



C-400-Wide Groundwater Conceptual Site Model

DRAFT WORKING COPY – FOR DISCUSSION ONLY 6/5/18

Setting – Land Use



Setting

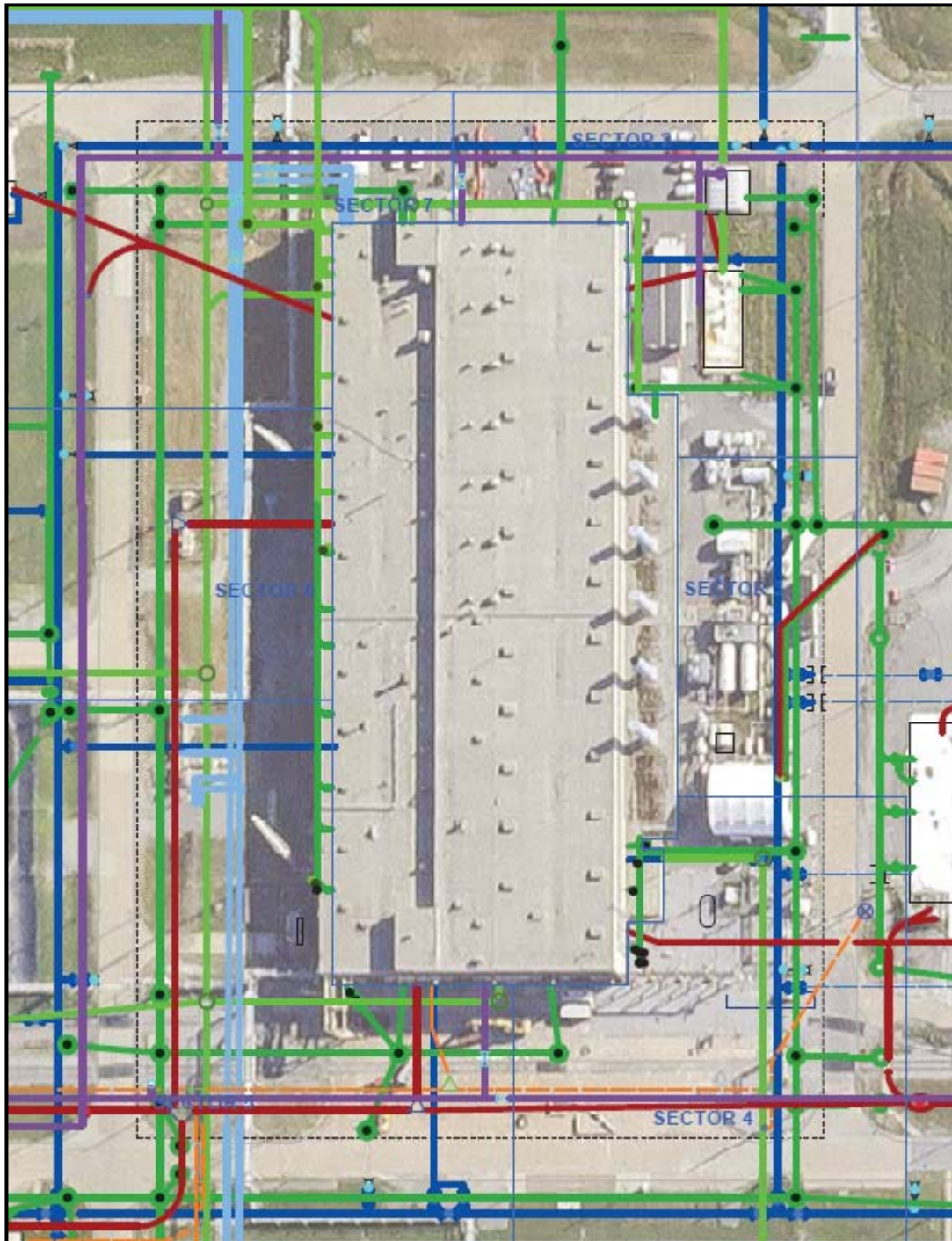
C-400 block is an industrial site

- Large roofed facility (**116,000 ft²**) within C-400 Complex Block (**350,000 ft²**):33 % of area
 - Roof drains leak runoff to gravel foundation
 - Storage and infiltration of water beneath building
- Paved surfaces to east, south, and north of C-400 and grading of land surface limit rainfall infiltration
- Ditches and storm drains on east and west sides of C-400 Block promote rapid transport of precipitation away from C-400 Block

- Below-ground utilities
 - All sides of C-400 Building
 - Depths to **16 ft**
 - Backfill = potential high hydraulic conductivity corridors
 - Utilities beneath C-400 Building are within sub slab gravel
 - Plant water lines and storm sewers primarily on south and east sides of C-400 Block
 - Potential anthropogenic source of water
 - Large RCW lines beneath west side of C-400 Block
 - Potential anthropogenic source of water



Setting – Subgrade Utilities



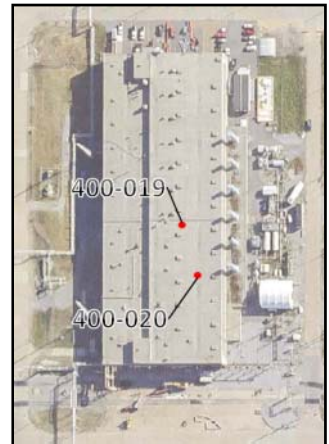
Setting

Shallow soils are “disturbed”

- Approximately **10 ft** of gravel fill beneath C-400 Building slab (400-019 and 400-020)
 - Bottom elevations: approximately **371 to 372 ft**
 - Not under basements

Boring 400-019									
Project: Paducah Gaseous Diffusion Plant Wag 6 RI					Coordinates: -4235.0000 E, -1505.0000 N				
Location: Paducah, KY					Geologist: T. Streufert				
Started at: 1555 on 11-22-97					Surface Elevation: 380.00 feet msl				
Completed at: 0820 on 11-22-97					Depth to Groundwater: NA feet bgs Measured: NA				
Drilling Method: Rotasonic					Groundwater Elevation: NA feet msl				
Drilling Company: Alliance					Total Depth: 48.0 feet				
DEPTH IN FEET	LITHOLOGIC SAMPLE	ANALYTICAL SAMPLE	% Recovery	RAD/Alpha	RAD/Beta	FID (ppm)	GRAPHIC LOG	GEOLOGIC DESCRIPTION	ELEV. (ft-MSL)
0			-	BG	BG	0	0	Clayey Gravel w/Sand; subang; prly sorted chert; med grn; moist; (2.5YR4/8) dk rd	371.5
1			-	BG	BG	0	0		371.5
2			-	BG	BG	0	0		371.5
3			-	BG	BG	0	0		371.5
4			-	BG	BG	0	0		371.5
5			-	BG	BG	0	0		371.5
6			-	BG	BG	0	0		371.5
7			-	BG	BG	0	0		371.5
8			-	BG	BG	0	0		371.5
9			-	BG	BG	0	0		371.5
10			-	BG	BG	0	0	Silt, slightly Clayey; Manganese Mineralization; v dry, hard; (10YR8/3) p brn, mtld & laminae (10YR5/8) yel brn	371.3

