# Appendix W

Groundwater Hydraulic Data
Revised August 2013

**Documents Included:**

W(a) Groundwater Hydraulic Data

W(b) Agricultural Well Aquifer Drawdown Potential

# Appendix W(a)

Groundwater Hydraulic Data
Revised August 2013

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

# Appendix W(a)
# Groundwater Hydraulic Data Summary

# December 2012
# Revised August 2013

## INTRODUCTION

Appendix W(a) contains a summary description and graphical representations of surface water and groundwater data acquired from the Ameren Missouri Labadie Energy Center proposed Utility Waste Landfill site during completion of the Detailed Site Investigation (DSI) in 2009-2010. The surface water and groundwater data have been evaluated to identify and describe the factors that influence the direction and flow rate of the uppermost aquifer beneath the proposed Utility Waste Landfill. Additional details on the data used for this evaluation can be found in the DSI report for this site on file with the Missouri Department of Natural Resources, Division of Geology and Land Survey in Rolla, Missouri and referenced at the end of this report.

The Ameren Missouri Labadie Energy Center is located near Missouri River Mile 57. Missouri River elevations obtained from the Labadie Energy Center gauging station, which is at the same approximate river mile, are provided for comparison to the groundwater data due to the significant influence river levels have on the groundwater potentiometric surface across the site.

## DISCUSSION OF DATA

Groundwater elevation readings were taken on a monthly basis for twelve consecutive months from all one hundred (100) piezometers installed at the site for the DSI. These readings were taken from December 2009 through November 2010. Seven additional sets of readings from select piezometers were obtained between late April and June 2010 to better evaluate what short term impacts rising Missouri River elevations have on the groundwater elevations and gradients beneath the proposed site. The DSI report also investigated what impact precipitation has on groundwater elevations. Following approval of the DSI report, 90 of the piezometers were properly plugged and abandoned in April 2011. The remaining 10 piezometers were properly plugged and abandoned in early September 2011.

During the year-long DSI monitoring period, it was determined that the direction of groundwater flow varied in response to Missouri River elevation. During periods of relatively low river elevations (November-February) the prevailing direction of groundwater flow was north-northwest toward the river. During periods of relatively high river elevations (March-October) the prevailing direction of groundwater flow shifted eastward. These changes in flow direction can be quite rapid. For example, from the "routine" monthly measurements made on May 11, 2010 to the supplemental measurements made on May 18, 2010, as the Missouri River rose 12 feet, groundwater flow shifted approximately 90 degrees from a northeasterly to a southeasterly direction. 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.

The behavior of groundwater elevations in response to changes in Missouri River stage as described in the DSI report indicated that at the beginning of the monitoring period (December 2009), river elevation was below the water table surface. It remained more or less below the local water table throughout the succeeding three months (January to March 2010) except for relatively short-term periods (4 to 9 days). Average water table elevation remained slightly above 459 feet during this period and overall groundwater flow direction was northward, toward the Missouri River. However, beginning in mid-March 2010, river level surged above 460 feet and generally remained above that elevation through late August 2010. During that same time period, average water table elevation also rose above 460 feet, where it remained throughout the five-month time span. Water table maps for this time period (March-August 2010) show overall groundwater flow direction with a strong easterly component. Northeasterly trends for the months of March and May 2010 coincided with relatively "low" average water table elevations (460.41 to 461.98 feet) and a southeasterly trend during July 2010 coincided with a relatively high and sustained water table exceeding 463 feet. By November 2010, as both the water table and river levels dropped below 460 feet, overall groundwater flow direction "reverted" to the northwest, essentially mirroring groundwater behavior observed during the first three months of monitoring.

Comparison of groundwater levels in the southeastern part of the site (farthest from the river) to groundwater levels in the northwestern part of the site (closest to the river) suggests that the reversal in groundwater flow occurs when the Missouri River level attains a more or less sustained elevation of between 461 and 463 feet.

As recorded in the DSI report, calculated groundwater velocities range from extremes of 0.1 to 584 feet per year (ft/yr). This wide range is chiefly attributable to both calculated hydraulic gradient and effective porosity values. Hydraulic conductivity values are relatively uniform across the site due to the homogeneous nature of the sandy soils comprising the alluvial aquifer. The DSI report indicated that the lower ranges in hydraulic gradient were believed more representative of prevailing groundwater movement at the site, which results in velocities ranging from 0.1 to 10 ft/yr. However, the report also noted the possibility of higher groundwater velocity values in the northwestern part of the site, where hydraulic gradient increases in response to changes in Missouri River elevation.

