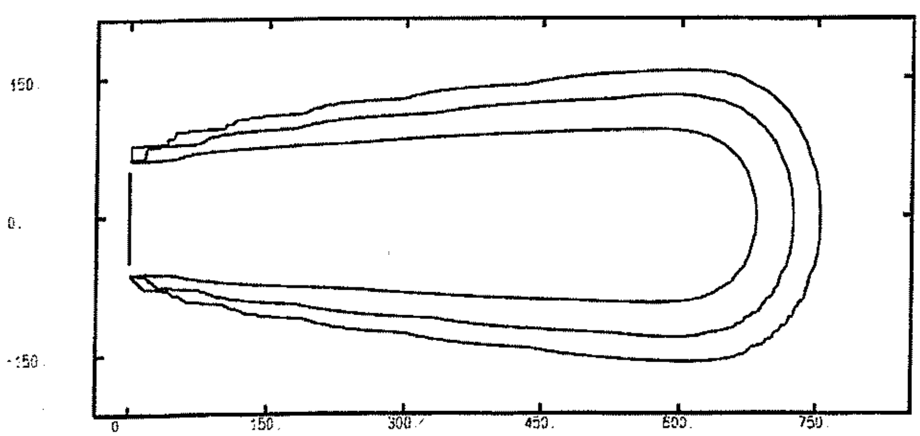


Contours at: .00100, .01000, .10000
Advection time = 528.00
Average contaminant velocity = 1.0130
Width of line source = 100.00

Longitudinal dispersivity = 1.74
Transverse dispersivity = 2.03
First-order decay constant = .000E+00
Diffusion coefficient = .000E+00

Construction Permit Application
Proposed Utility Waste Landfill
Ameren Missouri Labadie Energy Center
Cells 3 and 4
Plume Model Output for 44 Years

MAP ver 1.1 PLUME Simulation Golder Associates Inc.



Contours at: .00100, .01000, .10000
Advection time = 528.00
Average contaminant velocity = 1.2120
Width of line source = 100.00

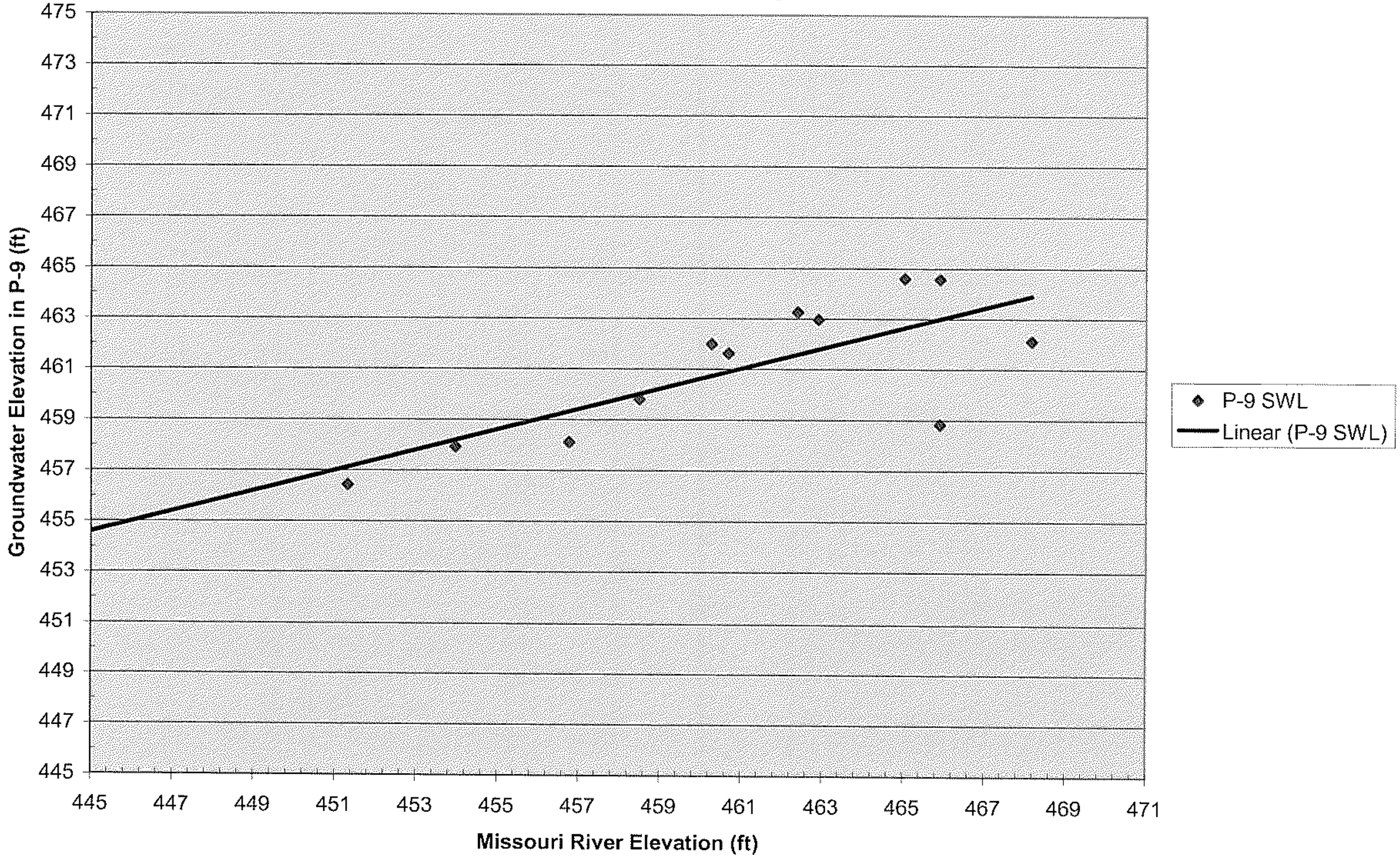
Longitudinal dispersivity = 1.07
Transverse dispersivity = 1.02
First-order decay constant = .000E+00
Diffusion coefficient = .000E+00

Attachment 4

Linear Regression Plots
Missouri River Elevation vs
Top of Water Table

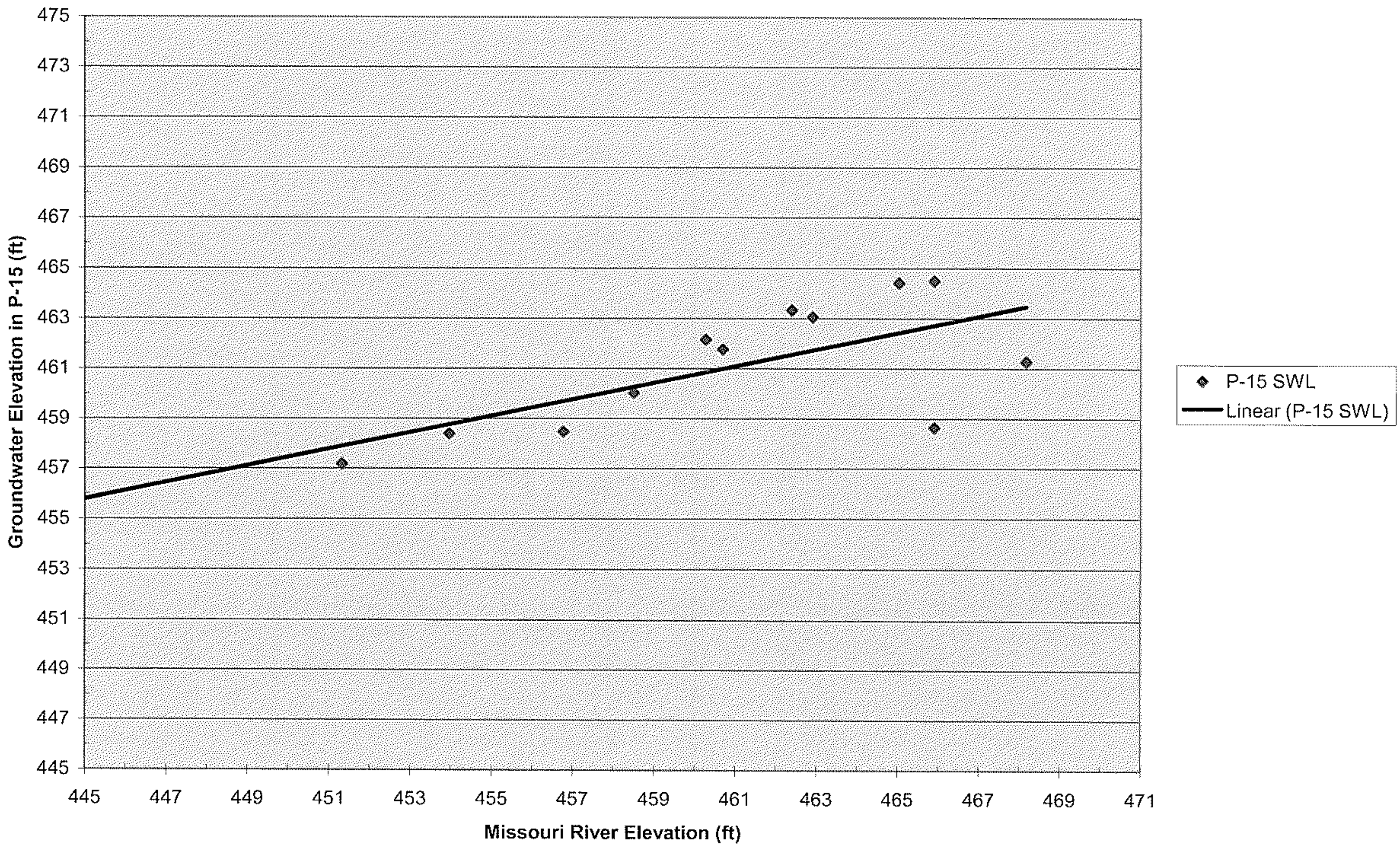
Construction Permit Application
Proposed Utility Waste Landfill
Ameren Missouri Labadie Energy Center

Missouri River Elevation vs Top of Water Table (P-9)
Attachment 4 - Figure 1



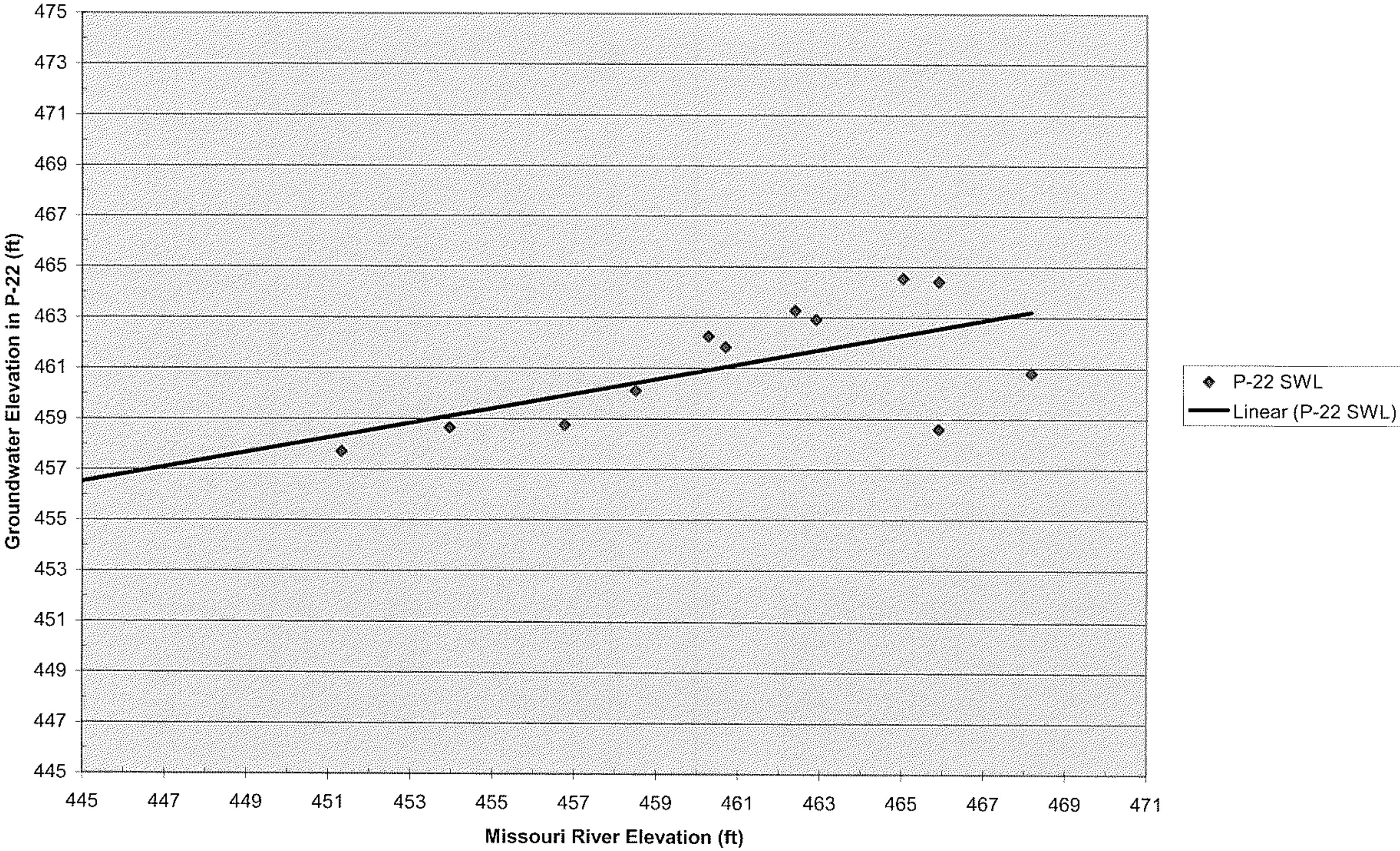
Construction Permit Application
Proposed Utility Waste Landfill
Ameren Missouri Labadie Energy Center

Missouri River Elevation vs Top of Water Table (P-15)
Attachment 4 - Figure 2



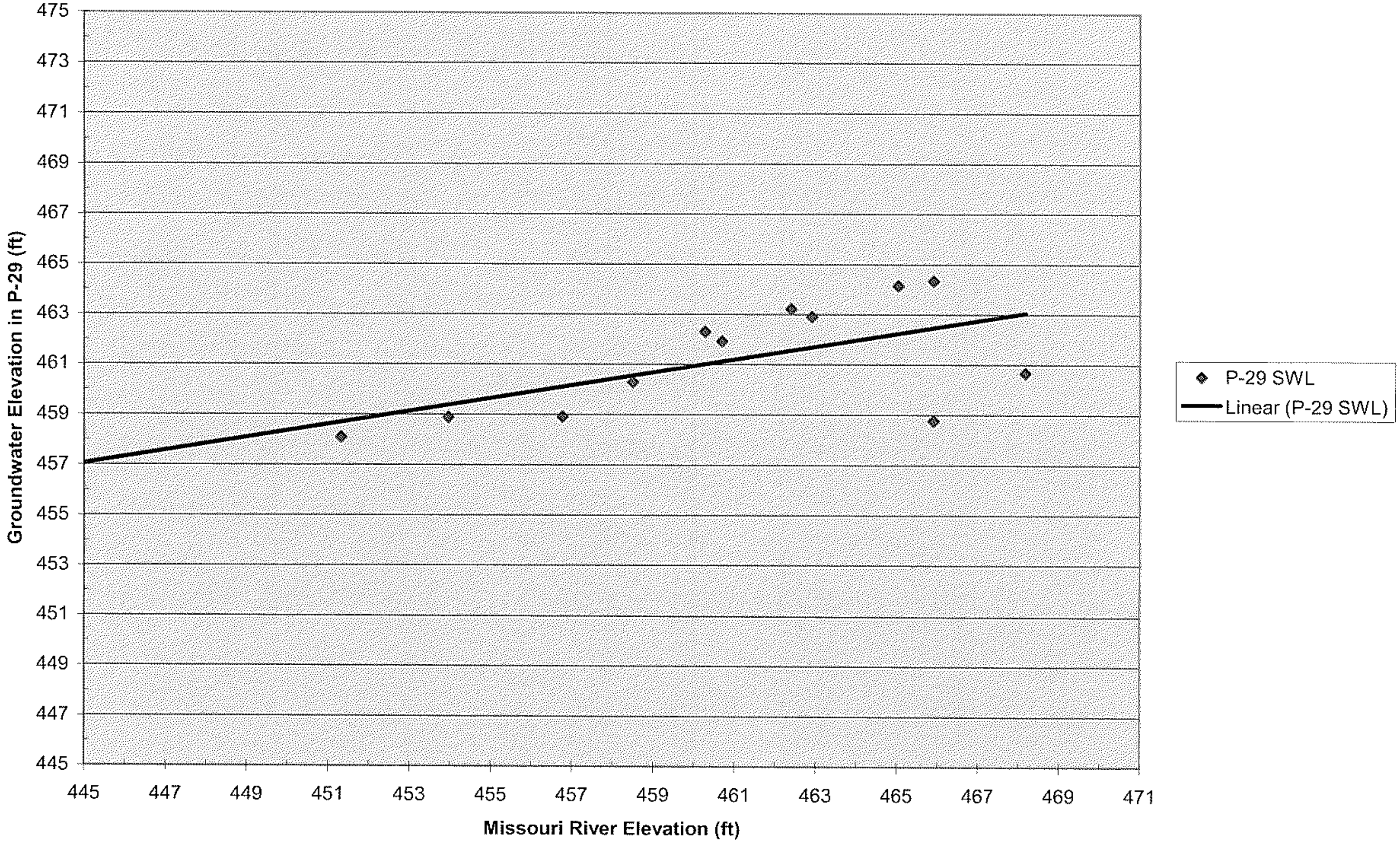
Construction Permit Application
Proposed Utility Waste Landfill
Ameren Missouri Labadie Energy Center

Missouri River Elevation vs Top of Water Table (P-22)
Attachment 4 - Figure 3



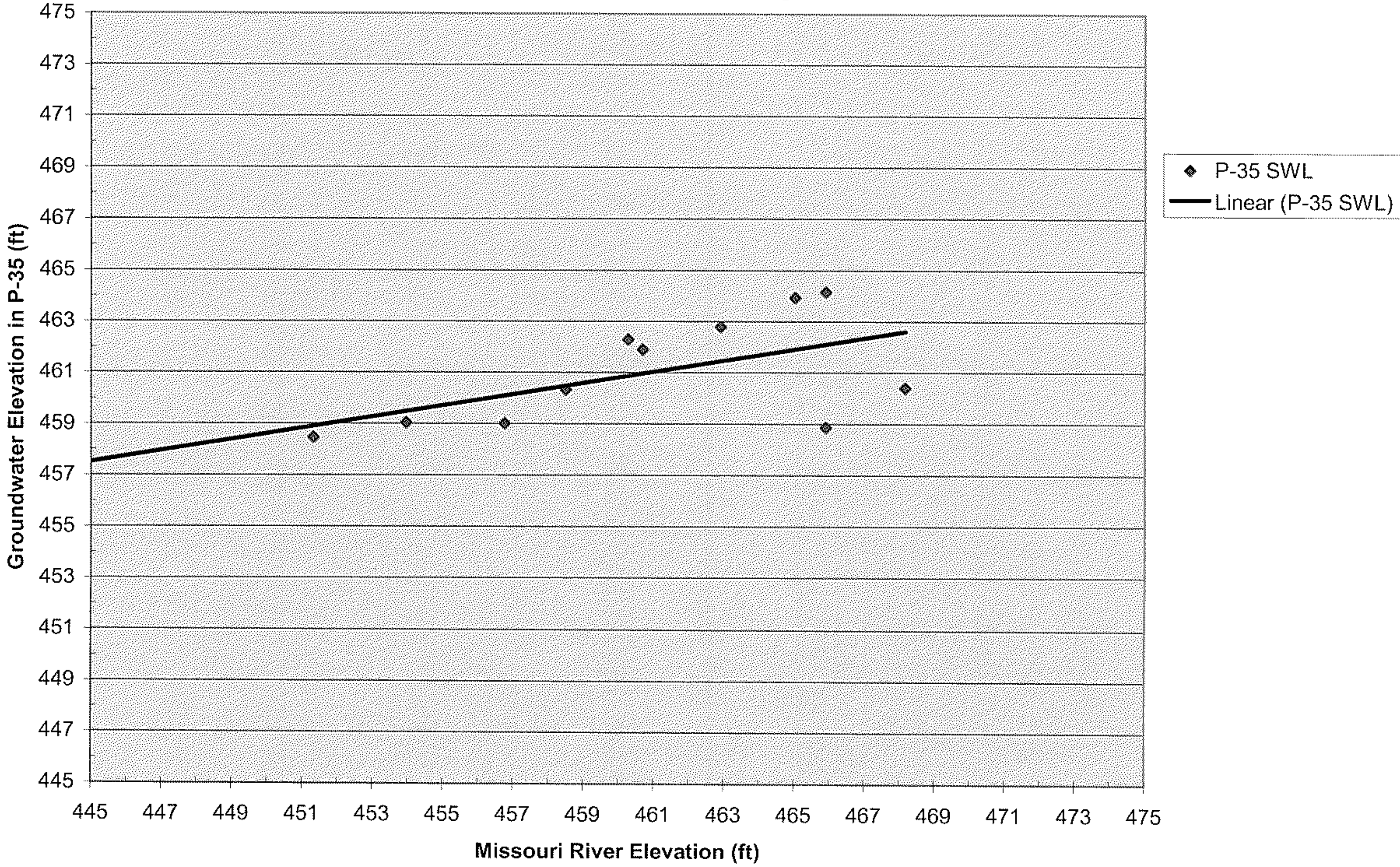
Construction Permit Application
Proposed Utility Waste Landfill
Ameren Missouri Labadie Energy Center