Gravel Fill



Boring 400-020									
Project: Paducah Gaseous Diffusion Plant Wag 6 RI					Coordinates: -4165.0000 E, -1620.0000 N				
Location: Paducah, KY					Geologist: T. Streufert				
Started at: 0900 on 11-22-97					Surface Elevation: 380.00 feet msl				
Completed at: 1510 on 11-22-97					Depth to Groundwater: NA feet bgs Measured: NA				
Drilling Method: Rotasonic					Groundwater Elevation: NA feet msl				
Drilling Company: Alliance					Total Depth: 48.0 feet				
DEPTH IN FEET	LITHOLOGIC SAMPLE	ANALYTICAL SAMPLE	% Recovery	RAD/Alpha	RAD/Beta	FID (ppm)	GRAPHIC LOG	GEOLOGIC DESCRIPTION	ELEV. (ft-MSL)
0			23	BG	BG	-	0	Clayey Gravel, w/Sand; subrnd/subang chert; med grn; (2.5YR4/8) dk rd	372
5			33	BG	BG	-	0		372
10			95	BG	BG	0	0		372
0			-	BG	BG	0	0	Silt, slightly Clayey; (10YR6/4) lt yel brn, (10YR7/2) mtld lt gry	368

Gravel Fill



UCRS Recharges RGA

Shallow soils are “disturbed”

- **7-to-10 ft** of disturbed soil around SE corner of building: expected condition across C-400 block
- Excavation to 17.3 ft at SWMU 11: “Clean” soil fill (~800 ft² area)
Clay cap

Upper Continental Deposits (Pleistocene-to-Holocene)

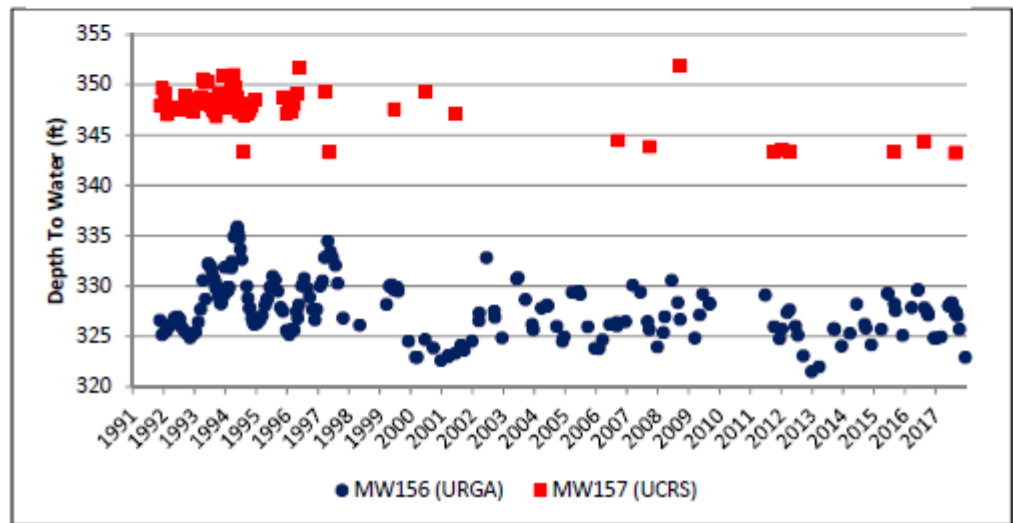
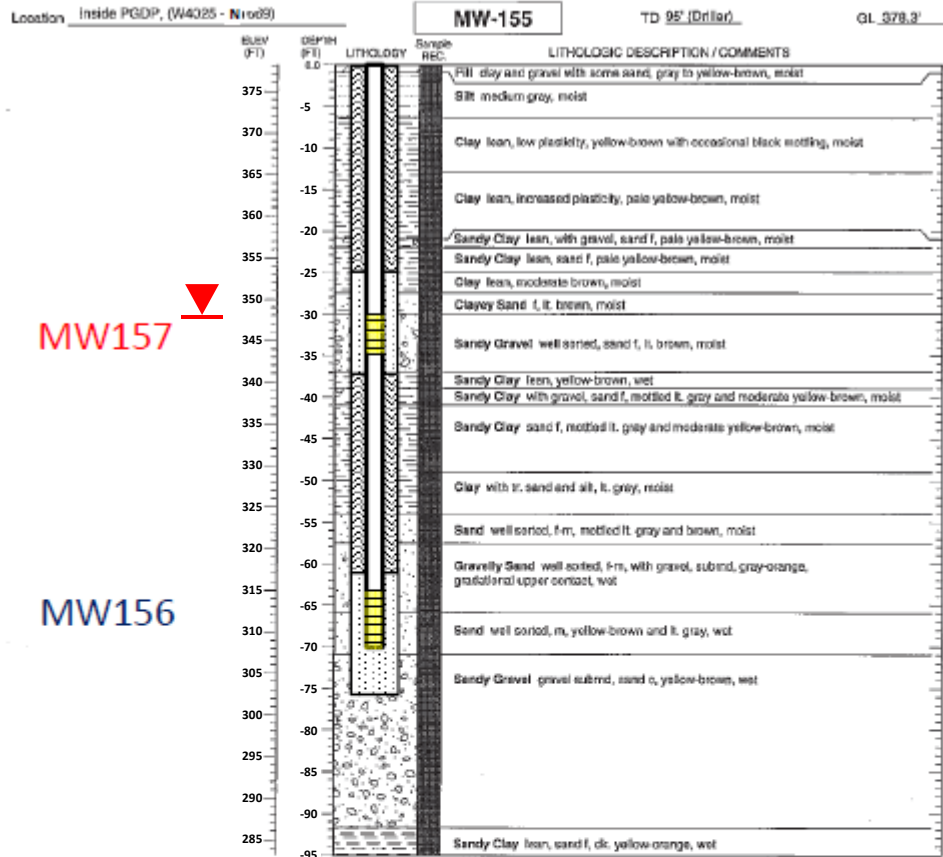
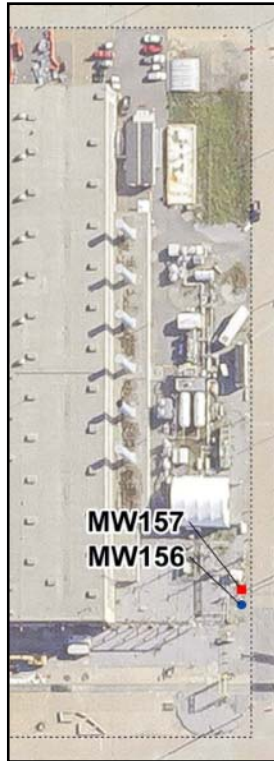
- “Package” of loess-dominated sedimentary units down to elevation of approximately **327 ft**
 - Intermittent sand and gravel lenses
- HU2: interval of common gravel horizons at elevations **339-to-348 ft**
 - Near continuous beneath C-400 Block
- Textural gradation of silt/clayey silt to fine sand at base of UCRS, approximately **327-down-to-323 ft** elevation