Figure 1 is a graphical representation of the relationship between groundwater and river elevations at the Ameren Missouri Labadie Energy Center proposed landfill site from the period December 2009 to November 2010. It is based on Figure 31 of the DSI Report. In addition,

Figure 2 provides a summary of groundwater movement for the twelve-month monitoring period (December 2009 to November 2010) during the DSI investigation. The figure is based on Figures 18-29 of the DSI Report.

## SUMMARY AND CONCLUSIONS

The variable direction of groundwater movement at the Ameren Missouri Labadie Energy Center proposed landfill site appears intrinsically related to Missouri River elevation. When river elevations are relatively high, it acts as a recharge source to the alluvial aquifer and groundwater movement is generally toward the east and southeast. Conversely, when river elevations are relatively low, the local water table appears to "unwater" toward the river and groundwater movement is generally toward the north and northwest. Based on the data presented in the DSI report, this change in flow direction occurs when the Missouri River reaches an elevation of between 461 and 463 feet. Comparison of the river gauge data acquired during the 12-month monitoring period to gauge data for the preceding ten years suggests that river levels were unseasonably high in 2010, relative to the years 2000-2009. Thus, "unwatering" of the local water table toward the Missouri River may be more prevalent than what was suggested by the DSI data. Regardless, groundwater movement throughout much of the site is along a shallow hydraulic gradient. Calculated groundwater velocities believed to be representative of this shallow gradient range from 0.1 to 10 ft/yr, but could be as high as 584 ft/yr. Higher velocities to the northwest are suggested, where hydraulic gradient increases.

