UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

ATOMIC SAFETY AND LICENSING BOARD

In the Matter of CROW BUTTE RESOURCES, INC. (Marsland Expansion Area)	Docket No. 40-8943-MLA-2 ASLBP No. 13-926-01-MLA-BD01

Hearing Exhibit

Exhibit Number: CBR012

Exhibit Title: Appendix AA-3 - Hydraulic Containment

AquiferTek

Mr. Doug Pavlick
Mr. Larry Teahon
Cameco Resources
Crow Butte Facility
P.O. Box 169
Crawford, NE 69339

December 17, 2014

Re: Response to ASLB Contention #2, Hydraulic Containment of Mining Solutions at the Marsland Expansion Area (MEA)

Gentlemen,

I've reviewed the discussion related to hydraulic containment of mining solutions at the Marsland Expansion Area (MEA) as expressed in Contention #2 by the MEA Atomic Safety Licensing Board (ASLB). The following is a summary of my evaluation.

CONTAINMENT OF MINING SOLUTIONS

Existing hydrogeologic and operations data support the conclusion that mining solutions will be fully contained both laterally and vertically at the MEA.

1) The steeply downward hydraulic gradient at the MEA prevents upward migration of mining solutions.

Mining solutions at the MEA are contained vertically given the steeply downward hydraulic gradient observed between the shallow Arikaree/Brule aquifer and the Basal Chadron production aquifer. Baseline water level data collected at the MEA to date indicate water level elevations in the shallow Arikaree/Brule aquifer are 350 to more than 500 feet higher than water levels in the production aquifer. Given an observed thickness of the Upper/Middle Chadron confining unit of 650 to 700 feet at the MEA, the observed downward hydraulic gradient at the site is approximately 0.5 to 0.8. Wellfield operations at the MEA will only act to increase the observed downward hydraulic gradient given the net drawdown produced by the wellfield bleed. Under no circumstances can the observed difference in water levels be overcome during wellfield operations. Given these facts, there is no hydrologic mechanism by which mining solutions could migrate upward from the production aquifer toward the shallow Arikaree/Brule aquifer. Therefore, vertical containment of mining solutions at the MEA can be assured

regardless of the physical characteristics of the shallow aquifer, confining unit, or production aquifer.

2) Geological and hydrologic data collected at the MEA indicates the Basal Chadron production aquifer is confined and hydraulically isolated from the shallow Arikaree/Brule aquifer.

Baseline water level data collected at the MEA indicate water level elevations in the Basal Chadron aquifer are more than 400 feet above the top of the Basal Chadron sandstone, indicating confined aquifer conditions exist. This is to be expected given the more than 650 feet of low permeability claystone and siltstone of the Upper/Middle Chadron confining unit that separate the shallow aquifer from the Basal Chadron production aquifer. Further, water level drawdown and recovery data collected during the regional aquifer test at the MEA are indicative of confined aquifer conditions. Further, water level data collected from shallow aquifer monitoring wells during the aquifer test did not show any evidence of drawdown during the test, indicating the production aquifer was isolated from the shallow aquifer. The Basal Chadron storage coefficient (2.6×10^{-4}) calculated from aquifer test data is also indicative of confined conditions. There is no evidence of leaky (e.g. semi-confined) aquifer conditions observed at the site from geologic data including borehole logs, core data, or geophysical well logs. Furthermore, as discussed previously, the strongly downward hydraulic gradient observed between the shallow aquifer and the Basal Chadron production aquifer prevents vertical migration of mining solutions upward from the production aquifer, regardless of the physical characteristics of the aquifers or confining units.

3) The Upper/Middle Chadron confining unit is sufficiently impermeable to hydraulically isolate the production aquifer from the shallow aquifer.

A review of geologic and geophysical logs from boreholes at the MEA indicates the Upper/Middle Chadron confining unit consists of more than 90 percent claystone and less than 10 percent coarser material (e.g. siltstone and sandstone). The average vertical hydraulic conductivity of Upper/Middle Chadron Formation claystone, as measured in two core samples in the laboratory using a falling head permeameter, is 1.3×10^{-7} cm/sec (**Attachment A**). Therefore, the Upper/Middle Chadron claystones can be classified as low permeability (e.g., Norris and others, 2012). The representative vertical hydraulic conductivity of the lesser coarser-grained materials (e.g. siltstone and fine sandstone) in the Upper/Middle Chadron Formation, as calculated from grain-size analysis (Kozeny-Carmen analysis) of six core samples, is 3.9×10^{-5} cm/sec (**Attachment A**).

The representative hydraulic conductivity of a stratified sequence of sediments undergoing vertical flow is characterized as the harmonic mean of the hydraulic conductivities of the individual strata (e.g. Norris and others, 2012). Given a conservative composition of the

Upper/Middle Chadron confining unit of 90 percent claystone and 10 percent coarser material, the representative vertical hydraulic conductivity of the Upper/Middle Chadron confining unit is 1.5×10^{-7} cm/sec. As a point of reference, one to two feet of clay having a vertical hydraulic conductivity of 1×10^{-7} cm/sec is considered sufficiently impermeable to be used as a liner in landfills and waste repositories to isolate waste from groundwater (e.g., Norris and others, 2012). For purposes of comparison, the Upper/Middle Chadron confining unit consists of more than 580 feet of claystone of this character.