UCRS hydraulic potential

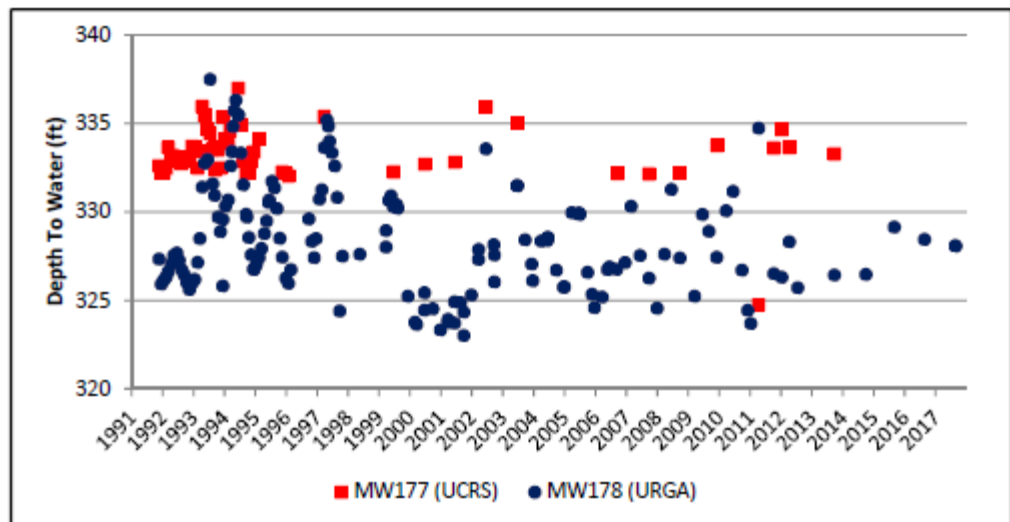
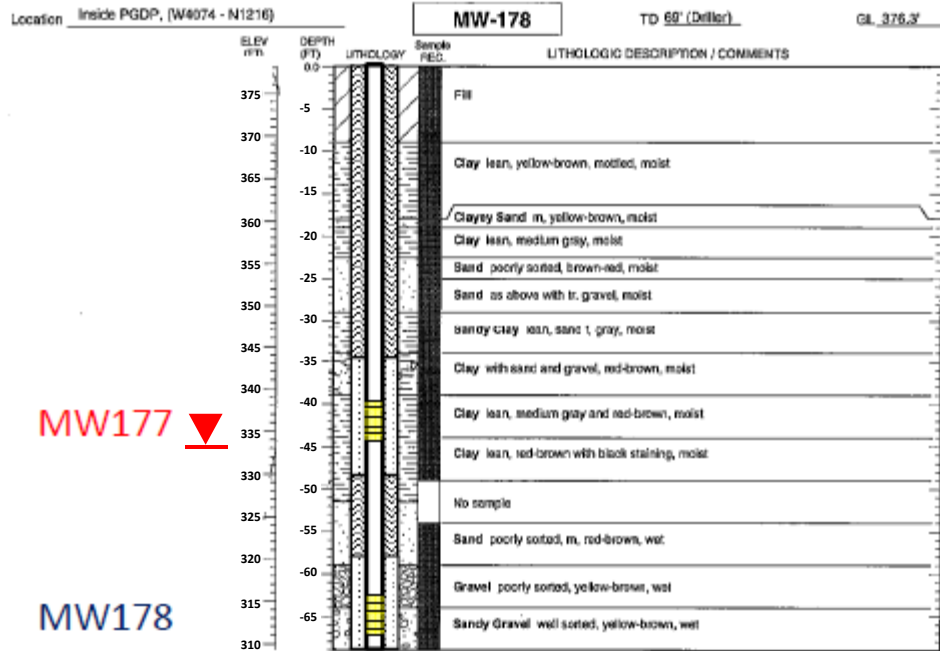
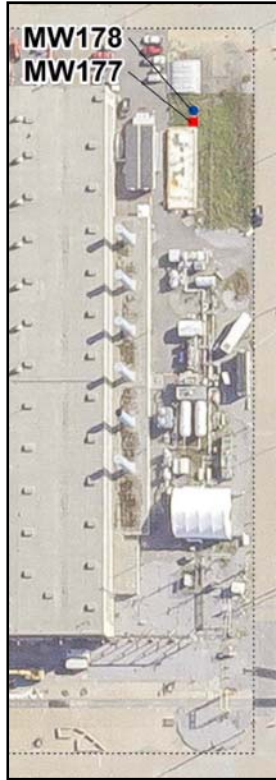
- Gravel fill beneath C-400 Building: episodically saturated by rains via roof drains
 - Storage and infiltration of water beneath C-400 Building
- Saturated below approximately **348 ft** under southeast C-400 Block (MW157)
- Saturated below approximately **333 ft** under northeast C-400 Block (MW177)
- Unsaturated above **341 ft** on west side of C-400 Building (MW176)



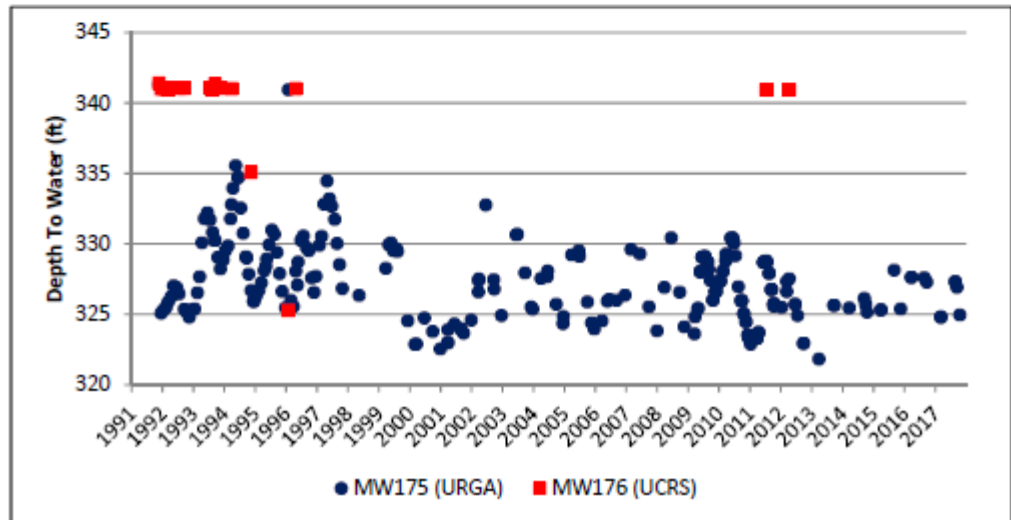
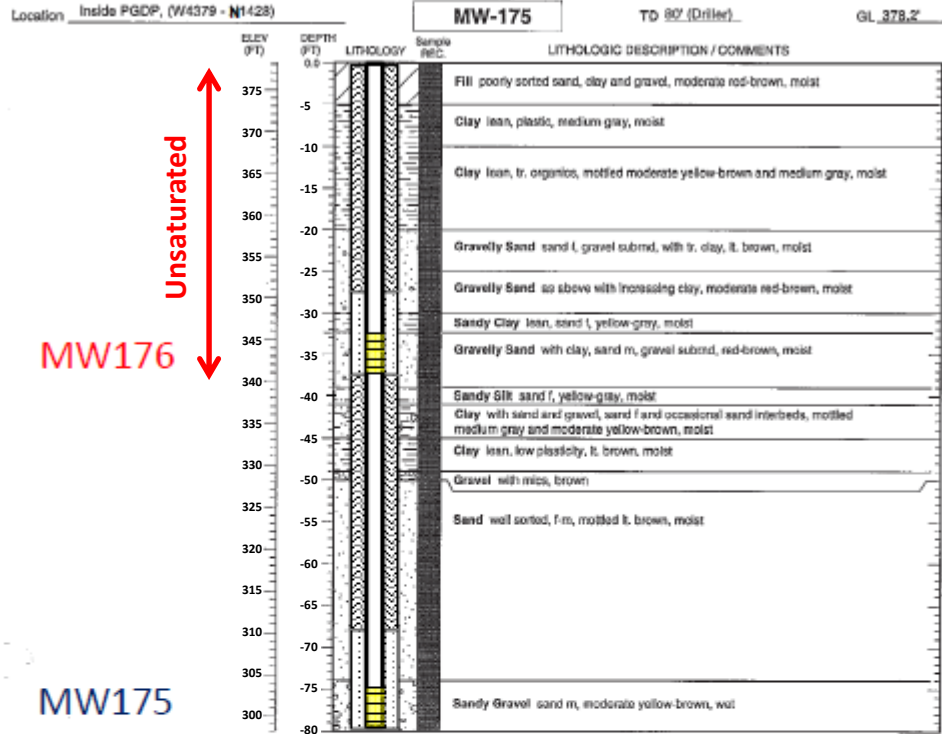
Hydraulic Potential - Southeast C-400