## REFERENCES

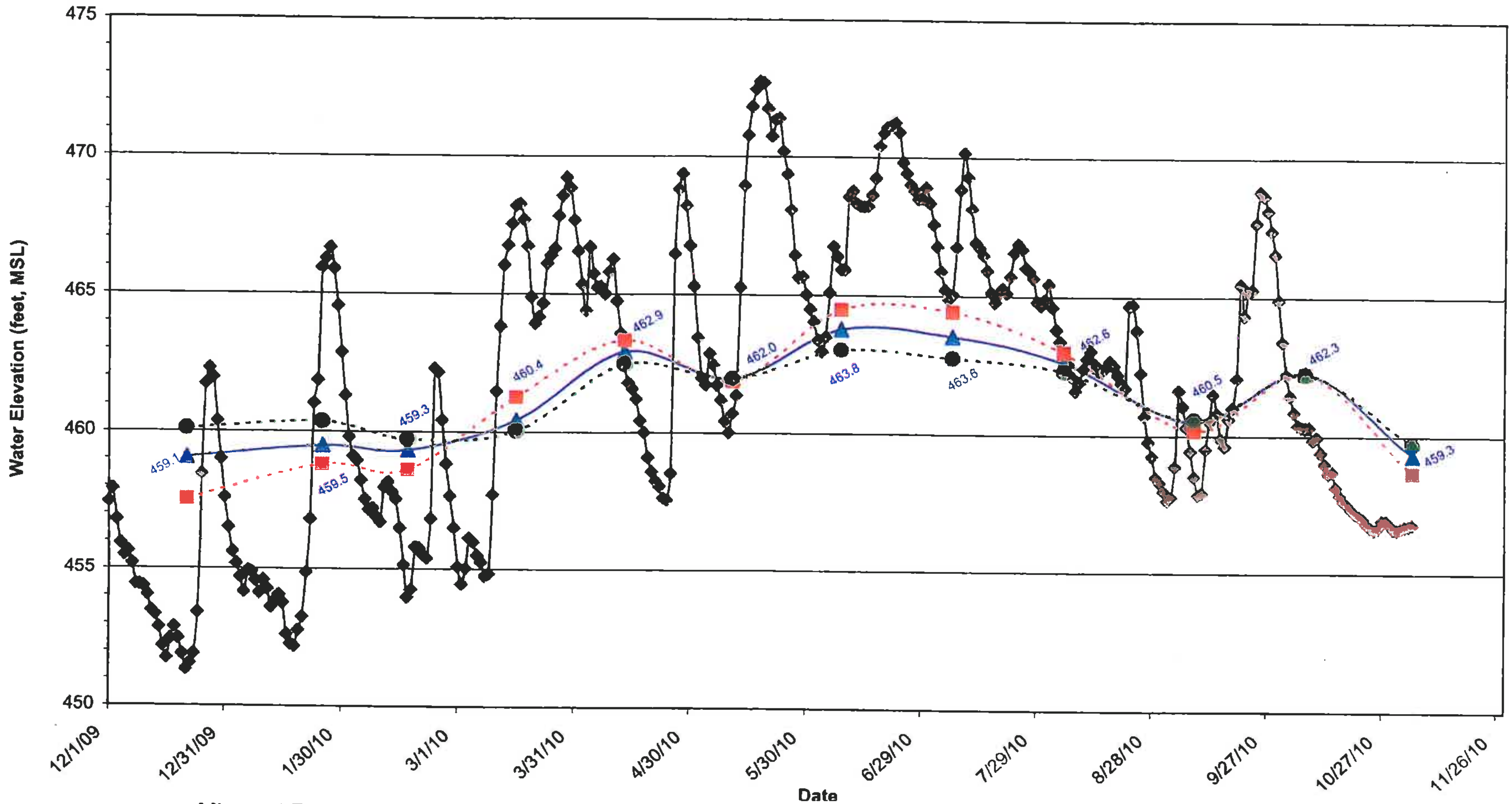

1. *Detailed Site Investigation Report For Ameren Missouri Labadie Power Plant Proposed Utility Waste Disposal Area, Franklin County, Missouri,* dated February 4, 2011, revised March 30, 2011 by GREDELL Engineering Resources, Inc. and Reitz & Jens, Inc.

# FIGURES

**AMEREN MISSOURI LABADIE POWER PLANT**
**GROUNDWATER HYDRAULIC DATA SUMMARY**
**APPENDIX W**

**Monthly Average Water Table Elevation vs Missouri River Elevation**

**FIGURE 1***




*From Figure 31 of the Detailed Site Investigation Report

| PRINT DIST. | |
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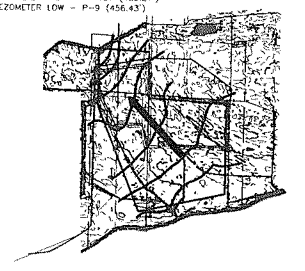
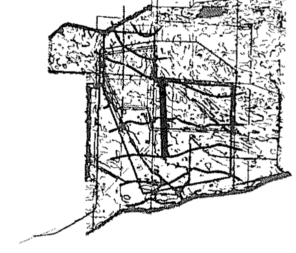
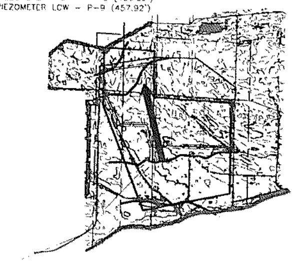