4) The rate of vertical groundwater movement is insignificant and further demonstrates vertical containment of mining solutions.

The rate of vertical movement between the shallow aquifer and the production aquifer can be calculated using Darcy's Law and available hydrogeologic data including vertical hydraulic conductivity and effective porosity of the Upper/Middle Chadron confining unit, and the hydraulic gradient between the shallow aquifer the production aquifer.

Given a maximum hydraulic gradient of 0.8, an effective porosity of the confining unit of 0.1, and a representative vertical hydraulic conductivity of 1.5×10^{-7} cm/sec from 3) above, the downward movement of fresh groundwater from the shallow aquifer is about 1.2 ft/year. At this rate of movement, and assuming a minimum thickness of 650 feet for the Upper/Middle Chadron confining unit, it would take more than 540 years for fresh groundwater to move downward from the shallow Arikaree/Brule aquifer to the Basal Chadron production aquifer.

5) Other chemical transport processes including hydrodynamic dispersion and chemical diffusion are insignificant.

Chemical transport processes including hydrodynamic dispersion and diffusion are insignificant relative to the velocity or advective movement of groundwater. Furthermore, movement of chemicals due to hydrodynamic dispersion only occurs in the direction of groundwater flow, which in the case of vertical movement at the MEA is downward. Vertical dispersion is typically only 0.01 to 0.1 percent of the total advective flow distance depending on scale (e.g. Gelhar, 1993). In the case of the MEA, we would expect no more than 0.0012 ft/year of downward chemical movement due to hydrodynamic dispersion based on calculations of vertical groundwater velocity previously provided in 4) above. Vertical diffusion of dissolved chemical constituents in low permeability sediments is less than either the advective or dispersive flow component, and can be ignored over practical time scales.

6) Water quality data indicates the shallow Arikaree/Brule aquifer and the Basal Chadron production aquifer are chemically and hydraulically distinct. Water quality data collected at

the MEA indicates the shallow Arikaree/Brule aquifer and the Basal Chadron production aquifer are chemically distinct. Significant differences in major ion chemistry observed between the shallow Arikaree/Brule aquifer and the Basal Chadron aquifer are indicative of relative hydraulic separation of the aquifers. Baseline TDS and major ion concentrations in the Basal Chadron production aquifer are typically two to five times greater than the shallow Arikaree/Brule aquifer, indicating groundwater in the production aquifer is more evolved (older) than the shallow aquifer. Water quality of the shallow aquifer and production aquifer would be expected to be very similar in the event there was significant hydraulic communication between the aquifers.

6) Lateral containment of mining solutions at the MEA has been demonstrated.

Lateral (horizontal) containment of mining solutions within the Basal Chadron production aquifer has been demonstrated through aquifer testing, groundwater modeling, and by analogy to observed containment at the existing Crow Butte ISR facility (CBR operates within the same aquifer system and under similar operating conditions as planned for the MEA). Regional aquifer testing at the MEA indicates excellent hydraulic communication between the pumped well and Basal Chadron monitor wells with a radius of influence of greater than 8,800 feet, indicating hydraulic containment of mining solutions (and excursion recovery) can be accomplished without difficulty. Further, groundwater modeling has been conducted at the MEA that demonstrates mining solutions will be contained under worse-case conditions (e.g. loss of power for extended period of time, etc.). In addition, operating experience at the existing Crow Butte ISR facility, which also produces from the Basal Chadron aquifer, indicates hydraulic containment can be achieved at the MEA given similar operating conditions (e.g. bleed rate, well spacing). Lateral containment of mining solutions is also verified by the installation and frequent sampling of mine unit monitor ring wells.

As further evidence to support the lateral containment of mining solutions at the MEA, a groundwater modeling simulation was performed to demonstrate hydraulic containment of mining solutions under typical operating conditions. The operation of Mine Unit 1 at the MEA was simulated for this purpose, given a total flow rate of 1600 gpm and bleed (net production rate) of 1.2 percent per MEA water balance. Details and results of the simulation are provided in **Attachment B**. Results of the simulation demonstrate hydraulic containment of mining solutions can be fully maintained given proposed operating parameters.

REFERENCES

Gelhar, L.W. (1993). *Stochastic Subsurface Hydrology*. Prentice-Hall, Englewood Cliffs, NJ.

S. Norris, J. Bruno, M. Cathelineau, P. Delage, C. Fairhurst, E.C. Gaucher, E.H. Hohn, A. Kalinichev, P. Lalieux, and P. Sellin (editors) (2012). *Clays in Natural and Engineered Barriers for Radioactive Waste Confinement*, 632p.

If you have any questions or comments concerning this report, please contact me directly at 303-522-1118.