Hydraulic Potential - Northeast C-400



Hydraulic Potential - West C-400



Measures of UCRS Hydraulic Conductivity

Phase II Site Investigation: Slug Tests

UCRS hydraulic conductivity (horizontal)

For C-400-area wells, slug tests measured hydraulic conductivity of **2.47E-05 cm/sec (MW157)** to **2.81E-04 cm/sec (MW177)**

Hydraulic Conductivities for All UCRS Well Tests of Phase II Site Investigation at PGDP ¹ (C-400 –area wells are highlighted)					
Well No., Test No.	K (cm/sec)	K (ft/day)	Data Analysis Method	Percent Recovery of Test	Total Displacement (ft)
MW157, RHT1	2.47E-05	7.00E-02	Bouwer	100	3.20
MW157, RHT2	Poor data	Poor data		98	4.01
MW160, RHT1	5.41E-06	1.53E-02	Bouwer	91	3.03
MW160, RHT2	8.45E-05	2.40E-01	Bouwer	93	3.07
MW162, RHT1	4.30E-05	1.22E-01	Cooper	99	4.00
MW162, RHT2	2.86E-05	8.11E-02	Bouwer	96	4.00
MW164, RHT1	6.54E-04	1.85E+00	Bouwer	80	3.38
MW166, RHT1	1.02E-08	2.89E-05	Bouwer	88	2.28
MW167, RHT1	3.65E-05	1.03E-01	Cooper	98	6.52
MW167, RHT2	3.64E-05	1.03E-01	Cooper	97	6.36
MW170, RHT1	1.63E-07	4.62E-04	Cooper	93	4.55
MW170, RHT2	9.93E-05	2.81E-01	Bouwer	52	4.52
MW177, RHT1	2.81E-04	7.97E-01	Bouwer	90	1.04
MW189, RHT1	4.27E-04	1.21E+00	Bouwer	100	3.61
MW189, RHT2	4.27E-05	1.21E-01	Bouwer	100	3.52
MW190, RHT1	1.16E-05	3.29E-02	Cooper	96	5.03

¹Adapted from Table 6-3. Hydraulic Conductivities for All Tests Conducted on Stage A Wells at PGDP, PGDP Phase II Site Investigation (page 1 of 4)



Measures of UCRS Hydraulic Conductivity

Phase II Site Investigation: Permeameter Tests

UCRS hydraulic conductivity (vertical)

Permeameter tests measured average vertical hydraulic conductivity of **4.3E-06 cm/sec** for silt/clay intervals

Hydraulic Conductivities of UCRS Samples with 80% or Greater Clay Content ¹				
Soil Boring	Hydraulic Conductivity		Sample Description	Reference
	(cm/sec)	(ft/day)		
026001SA010	3.85E-07	1.09E-03	Clay (90%), 10YR5/6 (yellowish brown) to 10YR2/2 (dark brown)	Remedial Investigation Report for WAG 6
400036SA010	2.75E-07	7.80E-04	Clay (80%), Silt (20%); 10YR8/2 (very pale brown) to 10YR6/6 (brownish yellow)	Remedial Investigation Report for WAG 6
400038SA010	2.07E-05	5.87E-02	Clay (90%), firm, cohesive; Silt (10%); slightly moist, 10YR4/8 (dark yellowish brown) with 10YR7/1 (light gray) and 10YR6/8 (brownish yellow) mottling	Remedial Investigation Report for WAG 6
400038SA045	2.04E-05	5.79E-02	Clay (90%), firm, cohesive, slightly moist; Silt (10%); trace Gravel; 10YR6/8 (brownish yellow) with 10YR6/2 (light brownish gray) mottling	Remedial Investigation Report for WAG 6
400208SA010	2.69E-07	7.63E-04	Clay with trace Silt, firm, hard, moist, heavily mottled and iron stained, 10YR6/8 (brownish yellow), 10YR6/1 (gray), and 10YR5/6 (brownish yellow), with occasional 10YR3/1 (very dark gray)	Remedial Investigation Report for WAG 6
400210SA045	1.71E-06	4.85E-03	Clay, Silt (20%), strong brown	Remedial Investigation Report for WAG 6
400212SA010	1.71E-08	4.85E-05	Clay (90%), firm, cohesive, moist; Silt (10%); 10YR6/6 (brownish yellow) with 10YR6/8 (brownish yellow) and 10YR7/1 (light gray) mottling, trace 10YR3/1 (very dark gray) organic stain	Remedial Investigation Report for WAG 6
GB-09S	9.88E-08	2.80E-04	Slightly Silty (10%) lean Clay	C-746-U Solid Waste Landfill Groundwater Monitoring Plan
GB-14S	1.19E-05	3.37E-02	Lean Clay with Silt (15-20%)	C-746-U Solid Waste Landfill Groundwater Monitoring Plan
GB-21S	1.66E-07	4.71E-04	Lean Clay with Silt (20%)	C-746-U Solid Waste Landfill Groundwater Monitoring Plan
GB-25S	2.26E-07	6.41E-04	Slightly Silty (10-20%) lean Clay	C-746-U Solid Waste Landfill Groundwater Monitoring Plan
GWW-01	3.39E-08	9.60E-05	Clay (80%) with Silt (20%), 7.5YR5/6 (strong brown) with 7.5YR7/1 (light gray) mottling and small black specs (1-2 mm) and larger (4 mm) 7.5YR3/4 (dark brown) concretions	Remedial Investigation Report for SWMUs 7 and 30 of WAG 22
SWMU 2-09	9.98E-09	2.83E-05	Clay (80%) with Silt (20%), mottled 7.5YR6/1 (gray) and 5YR4/6 (yellowish red)	Data Summary and Interpretation Report for Interim Remedial Design at SWMU 2 of WAG 22
Arithmetic Mean	4.34E-06	1.23E-02		
Geometric Mean	3.92E-07	1.11E-03		

¹Adapted from Table 3.6. Permeameter Results for Samples with 80% or Greater Clay Content of 2016 Update of the Paducah Gaseous Diffusion Plant Sitewide Groundwater Flow Model



UCRS Recharge - Modeled

UCRS recharge rate at C-400 (modeled)

Rate = **10-to-16 inches/year**

(Table 6.2 of 2016 Update of the Paducah Gaseous Diffusion Plant
Sitewide Groundwater Flow Model)