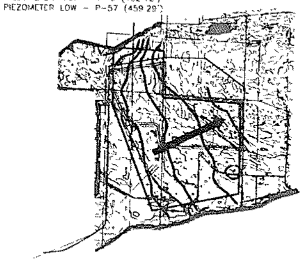

DECEMBER 21, 2009 GROUNDWATER MAP



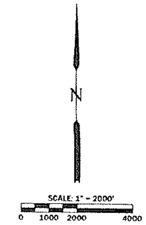

JANUARY 25, 2010 GROUNDWATER MAP

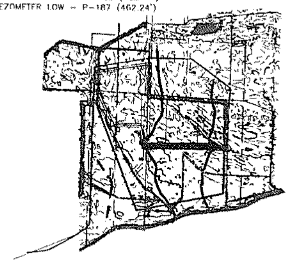



FEBRUARY 16, 2010 GROUNDWATER MAP

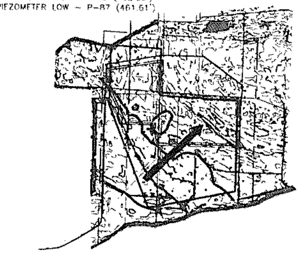



MARCH 16, 2010 GROUNDWATER MAP

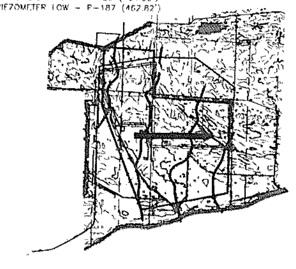


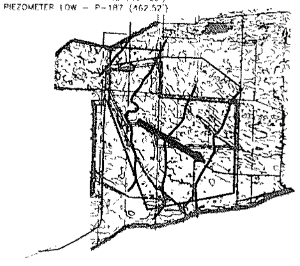

APRIL 13, 2010 GROUNDWATER MAP




MAY 11, 2010 GROUNDWATER MAP




JUNE 08, 2010 GROUNDWATER MAP



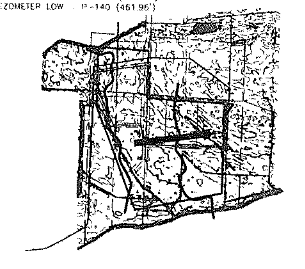

JULY 07, 2010 GROUNDWATER MAP

## LEGEND

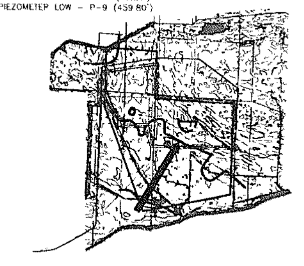
- GROUNDWATER FLOW DIRECTION
- 464.00 — GROUNDWATER CONTOUR NOTE: CONTOUR INTERVAL (C.I.) = 0.5 FT.
- DETAILED SITE INVESTIGATION AREA

NOTES:

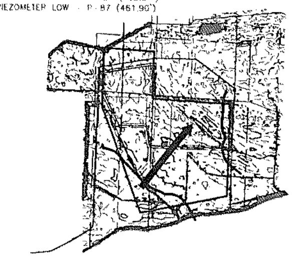
1. GROUNDWATER DATA NOT AVAILABLE FOR TEMPORARY BORINGS.
2. MEASUREMENTS RECORDED BY GREDELL ENGINEERING RESOURCES AND REITZ & JENS INC.



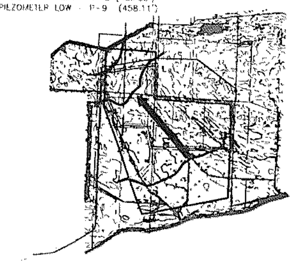

AUGUST 5, 2010 GROUNDWATER MAP




SEPTEMBER 8, 2010 GROUNDWATER MAP




OCTOBER 7, 2010 GROUNDWATER MAP




NOVEMBER 4, 2010 GROUNDWATER MAP

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REITZ & JENS, INC. CONSULTING ENGINEERS

GREDELL Engineering Resources, Inc.
ENVIRONMENTAL ENGINEERING
LAND AIR WATER

PREPARED FOR Ameren Missouri

| | |
|---|---|
| DRAWN 020411 W.J.A. (GER) | FIGURE 2<br>APPENDIX W<br>GENERALIZED GROUNDWATER SUMMARY<br>DECEMBER 2009 THROUGH NOVEMBER 2010 |
| CHKD. M.C.C. (GER) | |
| SUPV. M.C.C. (GER) | |
| APPD. M.C.C. (GER) | LOCATION 001004 — LABADIE PLANT — CLASS 02010 |
| Ameren Missouri ST. LOUIS, MISSOURI | FIGS (18) THRU (29)(33).DWG — REV. |

# Appendix W(b)

Agricultural Well Aquifer
Drawdown Potential
Revised August 2013

1505 E. High Street
Jefferson City, Missouri 65101
Telephone No. (573) 659-9078
Fax No. (573) 659-9079

**GREDELL Engineering Resources, Inc.**

# Memo

**To:** Jeff Fouse, P.E., Reitz & Jens, Inc.

**From:** Travis Doll, R.G., R.E.H.S. TAO

**CC:** Tom Gredell, P.E. and Mike Carlson, R.G., GREDELL Engineering MC

**Date:** July 31, 2013

**Re:** Ameren Missouri Labadie Energy Center – CPA Report Response to MDNR Comment No.25 Regarding Irrigation Well Aquifer Drawdown Potential

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This hydrologic memorandum was prepared for the exclusive use of Reitz & Jens, Inc. and Ameren Missouri. Gredell Engineering completed the evaluation using information obtained from the *Detailed Site Investigation Report for Ameren Missouri Labadie Power Plant Proposed Utility Waste Disposal Area Franklin County, Missouri February 4, 2011 (Revised March 30, 2011)*; hereinafter referred to as DSI, and customary practices for determining aquifer drawdown in an unconfined aquifer.