Sincerely,

AquiferTek

Robert L. Lewis, P.G.
Principal Hydrogeologist

ATTACHMENT A

HYDRAULIC CONDUCTIVITY DATA FOR THE UPPER/MIDDLE CHADRON CONFINING UNIT

PTS Laboratories, Inc.

8100 Secura Way • Santa Fe Springs, CA 90670
Telephone (562) 347-2500 • Fax (562) 907-3610

December 11, 2014

Wade Beins
Crow Butte Resources, Inc.
86 Crow Butte Rd.
Crawford, NE 69339

Re: PTS File No: 44735
Physical Properties Data
Marsland

Dear Mr. Beins:

Please find enclosed report for Physical Properties analyses conducted upon samples received from your Marsland project. All analyses were performed by applicable ASTM, EPA, or API methodologies. An electronic version of the report has previously been sent to your attention via the internet. The samples are currently in storage and will be retained for thirty days past completion of testing at no charge. Please note that the samples will be disposed of at that time. You may contact me regarding storage, disposal, or return of the samples.

PTS Laboratories appreciates the opportunity to be of service. If you have any questions or require additional information, please give me a call at (562) 347-2502.

Sincerely,
PTS Laboratories, Inc.

Michael Mark Brady, P.G.
Laboratory Director

Encl.

PTS File No: 44735
Client: Crow Butte Resources, Inc.
Report Date: 12/11/14

PTS Laboratories

PHYSICAL PROPERTIES DATA - HYDRAULIC CONDUCTIVITY

(Methodology: API RP 40; ASTM D5084; EPA 9100)

Project Name: Marsland
Project No: N/A

SAMPLE ID.	DEPTH, ft.	SAMPLE ORIENTATION (1)	ANALYSIS DATE	CONFINING PRESSURE, psi	EFFECTIVE (2,3) PERMEABILITY TO WATER, millidarcy	HYDRAULIC CONDUCTIVITY (2,3), cm/s
M-2169c Run 5-1	608.9-609.9	V	20141205	25	0.13	1.30E-07
					0.13	1.33E-07
					0.13	1.31E-07
					0.13	1.32E-07
				Average:	0.13	1.31E-07
M-1635c Run 3	530.0-531.0	V	20141205	25	0.13	1.30E-07
					0.13	1.33E-07
					0.13	1.32E-07
					0.13	1.32E-07
				Average:	0.13	1.32E-07

(1) Sample Orientation: H = horizontal; V = vertical; R = remold
(2) Effective (Native) = With as-received pore fluids in place.
(3) Permeability to water and hydraulic conductivity measured at saturated conditions.
Water = filtered Laboratory Fresh (tap) or Site water.

PTS Laboratories, Inc.

CHAIN OF CUSTODY RECORD

PAGE 1 OF 1

COMPANY	Crow Butte Resources, Inc
ADDRESS / CITY / ZIP CODE	86 Crow Butte Rd Crawford NE 69339
PROJECT MANAGER	Wade Beins
PROJECT NAME	Marsland
PHONE NUMBER	308 665 2215 (113)
PROJECT NUMBER	—
FAX NUMBER	308 665 2341
SITE LOCATION	Crow Butte Operation
SAMPLER SIGNATURE	Wade Beins

PO# Verbal - WB

TURNAROUND TIME: 24 HOURS ☐ 5 DAYS ☐ 48 HOURS ☐ NORMAL ☒ 72 HOURS ☐ OTHER: ______

SAMPLE INTEGRITY (CHECK): INTACT X ON ICE 72°F

PTS QUOTE NO.

PTS FILE: 44735

ANALYSIS REQUEST

SAMPLE ID NUMBER	DATE	TIME	DEPTH, FT	NUMBER OF SAMPLES	SOIL PROPERTIES PACKAGE	HYDRAULIC CONDUCTIVITY PACKAGE	PORE FLUID SATURATIONS PACKAGE	TCEQ/TNRCC PROPERTIES PACKAGE	CAPILLARITY PACKAGE	FLUID PROPERTIES PACKAGE	PHOTOLOG: CORE PHOTOGRAPHY	MOISTURE CONTENT, ASTM D2216	POROSITY: TOTAL, API RP40	POROSITY: EFFECTIVE, ASTM D425M	SPECIFIC GRAVITY, ASTM D854	BULK DENSITY (DRY), API RP40 or ASTM D2937	AIR PERMEABILITY, API RP40	HYDRAULIC CONDUCTIVITY, EPA9100, API RP40, D5084	GRAIN SIZE DISTRIBUTION, ASTM D422/4464M	TOC: WALKLEY-BLACK	ATTERBERG LIMITS, ASTM D4318	Falling Head Permeameter				COMMENTS
M-2169c Run 5-1	8/6/13	—	608.9-609.9	1																		X				
M-1635c Run 3	8-21-13	—	530.0-531.0	1																		X				

1. RELINQUISHED BY	2. RECEIVED BY	3. RELINQUISHED BY	4. RECEIVED BY
Wade Beins	[signature]		
COMPANY: Crow Butte Resources	COMPANY: PTS LABS	COMPANY	COMPANY
DATE 11-8-14 TIME 9:00 AM	DATE 11/10/14 TIME 12:55	DATE TIME	DATE TIME

PTS Laboratories, Inc. • 8100 Secura Way • Santa Fe Springs, CA 90670 • Phone (562) 347-2500 • Fax (562) 907-3610
PTS Laboratories, Inc. • 4342 W. 12th St. • Houston, TX 77055 • Phone (713) 316-1800 • Fax (713) 316-1882

PTS Laboratories

Project Name: Marsland
Project Number: N/A

PTS File No: 44735
Client: Crow Butte Resources, Inc.