Missouri River Elevation vs Top of Water Table (P-29)
Attachment 4 - Figure 4



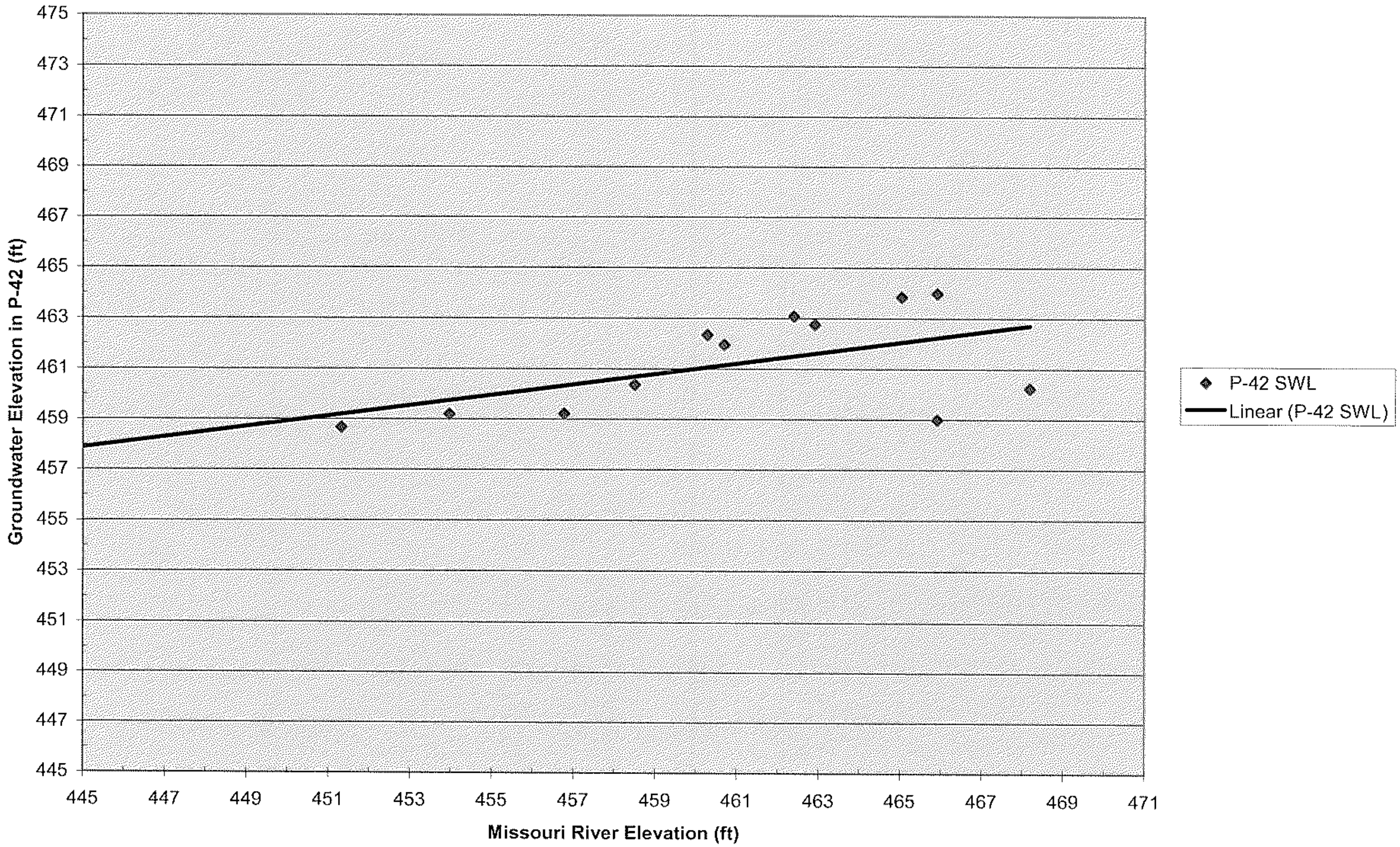
Construction Permit Application
Proposed Utility Waste Landfill
Ameren Missouri Labadie Energy Center

Missouri River Elevation vs Top of Water Table (P-35)
Attachment 4 - Figure 5



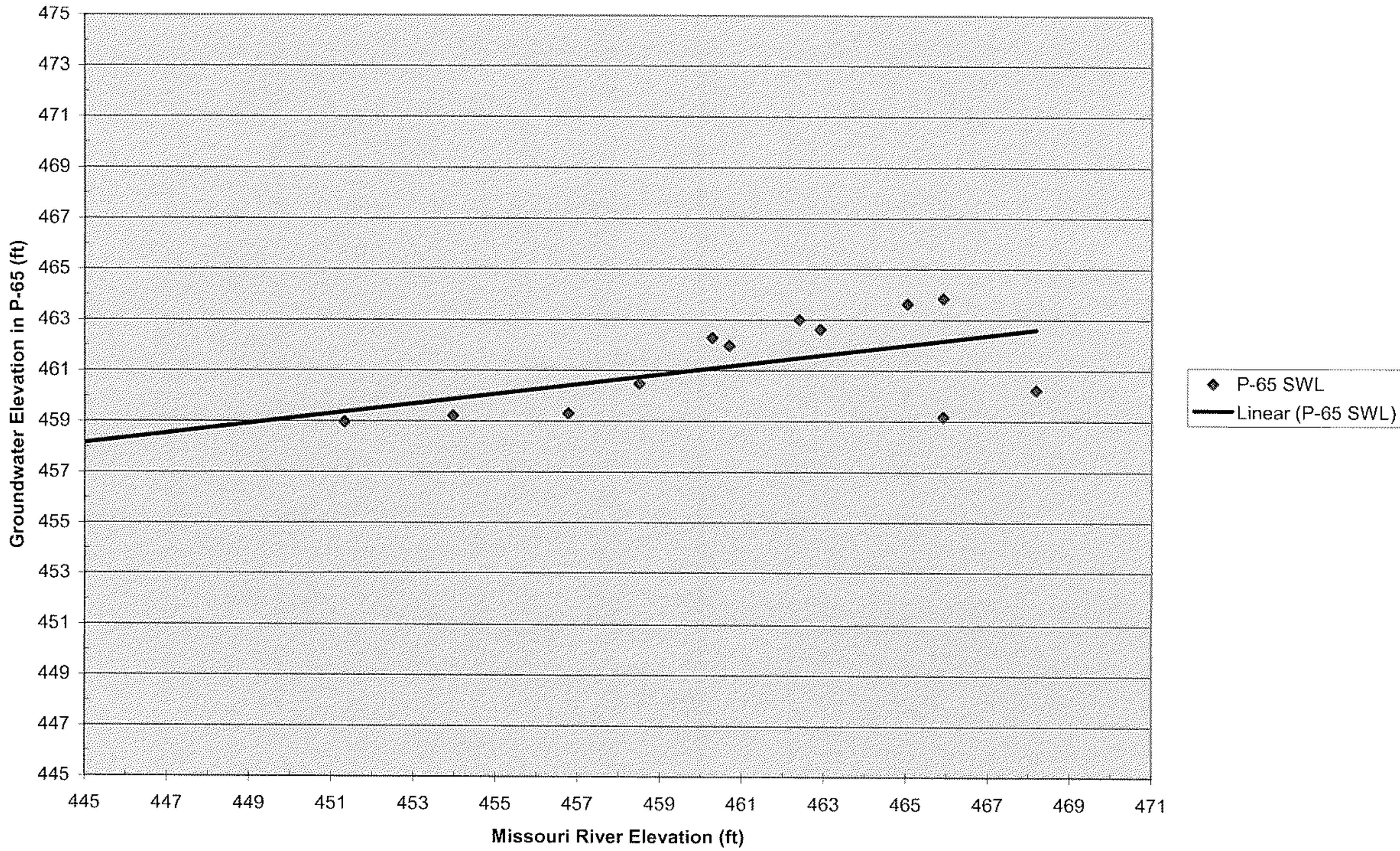
Construction Permit Application
Proposed Utility Waste Landfill
Ameren Missouri Labadie Energy Center

Missouri River Elevation vs Top of Water Table (P-42)
Attachment 4 - Figure 6



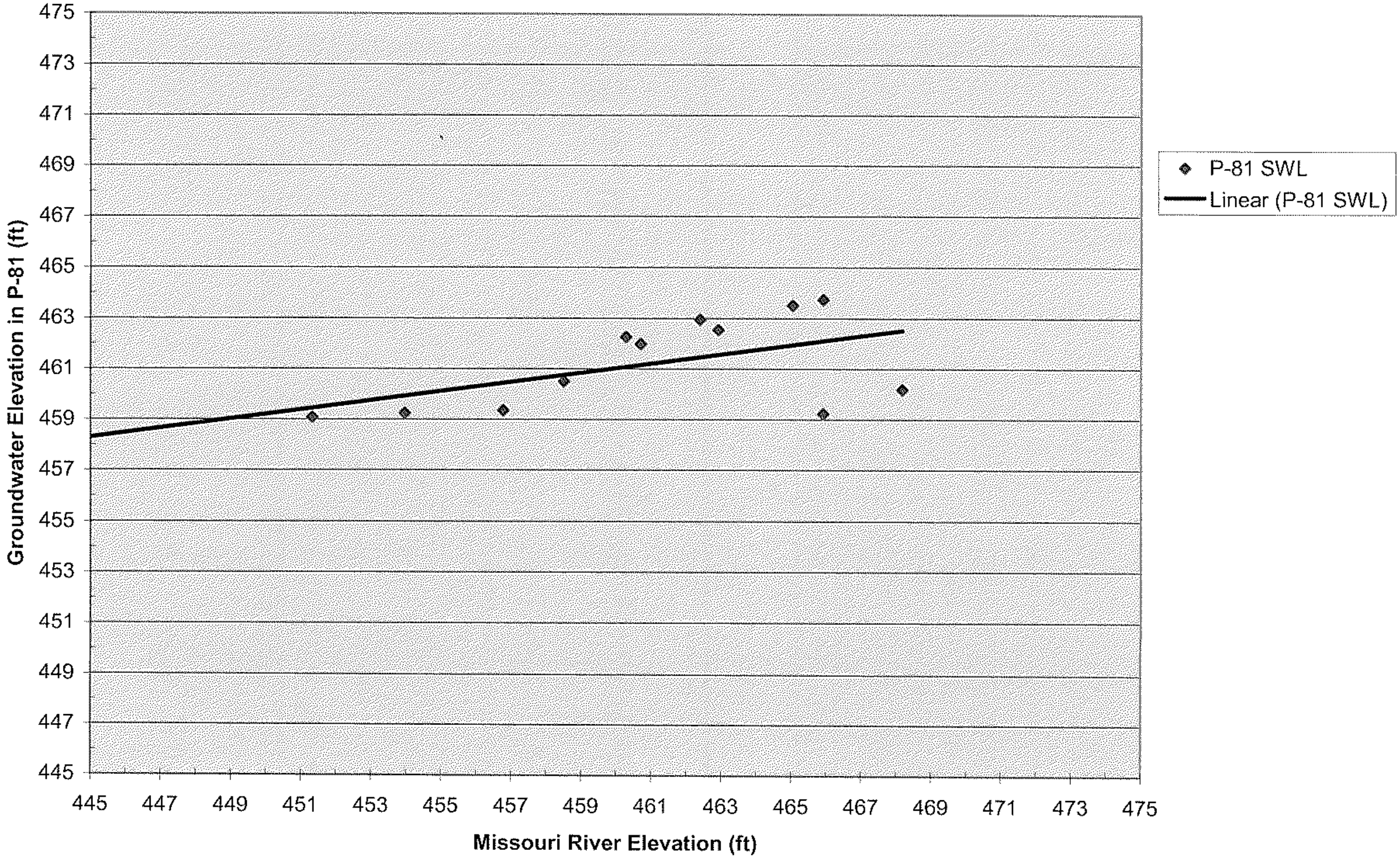
Construction Permit Application
Proposed Utility Waste Landfill
Ameren Missouri Labadie Energy Center

Missouri River Elevation vs Top of Water Table (P-65)
Attachment 4 - Figure 7



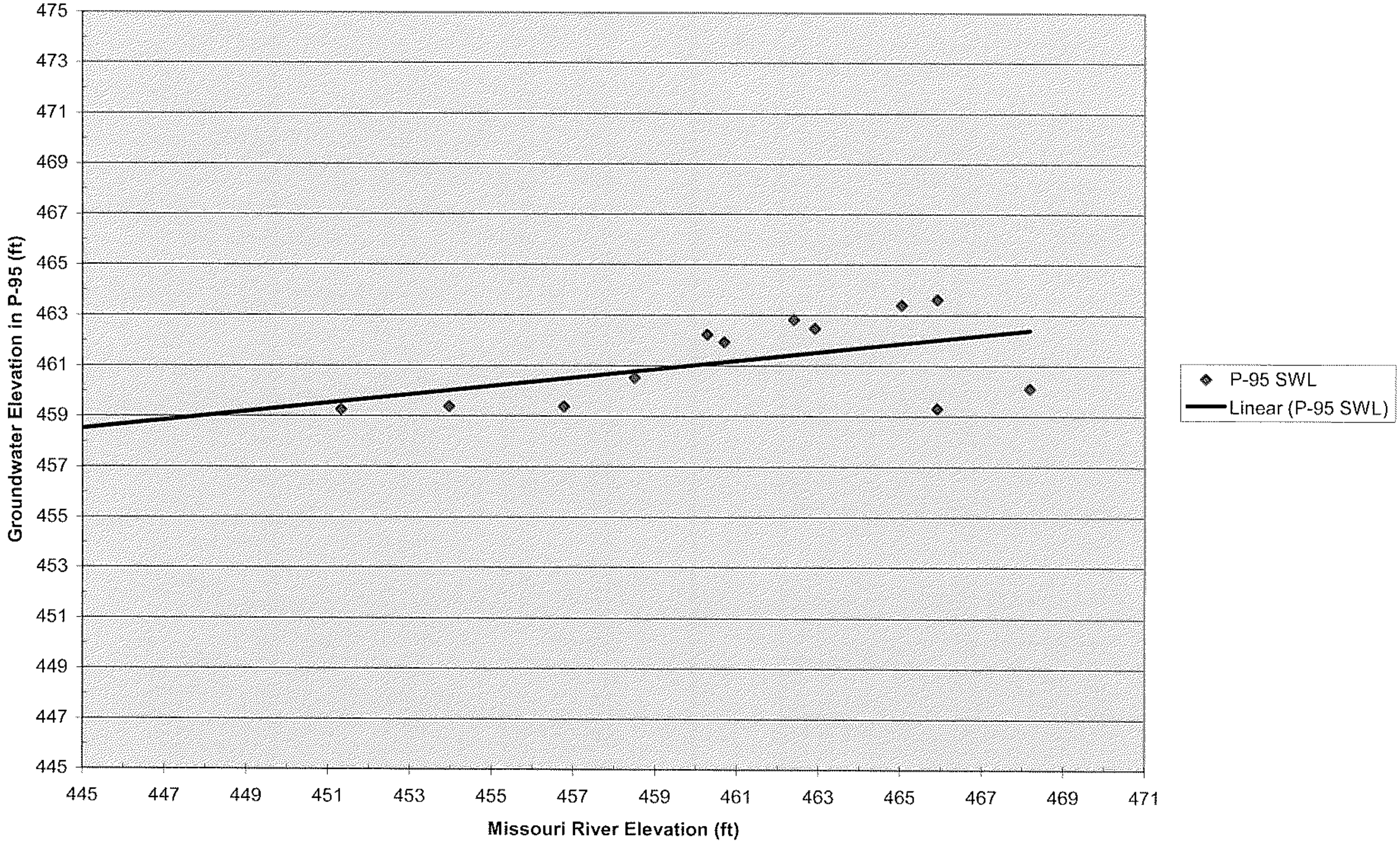
Construction Permit Application
Proposed Utility Waste Landfill
Ameren Missouri Labadie Energy Center

Missouri River Elevation vs Top of Water Table (P-81)
Attachment 4 - Figure 8



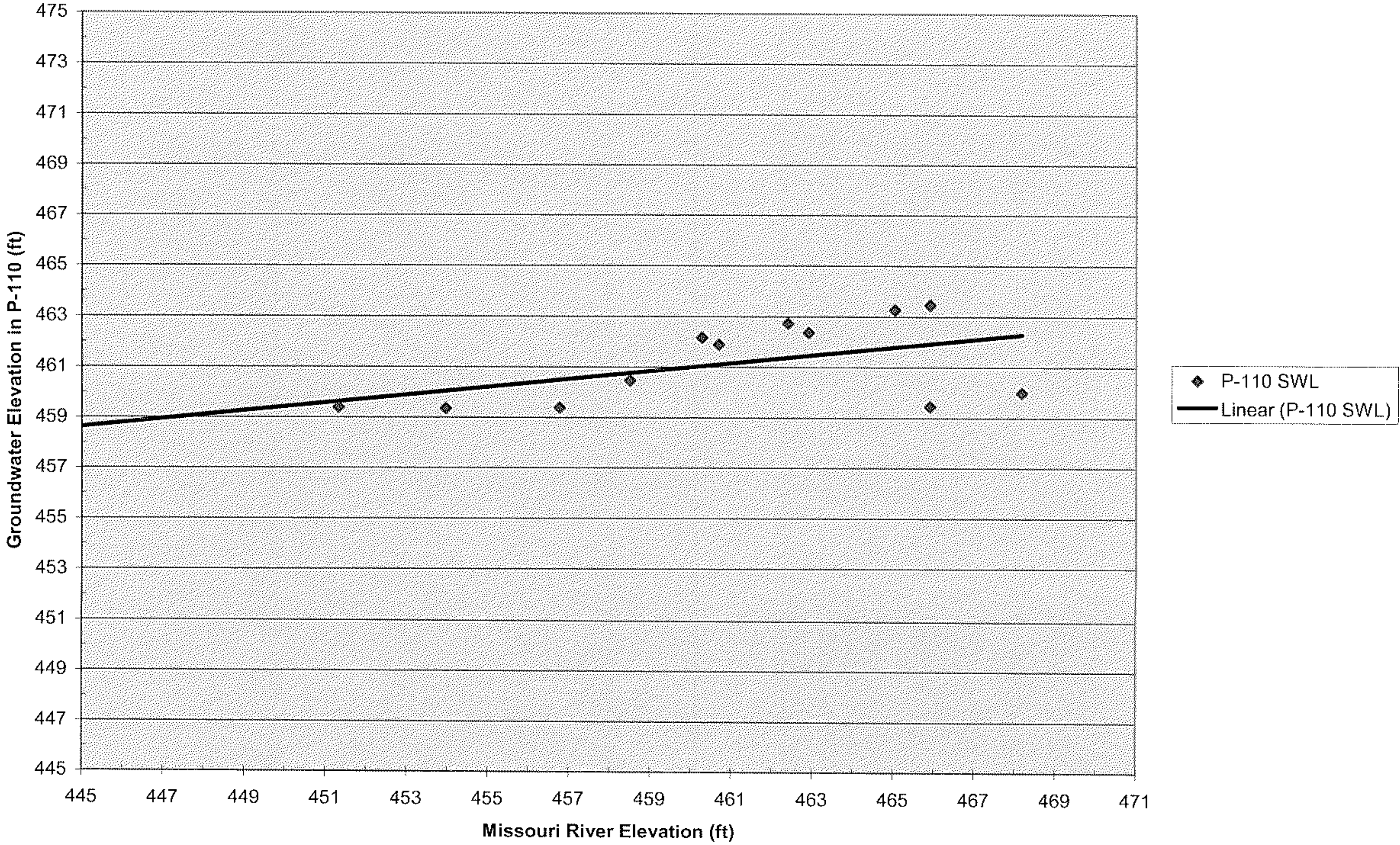
Construction Permit Application
Proposed Utility Waste Landfill
Ameren Missouri Labadie Energy Center