Reitz & Jens, Inc. requested that GREDELL Engineering Resources, Inc. (Gredell Engineering) provide a detailed evaluation and response to the Missouri Department of Natural Resources (MDNR) Comment No. 25 that was included in a May 7, 2013 letter from MDNR to Ameren Missouri, regarding Review and Comments on Construction Permit Application for a Proposed Utility Waste Landfill, Ameren Missouri Labadie Energy Center, Franklin County, Missouri. Comment No. 25 states the following:

> *During our April 4, 2013, site visit, the SWMP observed relocation of two groundwater monitoring wells to accommodate operation of a traveling irrigation boom supplied by water from a nearby irrigation well. A recent review of the DSI approval reveals, the Geological Survey Program expressly required information regarding the status and analysis of the influence of an operational well be provided during the permitting stage of the project. This information was not provided in the application as required. This evaluation and analysis shall be provided or the well shall be permanently decommissioned prior to the second quarter of background sampling.*

Gredell Engineering evaluated the aquifer drawdown potential of the irrigation well pumping on the monitoring wells at the Ameren Missouri Labadie Energy Center Proposed Utility Waste Landfill site when the irrigation well pumping is activated for the operation of the center pivot irrigation system. Of all monitoring wells on site, MW-11 is the closest monitoring well to the irrigation well, and therefore, it was selected in this evaluation (Figure 1). Based on Gredell Engineering's evaluation, we conclude that the closest monitoring well to the agricultural well will have an unmeasurable drawdown for the agricultural pumping rates described below.

Gredell Engineering referenced Freeze and Cherry, 1979, pp. 314-327 to determine the effects of pumping/aquifer drawdown in an unconfined aquifer. The user (Brunjes) of the irrigation well has reported pumping rates of 1,000 to 1,200 gallons per minute (gpm) from the well. This well will only operate periodically during periods of dry weather, typically for durations of up to four days. The periodic operation of this well will have unmeasurable impacts on the groundwater levels in the adjacent groundwater monitoring wells. Due to the unknown details of the irrigation well construction (e.g., depth of well, length of well screen, etc.), additional references that are mentioned later in this memorandum, were used to obtain practical values to include in the aquifer drawdown calculations.

Gredell Engineering chose the following well function equations, as referenced in Freeze and Cherry, 1979, p. 317, equations 8.6 and 8.7, to calculate the aquifer drawdown potential from the operation of the irrigation well.

**Equation 8.7**

$$h_o - h = \frac{Q}{4\pi T} W(u)$$

Where:

$h_o - h$ = drawdown, feet
$Q$ = Pumping rate of irrigation well, gallons per minute (gpm)
$\pi$ = 3.14, unitless
$T$ = Transmissivity = $K$ x $b$, gallons per day per foot (gpd/ft)
$K$ = Hydraulic Conductivity, gallons per day per square foot (gpd/ft$^2$)
$b$ = Unconfined Aquifer Initial Saturated Thickness, feet
$W(u)$ = Well function, unitless

**Equation 8.6**

$$u = \frac{r^2 S_y}{4Tt}$$

Where:

$u$ = Related to the Well Function *W (u),* unitless, reference (Freeze and Cherry, 1979, pp. 317)
$r$ = Radius from irrigation well to MW-11, feet
$S_y$ = Specific yield ≈ effective porosity in an unconfined aquifer (Sutch and Dirth, 2006, Ch. 8, p. 10), whereas ( $S_y$ ) ≈ Storativity ($S$) in an unconfined aquifer, unitless (Freeze and Cherry, 1979, pp. 317, 324-325)
$T$ = Transmissivity, gallons per day per foot
$t$ = Time, days

According to Freeze and Cherry, 1979, pp. 317, 324-325, the following is stated: *"If the aquifer properties, **T** and **S**, and the pumping rate, **Q**, are known, it is possible to predict the drawdown in any hydraulic head in a confined aquifer at any distance **r** from a well at any time **t** after the start of pumping. It is simply necessary to calculate **u** from Equation 8.6, look up the value of **W(u)** on Table 8.1, and calculate $\mathbf{h_o - h}$ from Equation 8.7." For unconfined aquifers, "...use the same equation as for a confined aquifer (Equation 8.7) but with the argument of the well function (Equation 8.6) defined in terms of the specific yield $\mathbf{S_y}$ rather than storativity **S**. The transmissivity **T** must be defined as **T = kb**, where **b** is the initial saturated thickness."*