TEST PROGRAM - 20141110

CORE ID	Depth ft.	Core Recovery ft.	Hydraulic Conductivity ASTM D5084						Comments
		Plugs:	Vert. 1.5"						
Date Received: 20141110									
M-2169c Run 5-1	**608.9-609.9**	**N/A**	**X**						
M-1635c Run 3	**530.0-531.0**	**N/A**	**X**						
TOTALS:	**2 bags**	**N/A**	**2**						**2**

Laboratory Test Program Notes
Contaminant identification:
Standard TAT for basic analysis is 10 business days.

CLIENT CONFIDENTIAL

Summary of Kozeny-Carmen Grain-Size Analyses

Analysis of K results				
Formation	**Geomean of K (cm/sec)**	**STD**	**Coeff of Variation**	**# of Samples**
Arikaree	1.4E-04	9.3E-04	6.69	10
Brule	9.2E-05	6.2E-05	0.67	12
Upper Chadron	5.2E-05	6.8E-06	0.13	4
Middle Chadron	2.2E-05	8.3E-06	0.37	2
Upper + Middle Chadron	3.9E-05	1.6E-05	0.42	6

Porosity	0.35	
Kozeny-Carman Coeff	4.8	Range 4.5 to 5.1
Shape Factor	6.5	Range 6 to 8.4
		Rounded 6.1 - 6.6
		Medium angular 7.4 - 7.5
		Very Angular 7.7 - 8.4
Effective Grain Size (cm)	0.006494829	
Intrinsic Permeability (cm2)	2.1E-08	
Rho (g/cm3)	1.03	
Viscosity (dyne-sec/cm2)	0.016	
Gravitational Const (cm/sec2)	980	
Hydraulic Conductivity K (cm/sec)	1.3E-03	

$$\text{Intrinsic Permeability} = \frac{\text{Porosity}^3}{\left(\text{K-C coefficient} \times \left(\frac{\text{Shape Factor}}{\text{Effective Grain Size}}\right)^2 \times (1 - \text{Porosity})^2\right)}$$

$$\text{Hydraulic Conductivity } (K) = \frac{\text{Intrinsic Permeability} \times \text{Density} \times \text{Gravity}}{\text{Viscosity}}$$