Missouri River Elevation vs Top of Water Table (P-95)
Attachment 4 - Figure 9



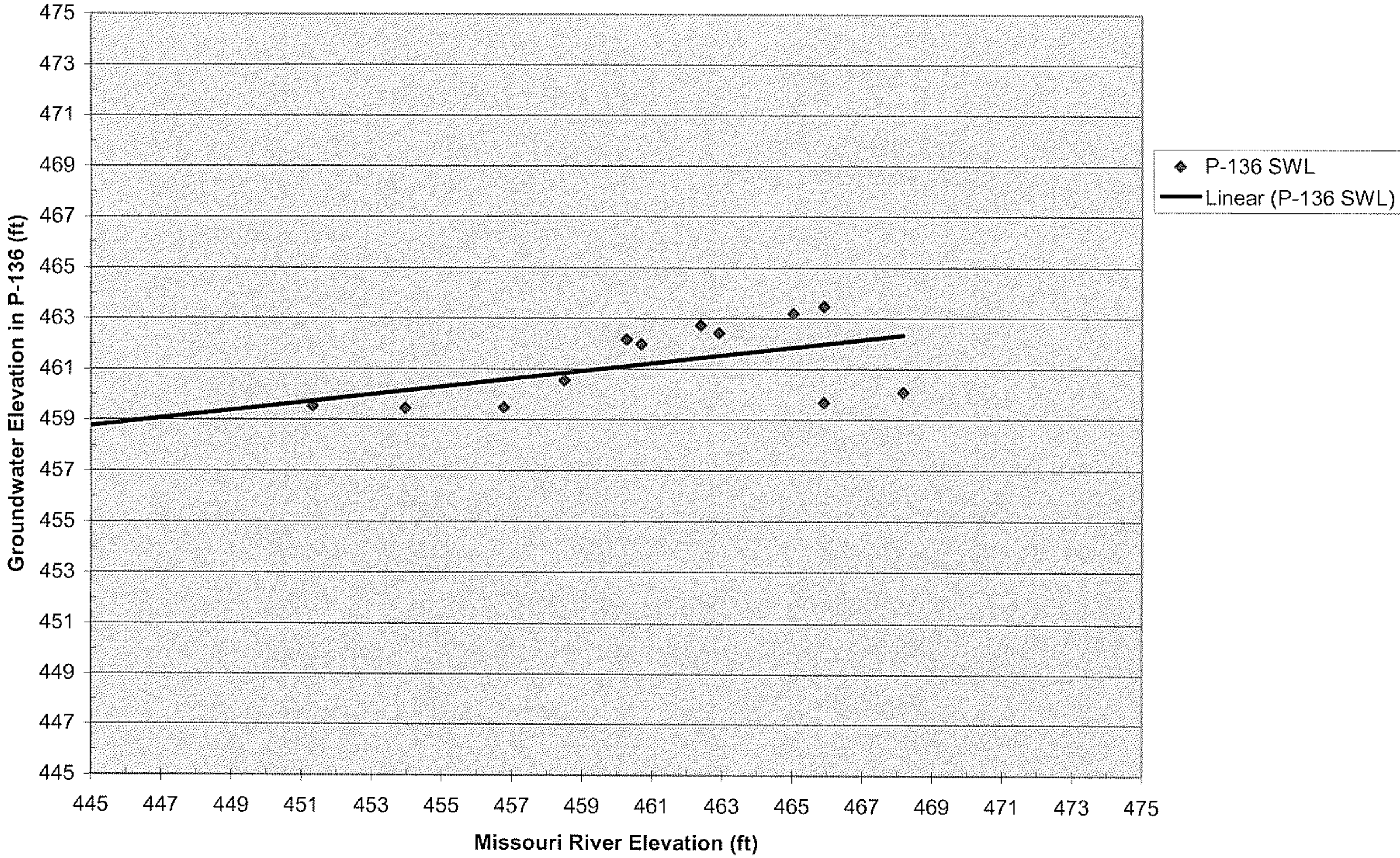
Construction Permit Application
Proposed Utility Waste Landfill
Ameren Missouri Labadie Energy Center

Missouri River Elevation vs Top of Water Table (P-110)
Attachment 4 - Figure 10



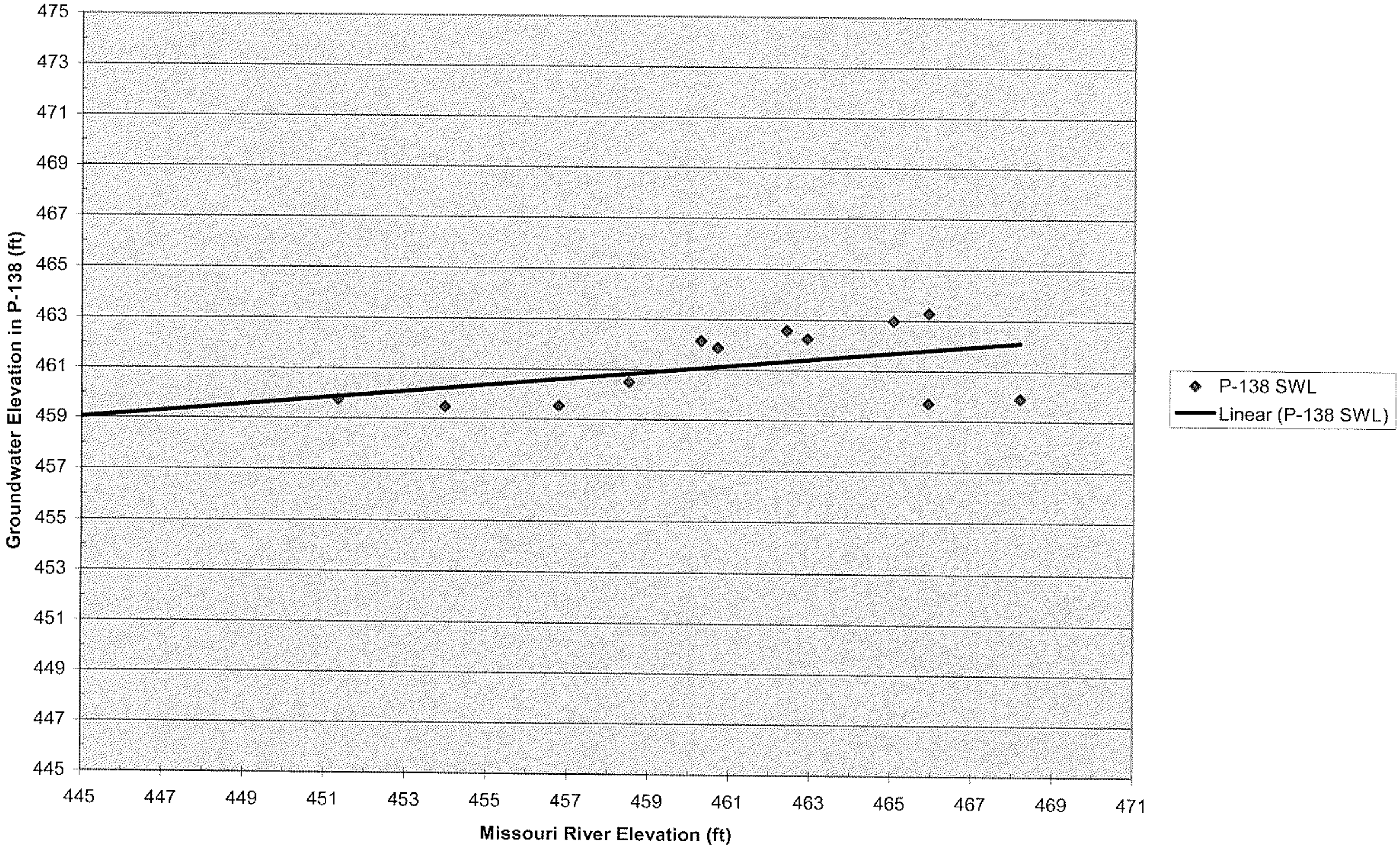
Construction Permit Application
Proposed Utility Waste Landfill
Ameren Missouri Labadie Energy Center

Missouri River Elevation vs Top of Water Table (P-136)
Attachment 4 - Figure 11



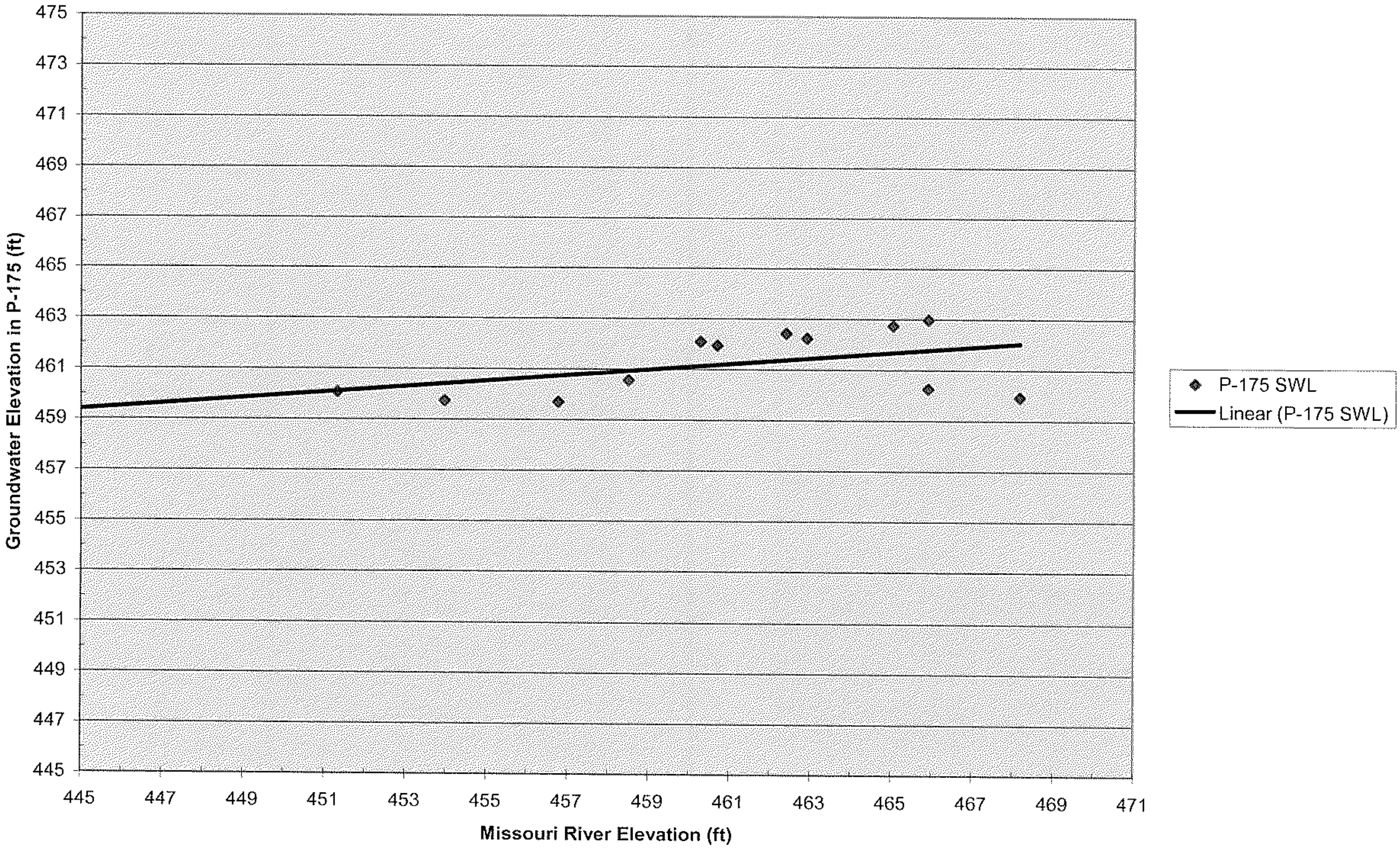
Construction Permit Application
Proposed Utility Waste Landfill
Ameren Missouri Labadie Energy Center

Missouri River Elevation vs Top of Water Table (P-138)
Attachment 4 - Figure 12



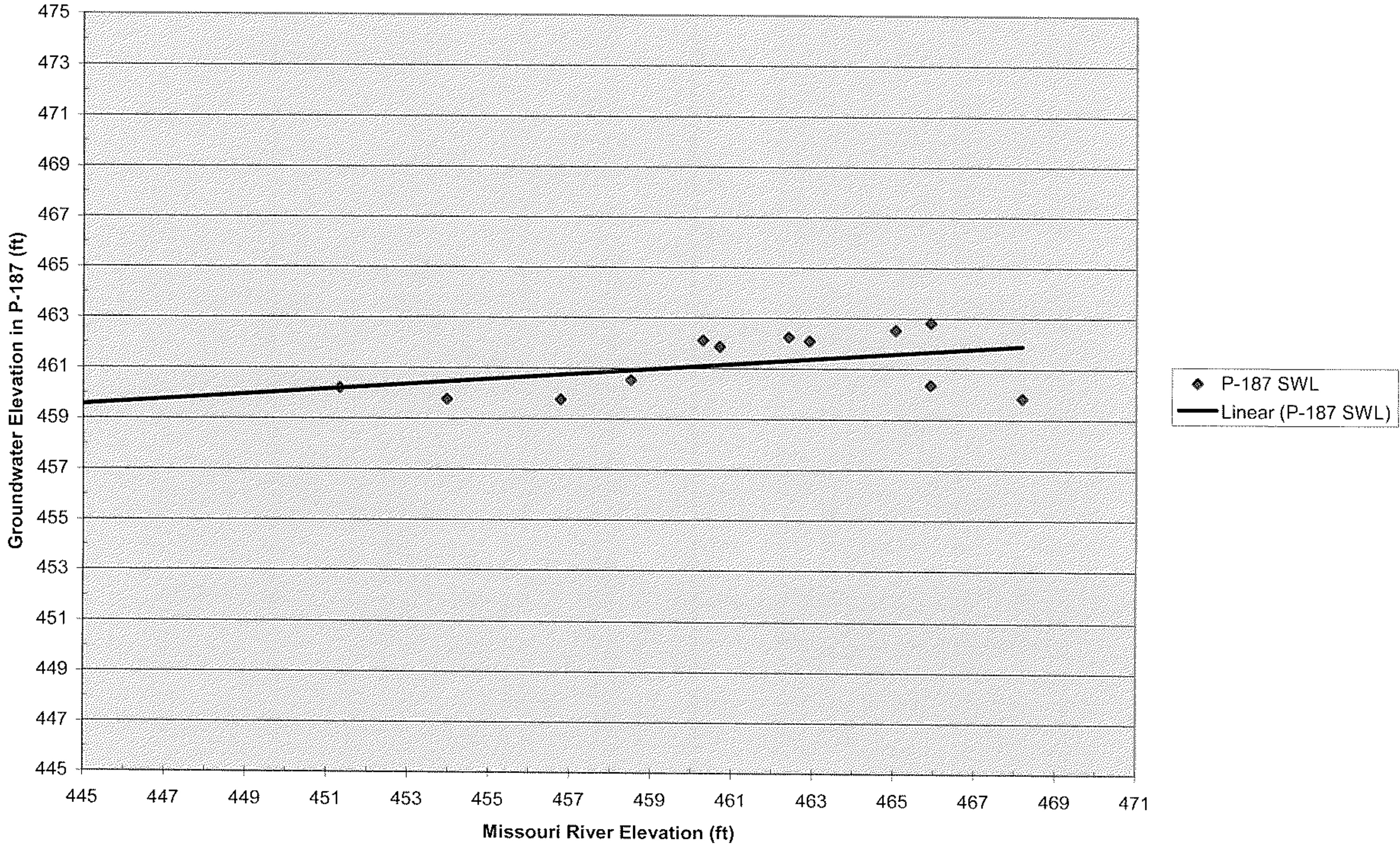
Construction Permit Application
Proposed Utility Waste Landfill
Ameren Missouri Labadie Energy Center

Missouri River Elevation vs Top of Water Table (P-175)
Attachment 4 - Figure 13



Construction Permit Application
Proposed Utility Waste Landfill
Ameren Missouri Labadie Energy Center

Missouri River Elevation vs Top of Water Table (P-187)
Attachment 4 - Figure 14



Appendix X(b)

Documentation of Supplemental Groundwater
Monitoring Well Design
New Document November 2013

Ameren Missouri
Labadie Energy Center
Documentation of Supplemental Groundwater Monitoring Well Design

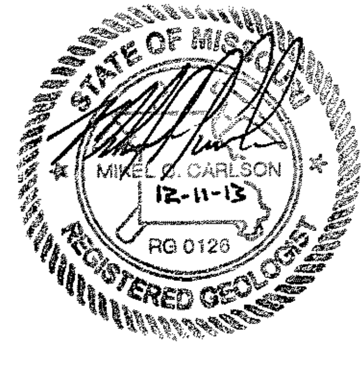
November, 2013

Prepared By:

Reitz & Jens, Inc.
1055 Corporate Square Drive
St. Louis, Missouri 63132
(314) 993-4132

and

GREDELL Engineering Resources, Inc.
1505 East High Street
Jefferson City, Missouri 65101
(573) 659-9078



Ameren Missouri
Labadie Energy Center
Documentation of Supplemental Groundwater Monitoring Well Design

November, 2013

Table of Contents

Ameren Missouri
Labadie Energy Center
Documentation of Supplemental Groundwater Monitoring Well Design

November, 2013

List of Tables

List of Figures

List of Appendices

1.0 INTRODUCTION

At the request of Ameren Missouri, this supplemental report has been prepared to provide additional documentation for the basis of groundwater monitoring well design at the Ameren Missouri Labadie Energy Center proposed Utility Waste Landfill (UWL). It is intended to supplement previous information contained in Appendix X of the Construction Permit Application (CPA) for the proposed UWL, which was originally submitted to both the Missouri Department of Natural Resources Solid Waste Management Program (MDNR-SWMP) and Franklin County on January 29, 2013. The supplemental information herein addresses various technical issues raised by Franklin County during their review process. In particular, alternative source widths are considered as well as a more detailed explanation of methods used to derive longitudinal and transverse dispersivity. At the County's request, Ameren Missouri has agreed to install additional wells at the proposed UWL, as detailed in this supplemental report.

1.1 Basis for Groundwater Monitoring Design

A fundamental basis for groundwater monitoring system design derives from the site-specific geologic and hydrologic data collected and evaluated during the Detailed Site Investigation (DSI) process. This DSI process, which ensued at the proposed Labadie UWL in 2009-2010, can be generally described as follows:

1. A work plan development meeting was held with the MDNR-GSP (now referred to as the Missouri Geological Survey (MGS)). MDNR-SWMP representatives were also in attendance. Discussion focused on the geology and hydrology of the proposed site, specific elements to be included in the DSI work plan, time frames for completion of the work, and review of the regulatory process.

2. Following that meeting, a detailed work plan was developed for review and approval by the MGS with input from MDNR-SWMP. It was based on the requirements of 10 CSR 80-2.015 Appendix 1, "*Guidance for Conducting and Reporting Detailed Geologic and Hydrologic Investigations at a Proposed Solid-Waste Disposal Area*" (commonly referred to simply as the "Guidance").

3. After work plan approval, the field investigation was completed in accordance with the approved work plan, applicable rules, and department guidance. The "Guidance" document also details the specific elements to be included in the DSI report, which was then submitted to the MGS and MDNR-SWMP for review and approval.

Approval of the DSI report for the proposed Labadie UWL by both the MGS and MDNR-SWMP indicates that the site was found to have suitable geologic and hydrologic characteristics for the development of an environmentally sound solid waste disposal area. Approval also indicated that the DSI report adequately addressed geologic or hydrologic conditions pursuant to 10 CSR 80-11.010(5)(A)3 for the development of an environmentally sound solid waste disposal area.

This is a rigorous and thorough regulatory process and is accompanied by two separate public participation events as required by Solid Waste Management Law.

1.2 Detection versus Compliance Monitoring Systems

Understanding the intent of the required detection monitoring system as described in 10 CSR 80-11.010(11)(C)4. and as presented in Appendix X of the CPA is essential to understanding the groundwater monitoring system developed at the Labadie UWL. The approved system at Labadie is not a compliance-based system. Rather, as described in 10 CSR 80-11.010(11)(B)4.B., the number, locations, and depths of the groundwater wells were designed to, "…*ensure that they detect any significant amounts of fluids generated by the UWL that migrate from the UWL to the groundwater*". Detection of "*any significant amounts of fluids*" is accomplished through statistical comparisons of groundwater analytical data to determine if statistically significant increases (SSIs) through time are occurring for any of the 32 required monitoring parameters listed in 10 CSR 80-11.010 Appendix I.

Compliance monitoring systems assume a specific standard (e.g. Federal MCL's, State Groundwater Protection Standards) must be met at the property boundary. Detection monitoring is a precursor to compliance monitoring because it examines SSIs in water chemistry through time irrespective of absolute chemical concentration or compliance with specific standards. If statistical evaluations reveal an increasing concentration over time for one or more of the required analytical parameters, then a demonstration must be made to MDNR in accordance with 10 CSR 80-11.010(11)(C)6 that a source other than the UWL caused the SSI or that the SSI is the result of an error in sampling, analysis, statistical evaluation, or natural geospatial variation.