Zone	Model Parameter	Units in Inches per Year					
		Initial Recharge		Calibrated Recharge			
		Minimum Constraint	Maximum Constraint	Stress Period 1 (February 1995)	Stress Period 2 (September 2014)	Stress Period 1 (February 1995)	Stress Period 2 (September 2014)
2	Ambient	2.6	7.6	3.7	4.3	3.6	4.3
3	Very Upper Bayou Creek	7.6	40.0	25.0	25.0	25.0	25.0
4	Bayou Creek	7.6	40.0	20.0	20.0	20.0	20.0
5	Bayou Creek Tributary	7.6	40.0	20.0	20.0	20.0	20.0
6	Little Bayou Creek	7.6	40.0	20.0	17.4	20.0	17.4
7	Little Bayou Creek Tributary	7.6	40.0	20.0	20.0	20.0	20.0
8	TVA Ponds	7.6	40.0	20.0	20.0	20.0	20.0
9	TVA Lines	7.6	40.0	9.0	9.0	9.0	9.0
10	Lagoon	7.6	40.0	12.0	12.0	12.0	12.0
11	Lagoon Ditch	7.6	40.0	10.0	10.0	10.0	10.0
12	Plant Area	2.6	7.6	3.7	4.3	3.6	4.3
13	East Terrace Recharge	45.6	763.8	70.0	60.0	70.0	60.0
14	West Terrace Recharge	23.4	392.0	35.9	30.8	35.9	30.8
15	Outfall 001	7.6	40.0	15.0	15.0	15.0	15.0
16	Storm Drains	7.6	40.0	14.4	22.0	14.4	22.0
17	High Pressure Fire Water Lines	7.6	40.0	18.8	30.0	18.8	30.0
18	Compromised Roof Drains - Process Buildings	7.6	40.0	30.0	30.0	30.0	30.0
19	Compromised Roof Drains - C400	7.6	40.0	10.0	16.0	10.0	16.0
20	Competent Roof Drain - C720	1.00E-06	1.0	0.001	0.001	0.001	0.001
21	Paved Areas	1.00E-06	1.0	0.001	0.001	0.001	0.001
22	Compacted Gravel	1.00E-06	1.0	0.001	0.001	0.001	0.001
23	Capped Landfill	1.00E-06	1.0	0.001	0.001	0.001	0.001
24	Enhanced Recharge at Thin Clay	7.6	83.0	45.0	45.0	45.0	45.0
25	Enhanced Recharge at Thin Clay	7.6	83.0	14.7	40.0	14.7	40.0
26	Enhanced Recharge at Thin Clay	7.6	83.0	15.0	20.0	15.0	20.0
27	Enhanced Recharge at Thin Clay	7.6	83.0	19.5	40.0	19.5	40.0
28	Enhanced Recharge at Thin Clay	7.6	83.0	28.9	20.4	28.9	20.4

Note: measured vertical gradients across the UCRS range from **0.5 to 1.0 ft/ft** while horizontal gradients range from **<0.02 to 0.05 ft/ft**. Therefore, groundwater flow in the UCRS has a strong vertical component.



RGA is the Shallow Aquifer (Discharges to the Ohio River)

Thin (5 ft or less) fine sand (HU4) – base of Upper Continental Deposits , underlain by thick sequence of gravelly sand–to–sandy gravel (HU5) – Lower Continental Deposits (Pleistocene beneath C-400)

- Upper contact: gradation of silts and fine sands (UCRS, HU3) to fine sand (RGA, HU4)
 - Top of RGA approximately **323 ft** elevation
- Lower contact: erosional unconformity with Cretaceous McNairy Formation

Base of RGA beneath C-400 Building is an undulating surface:

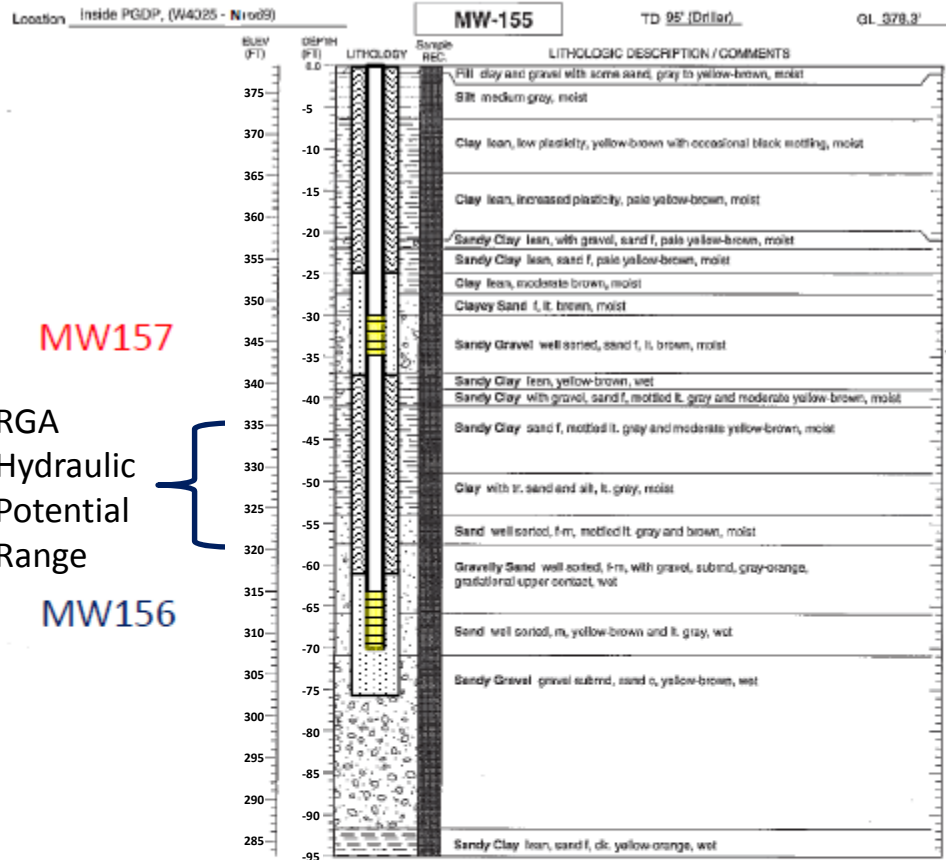
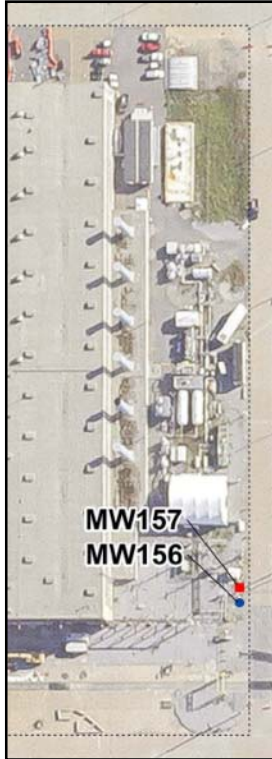
- ~**287.5 ft** elevation northeast C-400 (400-212)
- ~**291.5 ft** elevation southeast C-400 (400-038)
- ~**286.5 ft** elevation southwest C-400 (400-036)
- ~**290.0 ft** elevation northwest C-400 (400-035, 400-208 and 400-210)

RGA hydraulic potential

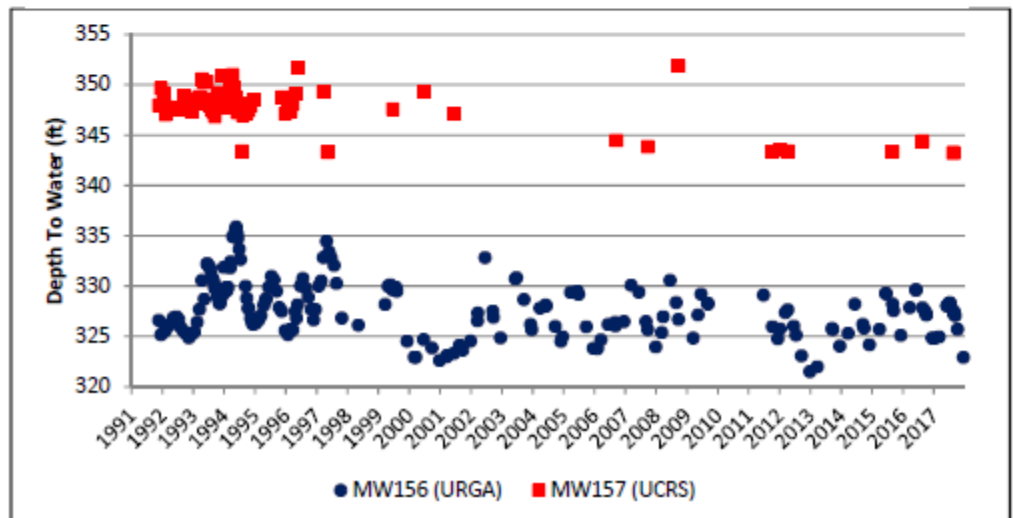
- Commonly ranges between **322 ft** elevation (late summer) and **332 ft** elevation (winter/spring) – semi-confined aquifer
- Horizontal gradient bifurcates: northwest to Northwest Plume and east to Northeast Plume – governed by pumping rates in pump-and-treat well fields
 - Gradient has been predominately to Northwest Plume: **1.79E-05 to 6.10E-04 ft/ft**
- Vertical hydraulic gradient poorly defined but approximately **0.1 ft** (down) over 30 ft thickness: **3.3E-03 ft/ft**