Sieves Size/Number	Sieve Size (mm)	M-533C Run 1, Sample 1		M-533C Run 1, Sample 2		M-1635C Run 1, Sample 1		M-1635C Run 1, Sample 2		M-1912C Run 1, Sample 1	
		Arikaree		Arikaree		Arikaree		Arikaree		Arikaree	
	Porosity	0.35		0.35		0.35		0.35		0.35	
		Retained (%)		Retained (%)		Retained (%)		Retained (%)		Retained (%)	
	6.35107	0.00		0.00		0.00		0.00		0.00	
	4.75683	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000
	3.36359	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000
	2.00000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000
Medium Sand	1.18921	3.42	2.110	0.00	0.000	0.00	0.000	0.00	0.000	0.82	0.506
	0.84090	2.47	2.389	0.00	0.000	0.00	0.000	0.00	0.000	0.69	0.668
	0.70711	1.42	1.810	0.00	0.000	0.00	0.000	0.00	0.000	0.32	0.408
	0.59460	2.07	3.137	0.00	0.000	0.00	0.000	0.00	0.000	0.35	0.531
	0.50000	3.50	6.307	0.00	0.000	0.00	0.000	0.00	0.000	0.56	1.010
	0.42045	5.55	11.892	0.00	0.000	0.00	0.000	0.00	0.000	1.11	2.381
Fine Sand	0.35355	6.39	16.280	0.00	0.007	0.00	0.000	0.00	0.000	1.76	4.488
	0.29730	11.20	33.927	0.11	0.333	0.00	0.000	0.00	0.000	4.49	13.615
	0.25000	10.90	39.258	0.41	1.477	0.00	0.005	0.00	0.004	6.17	22.245
	0.21022	10.80	46.250	0.83	3.555	0.08	0.343	0.09	0.377	8.16	34.937
	0.17678	9.65	49.136	1.24	6.315	0.67	3.413	0.88	4.485	9.53	48.523
	0.14865	7.85	47.525	1.75	10.597	1.98	11.993	2.96	17.936	10.31	62.421
	0.12500	5.92	42.614	2.41	17.351	3.41	24.558	5.43	39.122	10.51	75.660
	0.10511	4.21	36.033	3.35	28.677	5.23	44.785	8.03	68.789	10.00	85.591
#200	0.08839	2.94	29.919	4.59	46.718	7.43	75.648	10.41	105.930	8.75	89.034
	0.07433	2.12	25.652	5.84	70.675	9.08	109.920	11.81	142.906	6.87	83.211
Silt	0.06250	1.60	23.019	6.64	95.545	9.18	132.135	11.41	164.155	4.77	68.695
	0.05256	1.23	21.040	6.82	116.682	7.90	135.202	9.55	163.507	2.95	50.514
	0.04419	0.95	19.322	6.51	132.429	6.22	126.570	7.16	145.756	1.73	35.222
	0.03716	0.74	17.895	5.84	141.253	4.87	117.828	5.21	126.106	1.11	26.871
	0.03125	0.58	16.677	5.09	146.381	3.96	113.920	3.91	112.527	0.83	23.890
	0.02503	0.60	20.919	5.57	194.231	4.21	146.852	3.82	133.302	0.92	32.108
	0.02005	0.49	21.321	4.80	208.899	3.69	160.642	2.89	125.865	0.88	38.331
	0.01563	0.47	25.812	4.61	253.218	3.96	217.583	2.52	138.518	0.97	53.325
	0.01105	0.56	41.039	5.64	413.391	5.59	409.855	2.77	203.177	1.28	93.899
	0.00781	0.48	49.729	5.27	546.082	5.31	550.399	2.25	233.314	1.09	113.043
	0.00500	0.52	79.319	6.26	955.037	5.67	865.297	2.39	364.885	1.06	161.853
Clay	0.00195	0.80	232.691	10.50	3054.588	7.19	2092.322	3.82	1112.086	1.22	355.216
	0.00098	0.39	262.463	4.34	2921.239	2.79	1878.529	1.80	1212.444	0.49	330.098
	0.00049	0.20	269.006	1.49	2004.438	1.43	1924.326	0.80	1076.981	0.27	363.529
	0.00038	0.02	45.195	0.11	248.614	0.14	316.517	0.07	162.846	0.03	63.337
		Sum(fi/(dli^0.404	1539.687		11617.733		9458.645		5855.019		2335.161
		Deff (mm)	0.0649	Deff (mm)	0.0086	Deff (mm)	0.0106	Deff (mm)	0.0171	Deff (mm)	0.0428
		K (cm/sec)	**1.3E-03**	**K (cm/sec)**	**2.3E-05**	**K (cm/sec)**	**3.5E-05**	**K (cm/sec)**	**9.2E-05**	**K (cm/sec)**	**5.8E-04**
		K (ft/day)	3.77	K (ft/day)	0.07	K (ft/day)	0.10	K (ft/day)	0.26	K (ft/day)	1.64
		K (m/day)	1.15	K (m/day)	0.02	K (m/day)	0.03	K (m/day)	0.08	K (m/day)	0.50
		D10 (mm)	0.0649	D10 (mm)	0.0086	D10 (mm)	0.0106	D10 (mm)	0.0171	D10 (mm)	0.0428
		K Hazen (cm/sec	4.22E-03	K Hazen (cm/sec	7.41E-05	K Hazen (cm/sec	1.12E-04	K Hazen (cm/sec	2.92E-04	K Hazen (cm/sec	1.83E-03
		K (ft/day)	11.96	K (ft/day)	0.21	K (ft/day)	0.32	K (ft/day)	0.83	K (ft/day)	5.20
		K Hazen (cm/sec	2.18E-03	K Hazen (cm/sec	3.82E-05	K Hazen (cm/sec	5.77E-05	K Hazen (cm/sec	1.50E-04	K Hazen (cm/sec	9.46E-04
		K (ft/day)	6.17	K (ft/day)	0.11	K (ft/day)	0.16	K (ft/day)	0.43	K (ft/day)	2.68
	Sand (%)	90.37		20.53		27.88		39.61		80.39	
	Silt (%)	8.22		63.04		60.57		53.90		17.60	
	Clay (%)	1.41		16.44		11.55		6.50		2.01	