If a demonstration cannot be made that the statistical increase is not due to the UWL, then Assessment Monitoring is required by regulation. Assessment monitoring includes the installation of additional wells, an increased frequency in sample collection and analysis, and an evaluation of the rate and extent of migration of the contaminant plume, including documentation of contaminant concentrations. It is during the assessment monitoring process that comparisons to groundwater protection standards are required and in that sense any additional wells installed essentially create a compliance-based system. The detection monitoring system presented in Appendix X of the CPA is better understood by reference to Figure 1 of this supplemental report. This figure was not originally included in Appendix X. It visually illustrates the derivation and selection of the spacing criteria for the down gradient wells, as described on pages 5 and 6 of Appendix X, by showing the dispersion plumes in relationship to one another and to solid waste disposal boundaries. The dimensions of the dispersion plumes, which are the same as those presented in Attachment 3 of Appendix X, are based on a 44-year (528 months) time period. These plumes demonstrate a high degree of probability for detecting contaminant plumes along the eastern and northern (i.e. down gradient) perimeters of the proposed UWL using the baseline model parameters described in Appendix X.

2.0 SOURCE WIDTH

We have re-evaluated the dispersion plumes using the original model parameters presented in Appendix X of the CPA except for source width. Source widths (initial liner "tears") of five feet and 25 feet were assumed. PLUME model outputs showing the resultant dimensions for each modeling scenario, including the original 100-foot source width, are presented as Figures 2 through 7. The PLUME model outputs shown in Figures 2, 3, and 4 pertain to Cell 1 and 2. The PLUME Model outputs shown in Figures 5, 6, and 7 pertain to Cell 3 and 4. The dimensions for each modeling scenario are summarized in Table 1. Resultant plume widths are based on the average distance between proposed wells and the inside toe of the containment berm around the waste disposal cells.

The results of this re-evaluation concluded that a smaller initial source width results in a slightly shorter dispersion plume and a more pronounced narrowing of the dispersion plume width. For comparison, the difference in plume length between the 100-foot and five-foot "tears" is between 5 and 6 percent. The difference in plume width is between 38 and 39 percent.

The effect a narrower plume from a five-foot "tear" has on the MDNR-approved groundwater monitoring system is graphically illustrated on Figure 8. For each well location, the dispersion plumes generated for the five-foot "tears" (Figures 4 and 7) have been superimposed (in green) on the dispersion plumes for the 100-foot "tears". Lines drawn tangentially from the widest part of each "five-foot" dispersion plume are shown extending into the solid waste area until they either intersect or the inside toe of slope is reached. These triangular shapes provide an estimate of the area where a failure in the liner system could escape detection by the approved and installed groundwater monitoring system.

3.0 LONGITUDINAL & TRANSVERSE DISPERSIVITY

The groundwater model approach used to determine longitudinal and transverse dispersivity values was developed in response to the data obtained during the 12-month DSI time period (December 2009 to November 2010). During that period, groundwater flow direction fluctuated widely in response to changes in Missouri River elevation. Groundwater movement generally was north-northwestward toward the Missouri River during periods of low river stage and generally shifted eastward away from the river during periods of high river stage. These changes in flow direction commonly occurred from month-to-month during the DSI time period with a 90 degree shift in groundwater flow documented over the span of one week in May 2010. The overall effect imposed by the Missouri River on groundwater movement is not unlike the ebb and flow of water in the tidal zone of an ocean beach. This “swash” effect is not uncommon in alluvial aquifers and conventional modeling literature emphasizes the need to acquire as much site-specific data as possible because of the “profound influence” such variations can have on contaminant transport (Wiedemeier et al., 1998). However, conventional modeling techniques do not account for the degree of variation observed during the 12-month DSI time period and for that reason the method of analysis used a multidirectional aspect of groundwater flow to develop an overall detection groundwater monitoring system.

An expanded discussion of the approach used to derive longitudinal and transverse dispersivity values is provided in Appendix 1 of this supplemental report. It is based on the concepts and techniques cited in Freeze and Cherry (1979), Gelahar et al., (1992), Wang and Anderson (1982), and Wilson et al., (1992).

4.0 OTHER MODEL CONSIDERATIONS

The following information addresses other model considerations raised during the County's review process that have a minor impact on the groundwater model results.

4.1 Source Concentrations

In instances of a known, contaminated site (e.g. a leaking underground petroleum storage tank) we recognize the need for reasonable, site-specific source concentrations in modeling the impact to forecast the potential time of travel, concentration, and impact of contaminant plumes on adjacent properties and/or existing groundwater uses. However, the intent of the PLUME model used for the Labadie UWL is to develop hypothetical plume shapes and sizes for the purpose of designing and evaluating a detection groundwater monitoring system. The PLUME model does not require or allow the entry of a source concentration – therefore the choice of an initial source concentration does not impact the PLUME model and does not impact the overall shape, length, or width of the resultant plume developed by the model.

The PLUME model develops plume shapes represented by "concentration contours" that are a percentage of an initial source concentration. In this case, "concentration contours" of one-tenth (0.1), one-one hundredth (0.01) and one-one thousandth (0.001) of an initial source concentration were modeled. Primarily for illustrative purposes, we chose to use an initial source concentration of 3,000 mg/l for the contaminant, Chloride, in the original model. Chloride was chosen as a contaminant that can be expected to be present in the UWL at some concentration, is recognized by the scientific community as mobile in groundwater flow regimes, and is commonly used as a conservative "tracer" contaminant. The following excerpt supports the use of Chloride (Wiedemeier et al, 1998):

> *Chloride (Cl-) forms ion pairs or complex ions with some of the cations present in natural waters, but these complexes are not strong enough to be of significance in the chemistry of fresh water. Chloride ions generally do not enter into oxidation-reduction reactions, form no important solute complexes with other ions unless the chloride concentration is extremely high, do not form salts of low solubility, are not significantly adsorbed on mineral surfaces, and play few biochemical roles. Thus, physical processes control the migration of chloride ions in the subsurface. Because of the neutral chemical behavior of chloride, it can be used as a conservative tracer to estimate biodegradation rates (in chlorinated solvents).*

The plume shape defined by the outermost 0.001 concentration contour was used as the basis for the number and location of groundwater monitoring wells that would result in a highly efficient detection monitoring system. The initial source concentration (in this case, 3,000 mg/l Chloride) was used to provide a numerical value for the 0.001 concentration contour (3 mg/l) that generally approximates the Practical Quantitation Limit (PQL) of Chloride.

Modeling is a hypothetical exercise, albeit a scientific one. Modeling using scientific parameters is the best available predictor of future performance of landfills. However, an actual source concentration from a potential future leak from a UWL with a composite liner and leachate collection system cannot be predicted. The “leak” may be very small (the HELP model uses 2 centimeter diameter holes in the geomembrane liner, not a 5-foot tear) or it may be very minor volumes (the HELP model predicts that the maximum head on the Labadie UWL composite liner will be less than 1 inch). Therefore, despite the actual contaminant concentrations in the “leak”, the contaminant will be diluted once it reaches the large volumes of groundwater within the alluvial aquifer of the Missouri River valley. As a result, an estimated source concentration was used for illustrative purposes that may represent a “worst case” scenario, while the source concentration of an actual event could be higher or lower than the concentration modeled.

It is our professional opinion that initial source concentration is a minor factor in the design of a detection groundwater monitoring system and its value is primarily used to model only one of many possible scenarios. Regardless of the source concentration, the PLUME model predicts the size and shape of a future contaminant plume as defined by the 0.001 concentration contour. Depending on the source concentration and analytical limitations, a specific contaminant may not be detected at one-one thousandth of the initial concentration. Under the current Missouri regulatory framework for detection monitoring of landfills, the use of “indicator” or “tracer” parameters and the regular statistical evaluation of groundwater data for SSIs seeks to identify potential containment system failures at small quantities and concentrations as soon as they can be practically detected, but before they exceed a compliance concentration.

4.2 Effective Porosity

The range of effective porosity values presented in Table 1 of Appendix X (0.30, 0.35, and 0.40) are the same values as used in Table 8 of the DSI Report and are based on the data of Peck (1953) for mixed-grain sands. Our model uses the middle value (0.35). In response to County comments, a lower value of 0.265 was evaluated and was found to result in a slight increase in dispersion plume length and virtually no change in dispersion plume width. Thus, effective porosity values have a minor impact on plume width, but to a much lesser degree than source width considerations. In situ testing of effective porosity to acquire a one or more site-specific values has limited value to the modeling process. The sand grain sizes, and therefore the geometry of the pore apertures and the degree of interconnectivity of pore throats that define effective porosity found in an alluvial aquifer can vary considerably both vertically and laterally across a site. For purposes of designing a detection monitoring system, there is little apparent benefit to further refining an effective porosity value.

4.3 Model Efficiency

Modeling is a subjective process and is used as a tool to evaluate the potential efficiency of a detection groundwater monitoring system. Model parameters can be adjusted based on various assumptions and the desired degree of conservatism, with the end result being a monitoring system design that is not expected nor required to be 100 percent efficient. Rather, the intent of the modeling process is to support the development of a detection monitoring system that is considered "highly efficient" (no regulatory definition for "highly efficient" exists in Missouri State Solid Waste Management Law and Rules).

4.4 Vertical Hydraulic Gradient

The groundwater transport model presented in Appendix X of the CPA considered the vertical component of dispersion insignificant "*because contaminant concentrations are assumed to be preferentially moving parallel with groundwater flow direction*" (p. 5). This assumption is confirmed by previous studies, particularly the work by Gelhar et al. (1992), who after review of multiple field studies determined that, "*In all of these cases, vertical transverse dispersivity is 1-2 orders of magnitude smaller than the horizontal transverse dispersivity*".

The data presented by Gelhar for what was considered high reliability field studies show vertical-to-horizontal dispersivity ratios greater than two orders of magnitude (see Gelhar's Table 1, data for the Garabedian et al. (1988) and Rajaram & Gelhar (1991) field studies). These data suggest that for every foot of vertical movement, the horizontal movement is in excess of 100 feet and possibly in excess of 600 feet. Thus, modeling a maximum width for the Labadie UWL of approximately 3,000 feet (Cell 3 as measured southeast to northwest) and an alluvial aquifer thickness of approximately 100 feet, the horizontal movement of groundwater will transport potential contaminants toward the approved shallow detection monitoring system well in advance of contaminant conveyance and detection in deeper wells.

5.0 EVALUATION OF ALTERNATIVE FLOW DIRECTION

The modeling approach presented in Appendix X of the CPA was based on the results of the 12-month DSI time period. Those data show that groundwater exhibits considerable variation in flow direction in response to changes in Missouri River elevation. During periods of low river stage, groundwater generally flows north-northwest toward the river. During periods of high river stage, groundwater flow shifts eastward away from the river. This "swash" effect on groundwater movement and resultant velocities are accounted for in our modeling approach. Alternative model scenarios that envision a constant groundwater flow direction throughout the 44-year time period are not an accurate reflection of the behavior of the alluvial aquifer at this site and its response to changes in Missouri River elevation.

The representativeness of Missouri River levels and their consequent impacts on groundwater flow behavior during the 12-month DSI time period in relationship to the preceding ten-year time period (2000-2009) is described on page 40 of the DSI report. The DSI recognized that Missouri River levels generally were higher during the DSI than in preceding years and is the reason why one of the conclusions stated in the DSI report (p. 52) was, "*…"unwatering" of the local water table toward the Missouri River may be more prevalent than what is suggested by the current data*". Thus, the DSI acknowledged that the 12-month DSI timeframe (2009-2010) on which our modeling effort was based coincided with a period of unseasonably high river levels and consequently, the DSI data do not positively predict groundwater behavior under "normal" river stage conditions. However, the DSI data does provide a basis for understanding how groundwater movement behaves under more seasonal river stage conditions.

In the absence of piezometric data during periods of "normal" river stage conditions, it is not possible to accurately model or predict the resultant impacts on groundwater movement. However, general conclusions can be made by extrapolating piezometric readings during the 12-month DSI investigation to the historical river elevation readings as recorded at the Labadie Power Plant gauging station.

Figure 9 is a hydrograph depicting the daily Missouri River elevations as obtained from Ameren personnel for the Labadie gauging station. The figure is identical to the hydrograph presented as Figure 32 of the DSI report except for the addition of data from 2011, 2012, and the first quarter of 2013. As noted on page 40 of the DSI report, a reversal in groundwater flow direction appears to occur when Missouri River levels attain a more or less sustained elevation of between 461 and 463 feet. Groundwater flow direction generally is toward the river below this range in elevation and generally moves away from the river above this range in elevation. As can be seen from the hydrograph, using a midpoint elevation of 462 feet, groundwater movement toward the river is predicted to occur more frequently in the timeframes both before and after the 12-month DSI time period. The hydrograph also indicates that the longest sustained period of time river elevations remained below 462 feet is approximately 678 days. Conversely, the hydrograph indicates that the longest sustained period of time river elevations remain above 462 feet is approximately 166 days. This suggests that groundwater movement typically has a more northerly component than evidenced by the data acquired during the DSI timeframe and that the maximum length of time before a shift from this northerly flow occurs is slightly less than two years. Sustained periods of high river flow are of shorter duration (<6 months), which supports the modeled impact the "swash" effect has on groundwater velocity values.

An evaluation of what constitutes more typical river flow conditions can be approximated by considering the average or mean value of the daily river elevations as measured over the 2000-1st Q 2013 period at Labadie. This is shown in the frequency histogram presented as Figure 10 that indicates the mean river elevation over the 13-year (4,817 days) time period is 454.9 feet. This is approximately seven feet lower than the estimated elevation (462 feet) at which groundwater begins moving toward the Missouri River and is further evidence that a northerly flow component is more frequent than shown by the data acquired during the DSI. The longest time period the river remains below this typical flow condition is approximately 309 days (Figure 9).

Based on a more northerly component of groundwater flow (toward the Missouri River) as suggested by the 13-year historical time period of river stage analysis, we graphically re-evaluated the northern tier of wells in the approved detection monitoring system, located immediately north of Cell 2. The results of this re-evaluation are presented in Figure 11. For the purposes of demonstration, a northerly orientation perpendicular to the solid waste boundary was selected for the axis of the dispersion plumes (a plume axis perpendicular to the solid waste boundary requires the narrowest well spacing). The dispersion plumes used are based on the five-foot source width as shown in Figures 4 and 8. All other model parameters were unchanged. As shown, using the more northerly direction of groundwater flow, four (4) additional shallow groundwater wells at the approximate locations noted on Figure 11 will be installed.

6.0 DEEP WELLS

Ameren Missouri has agreed to install three deep wells (one upgradient and two downgradient) in recognition of Franklin County's Ordinance that allows reasonable groundwater monitoring measures, in addition to the requirements of the Missouri Solid Waste Management Law and Rules. The deep groundwater monitoring wells will be designated MW-33(D), MW-34(D), and MW-35(D). Wells MW-33(D) and MW-34(D) will generally be located hydraulically downgradient of the proposed UWL. Well MW-35(D) will generally be located hydraulically upgradient of the proposed UWL. Each well will be screened to monitor groundwater quality within the lower part of the alluvial aquifer. Proposed deep well locations are shown on Figure 12.

The purpose of the deep wells will be to provide background water quality data for the lower portion of the alluvial aquifer, which can then be compared to shallower groundwater quality data.

The proposed deep well locations are adjacent to shallow wells MW-5, MW-25, and MW-30 (Figure 12). These locations were selected to simplify future sampling access, consolidate wells within the agricultural fields for long-term maintenance, and to serve as part of the detection groundwater monitoring system for the first disposal cell (Phase 1). They also facilitate well installation and avoid future site improvements that could impact the wells (e.g. the UWL access road at the northwest corner of Phase 1).

The deep wells will be drilled and installed in conformance with 10 CSR 23-4 or to approved variances. Construction specifications will be similar to that used for the existing shallow wells to the extent applicable or practicable. However, because of the deeper depth of drilling, different drilling techniques may be necessary. The estimated bottom of screen depth for each deep well is 75 to 85 feet. Schedule 40 PVC riser pipe and well screen will be used. Well screen lengths will be 10 feet.

7.0 SUMMARY AND CONCLUSIONS

The groundwater model design presented in Appendix X of the CPA for the Labadie Energy Center Proposed Utility Waste Landfill is based on the results of the DSI investigation conducted for the facility in 2009-2010. The DSI included an evaluation of groundwater flow based on measurements taken from 100 piezometers over a period of 12 consecutive months (December 2009 to November 2010). These site-specific data are considered appropriate for the development of a rational, scientifically based groundwater well design intended specifically as a detection monitoring system as required by Missouri State Solid Waste Management Law and Rules. A 29-well detection monitoring system has been approved by MDNR-SWMP, in conjunction with joint review by MGS and MDNR-WPP. However, subsequent discussions between Ameren Missouri and the County have resulted in the proposed addition of seven new wells (4 shallow; 3 deep).

1. Conclusions reached by this supplemental report include the following: Based on the past 13 years of historical Missouri River elevations, groundwater movement trends more northerly than what was indicated by the 12-month DSI investigative time period. In combination with the narrower plume widths generated assuming a five-foot "tear" width in the liner system, four (4) additional shallow wells in the area north of Cell 2 warrant consideration. Recommended locations for four (4) new shallow wells are depicted on Figure 11 of this supplemental report. Wells installed in this area should be of the same approximate depth as the existing wells and integrated into the current detection groundwater monitoring system.

Although literature sources confirm that the horizontal component of contaminant migration is much greater than the vertical component of contaminant migration, Ameren Missouri has agreed to install three deep groundwater monitoring wells (one upgradient; two downgradient) at the locations noted on Figure 12 of this supplemental report. Our interpretation of MDNR's approach to groundwater detection monitoring at landfills is that groundwater monitoring is a dynamic process, subject to ongoing re-evaluation and conclusion based on data from each background or semi-annual sampling event. As such, future data collected during routine detection monitoring events will provide additional information that will be evaluated by Ameren Missouri, MDNR and/or Franklin County in order to consider the need for modifications to the currently approved groundwater monitoring system. Until such time, the current detection groundwater monitoring system, which is proposed to be supplemented by the addition of four shallow wells and three deep wells, meets the requirements and the intent of 10 CSR 80-11.010.

8.0 REFERENCES

Freeze, R.A. and Cherry, J.A., 1979, "*Groundwater*, *Chapter 9 Groundwater Contamination";* Department of Earth Sciences, University of Waterloo, Waterloo, Ontario.

Gelahar, L.W., Welty, C., and Rehfeldt, K.R., 1992, "*A Critical Review of Data on Field-Scale Dispersion in Aquifers*", Water Resources Research, Vol. 28, No.7, pp. 1955-1074.

Peck, R.B., Hanson, W.E., and Thornburn, T.H., 1953, Foundation Engineering, John Wiley & Sons, New York, London, Sydney, Second Edition, p.13, Table 1.4.

Prickett, T.A., Naymik, T.G., and Lonnquist, C.G., 1981, "*A "Random-Walk" Solute Transport Model for Selected Groundwater Quality Evaluations*", Illinois State Water Survey Bulletin 65/81 (found at http://www.isws.illinois.edu/pubdoc/b/iswsb-65.pdf).

Wang, H.F. and Anderson, M.P., 1982, "*Introduction to Groundwater Modeling: Finite Difference and Finite Element Methods, Chapter 8 Advective-Dispersive Transport";* W. H. Freeman and Company, San Francisco.

Weidemeier, T.H., Swanson, M.A., Montoux, D.E., Gordon, E.K., Wilson, J.T., Wilson, B.H., Kampbell, D.H., Hansen, J.E., Haas, P., and Chapelle, F.H., 1998, "*Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Groundwater*", EPA/600/R-98/128, National Risk Management Research Laboratory Office of Research and Development, Cincinnati, Ohio, U.S. EPA.

Wilson, C.R., Einberger, C.M., Jackson, R.L., and Mercer, R.B., 1992, "*Design of Ground-Water Monitoring Networks Using Monitoring Efficiency Model (MEMO)*", GROUND WATER, Vol. 30 No. 6, pp. 965–970.