RGA Hydraulic Potential: Southeast C-400

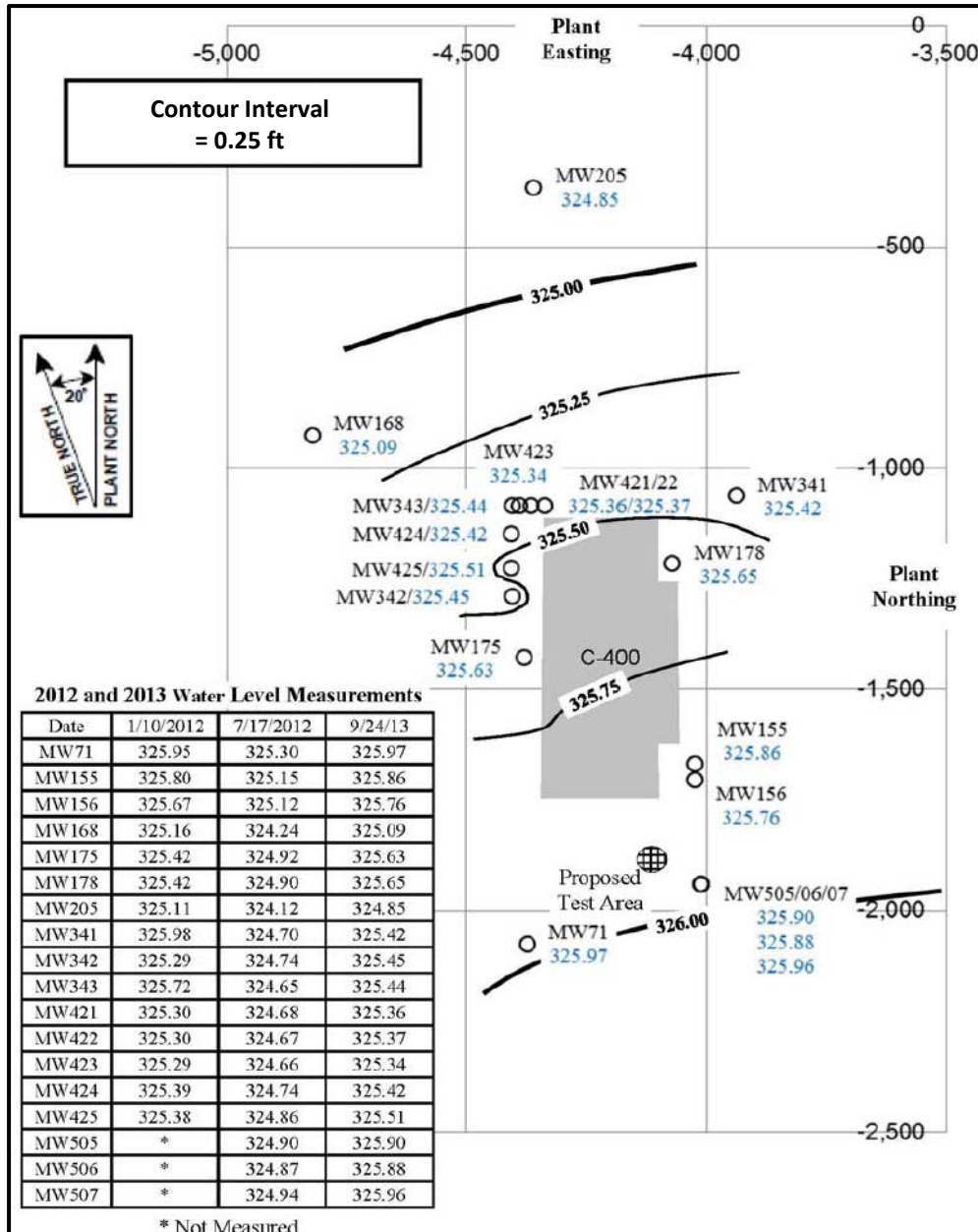


MW157
RGA Hydraulic Potential Range
MW156



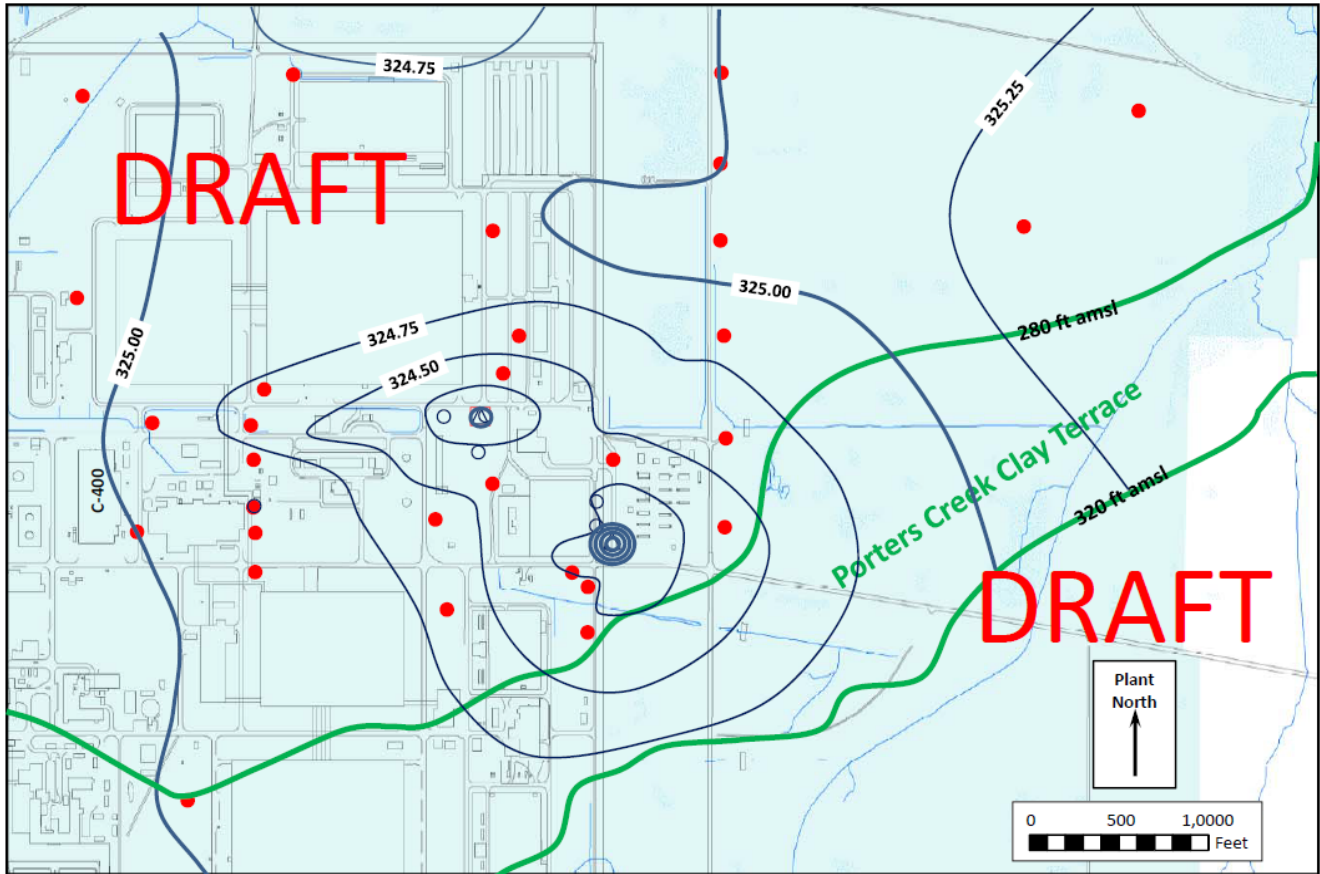
RGA Potentiometric Surface (September 24, 2013)