The following values (constants) where obtained from the DSI (Tables 7 and 8) for performing the calculations of potential aquifer drawdown in reference to the monitoring well MW-11:

$K_{avg}$ = 4.905 x 10$^{-2}$ feet per minute or 528.32736 gpd/ft$^2$
$b$ = 90 feet
n = 0.35 = Effective porosity, unitless. As discussed above, specific yield ( $S_y$ ) ≈ effective porosity (n) in an unconfined aquifer, whereas ( $S_y$ ) ≈ Storativity ($S$) in an unconfined aquifer

Additional references were utilized to obtain estimated values of Q in the Missouri River Alluvium Aquifer in the lower Missouri River valley. "*Data from an U.S. Geological Survey test drilling program along this reach of the river indicates that in most places the alluvium is capable of yielding 1,000 to 3,000 gpm. Yields of from 2,500 gpm to 3,000 gpm, with transmissivities of 200,000 gpd/ft to 250,000 gpd/ft (26,700 $ft^2$/day to 33,400 $ft^2$/day), are not unusual…For example, a well producing 2,000 gpm from an aquifer with a transmissivity of 250,000 gpd/ft and a specific yield of 0.15 will create only about 5.7 ft of drawdown in the aquifer a distance of 100 ft from the pumped well after 10 days of continuous pumping. Drawdown in the aquifer adjacent to the well will be only about 15 ft, and 10 ft from the well it will be about 10 ft.*" (Miller and Vandike, 1997, p. 150).

The following values were used in the above equations for:

$r$ = 1,525 feet (approximate distance from the irrigation well to closest monitoring well MW-11).
$Q$ = 1,000 gpm, 1,500 gpm, and 2,000 gpm.

Attached to this memo are sample computations for MW-11 when the irrigation well is pumping at 1,000 gpm, 1,500 gpm and 2,000 gpm for durations of 24 hours (1 day) and 96 hours (4 days) of continuous pumping. At 1,000 gpm for 1 day of continuous irrigation well pumping, the drawdown in MW-11 is calculated to be less than 1.1 x E-05 feet. Additionally, at 2,000 gpm for 4 days of continuous irrigation well pumping, the drawdown in MW-11 is calculated to be less than 1.8 x E-04 feet. Hand calculations using the *W(u)* values in Table 5 *Values of W(u) for values of u between* $10^{-15}$ *and 9.9* (Lohman, 1972, p. 16) are included as Attachment 1.

## Conclusions

Because the calculated drawdown is unmeasurable additional computations have not been pursued.
It is recommended that groundwater sampling occur a minimum of 24 hours after the agricultural well was last operated to mitigate any potential impacts on the adjacent groundwater monitoring wells.

## REFERENCES

Freeze, R.A. and Cherry, John. A, *Groundwater*, Prentice-Hall, Inc., Englewood Cliffs, N.J., 1979, pp. 315-327.

GREDELL Engineering Resources, Inc. and Reitz & Jens, Inc., *Detailed Site Investigation Report for Ameren Missouri Labadie Power Plant Proposed Utility Waste Disposal Area Franklin County, Missouri February 4, 2011 (Revised March 30, 2011).*

Lohman, S.W., *Ground-Water Hydraulics*, Geological Survey Professional Paper 708, United States Government Printing Office, Washington: 1972, p. 16.

Miller, Don E. and Vandike, James E., *Water Resources Report Number 46, Missouri State Water Plan Series Volume II, Groundwater Resources of Missouri*, Missouri Department of Natural Resources, Division of Geology and Land Survey,1997, pp. 147-151.

Sutch, Patti and Dirth, Lisa, *Geology Study Manual: 2006 Review for the National (ASBOG) Geology Licensing Exam*, Reg Review, Inc., 2006, Chapter 8, p. 10.