TABLE

Ameren Missouri Labadie Energy Center Utility Waste Landfill
Documentation of Supplemental Groundwater Monitoring Well Design
Plume Dimensions for 100-ft, 25-ft, and 5-ft "Tears"
Table 1

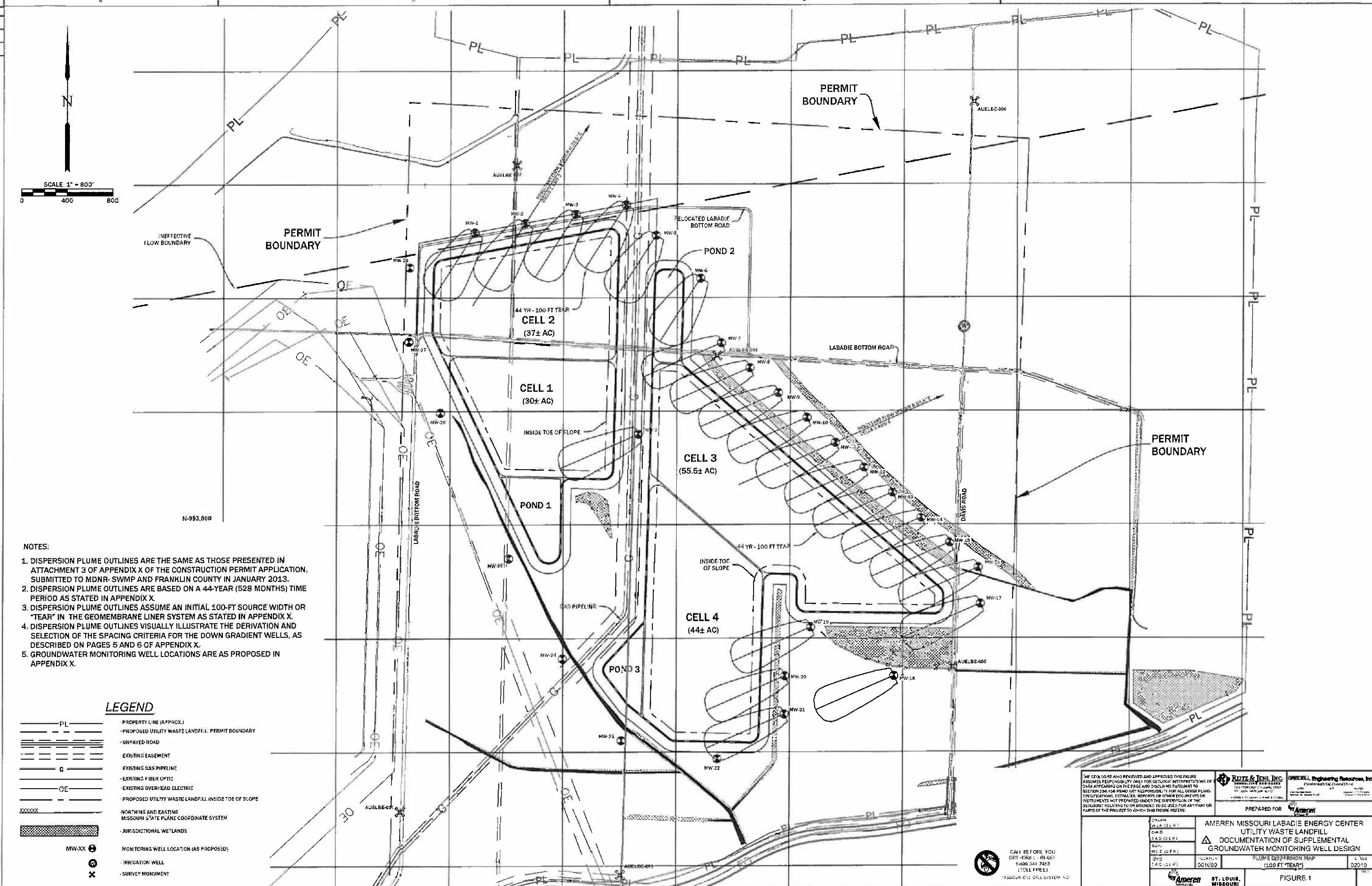
Cells 1 and 2 Dispersion Plume Dimensions		
Source Width, Y (feet)	Length of Plume (0.001 contour), x (feet)	Width of Plume[1] at 243 feet (0.001 contour) (feet)
100	662	298
25	649	220
5	620	184

1. Referenced measurement reflects averaged distance of proposed well locations MW-1, MW-2, and MW-3 from edge of waste (inside toe of berm).

Cells 3 and 4 Dispersion Plume Dimensions		
Source Width, Y (feet)	Length of Plume (0.001 contour), x (feet)	Width of Plume[1] at 434 feet (0.001 contour) (feet)
100	750	288
25	736	213
5	711	177

1. Referenced measurement reflects averaged distance of proposed well locations MW-7 through MW-15 from edge of waste (inside toe of berm).

FIGURES



NOTES:

1. DISPERSION PLUME OUTLINES ARE THE SAME AS THOSE PRESENTED IN ATTACHMENT 3 OF APPENDIX X OF THE CONSTRUCTION PERMIT APPLICATION, SUBMITTED TO MDNR- SWMP AND FRANKLIN COUNTY IN JANUARY 2013.
2. DISPERSION PLUME OUTLINES ARE BASED ON A 44-YEAR (528 MONTHS) TIME PERIOD AS STATED IN APPENDIX X.
3. DISPERSION PLUME OUTLINES ASSUME AN INITIAL 100-FT SOURCE WIDTH OR "TEAR" IN THE GEOMEMBRANE LINER SYSTEM AS STATED IN APPENDIX X.
4. DISPERSION PLUME OUTLINES VISUALLY ILLUSTRATE THE DERIVATION AND SELECTION OF THE SPACING CRITERIA FOR THE DOWN GRADIENT WELLS, AS DESCRIBED ON PAGES 5 AND 6 OF APPENDIX X.
5. GROUNDWATER MONITORING WELL LOCATIONS ARE AS PROPOSED IN APPENDIX X.

LEGEND

- PROPERTY LINE (APPROX.)
- PROPOSED UTILITY WASTE LANDFILL PERMIT BOUNDARY
- UNPAVED ROAD
- EXISTING EASEMENT
- EXISTING GAS PIPELINE
- EXISTING FIBER OPTIC
- EXISTING OVERHEAD ELECTRIC
- PROPOSED UTILITY WASTE LANDFILL INSIDE TOE OF SLOPE
- NORTHING AND EASTING MISSOURI STATE PLANE COORDINATE SYSTEM
- JURISDICTIONAL WETLANDS
- MW-XX MONITORING WELL LOCATION (AS PROPOSED)
- IRRIGATION WELL
- SURVEY MONUMENT

CALL BEFORE YOU DIG - DRILL - BLAST 1-800-344-7483 (TOLL FREE) MISSOURI ONE CALL SYSTEM, INC.

THE GEOLOGIST WHO REVIEWED AND APPROVED THIS FIGURE ASSUMES RESPONSIBILITY ONLY FOR GEOLOGIC INTERPRETATIONS OF DATA APPEARING ON THE PAGE AND DISCLAIMS PURSUANT TO SECTION 256.456 RSMO ANY RESPONSIBILITY FOR ALL OTHER PLANS, SPECIFICATIONS, ESTIMATES, REPORTS OR OTHER DOCUMENTS OR INSTRUMENTS NOT PREPARED UNDER THE SUPERVISION OF THE GEOLOGIST RELATING TO OR INTENDED TO BE USED FOR ANY PART OR PARTS OF THE PROJECT TO WHICH THIS FIGURE REFERS.

REITZ & JENS, INC. CONSULTING ENGINEERS

GREDELL Engineering Resources, Inc. ENVIRONMENTAL ENGINEERING

PREPARED FOR Ameren

AMEREN MISSOURI LABADIE ENERGY CENTER
UTILITY WASTE LANDFILL
DOCUMENTATION OF SUPPLEMENTAL GROUNDWATER MONITORING WELL DESIGN

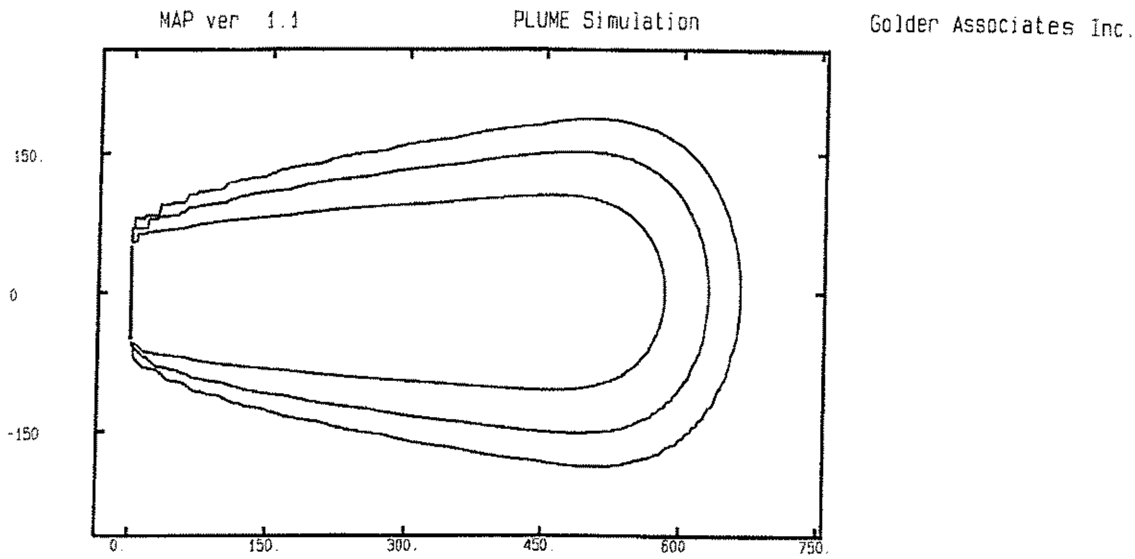
DRAWN	WJA (GER)
CHKD	TAD (GER)
SURV	MCC (GER)
APPD	TAS (GER)
LOCATION	001009
PLUME DISPERSION MAP (100 FT "TEAR")	
CLASS	02010

Ameren ST. LOUIS, MISSOURI

FIGURE 1

M:\Share\CADDFiles\AMEREN\UE\LABADIE\CONSTRUCTION PERMIT\2012 DRAWINGS\GROUNDWATER 06 2012\WELL LOCATIONS 10-12\GROUNDWATER MONITORING WELLS REV 05-15-2013.dwg, (CELL 1-2-3-4_FIG1_100YR), 11/11/2013 9:16:42 AM.

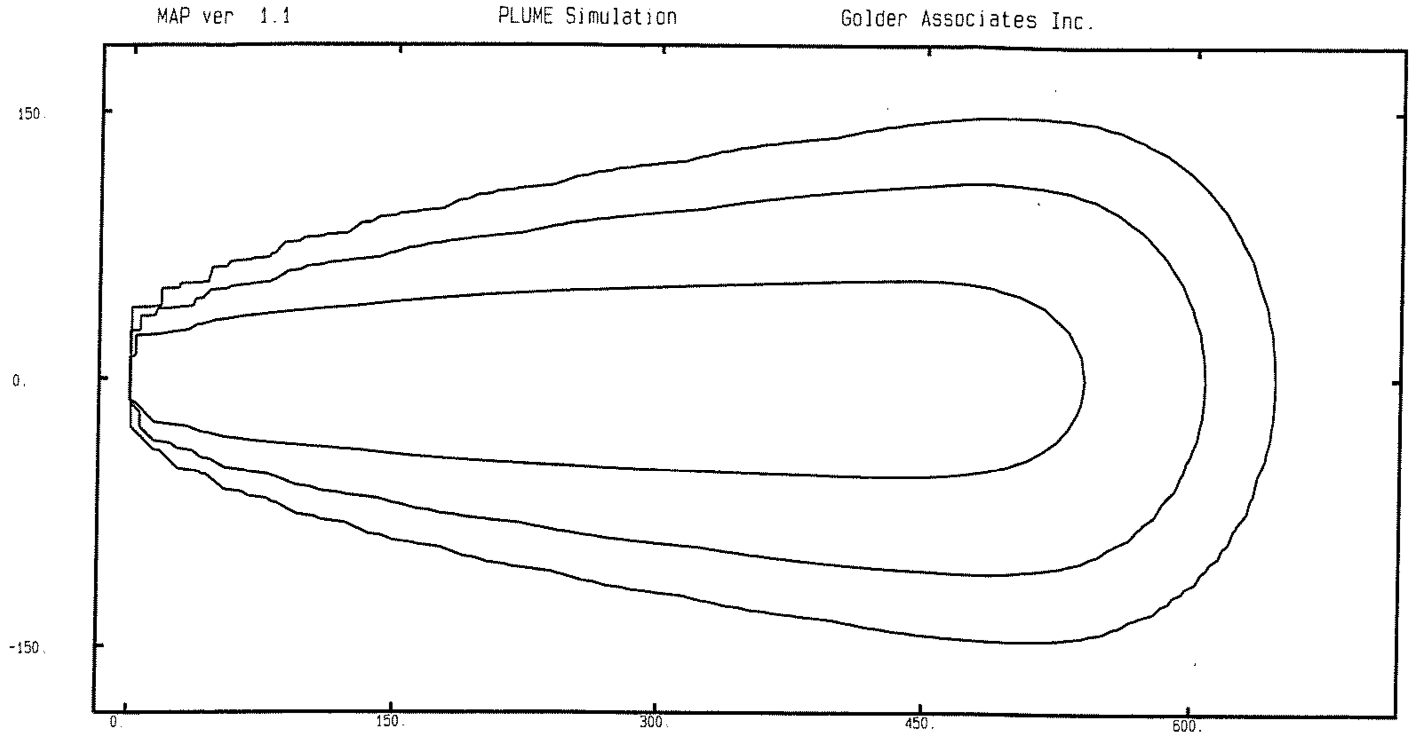
Ameren Missouri Labadie Energy Center Utility Waste Landfill
Documentation of Supplemental Groundwater Monitoring Well Design
Cells 1 and 2
Plume Model Output for 44 Years - 100 ft. "Tear"
Figure 2



Contours at: .00100, .01000, .10000
Advection time = 528.00
Average contaminant velocity = 1.0130
Width of line source = 100.00

Longitudinal dispersivity = 1.74
Transverse dispersivity = 2.03
First-order decay constant = .000E+00
Diffusion coefficient = .000E+00

Ameren Missouri Labadie Energy Center Utility Waste Landfill
Documentation of Supplemental Groundwater Monitoring Well Design
Cells 1 and 2
Plume Model Output for 44 Years - 25 ft. "Tear"
Figure 3



Contours at: .00100, .01000, .10000
Advection time = 528.00
Average contaminant velocity = 1.0130
Width of line source = 25.00
Longitudinal dispersivity = 1.74
Transverse dispersivity = 2.03
First-order decay constant = .000E+00
Diffusion coefficient = .000E+00

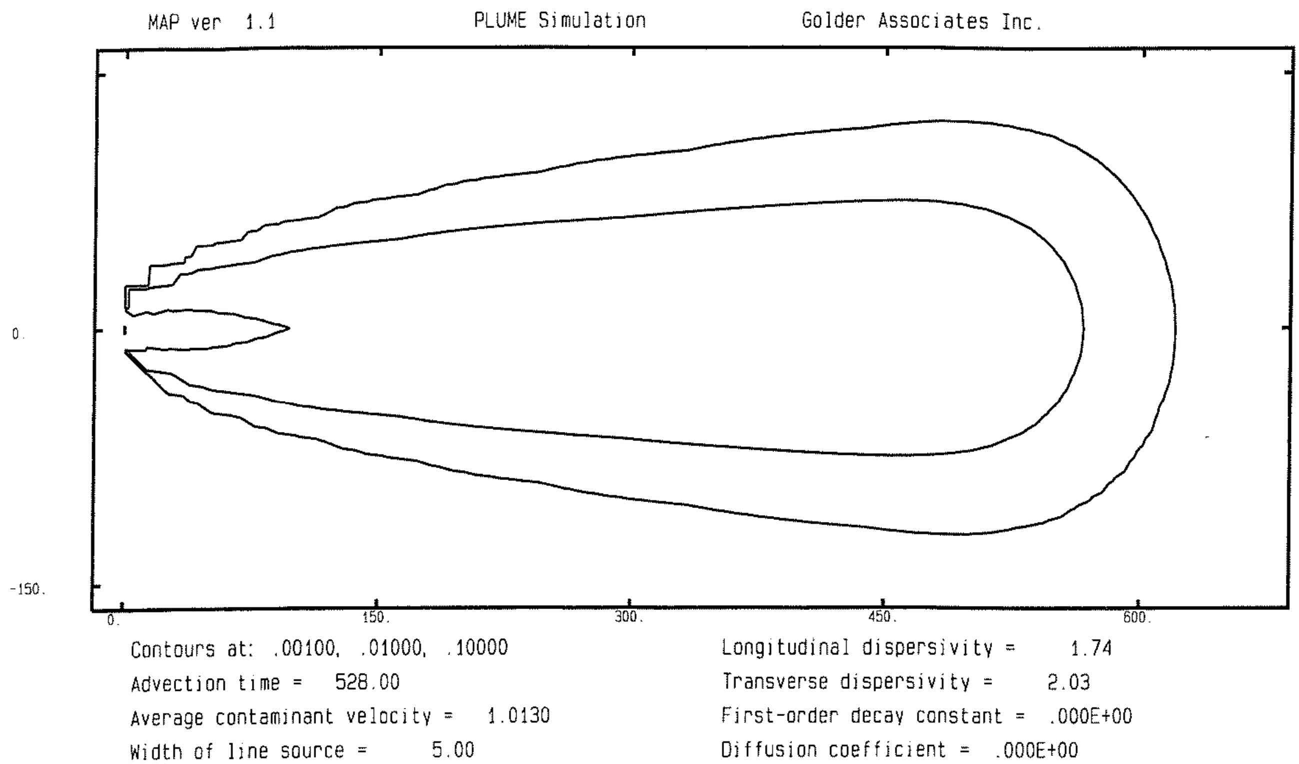
Ameren Missouri Labadie Energy Center Utility Waste Landfill

Documentation of Supplemental Groundwater Monitoring Well Design

Cells 1 and 2

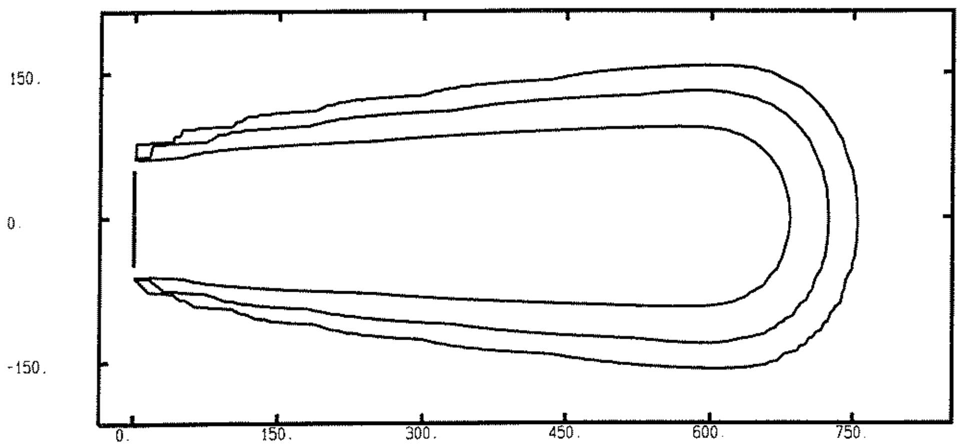
Plume Model Output for 44 Years - 5 ft. "Tear"

Figure 4



Ameren Missouri Labadie Energy Center Utility Waste Landfill
Documentation of Supplemental Groundwater Monitoring Well Design
Cells 3 and 4
Plume Model Output for 44 Years - 100 ft. "Tear"
Figure 5

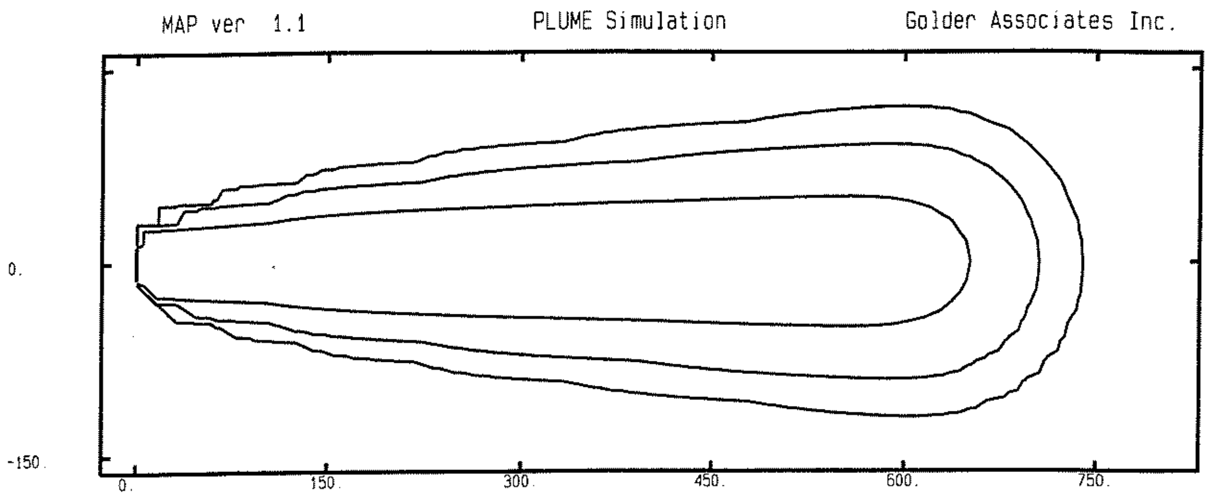
MAP ver 1.1 PLUME Simulation Golder Associates Inc.