Sieves Size/Number	Sieve Size (mm)	M-1912C Run 2, Sample 1		M-1956C Run 1, Sample 1		M-1956C Run 3, Sample 1		M-2169C Run 1, Sample 1		M-2169C Run 2, Sample 3	
		Arikaree		Arikaree		Arikaree		Arikaree		Arikaree	
	Porosity	0.35		0.35		0.35		0.35		0.35	
		Retained (%)		Retained (%)		Retained (%)		Retained (%)		Retained (%)	
	6.35107	0.00		0.00		0.00		0.00		0.00	
	4.75683	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000
	3.36359	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000
	2.00000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000
Medium Sand	1.18921	0.74	0.457	1.37	0.845	0.00	0.000	0.00	0.000	0.00	0.000
	0.84090	2.75	2.661	1.79	1.731	0.00	0.000	0.00	0.000	0.00	0.000
	0.70711	0.96	1.224	1.31	1.670	0.01	0.018	0.00	0.000	0.00	0.000
	0.59460	0.89	1.350	2.02	3.061	0.14	0.212	0.00	0.000	0.00	0.000
	0.50000	1.17	2.109	3.82	6.883	0.39	0.703	0.00	0.000	0.00	0.000
	0.42045	1.33	2.851	6.67	14.289	0.46	0.986	0.00	0.000	0.00	0.000
Fine Sand	0.35355	0.98	2.498	8.24	20.989	0.27	0.688	0.00	0.000	0.00	0.000
	0.29730	1.10	3.334	15.19	46.034	0.19	0.576	0.00	0.008	0.00	0.000
	0.25000	1.17	4.216	14.79	53.294	0.25	0.901	0.06	0.213	0.00	0.003
	0.21022	2.13	9.126	13.69	58.657	0.78	3.341	0.32	1.371	0.07	0.308
	0.17678	3.87	19.714	10.59	53.962	1.77	9.015	0.85	4.330	0.73	3.716
	0.14865	6.15	37.250	7.02	42.492	3.04	18.410	1.60	9.690	2.55	15.435
	0.12500	8.05	57.974	4.36	31.379	4.33	31.178	2.43	17.499	4.98	35.840
	0.10511	9.01	77.152	2.69	23.019	5.74	49.142	3.54	30.310	7.70	65.890
#200	0.08839	8.83	89.901	1.72	17.500	7.32	74.513	5.07	51.615	10.09	102.761
	0.07433	7.73	93.576	1.08	13.065	8.67	104.935	6.71	81.221	11.09	134.281
Silt	0.06250	6.16	88.664	0.62	8.918	9.27	133.403	7.79	112.116	10.19	146.715
	0.05256	4.63	79.238	0.34	5.815	8.89	152.114	7.92	135.531	8.29	141.949
	0.04419	3.46	70.406	0.22	4.474	7.85	159.705	7.37	149.956	6.38	129.735
	0.03716	2.74	66.293	0.18	4.352	6.58	159.169	6.51	157.492	5.02	121.373
	0.03125	2.34	67.315	0.15	4.312	5.41	155.600	5.65	162.520	4.11	118.153
	0.02503	2.67	93.133	0.17	5.926	5.49	191.461	6.07	211.711	4.26	148.493
	0.02005	2.44	106.222	0.18	7.831	4.19	182.371	4.94	215.038	3.36	146.174
	0.01563	2.50	137.361	0.19	10.432	3.60	197.762	4.56	250.525	3.06	168.016
	0.01105	3.19	233.885	0.23	16.852	3.74	274.158	5.32	390.020	3.52	257.905
	0.00781	2.85	295.408	0.21	21.752	2.78	288.097	4.59	475.721	2.95	305.565
	0.00500	3.12	476.135	0.26	39.651	2.64	402.806	5.01	764.497	3.15	480.387
Clay	0.00195	4.56	1326.961	0.47	136.678	3.67	1067.766	8.07	2348.169	5.08	1477.277
	0.00098	1.77	1191.737	0.32	215.311	1.71	1151.118	3.87	2605.438	2.41	1621.546
	0.00049	0.65	874.681	0.13	174.819	0.76	1022.507	1.61	2166.330	0.95	1277.512
	0.00038	0.05	119.823	0.00	0.000	0.07	153.705	0.14	316.486	0.08	176.223
			5632.654		1045.993		5986.360		10657.807		7075.259
		Deff (mm)	0.0178	Deff (mm)	0.0956	Deff (mm)	0.0167	Deff (mm)	0.0094	Deff (mm)	0.0141
		K (cm/sec)	**1.0E-04**	**K (cm/sec)**	**2.9E-03**	**K (cm/sec)**	**8.8E-05**	**K (cm/sec)**	**2.8E-05**	**K (cm/sec)**	**6.3E-05**
		K (ft/day)	0.28	K (ft/day)	8.18	K (ft/day)	0.25	K (ft/day)	0.08	K (ft/day)	0.18
		K (m/day)	0.09	K (m/day)	2.49	K (m/day)	0.08	K (m/day)	0.02	K (m/day)	0.05
		D10 (mm)	0.0178	D10 (mm)	0.0956	D10 (mm)	0.0167	D10 (mm)	0.0094	D10 (mm)	0.0141
		K Hazen (cm/sec	3.15E-04	K Hazen (cm/sec	9.14E-03	K Hazen (cm/sec	2.79E-04	K Hazen (cm/sec	8.80E-05	K Hazen (cm/sec	2.00E-04
		K (ft/day)	0.89	K (ft/day)	25.91	K (ft/day)	0.79	K (ft/day)	0.25	K (ft/day)	0.57
		K Hazen (cm/sec	1.63E-04	K Hazen (cm/sec	4.72E-03	K Hazen (cm/sec	1.44E-04	K Hazen (cm/sec	4.54E-05	K Hazen (cm/sec	1.03E-04
		K (ft/day)	0.46	K (ft/day)	13.37	K (ft/day)	0.41	K (ft/day)	0.13	K (ft/day)	0.29
	Sand (%)	56.86		96.33		33.36		20.58		37.21	
	Silt (%)	36.10		2.75		60.43		65.73		54.28	
	Clay (%)	7.03		0.92		6.21		13.69		8.51	