###

$$h_0 - h = \frac{Q}{4\pi T} W(u) \quad \text{where } u = \frac{r^2 S}{4Tt} = \frac{r^2 S_y}{4Tt}$$

$W(u)$ = well function

$Q$ = pumping rate (gpm)

$r$ = radius from well MW-11

$S$ = Storativity, which is = Specific Yield ($S_y$) in Unconfined Aquifer
$S_y \approx n_e$ (effective Porosity)

$T$ = Transmissivity, which is
$T = Kb$ (gpd/ft or ft²/day)

$K$ = Hydraulic Conductivity (gpd/ft²)

$b$ = Saturated Thickness of Aquifer

$t$ = time

$h_0 - h$ = drawdown

ATTACHMENT 1

**EXAMPLE 1. – 1 Day @ 1,000 gpm pump rate**

$$h_o - h = \frac{Q}{4\pi T} W(u) \quad \text{where } u = \frac{r^2 S_y}{4Tt}$$

$Q = 1{,}000$ gpm  $r = 1{,}525$ ft  $S_y = 0.35$  $t = 1$ day

$K_{avg} = 4.905 \times 10^{-2}$ ft/min $\times$ 1,440 min/day $\times$ 7.48 gal/ft³ $= 528.32736$ gpd/ft²

$b = 90$ ft.

$T = Kb = 528.32736$ gpd/ft² $\times$ 90 ft $= 47{,}549.4624$ gpd/ft

$$u = \frac{(1{,}525 \text{ ft})^2 \times 0.35}{4(47{,}549.4624 \text{ gpd/ft})(1 \text{ Day})}$$

$$u = \frac{813{,}968.75 \text{ ft}^2}{4(47{,}549.4624 \text{ gpd/ft} \times 1 \text{ Day} \times \frac{1 \text{ ft}^3}{7.48 \text{ gal}})} = 32.01$$

$32.01 >> 9.9 \therefore W(u) < 0.000004637$ from Ground-Water Hydraulics Table 5

$$h_o - h = \frac{1{,}000 \text{ gpm}}{4\pi(47{,}549.4624 \text{ gpd/ft}^2)} \times 0.000004637$$

$$'' = \frac{1{,}000 \text{ gpm} \times 1{,}440 \text{ min/day}}{597{,}524.167032 \text{ gpd/ft}} \times 0.000004637$$

$$'' = 1.117 \times 10^{-5} \text{ ft}$$

**EXAMPLE 2. – 1 Day @ 1,500 gpm = Q**

$$h_o - h = \frac{1{,}500 \text{ gpm} \times 1{,}440 \text{ min/day}}{597{,}524.167032 \text{ gpd/ft}} \times 0.000004637$$

$$'' = 1.676 \times 10^{-5} \text{ ft}$$

**Example 3. – 1 Day @ 2,000 gpm = Q**

$$h_o - h = \frac{2{,}000 \text{ gpm} \times 1{,}440 \text{ min/day}}{597{,}524.167032 \text{ gpd/ft}} \times 0.000004637$$

$$'' = 2.235 \times 10^{-5} \text{ ft}$$

| GREDELL Engineering Resources, Inc. ENVIRONMENTAL ENGINEERING LAND - AIR - WATER Telephone (573) 659-9078 | | Date: 07/29/13 | Page No: 3 of 3 |
|---|---|---|---|
| | | Client: Reitz & Jens, Inc. | |
| Prepared By: TAO | Checked By: TG | Project: Ameren MO Labadie UWL - CHA | |
| Subject: Irrigation Well Influence Calcs. | | | |

**EXAMPLE 4. - 4 days @ 1,000 gpm**

$$u = \frac{(1{,}525 ft)^2 \times 0.35}{4(47{,}549.4624 gpd/ft)(4 days)}$$

$$u = \frac{813{,}968.75 ft^2}{4(47{,}549.4624 gpd/ft \times 4 days \times \frac{1 ft^3}{7.48 gal}}$$

$$u = \frac{813{,}968.75 ft^2}{101{,}710.08 ft^2} = 8.00$$

$W(u) = 0.00003767$ from Table 5

$$h_0 - h = \frac{1{,}000 gpm}{4\pi(47{,}549.4624 gpd/ft^2)} \times 0.00003767$$

$$'' = \frac{1{,}000 gpm \times 1{,}440 min/day}{597{,}524.167032 gpd/ft} \times 0.00003767$$