Contours at: .00100, .01000, .10000
Advection time = 528.00
Average contaminant velocity = 1.2120
Width of line source = 100.00

Longitudinal dispersivity = 1.08
Transverse dispersivity = 1.02
First-order decay constant = .000E+00
Diffusion coefficient = .000E+00

Ameren Missouri Labadie Energy Center Utility Waste Landfill
Documentation of Supplemental Groundwater Monitoring Well Design
Cells 3 and 4
Plume Model Output for 44 Years - 25 ft. "Tear"
Figure 6



Contours at: .00100, .01000, .10000
Advection time = 528.00
Average contaminant velocity = 1.2120
Width of line source = 25.00

Longitudinal dispersivity = 1.07
Transverse dispersivity = 1.02
First-order decay constant = .000E+00
Diffusion coefficient = .000E+00

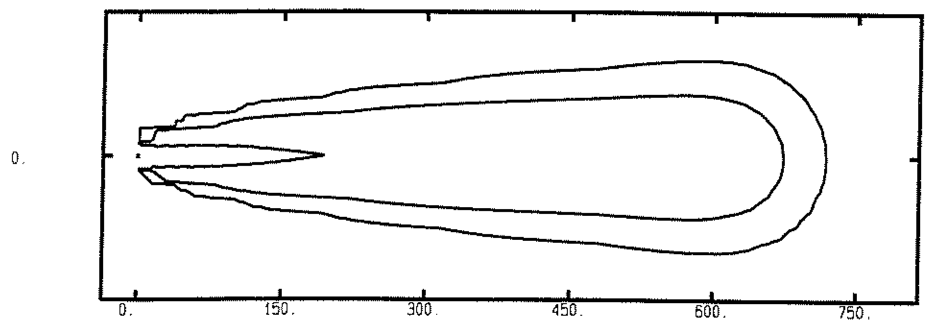
Ameren Missouri Labadie Energy Center Utility Waste Landfill

Documentation of Supplemental Groundwater Monitoring Well Design
Cells 3 and 4

Plume Model Output for 44 Years - 5 ft. "Tear"

Figure 7

MAP ver 1.1 PLUME Simulation Golder Associates Inc.



Contours at: .00100, .01000, .10000

Advection time = 528.00

Average contaminant velocity = 1.2120

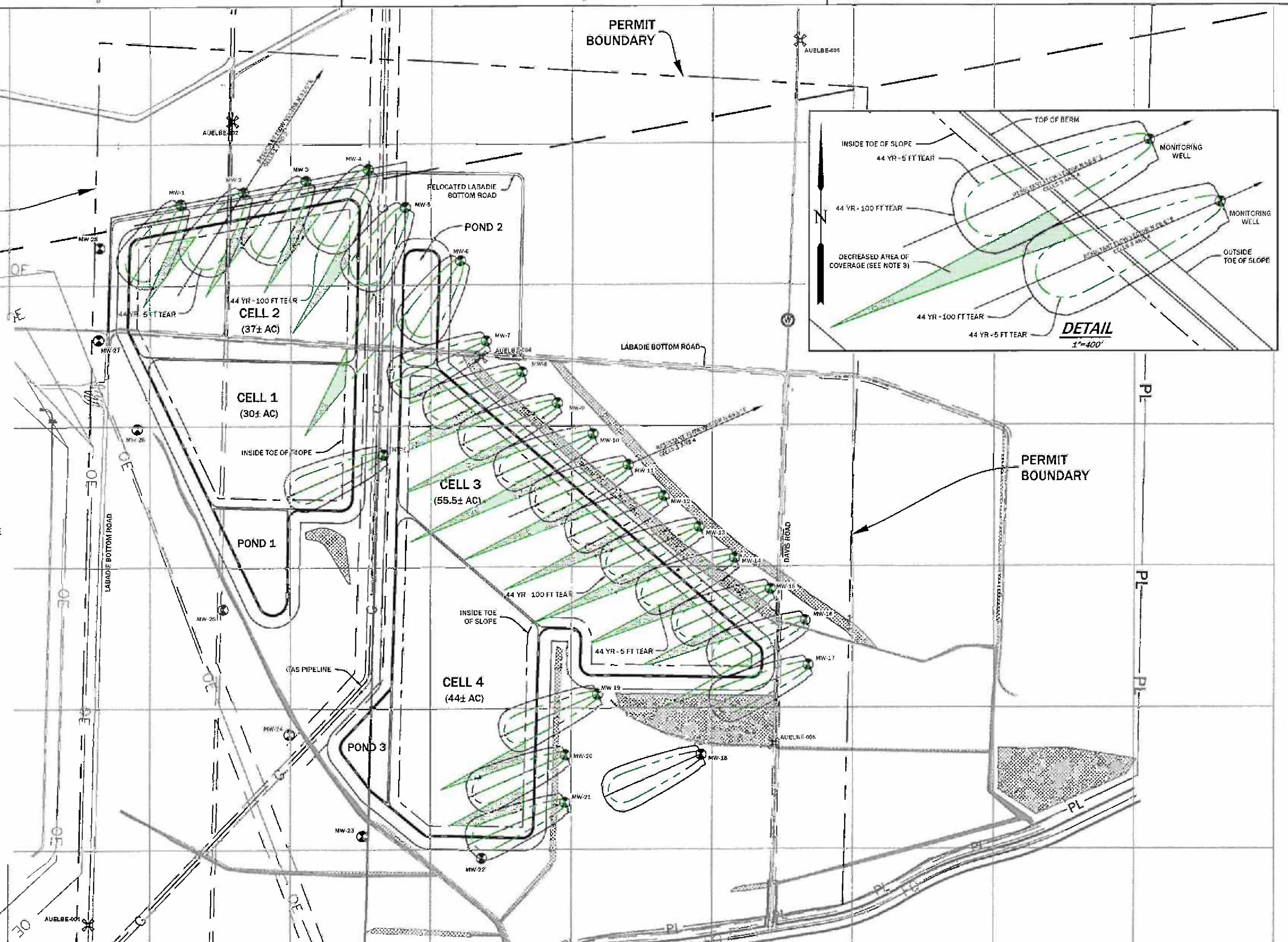
Width of line source = 5.00

Longitudinal dispersivity = 1.07

Transverse dispersivity = 1.02

First-order decay constant = .000E+00

Diffusion coefficient = .000E+00



N

SCALE: 1" = 800'

0 400 800

NOTES:

1. DISPERSION PLUME OUTLINES FOR 44 YR - 100 FT TEAR ARE IDENTICAL TO THOSE DEPICTED IN FIGURE 1.
2. DISPERSION PLUME OUTLINES FOR 44 YR - 5 FT TEAR ARE SUPERIMPOSED IN GREEN AND ARE THE SAME AS THOSE PRESENTED IN FIGURES 4 AND 7 OF THIS REPORT.
3. TRIANGULAR REGIONS IN GREEN PROVIDE A VISUAL ILLUSTRATION OF AREAS WHERE RE-MODELED PLUME MIGRATION USING A 5 FT TEAR COULD ESCAPE DETECTION USING THE ORIGINAL RESULTANT FLOW VECTORS OF N66.6°E and N32.6°E (SEE DETAIL). SEE ALSO SECTION 2.0 OF REPORT

LEGEND

PL	PROPERTY LINE (APPROX.)
	PROPOSED UTILITY WASTE LANDFILL PERMIT BOUNDARY
	UNPAVED ROAD
	EXISTING EASEMENT
G	EXISTING GAS PIPELINE
	EXISTING FIBER OPTIC
OE	EXISTING OVERHEAD ELECTRIC
	PROPOSED UTILITY WASTE LANDFILL INSIDE TOE OF SLOPE
XXXXXX	NORTHING AND EASTING MISSOURI STATE PLANE COORDINATE SYSTEM
	JURISDICTIONAL WETLANDS
MW-XX	MONITORING WELL LOCATION (AS PROPOSED)
	IRRIGATION WELL
	SURVEY MONUMENT

THE GEOLOGIST WHO REVIEWED AND APPROVED THIS FIGURE ASSUMES RESPONSIBILITY ONLY FOR GEOLOGIC INTERPRETATIONS OF DATA APPEARING ON THE PAGE AND DISCLAIMS PURSUANT TO SECTION 256.456 RSMO ANY RESPONSIBILITY FOR ALL OTHER PLANS, SPECIFICATIONS, ESTIMATES, REPORTS OR OTHER DOCUMENTS OR INSTRUMENTS NOT PREPARED UNDER THE SUPERVISION OF THE GEOLOGIST RELATING TO OR INTENDED TO BE USED FOR ANY PART OR PARTS OF THE PROJECT TO WHICH THIS FIGURE REFERS.

REITZ & JENS, INC. CONSULTING ENGINEERS

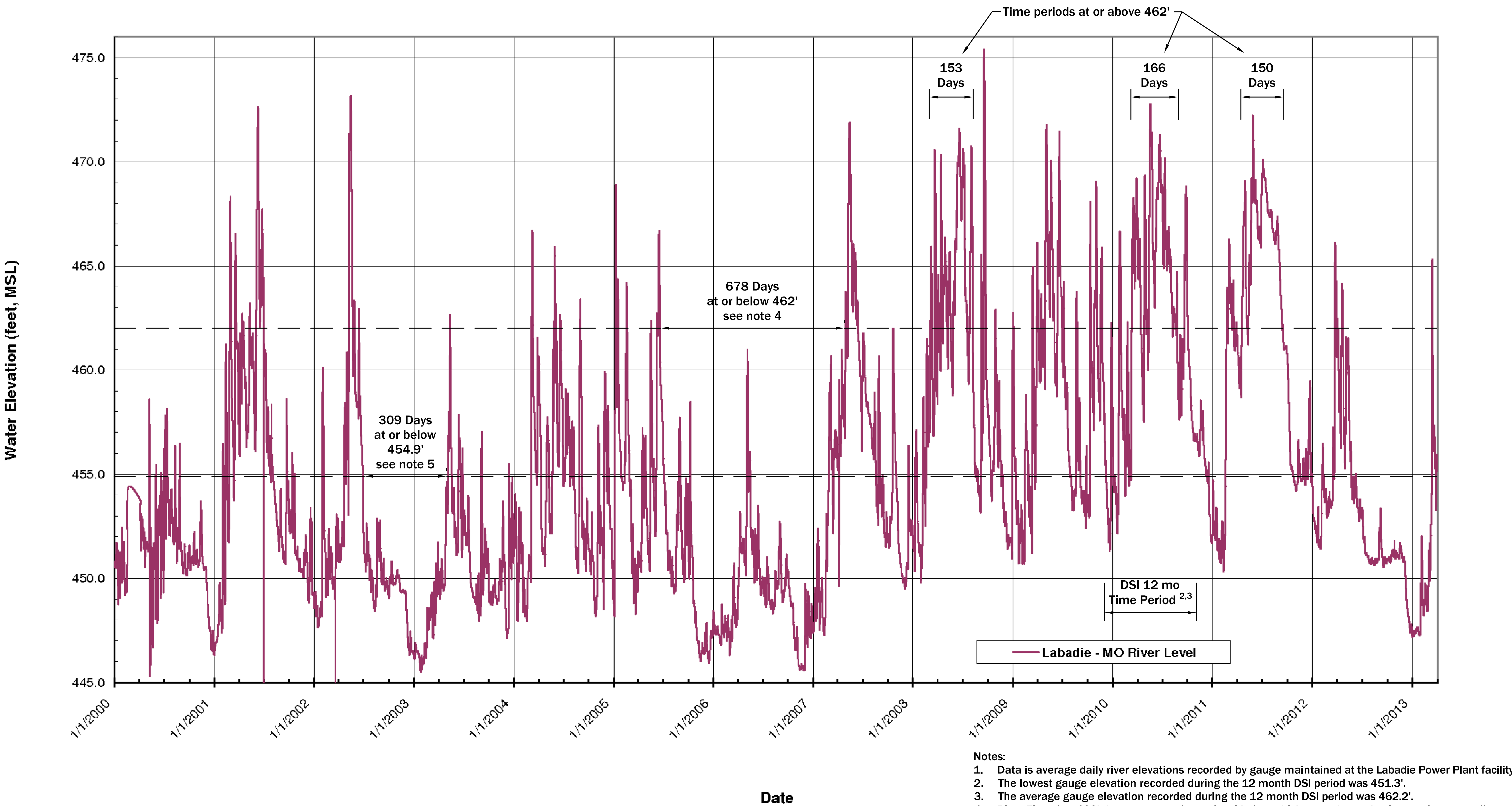
GREDELL Engineering Resources, Inc. ENVIRONMENTAL ENGINEERING

PREPARED FOR Ameren

DRAWN W.J.A. (GER)	AMEREN MISSOURI LABADIE ENERGY CENTER UTILITY WASTE LANDFILL DOCUMENTATION OF SUPPLEMENTAL GROUNDWATER MONITORING WELL DESIGN
CHKD T.A.D. (GER)	
SUPV M.C.C. (GER)	
APPD T.R.G. (GER)	LOCATION 001009 — PLUME DISPERSION MAP COMPARISON (100 FT AND 5 FT "TEARS") — SCALE 02010
Ameren ST. LOUIS, MISSOURI	FIGURE 8

M:\Share\CADDFiles\AMEREN-UE\LABADIE\CONSTRUCTION PERMIT\2012 DRAWINGS\GROUNDWATER 06 2012\WELL LOCATIONS 10-12\GROUNDWATER MONITORING WELLS REV 05-15-2013.dwg, (CELL 1-2-3-4_FIG8_5_100YR), 11/11/2013 9:15:39 AM

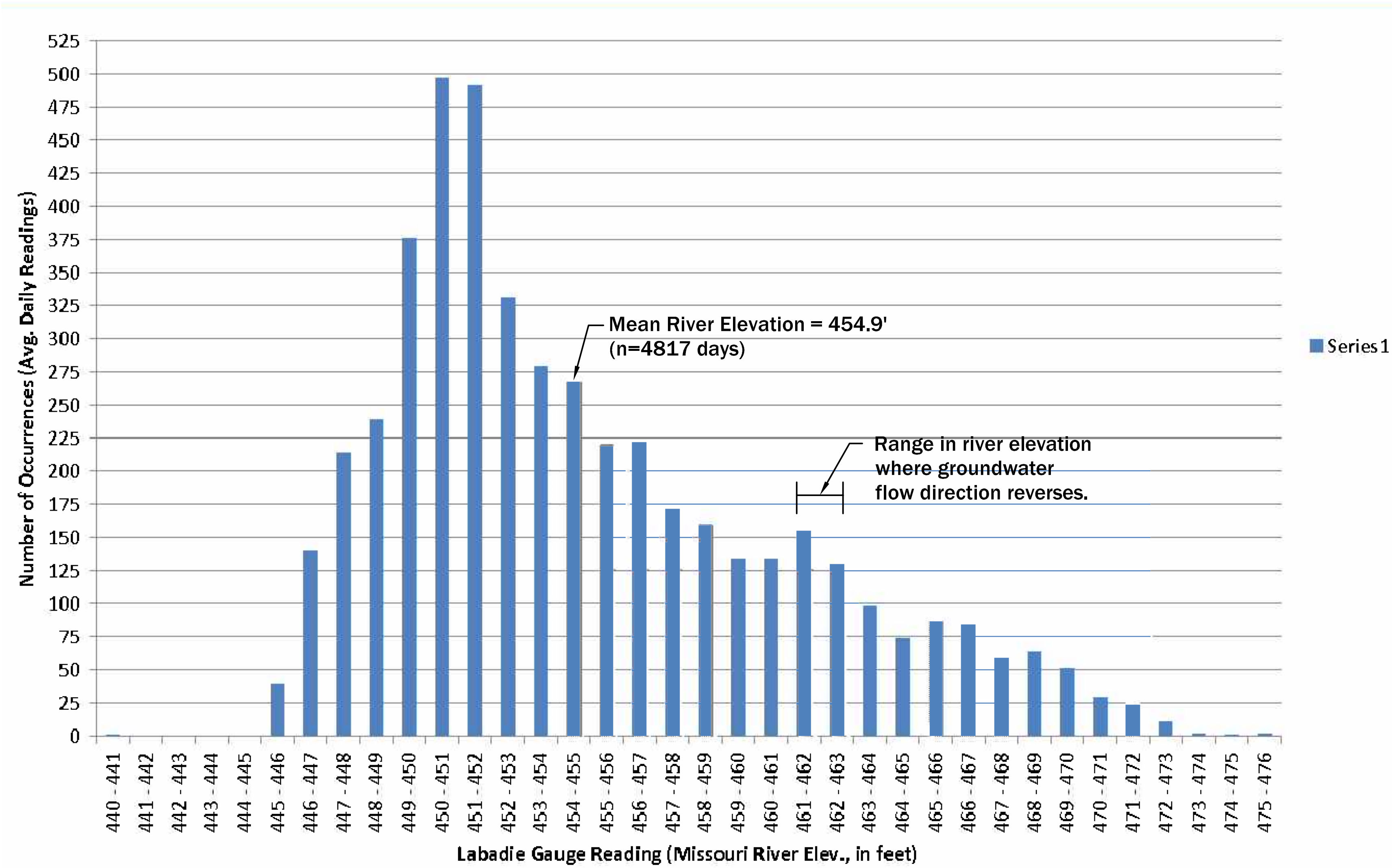
Ameren Missouri Labadie Energy Center
Documentation of Supplemental
Groundwater Monitoring Well Design
Hydrograph of Missouri River Elevation (2000-2013)[1]
Figure 9



Notes:
1. Data is average daily river elevations recorded by gauge maintained at the Labadie Power Plant facility.
2. The lowest gauge elevation recorded during the 12 month DSI period was 451.3'.
3. The average gauge elevation recorded during the 12 month DSI period was 462.2'.
4. River Elevation 462' denotes approximate level below which groundwater begins moving generally toward the Missouri River (see page 39 of DSI report).
5. River Elevation 454.9' denotes approximate average river level over the 13 year time period.

Prepared by: Gredell Engineering Resources, Inc.

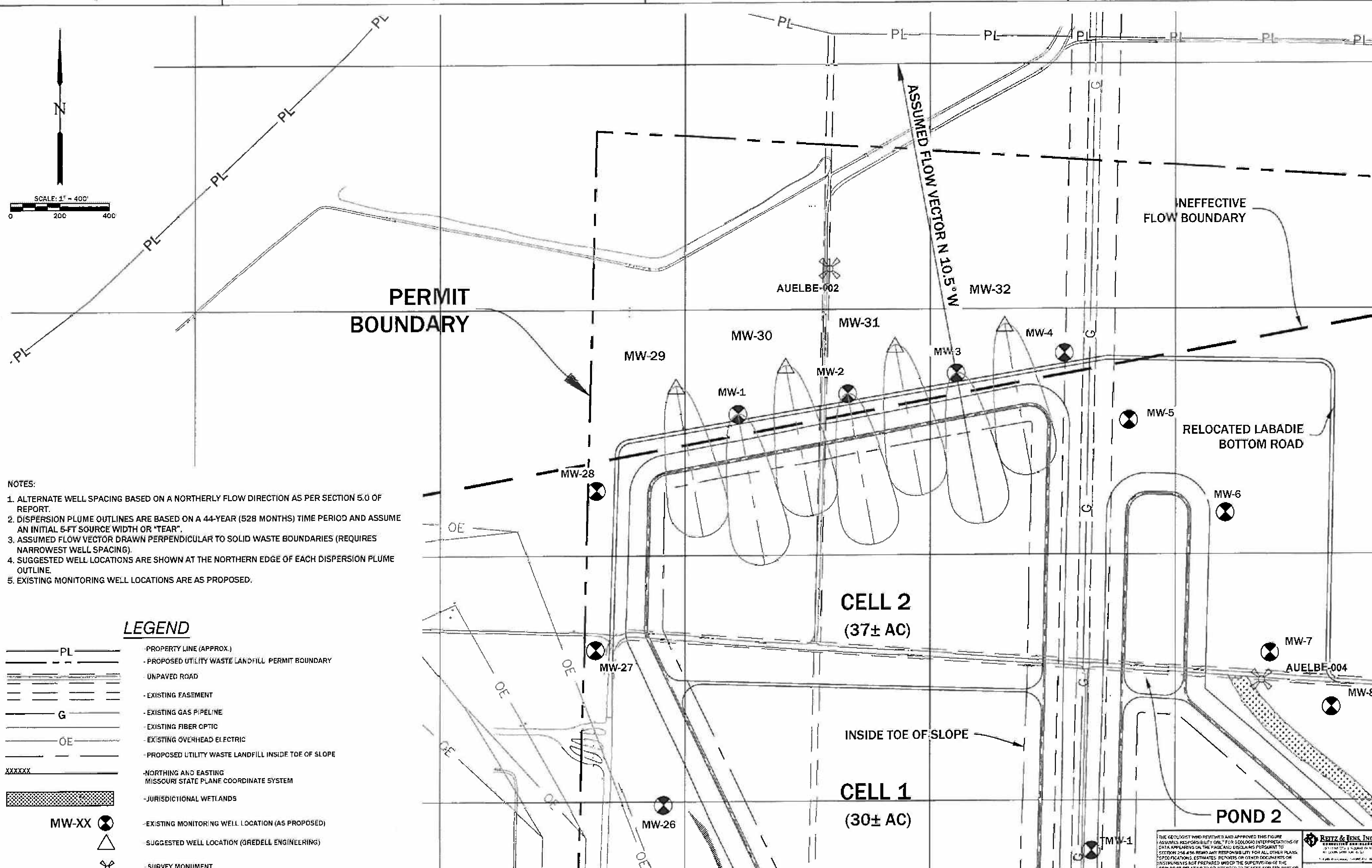
Ameren Missouri Labadie Energy Center
Documentation of Supplemental
Groundwater Monitoring Well Design
Frequency Histogram of Missouri River Elevations (2000-2013)
Figure 10



M:\Share\CADDFiles\AMEREN-UE\LABADIE\CONSTRUCTION PERMIT\2012 DRAWINGS\GROUNDWATER 2013\MISSOURI RIVER WATER LEVELS.dwg, Model, 11/11/2013 10:26:06 AM

Notes:
1. Gauge readings span time period 1/1/2000 to 3/31/2013.
2. Median gauge elevation = 453.2'.