Analysis of K results

Formation	Geomean of K (cm/sec)	STD	# of Samples
Arikaree	1.4E-04	9.3E-04	10

Porosity	0.35	
Kozeny-Carman Coeff	4.8	Range 4.5 to 5.1
Shape Factor	6.5	Range 6 to 8.4 — Rounded 6.1 - 6.6; Medium angular 7.4 - 7.5; Very Angular 7.7 - 8.4
Effective Grain Size (cm)	0.00152912	
Intrinsic Permeability (cm2)	1.2E-09	
Rho (g/cm3)	1.03	
Viscosity (dyne-sec/cm2)	0.016	
Gravitational Const (cm/sec2)	980	
Hydraulic Conductivity K (cm/sec)	7.4E-05	

$$\text{Intrinsic Permeability} = \frac{\text{Porosity}^3}{\left(\text{K-C coefficient} \times \left(\frac{\text{Shape Factor}}{\text{Effective Grain Size}}\right)^2 \times (1 - \text{Porosity})^2\right)}$$

$$\text{Hydraulic Conductivity } (K) = \frac{\text{Intrinsic Permeability} \times \text{Density} \times \text{Gravity}}{\text{Viscosity}}$$

		Brule		Brule		Brule		Brule	
	Porosity	0.35		0.35		0.35		0.35	
		M-533C Run 3, Sample 1		M-533C Run 3, Sample 2		M-1635C Run 2, Sample 1		M-1635C Run 2, Sample 2	
Sieves Size/Number	Sieve Size (mm)	Retained (%)		Retained (%)		Retained (%)		Retained (%)	
	6.35107	0.00		0.00		0.00		0.00	
	4.75683	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000
	3.36359	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000
	2.00000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000
Medium Sand	1.18921	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000
	0.84090	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000
	0.70711	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000
	0.59460	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000
	0.50000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000
	0.42045	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000
Fine Sand	0.35355	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000
	0.29730	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000
	0.25000	0.00	0.002	0.00	0.001	0.00	0.000	0.00	0.001
	0.21022	0.03	0.111	0.02	0.094	0.00	0.018	0.03	0.124
	0.17678	0.23	1.172	0.32	1.628	0.11	0.560	0.39	1.986
	0.14865	0.75	4.544	1.46	8.834	0.66	3.997	1.67	10.111
	0.12500	1.43	10.302	3.09	22.230	1.41	10.153	3.49	25.124
	0.10511	2.30	19.701	4.89	41.829	2.24	19.179	5.56	47.591
#200	0.08839	3.43	34.934	6.98	71.093	3.58	36.445	7.91	80.503
	0.07433	4.80	58.127	9.24	111.860	5.73	69.358	10.20	123.429
Silt	0.06250	6.25	89.991	10.99	158.164	8.34	120.030	11.70	168.339
	0.05256	7.61	130.282	11.49	196.606	10.60	181.389	11.70	200.155
	0.04419	8.79	178.925	10.69	217.502	12.00	244.157	10.40	211.541
	0.03716	9.40	227.506	8.91	215.589	11.70	283.046	8.38	202.670
	0.03125	9.40	270.505	6.97	200.586	10.20	293.395	6.39	183.750
	0.02503	11.00	383.827	6.52	227.538	10.00	348.777	5.85	203.975
	0.02005	9.01	392.374	4.48	194.828	6.66	289.905	3.93	171.020
	0.01563	7.36	404.531	3.45	189.361	4.67	256.564	2.97	163.121
	0.01105	6.32	463.531	3.10	227.050	3.67	269.051	2.65	194.217
	0.00781	3.60	373.275	1.98	205.017	2.16	223.865	1.73	179.247
	0.00500	2.68	409.129	1.66	253.065	1.80	274.665	1.49	227.296
Clay	0.00195	3.23	940.255	2.08	604.651	2.48	721.607	1.96	570.137
	0.00098	1.58	1064.178	1.08	726.405	1.30	875.198	1.03	693.225
	0.00049	0.70	942.289	0.56	752.787	0.63	847.681	0.55	739.824
	0.00038	0.06	140.218	0.05	124.215	0.06	133.374	0.05	119.776
			6539.709		4750.934		5502.415		4517.161
		Deff (mm)	0.0153	Deff (mm)	0.0210	Deff (mm)	0.0182	Deff (mm)	0.0221
		K (cm/sec)	**7.4E-05**	**K (cm/sec)**	**1.4E-04**	**K (cm/sec)**	**1.0E-04**	**K (cm/sec)**	**1.5E-04**
		K (ft/day)	0.21	K (ft/day)	0.40	K (ft/day)	0.30	K (ft/day)	0.44
		K (m/day)	0.06	K (m/day)	0.12	K (m/day)	0.09	K (m/day)	0.13
		D10 (mm)	0.0153	D10 (mm)	0.0210	D10 (mm)	0.0182	D10 (mm)	0.0221
		K Hazen (cm/sec	2.34E-04	K Hazen (cm/sec	4.43E-04	K Hazen (cm/sec	3.30E-04	K Hazen (cm/sec	4.90E-04
		K (ft/day)	0.66	K (ft/day)	1.26	K (ft/day)	0.94	K (ft/day)	1.39
		K Hazen (cm/sec	1.21E-04	K Hazen (cm/sec	2.29E-04	K Hazen (cm/sec	1.70E-04	K Hazen (cm/sec	2.53E-04
		K (ft/day)	0.34	K (ft/day)	0.65	K (ft/day)	0.48	K (ft/day)	0.72
	Sand (%)	12.97		26.00		13.73		29.24	
	Silt (%)	81.45		70.23		81.80		67.17	
	Clay (%)	5.57		3.77		4.47		3.59	