(Figure 8 of *Treatability Study Work Plan for Steam Injection, Groundwater Operable Unit, at Paducah Gaseous Diffusion Plant, Paducah, Kentucky*)



RGA Potentiometric Surface Northeast Plume Optimization (Northeast Plume Hydraulic Assessment)

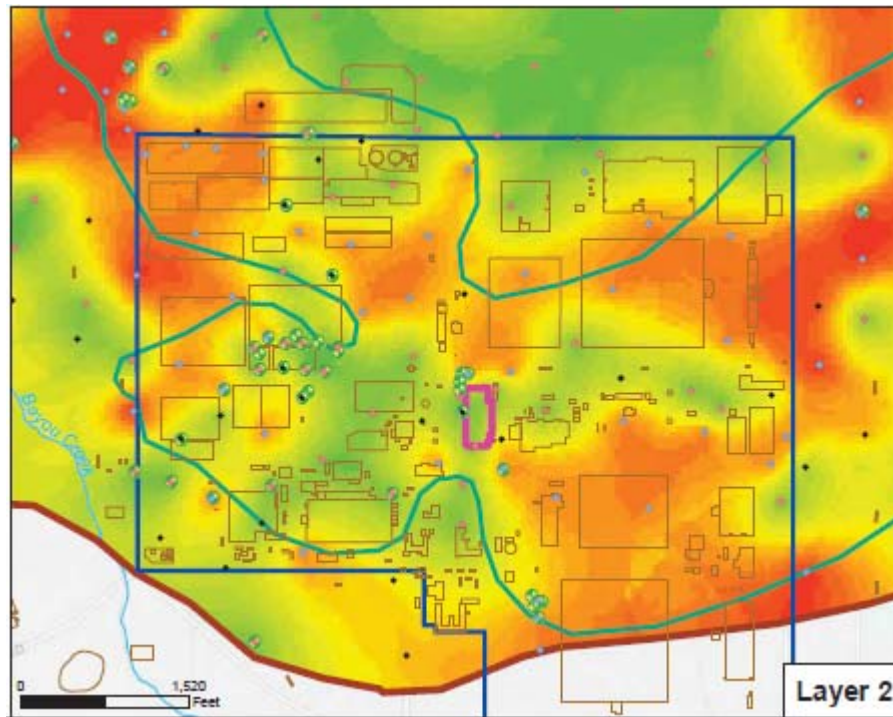
March 27, 2018



RGA Hydraulic Conductivity at C-400

RGA hydraulic conductivity at C-400

- Site-wide flow model: approximately **100-to-200 ft/day (3.53E-02-to-7.06E-02 cm/sec)**
- Steam treatability study: **100 ft/day (3.53E-02 cm/sec)** in upper RGA and **300 ft/day (1.06E-01 cm/sec)** in lower RGA



Hydraulic Conductivity (ft/d)

86 - 97	132 - 156	466 - 679	1,503 - 1,856
97 - 100	156 - 190	679 - 827	1,856 - 2,392
100 - 104	190 - 251	827 - 1,009	2,392 - 3,119
104 - 116	251 - 335	1,009 - 1,237	3,119 - 3,600
116 - 132	335 - 466	1,237 - 1,503	

RGA flow velocity - uncertain

- ERH: failure of RGA treatment attributed to high flow velocity
- Steam Treatability Study: supports calculation of **2-to-8 ft/yr (0.6-to-2.4 m/yr)**



McNairy Flow System (McNairy Formation)

- Basal aquitard to RGA
- Discharges to Ohio River

Interbedded fine sands, silts, and clays

- Sharp hydraulic conductivity contrast with overlying RGA

Hydraulic potential (*The McNairy Formation in the Area of the Paducah Gaseous Diffusion Plant*)

- Downward gradient (from RGA to McNairy and within McNairy): **0.02 ft/ft** (MW121/MW122) to **0.04 ft/ft** (MW140) expected in C-400 area
- Lateral gradient: northward to Ohio River, approximately **4.4 E-04 ft/ft**
 - Similar to RGA beneath C-400



McNairy Potentiometric Surface

(Figure 17 of *The McNairy Formation in the Area of the Paducah Gaseous Diffusion Plant, KY/EM-148*)