$$'' = 9.078 \times 10^{-5} ft.$$

**EXAMPLE 5. - 4 days @ 1,500 gpm**

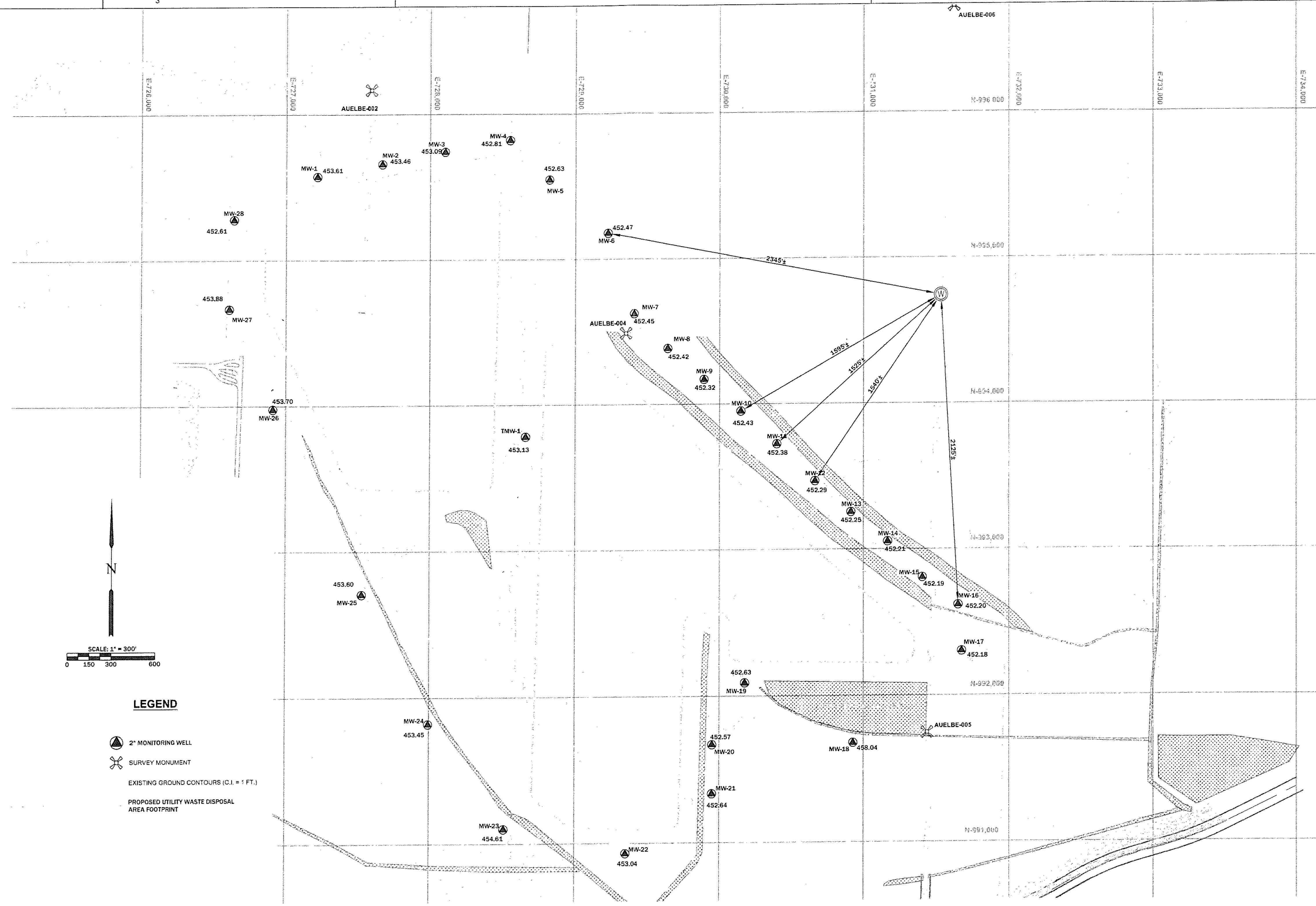
$$h_0 - h = \frac{1{,}500 gpm \times 1{,}440 min/day}{597{,}524.167032 gpd/ft} \times 0.00003767$$

$$'' = 1.362 \times 10^{-4} ft.$$

**EXAMPLE 6. - 4 days @ 2,000 gpm**

$$h_0 - h = \frac{2{,}000 gpm \times 1{,}440 min/day}{597{,}524.167032 gpd/ft} \times 0.00003767$$

$$'' = 1.816 \times 10^{-4} ft.$$




## 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

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**FIGURE 1**
**DISTANCES BETWEEN IRRIGATION WELL AND SELECT MONITORING WELLS PROPOSED UTILITY WASTE LANDFILL**

| LOCATION | | CLASS |
|---|---|---|
| 001009 | LABADIE ENERGY CENTER | 02010 |

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