Prepared by: Gredell Engineering Resources, Inc.



NOTES:

1. ALTERNATE WELL SPACING BASED ON A NORTHERLY FLOW DIRECTION AS PER SECTION 5.0 OF REPORT.
2. DISPERSION PLUME OUTLINES ARE BASED ON A 44-YEAR (528 MONTHS) TIME PERIOD AND ASSUME AN INITIAL 5-FT SOURCE WIDTH OR "TEAR".
3. ASSUMED FLOW VECTOR DRAWN PERPENDICULAR TO SOLID WASTE BOUNDARIES (REQUIRES NARROWEST WELL SPACING).
4. SUGGESTED WELL LOCATIONS ARE SHOWN AT THE NORTHERN EDGE OF EACH DISPERSION PLUME OUTLINE.
5. EXISTING MONITORING WELL LOCATIONS ARE AS PROPOSED.

LEGEND

- PL — PROPERTY LINE (APPROX.)
- PROPOSED UTILITY WASTE LANDFILL PERMIT BOUNDARY
- UNPAVED ROAD
- EXISTING EASEMENT
- G — EXISTING GAS PIPELINE
- EXISTING FIBER OPTIC
- OE — EXISTING OVERHEAD ELECTRIC
- PROPOSED UTILITY WASTE LANDFILL INSIDE TOE OF SLOPE
- XXXXXX — NORTHING AND EASTING MISSOURI STATE PLANE COORDINATE SYSTEM
- JURISDICTIONAL WETLANDS
- MW-XX — EXISTING MONITORING WELL LOCATION (AS PROPOSED)
- SUGGESTED WELL LOCATION (GREDELL ENGINEERING)
- SURVEY MONUMENT
- DISPERSION PLUME (BASED ON 44 YR TIME PERIOD AND 5 FT SOURCE WIDTH)

CALL BEFORE YOU DIG - DRILL - BLAST
1-800-344-7483
(TOLL FREE)
MISSOURI ONE CALL SYSTEM, INC

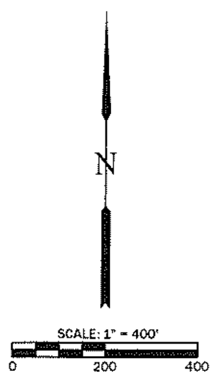
THE GEOLOGIST WHO REVIEWED AND APPROVED THIS FIGURE ASSUMES RESPONSIBILITY ONLY FOR GEOLOGIC INTERPRETATIONS OF DATA APPEARING ON THE PAGE AND DISCLAIMS PURSUANT TO SECTION 256.456 RSMO ANY RESPONSIBILITY FOR ALL OTHER PLANS, SPECIFICATIONS, ESTIMATES, REPORTS OR OTHER DOCUMENTS OR INSTRUMENTS NOT PREPARED UNDER THE SUPERVISION OF THE GEOLOGIST RELATING TO OR INTENDED TO BE USED FOR ANY PART OR PARTS OF THE PROJECT TO WHICH THIS FIGURE REFERS.

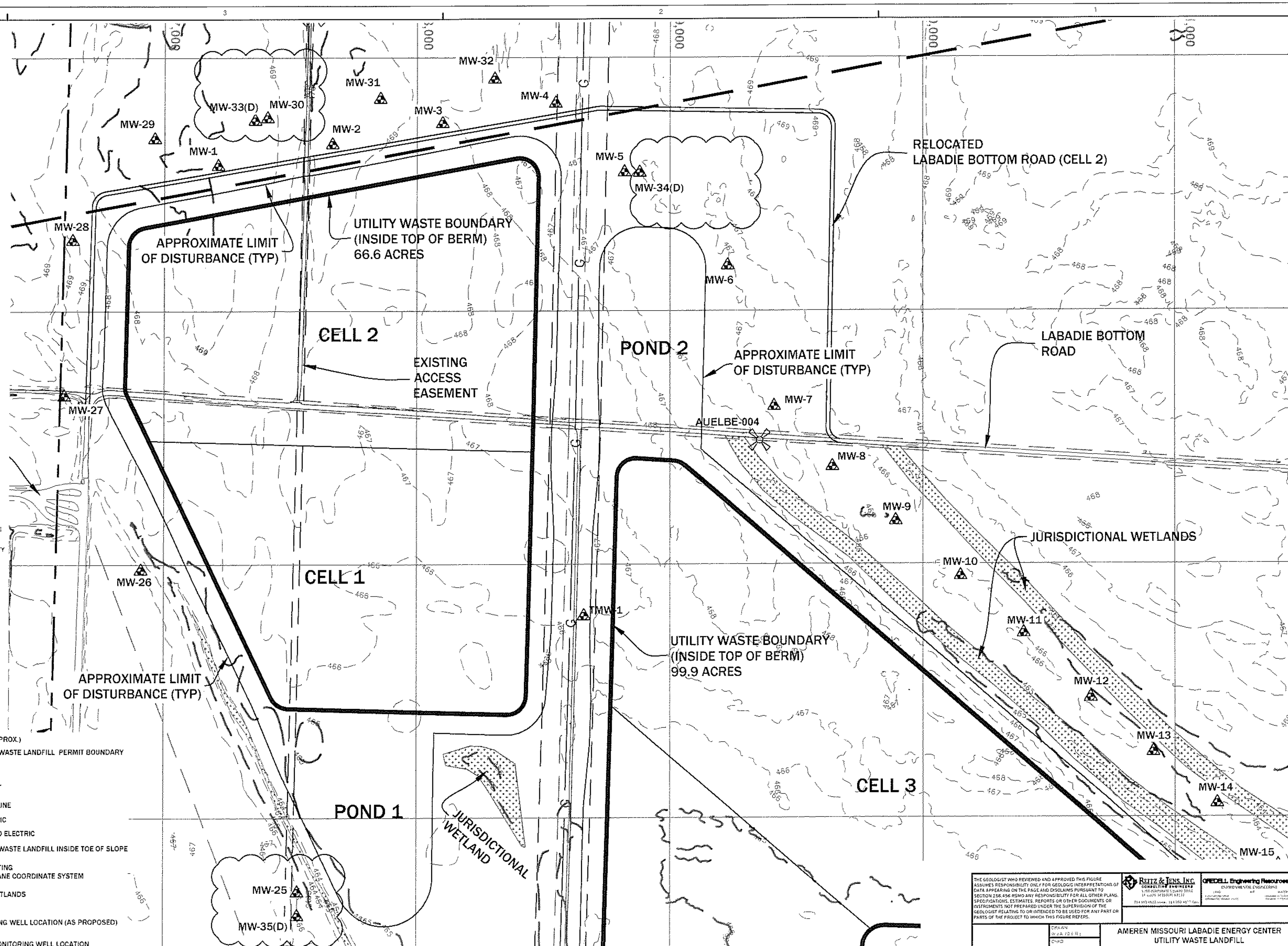
REITZ & JENS, INC. CONSULTING ENGINEERS

GREDELL Engineering Resources, Inc. ENVIRONMENTAL ENGINEERING

PREPARED FOR Ameren

DRAWN WJA (GER)	AMEREN MISSOURI LABADIE ENERGY CENTER UTILITY WASTE LANDFILL △1 DOCUMENTATION OF SUPPLEMENTAL GROUNDWATER MONITORING WELL DESIGN
CHKD TAD (GER)	
SURV MCG (GER)	
APPD ERG (GER)	LOCATION 001009 — ALTERNATE WELL SPACING NORTHERN PERIMETER OF CELL 2 — DRAWN 02010
Ameren ST. LOUIS, MISSOURI	FIGURE 11





NOTES TO THE CONTRACTOR:

UNDERGROUND FACILITIES, STRUCTURES, AND UTILITIES HAVE BEEN PLOTTED FROM AVAILABLE SURVEYS AND RECORDS AND THEREFORE, THEIR LOCATIONS MUST BE CONSIDERED APPROXIMATE ONLY. THERE MAY BE OTHERS, THE EXISTENCE OF WHICH IS AT PRESENT NOT KNOWN. VERIFICATION OF THE LOCATIONS OF UNDERGROUND UTILITIES, SHOWN OR NOT SHOWN, WILL BE THE RESPONSIBILITY OF THE CONSTRUCTION CONTRACTOR.

THE CONTRACTOR SHALL MAKE SUITABLE AND TIMELY REQUESTS TO ALL UTILITY OWNERS, PIPELINE OWNERS, OR OTHER PARTIES AFFECTED TO HAVE ALL NECESSARY ADJUSTMENTS OF PUBLIC OR PRIVATE UTILITIES, PIPE LINES, OR OTHER APPURTENANCES WITHIN, OR ADJACENT TO THE LIMITS OF CONSTRUCTION, AS SOON AS PRACTICAL OR POSSIBLE.

MISSOURI ONE CALL SYSTEM (DIG-RITE) 1-800-344-7483

LEGEND

- PL - PROPERTY LINE (APPROX.)
- PROPOSED UTILITY WASTE LANDFILL PERMIT BOUNDARY
- UNPAVED ROAD
- EXISTING EASEMENT
- G - EXISTING GAS PIPELINE
- EXISTING FIBER OPTIC
- OE - EXISTING OVERHEAD ELECTRIC
- PROPOSED UTILITY WASTE LANDFILL INSIDE TOE OF SLOPE
- XXXXXX - NORTHING AND EASTING MISSOURI STATE PLANE COORDINATE SYSTEM
- JURISDICTIONAL WETLANDS
- MW-XX - EXISTING MONITORING WELL LOCATION (AS PROPOSED)
- MW-XX (D) - PROPOSED DEEP MONITORING WELL LOCATION
- SURVEY MONUMENT

CALL BEFORE YOU DIG - DRILL - BLAST 1-800-344-7483 (TOLL FREE) MISSOURI ONE CALL SYSTEM, INC.

THE GEOLOGIST WHO REVIEWED AND APPROVED THIS FIGURE ASSUMES RESPONSIBILITY ONLY FOR GEOLOGIC INTERPRETATIONS OF DATA APPEARING ON THE PAGE AND DISCLAIMS PURSUANT TO SECTION 256.456 RSMO ANY RESPONSIBILITY FOR ALL OTHER PLANS, SPECIFICATIONS, ESTIMATES, REPORTS OR OTHER DOCUMENTS OR INSTRUMENTS NOT PREPARED UNDER THE SUPERVISION OF THE GEOLOGIST RELATING TO OR INTENDED TO BE USED FOR ANY PART OR PARTS OF THE PROJECT TO WHICH THIS FIGURE REFERS.

REITZ & JENS, INC. CONSULTING ENGINEERS

GREDELL Engineering Resources, Inc. ENVIRONMENTAL ENGINEERING

DRAWN W.J.A. (G.E.R.) | CHKD T.A.D. (G.E.R.) | SUPV M.G.G. (G.E.R.) | APPD T.R.G. (G.E.R.)

AMEREN MISSOURI LABADIE ENERGY CENTER
UTILITY WASTE LANDFILL
DOCUMENTATION OF SUPPLEMENTAL
GROUNDWATER MONITORING WELL DESIGN

LOCATION 001009 | PROPOSED DEEP GROUNDWATER WELL LOCATIONS | CLASS 02010

ST. LOUIS, MISSOURI

FIGURE 12

M:\Share\CADDFiles\AMEREN-UE\LABADIE\CONSTRUCTION PERMIT\2012 DRAWINGS\GROUNDWATER 06 2012\FIG 12.dwg, FIG 12, 11/22/2013 4:33:52 PM,
DWG To PDF.pc3

APPENDIX 1

Longitudinal & Transverse Dispersivity Documentation

AMEREN MISSOURI LABADIE ENERGY CENTER UTILITY WASTE LANDFILL
Documentation of Supplemental Groundwater Monitoring Well Design

November 2013

Appendix 1

LONGITUDINAL & TRANSVERSE DISPERSIVITY DOCUMENTATION

A discussion of the methodology used to derive longitudinal and transverse dispersivity values is presented below. It compliments data previously presented in Appendix X – Documentation of Groundwater Monitoring System Design included as part of the Construction Permit Application for the Ameren Missouri Labadie Energy Center Proposed Utility Waste Landfill. In support of this discussion, a modified version of Table 2b (Plume Definition for Cells 3 and 4) from Appendix X is provided as Attachment 1. Modifications include the removal of columns of extraneous data, the rearrangement and identification of key elements of the calculations, and the addition of footnotes. The top of each column has also been designated by a capital A, B, C, etc. so that the information presented below can be cross-referenced to the modified table to facilitate a better understanding of the approach used. All calculations and results are exactly the same as presented in the original Table 2b. Referenced sources of information are included at the end of this discussion.

The method of solution used to determine longitudinal and transverse dispersivity values for the modeling effort considers three primary sequential tasks.

1. Use the monthly azimuths and velocities shown in Columns A and C of Attachment 1. These monthly azimuths and velocities are derived from the 12-month Detailed Site Investigation (DSI) time period (December 2009 through November 2010). Note that in the original Appendix X submittal, the monthly velocities identified in Column C were to have correlated to the middle column of the Cell 3 and 4 data presented in Table 1 (Calculated Groundwater Velocities by Month). However, the velocity calculations shown in that table for Cells 3 and 4 were incorrectly based on a maximum value for hydraulic conductivity (K) rather than the average value for hydraulic conductivity as shown. For that reason, Table 1 has been corrected and is included for reference as Attachment 2. It now accurately portrays the monthly velocity values originally used as well as the values shown in Attachment 1.

2. Solve for the model by using the monthly northern and eastern components of flow as shown in Columns E and F of Attachment 1 to determine a resultant sum based on the 12 monthly changes in flow direction. The resultant velocities for both the east vector and north vector are shown at the bottom of Columns G and H of Attachment 1, respectively.

3. Solve by determining the monthly displacement of flow in both the longitudinal and transverse directions using the sum of transformed axes shown in Columns L and M of Attachment 1, respectively.

Further explanation and relevant calculations using the methods of Freeze and Cherry (1979) and Wang and Anderson (1982) are as follows:

- Divide the velocity of each monthly vector into North and East components (Columns E and F of Attachment 1)

  North component = monthly velocity (Column D) X cosine of the azimuth (Column A)

  East component = monthly velocity (Column D) X sine of the azimuth (Column A)

- Derive resultant vectors for each of the twelve monthly data sets for the North and East components and determine an overall resultant North and East vector. These values, which are based on the 12-month DSI time period, are shown at the bottom of Columns G (13.34 ft/yr) and H (5.78 ft/yr), respectively. A graphical illustration of a resultant vector and its development is shown in Attachment 3 for reference.

- Determine the Average Velocity. The Average Velocity is shown below the primary table in Attachment 1. It is calculated as the square root of the sum of the resultant east vectors (squared) plus the sum of the resultant north vectors (squared). Note that the unit of time (year) is based on the 12-month DSI time period and is not a representation of a calendar year.

  Average Velocity = Sq Root $((\Sigma \text{ East})^2 + (\Sigma \text{ North})^2)$ = 14.54 feet/year

- Determine an Intermediary Angle as shown in the table immediately below the average velocity. This angle is determined as the arctangent of the sum of the resultant north vectors (Column H) divided by the sum of the resultant east vectors (Column G). It is also graphically depicted in Attachment 3 for reference.

  Intermediary Angle = ArcTan $((\Sigma \text{ North}) / (\Sigma \text{ East})) = 23.42^o$.

- Determine a Bearing for the average velocity as shown in the table immediately below the intermediary angle. The bearing is determined by using an angle of 90^o minus the intermediary angle. This angle is also graphically depicted in Attachment 3 for reference.

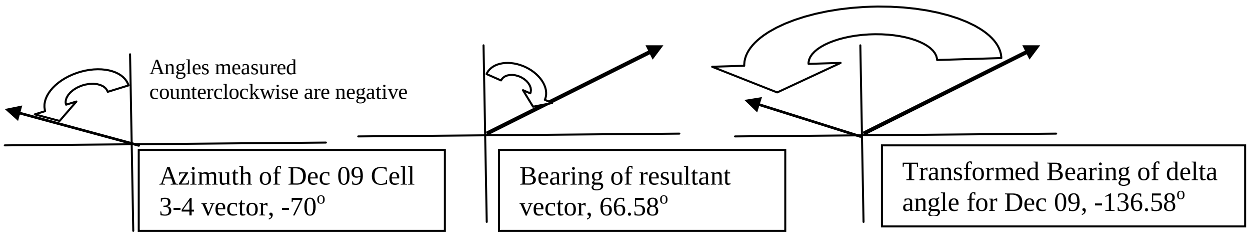
  Bearing = 90^o – Intermediary Angle (23.42^o) = 66.58^o

- Instead of measuring the velocity for each monthly vector using a northward bearing (i.e. azimuth), measure using a calculated angle based on the resultant vector. This treatment of monthly velocities allows for the measurement of each monthly velocity along (longitudinal) and across (transverse) the calculated, northeasterly bearing of 66.58^o. This is shown in Column I by the development of delta angles. The delta angles are calculated by taking the monthly azimuth values (Column A) and subtracting the 66.58^o bearing.

Delta Angle = Azimuth – Bearing (Northeast)

A graphical example using the December 2009 azimuth in Column A of Attachment 1 would be:

$$\text{Delta Angle} = -70^{o} - 66.58^{o} = -136.58^{o}$$



- The longitudinal distance components are shown in Column L. They are calculated as the monthly velocity (Column D) X the cosine of the delta angle (Column J). These values show the distance along the resultant vector.
- The transverse distance components are shown in Column M. They are calculated as the monthly velocity (Column D) X the sine of the delta angle (Column K). These values show the distance across the resultant vector. Attachment 4 provides a graphical depiction of the rotated axis and the movement of groundwater along (longitudinal) and across (transverse) the bearing of the resultant vector.
- The Average Monthly Velocity along (longitudinal) and across (transverse) the resultant vector is the average of the monthly vectors as shown in the cells immediately below Columns L and M.

$$\text{Average Monthly Velocity} = \frac{\Sigma \text{ Monthly Vectors}}{\text{No. of Months (12)}}$$

- The Average 12-Month Velocity, which is shown below the average monthly velocities, is calculated as the average monthly velocity along each resultant vector X 12 months. Normally, this equation would be 12 X square root ((average monthly longitudinal velocity vector)^2 + (average monthly transverse velocity vector)^2), but the average monthly transverse velocity vector = 0. Consequently, the equation can be simplified as shown above and the result is 14.54 feet over the 12-month DSI time period.
- There are two other control checks used in the evaluation:
  1) The annual "speed" calculated from the North and East velocity components has to equal the annual "speed" from the average monthly velocities x 12 months (speed is related to velocity, but is unassociated with a specific direction of movement).

2) The average monthly velocity across (transverse) the resultant vector has to be ZERO. If a different result was obtained, an error in the calculations would be suspected.