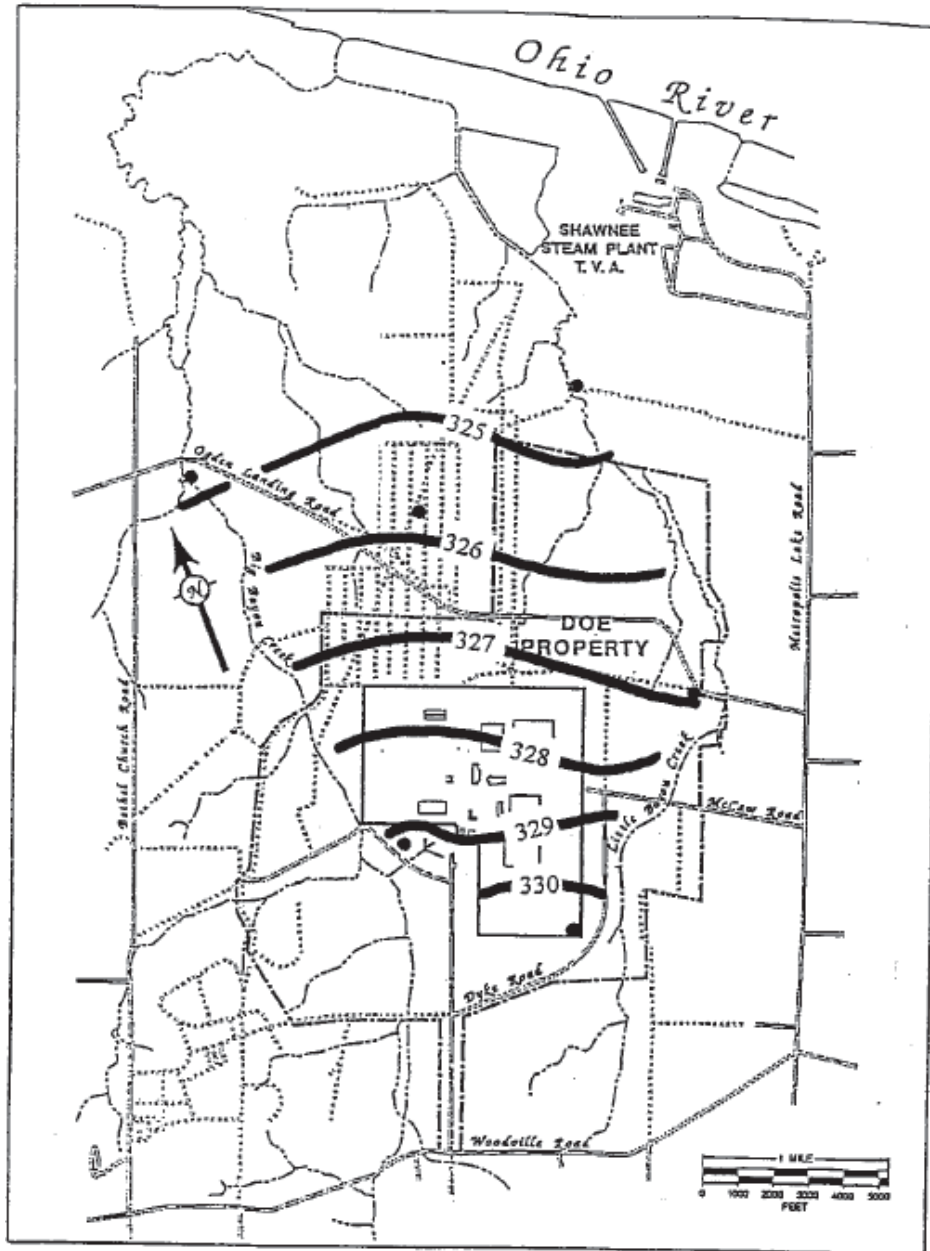


Figure 17. Hydraulic potential (feet AMSL) in the McNairy Formation at elevation 219 feet AMSL.



Measures of McNairy Hydraulic Conductivity

(Adapted from Table 2 of *The McNairy Formation in the Area of the Paducah Gaseous Diffusion Plant, KY/EM-148*)

- Slug tests (3): **2.9E-05 cm/sec** (MW121) to **1.8E-04 cm/sec** (MW120)
- Permeameter tests (25): **1.8E-08** to **5.0E-04 cm/sec** (majority are **<5E-07 cm/sec**)

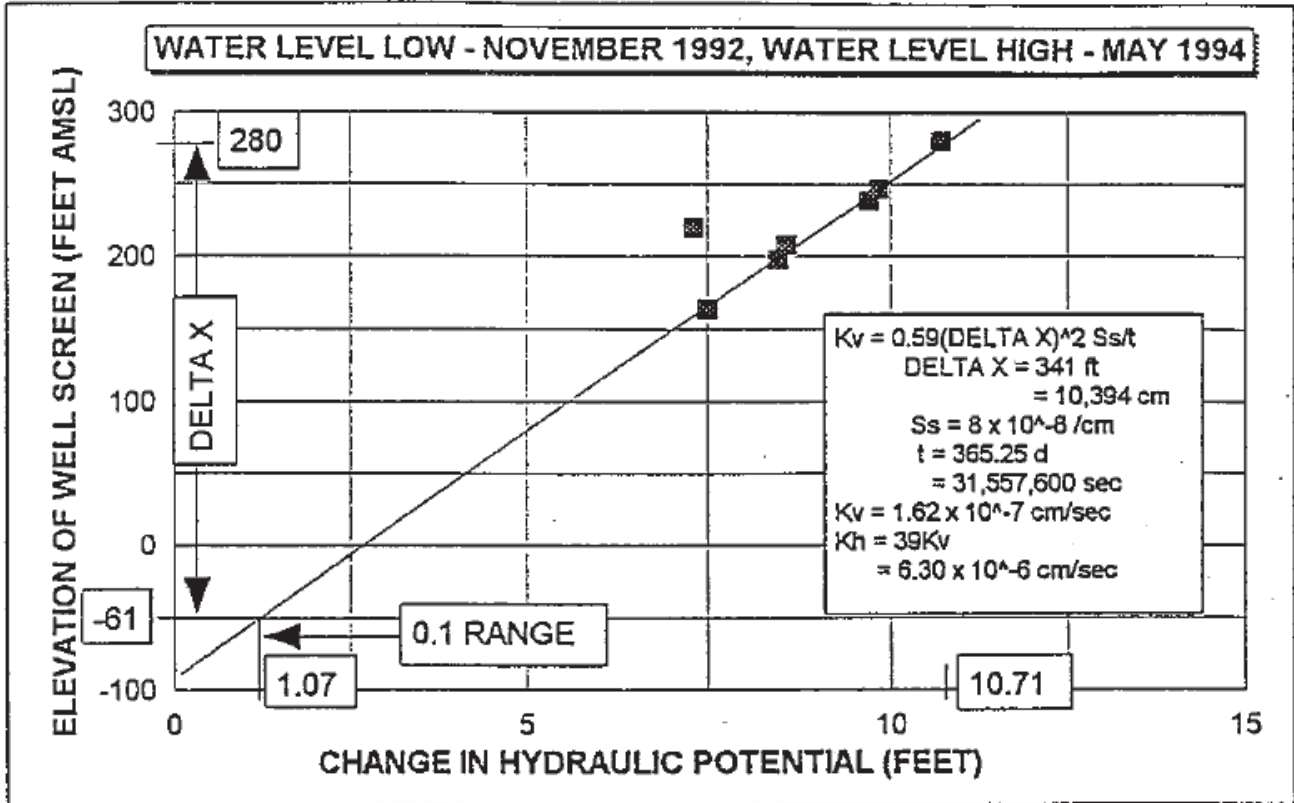
McNairy Hydraulic Conductivity							
Well/ Boring ID	Depth (ft)	Hydraulic Conductivity (cm/sec)	Hydraulic Conductivity (ft/day)	Well/ Boring ID	Depth (ft)	Hydraulic Conductivity (cm/sec)	Hydraulic Conductivity (ft/day)
Northwest Plume Pump and Treat Wells/Boreholes (Permeameter)				C-746-U Landfill Boreholes (Permeameter)			
MW239	124-126	2.10E-07	5.95E-04	GB01D	86-88 #2	2.75E-07	7.80E-04
MW245	95-97	5.00E-04	1.42E+00		86-88 #3	3.67E-07	1.04E-03
MW247	118-120	5.90E-06	1.67E-02	GB02D	88-90 #2	4.09E-08	1.16E-04
MW248	98-100	9.80E-05	2.78E-01		88-90 #3	7.25E-08	2.06E-04
MW250	95-97	1.20E-07	3.40E-04	GB03D	88-90 #2	4.66E-06	1.32E-02
SB28	114-116	4.10E-06	1.16E-02		88-90 #3	2.67E-06	7.57E-03
SB29	114-116	3.90E-08	1.11E-04	GB04D	83-85 #2	4.71E-05	1.34E-01
SB30	114-116	2.50E-07	7.09E-04		83-85 #3	4.12E-06	1.17E-02
SB31	114-116	1.60E-07	4.54E-04	GB05D	83-85 #2	1.25E-06	3.54E-03
SB33	98-100	1.80E-08	5.10E-05		83-85 #3	2.05E-06	5.81E-03
SB33	174-176	1.30E-07	3.69E-04	CERCLA Site Investigation - Phase I (Slug Test)			
SB36	118-120	1.50E-04	4.25E-01	MW120	155-170	1.84E-04	5.22E-01
SB37	88-90	4.80E-07	1.36E-03	MW121	198-210	2.88E-05	8.16E-02
SB37	114-116	3.30E-07	9.35E-04	MW122	144-158	9.69E-05	2.75E-01
SB38	118-120	5.40E-08	1.53E-04				



Measures of McNairy Hydraulic Conductivity

(Figure 16 of *The McNairy Formation in the Area of the Paducah Gaseous Diffusion Plant, KY/EM-148*)

- Analysis of Cyclic Water Level Trends: **1.62 E-07 cm/sec (4.59E-04 ft/day)** vertical and **6.30 E-06 cm/sec (1.79E-02 ft/day)** horizontal



- Little flow from RGA to McNairy because of slight vertical gradient into McNairy and much lower hydraulic conductivity of McNairy