- The longitudinal and transverse distance components, or dispersion values, shown in Columns L and M are a measure of the variation in the velocity of flow along and across the resultant vector (i.e. Bearing = 66.58^o).
- To arrive at values for dispersivity, first calculate the standard deviation of the values shown in Columns L and M. This calculation, which is shown below the average monthly velocities, provides a measure of the changes in the longitudinal and transverse dispersions for the 66.58^o Bearing.
- The "Random Walk" model (Prickett et al., 1981) shows the standard deviations (dispersions) as statistical variations of the velocity. Both Alpha values for the dispersivities (α_L *and* α_T) are calculated by dividing their respective standard deviations (SD) by the average monthly velocities as shown below Columns L and M.

$$\alpha_L = \textit{SD (longitudinal) / average monthly velocity}$$

$$\alpha_T = \textit{SD (transverse) / average monthly velocity}$$

The two alpha values (α_L *and* α_T) derived are then used to develop the dispersion plume outline that is used to gauge the distance between wells for the facility.

ATTACHMENTS

Ameren Missouri Labadie Energy Center Utility Waste Landfill
Documentation of Supplemental Groundwater Monitoring Well Design
Plume Definition for Cells 3 and 4[1,2,3]
Attachment 1

		A	B	C	D	E	F	G	H	I	J	K	L	M
Cells 3 & 4	Month/Year	Azimuth	Hydaulic Gradient	Velocity (ft/yr)	Velocity (ft/month)	East Component =x	North Component= y	Resultant Velocity East Vector[4]	Resultant Velocity North Vector[4]	delta angle	Cos (delta angle)	Sin (delta angle)	Monthly Velocity *Cos(delta angle)	Monthly Velocity *Sin(delta angle)
	Dec-09	-70	0.0003	25	2.08	-1.96	0.71			-136.58	-0.726	-0.687	-1.513	-1.432
								-1.96	0.71					
	January-10	3	0.0004	33	2.75	0.14	2.75			-63.58	0.445	-0.896	1.224	-2.463
								-1.81	3.46					
	February-10	-11	0.0001	8	0.67	-0.13	0.65			-77.58	0.215	-0.977	0.143	-0.651
								-1.94	4.11					
	March-10	63	0.0005	42	3.50	3.12	1.59			-3.58	0.998	-0.062	3.493	-0.219
								1.18	5.70					
	April-10	84	0.0003	25	2.08	2.07	0.22			17.42	0.954	0.299	1.988	0.624
								3.25	5.92					
	May-10	70	0.0002	17	1.42	1.33	0.48			3.42	0.998	0.060	1.414	0.084
								4.58	6.40					
	June-10	105	0.0004	33	2.75	2.66	-0.71			38.42	0.784	0.621	2.155	1.709
								7.24	5.69					
	July-10	109	0.0004	33	2.75	2.60	-0.90			42.42	0.738	0.675	2.030	1.855
								9.84	4.80					
	August-10	95	0.0003	25	2.08	2.08	-0.18			28.42	0.880	0.476	1.832	0.991
								11.91	4.62					
	September-10	47	0.0001	8	0.67	0.49	0.45			-19.58	0.942	-0.335	0.628	-0.223
								12.40	5.07					
	October-10	81	0.0002	17	1.42	1.40	0.22			14.42	0.969	0.249	1.372	0.353
								13.80	5.29					
	November-10	-43	0.0001	8	0.67	-0.45	0.49			-109.58	-0.335	-0.942	-0.223	-0.628
								13.34	5.78					

	Longitudinal	Transverse
Average monthly velocity	1.212	0.000
Standard Deviation (SD) in monthly velocity	1.307	1.239
Alpha values (used in PLUME)	1.078	1.023
Average 12 month velocity (1.212 x 12)[5]	14.54	0.00

Notes
1. Modified from Table 2b of Appendix X to facilitate discussion of model parameters and calculations.
2. Values depicted for hydraulic conductivity in original Table 2b omitted for clarity.
3. Value depicted for effective porosity in original Table 2b omitted for clarity.
4. Resultant velocity calculations for east and north vectors (Columns G and H) are graphically depicted in Attachment 3.
5. Average 12 month velocity value should equal value based on east and north velocity vectors.

Average velocity, ft/yr =	14.54	Distance formula for an East resultant value of 13.34 and North resultant value of 5.78
Intermediary angle =	23.42	Arc whose tangent =5.78 / 13.34
Bearing =	66.58	90 degrees - intermediary angle, 23.42 Bearing, northeast in degrees

Ameren Missouri Labadie Energy Center Utility Waste Landfill
Documentation of Supplemental Groundwater Monitoring Well Design
Calculated Groundwater Velocities by Month[1]
Attachment 2[2]

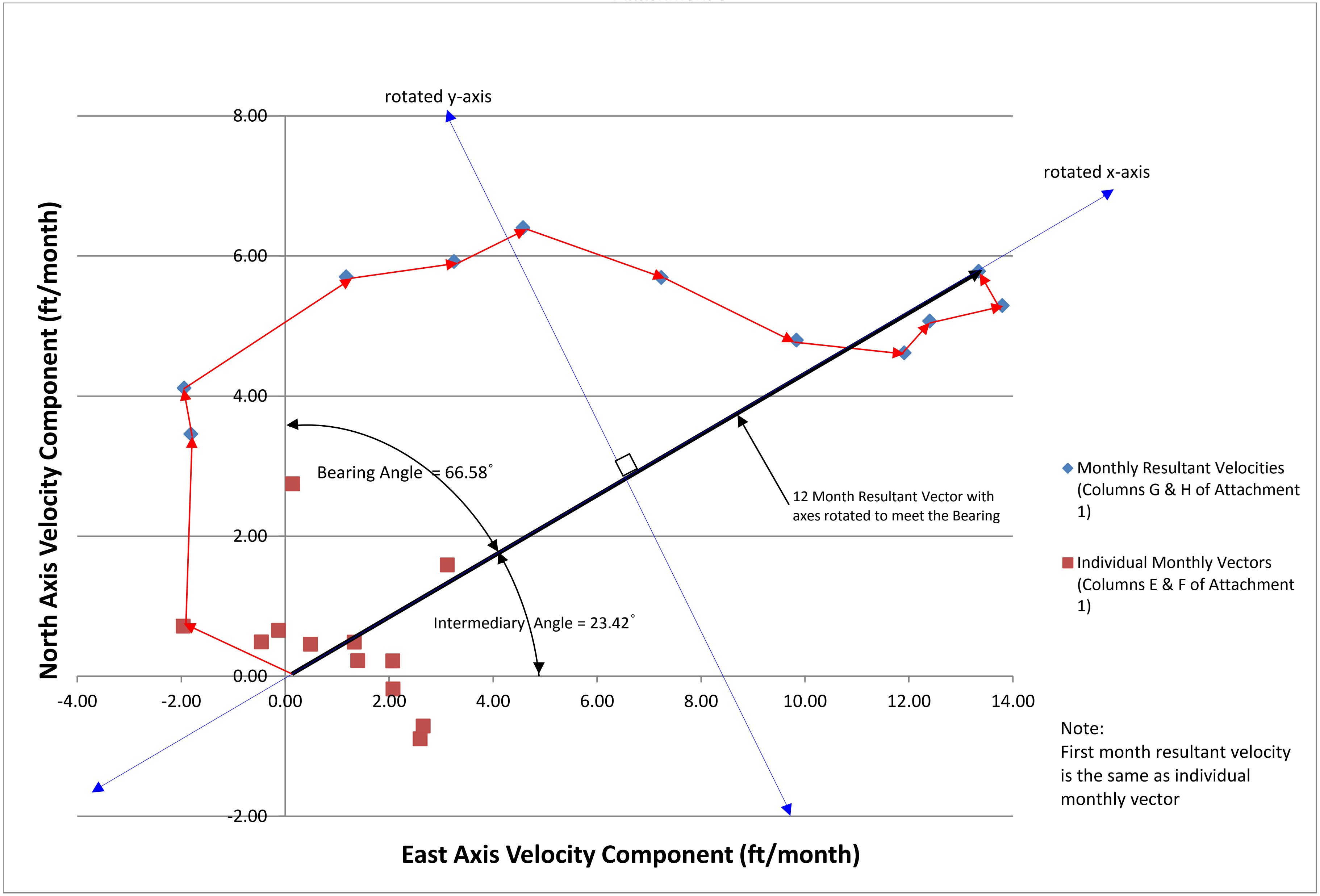
Cells 1 and 2			
December 21, 2009			
Hydraulic Conductivity (K)	Cells 1 & 2 Site K_{avg} = 5.002 x 10^{-2} ft/min		
Hydraulic Gradient (*i*)	i = 0.0007 ft/ft		
Effective Porosity (n)	0.30	0.35	0.40
Velocity (=Ki/n) (ft/yr)	61	53	46
January 25, 2010			
Hydraulic Conductivity (K)	Cells 1 & 2 Site K_{avg} = 5.002 x 10^{-2} ft/min		
Hydraulic Gradient (*i*)	i = 0.0008 ft/ft		
Effective Porosity (n)	0.30	0.35	0.40
Velocity (=Ki/n) (ft/yr)	70	60	53
February 16, 2010			
Hydraulic Conductivity (K)	Cells 1 & 2 Site K_{avg} = 5.002 x 10^{-2} ft/min		
Hydraulic Gradient (*i*)	i = 0.0003 ft/ft		
Effective Porosity (n)	0.30	0.35	0.40
Velocity (=Ki/n) (ft/yr)	26	23	20
March 16, 2010			
Hydraulic Conductivity (K)	Cells 1 & 2 Site K_{avg} = 5.002 x 10^{-2} ft/min		
Hydraulic Gradient (*i*)	i = 0.0008 ft/ft		
Effective Porosity (n)	0.30	0.35	0.40
Velocity (=Ki/n) (ft/yr)	70	60	53
April 13, 2010			
Hydraulic Conductivity (K)	Cells 1 & 2 Site K_{avg} = 5.002 x 10^{-2} ft/min		
Hydraulic Gradient (*i*)	i = 0.0002 ft/ft		
Effective Porosity (n)	0.30	0.35	0.40
Velocity (=Ki/n) (ft/yr)	18	15	13
May 11, 2010			
Hydraulic Conductivity (K)	Cells 1 & 2 Site K_{avg} = 5.002 x 10^{-2} ft/min		
Hydraulic Gradient (*i*)	i = 0.0001 ft/ft		
Effective Porosity (n)	0.30	0.35	0.40
Velocity (=Ki/n) (ft/yr)	9	8	7
June 8, 2010			
Hydraulic Conductivity (K)	Cells 1 & 2 Site K_{avg} = 5.002 x 10^{-2} ft/min		
Hydraulic Gradient (*i*)	i = 0.0004 ft/ft		
Effective Porosity (n)	0.30	0.35	0.40
Velocity (=Ki/n) (ft/yr)	35	30	26
July 7, 2010			
Hydraulic Conductivity (K)	Cells 1 & 2 Site K_{avg} = 5.002 x 10^{-2} ft/min		
Hydraulic Gradient (*i*)	i = 0.0004 ft/ft		
Effective Porosity (n)	0.30	0.35	0.40
Velocity (=Ki/n) (ft/yr)	35	30	26
August 5, 2010			
Hydraulic Conductivity (K)	Cells 1 & 2 Site K_{avg} = 5.002 x 10^{-2} ft/min		
Hydraulic Gradient (*i*)	i = 0.0002 ft/ft		
Effective Porosity (n)	0.30	0.35	0.40
Velocity (=Ki/n) (ft/yr)	18	15	13
September 8, 2010			
Hydraulic Conductivity (K)	Cells 1 & 2 Site K_{avg} = 5.002 x 10^{-2} ft/min		
Hydraulic Gradient (*i*)	i = 0.0001 ft/ft		
Effective Porosity (n)	0.30	0.35	0.40
Velocity (=Ki/n) (ft/yr)	9	8	7
October 7, 2010			
Hydraulic Conductivity (K)	Cells 1 & 2 Site K_{avg} = 5.002 x 10^{-2} ft/min		
Hydraulic Gradient (*i*)	i = 0.0001 ft/ft		
Effective Porosity (n)	0.30	0.35	0.40
Velocity (=Ki/n) (ft/yr)	9	8	7
November 4, 2010			
Hydraulic Conductivity (K)	Cells 1 & 2 Site K_{avg} = 5.002 x 10^{-2} ft/min		
Hydraulic Gradient (*i*)	i = 0.0003 ft/ft		
Effective Porosity (n)	0.30	0.35	0.40
Velocity (=Ki/n) (ft/yr)	26	23	20

Cells 3 and 4			
December 21, 2009			
Hydraulic Conductivity (K)	Cells 3 & 4 Site K_{avg} = 5.567 x 10^{-2} ft/min		
Hydraulic Gradient (*i*)	i = 0.0003 ft/ft		
Effective Porosity (n)	0.30	0.35	0.40
Velocity (=Ki/n) (ft/yr)	29	25	22
January 25, 2010			
Hydraulic Conductivity (K)	Cells 3 & 4 Site K_{avg} = 5.567 x 10^{-2} ft/min		
Hydraulic Gradient (*i*)	i = 0.0004 ft/ft		
Effective Porosity (n)	0.30	0.35	0.40
Velocity (=Ki/n) (ft/yr)	39	33	29
February 16, 2010			
Hydraulic Conductivity (K)	Cells 3 & 4 Site K_{avg} = 5.567 x 10^{-2} ft/min		
Hydraulic Gradient (*i*)	i = 0.0001 ft/ft		
Effective Porosity (n)	0.30	0.35	0.40
Velocity (=Ki/n) (ft/yr)	10	8	7
March 16, 2010			
Hydraulic Conductivity (K)	Cells 3 & 4 Site K_{avg} = 5.567 x 10^{-2} ft/min		
Hydraulic Gradient (*i*)	i = 0.0005 ft/ft		
Effective Porosity (n)	0.30	0.35	0.40
Velocity (=Ki/n) (ft/yr)	49	42	37
April 13, 2010			
Hydraulic Conductivity (K)	Cells 3 & 4 Site K_{avg} = 5.567 x 10^{-2} ft/min		
Hydraulic Gradient (*i*)	i = 0.0003 ft/ft		
Effective Porosity (n)	0.30	0.35	0.40
Velocity (=Ki/n) (ft/yr)	29	25	22
May 11, 2010			
Hydraulic Conductivity (K)	Cells 3 & 4 Site K_{avg} = 5.567 x 10^{-2} ft/min		
Hydraulic Gradient (*i*)	i = 0.0002 ft/ft		
Effective Porosity (n)	0.30	0.35	0.40
Velocity (=Ki/n) (ft/yr)	20	17	15
June 8, 2010			
Hydraulic Conductivity (K)	Cells 3 & 4 Site K_{avg} = 5.567 x 10^{-2} ft/min		
Hydraulic Gradient (*i*)	i = 0.0004 ft/ft		
Effective Porosity (n)	0.30	0.35	0.40
Velocity (=Ki/n) (ft/yr)	39	33	29
July 7, 2010			
Hydraulic Conductivity (K)	Cells 3 & 4 Site K_{avg} = 5.567 x 10^{-2} ft/min		
Hydraulic Gradient (*i*)	i = 0.0004 ft/ft		
Effective Porosity (n)	0.30	0.35	0.40
Velocity (=Ki/n) (ft/yr)	39	33	29
August 5, 2010			
Hydraulic Conductivity (K)	Cells 3 & 4 Site K_{avg} = 5.567 x 10^{-2} ft/min		
Hydraulic Gradient (*i*)	i = 0.0003 ft/ft		
Effective Porosity (n)	0.30	0.35	0.40
Velocity (=Ki/n) (ft/yr)	29	25	22
September 8, 2010			
Hydraulic Conductivity (K)	Cells 3 & 4 Site K_{avg} = 5.567 x 10^{-2} ft/min		
Hydraulic Gradient (*i*)	i = 0.0001 ft/ft		
Effective Porosity (n)	0.30	0.35	0.40
Velocity (=Ki/n) (ft/yr)	10	8	7
October 7, 2010			
Hydraulic Conductivity (K)	Cells 3 & 4 Site K_{avg} = 5.567 x 10^{-2} ft/min		
Hydraulic Gradient (*i*)	i = 0.0002 ft/ft		
Effective Porosity (n)	0.30	0.35	0.40
Velocity (=Ki/n) (ft/yr)	20	17	15
November 4, 2010			
Hydraulic Conductivity (K)	Cells 3 & 4 Site K_{avg} = 5.567 x 10^{-2} ft/min		
Hydraulic Gradient (*i*)	i = 0.0001 ft/ft		
Effective Porosity (n)	0.30	0.35	0.40
Velocity (=Ki/n) (ft/yr)	10	8	7

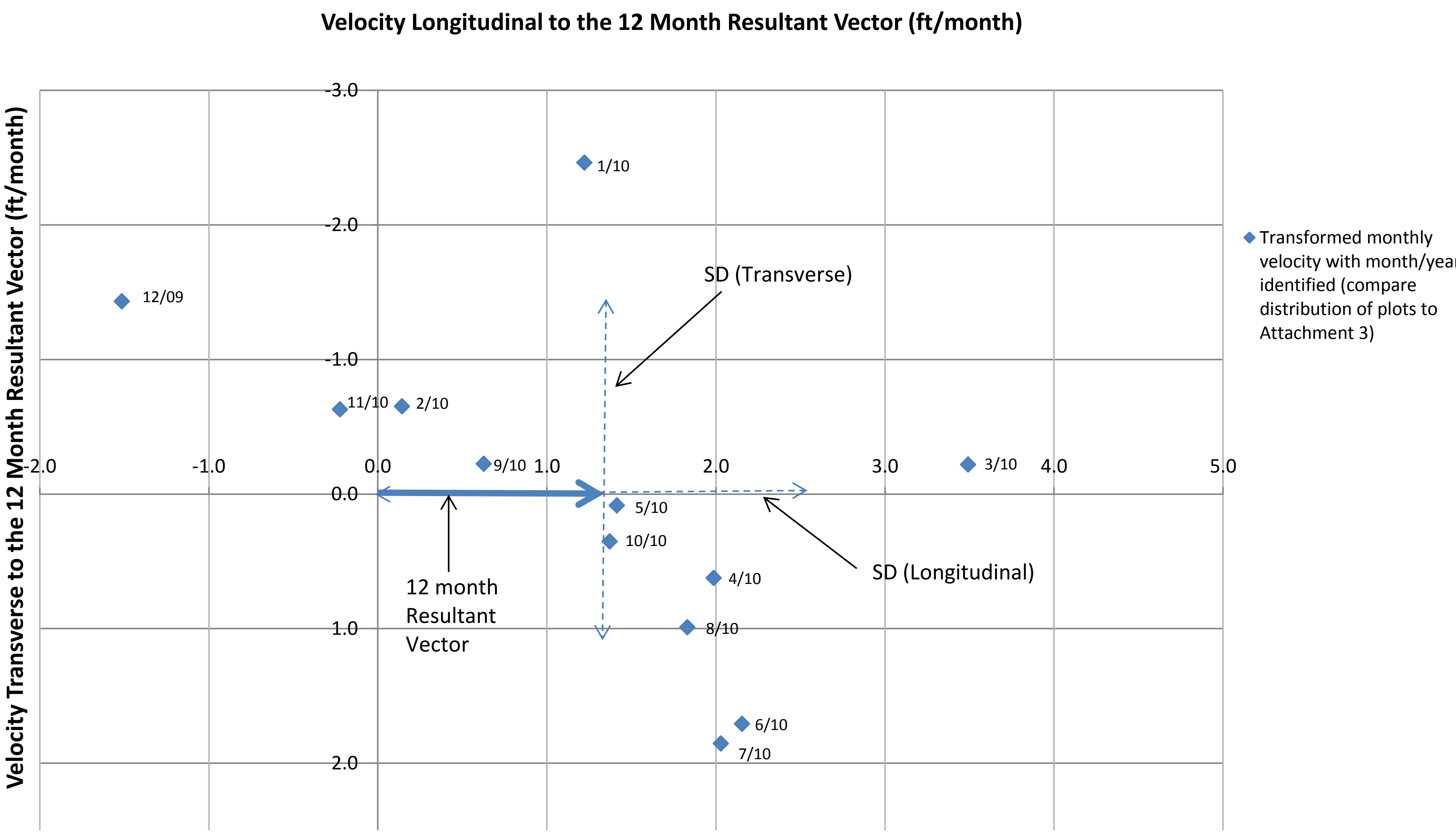
Notes

1. Hydraulic gradient values derived using 3-point methods for 12 month monitoring period 12/09-11/10.
2. Corrected version of Table 1 of Appendix X Documentation of Groundwater Monitoring System Design.

Ameren Missouri Labadie Energy Center Utility Waste Landfill
Documentation of Supplemental Groundwater Monitoring Well Design
Graphical Solution for 12 Month Resultant Vector: Cells 3 and 4
Attachment 3



Prepared by: GREDELL Engineering Resources, Inc.　　November 2013



Relationship of transformed monthly velocities (Columns L & M of Attachment 1) as described along (longitudinal) and across (transverse) the 12-month resultant vector (scaled to equal the average monthly velocity, 1.212 ft/month). The sum of the standard deviations (SD) of these dispersions divided by the average monthly equals the longitudinal and transverse dispersivity alpha values.