		Brule		Brule		Brule		Brule	
	Porosity	0.35		0.35		0.35		0.35	
		M-1912C Run 3, Sample 1		M-1912C Run 3, Sample 2		M-1956C Run 4, Sample 1		M-1956C Run 4, Sample 2	
Sieves Size/Number	Sieve Size (mm)	Retained (%)		Retained (%)		Retained (%)		Retained (%)	
	6.35107	0.00		0.00		0.00		0.00	
	4.75683	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000
	3.36359	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000
	2.00000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000
Medium Sand	1.18921	0.02	0.013	0.00	0.000	0.03	0.015	0.00	0.000
	0.84090	0.35	0.339	0.00	0.000	0.30	0.290	0.00	0.000
	0.70711	0.41	0.523	0.00	0.000	0.19	0.242	0.00	0.000
	0.59460	0.78	1.183	0.00	0.000	0.34	0.516	0.00	0.000
	0.50000	1.28	2.307	0.00	0.000	0.64	1.154	0.00	0.000
	0.42045	1.58	3.387	0.00	0.000	0.72	1.544	0.00	0.000
Fine Sand	0.35355	1.38	3.517	0.00	0.000	0.48	1.224	0.00	0.000
	0.29730	1.89	5.727	0.00	0.000	0.46	1.394	0.00	0.000
	0.25000	1.77	6.377	0.01	0.033	0.47	1.694	0.00	0.000
	0.21022	2.28	9.767	0.21	0.901	0.97	4.157	0.02	0.086
	0.17678	3.12	15.892	1.09	5.558	1.90	9.682	0.32	1.630
	0.14865	4.20	25.436	2.62	15.884	3.20	19.388	1.54	9.329
	0.12500	5.30	38.165	4.42	31.861	4.74	34.147	3.30	23.768
	0.10511	6.58	56.337	6.73	57.596	6.58	56.361	5.27	45.131
#200	0.08839	8.00	81.441	9.53	97.015	8.47	86.262	7.51	76.468
	0.07433	9.15	110.753	12.01	145.401	9.81	118.791	9.69	117.314
Silt	0.06250	9.44	135.859	13.01	187.288	10.00	143.979	10.90	156.904
	0.05256	8.62	147.505	11.91	203.843	9.08	155.441	10.80	184.847
	0.04419	7.06	143.643	9.35	190.230	7.55	153.677	9.50	193.328
	0.03716	5.39	130.392	6.59	159.345	6.03	145.936	7.74	187.281
	0.03125	4.08	117.356	4.53	130.435	4.83	138.987	6.13	176.358
	0.02503	3.90	136.021	4.03	140.701	4.86	169.574	5.99	208.957
	0.02005	2.85	124.056	2.87	125.057	3.68	160.252	4.42	192.436
	0.01563	2.36	129.653	2.36	129.788	3.10	170.379	3.66	201.114
	0.01105	2.31	169.345	2.30	168.787	3.08	225.888	3.57	261.770
	0.00781	1.58	163.750	1.59	164.958	2.15	222.918	2.46	255.006
	0.00500	1.36	207.521	1.42	216.902	1.92	293.094	2.16	329.661
Clay	0.00195	1.66	483.002	1.87	544.670	2.50	727.719	2.84	826.514
	0.00098	0.82	552.038	0.95	640.221	1.22	821.670	1.41	949.435
	0.00049	0.44	592.020	0.52	700.388	0.61	821.101	0.69	928.590
	0.00038	0.04	99.463	0.05	117.670	0.06	131.166	0.06	144.704
			3692.789		4174.529		4818.643		5470.632
		Deff (mm)	0.0271	Deff (mm)	0.0240	Deff (mm)	0.0208	Deff (mm)	0.0183
		K (cm/sec)	**2.3E-04**	**K (cm/sec)**	**1.8E-04**	**K (cm/sec)**	**1.4E-04**	**K (cm/sec)**	**1.1E-04**
		K (ft/day)	0.66	K (ft/day)	0.51	K (ft/day)	0.39	K (ft/day)	0.30
		K (m/day)	0.20	K (m/day)	0.16	K (m/day)	0.12	K (m/day)	0.09
		D10 (mm)	0.0271	D10 (mm)	0.0240	D10 (mm)	0.0208	D10 (mm)	0.0183
		K Hazen (cm/sec	7.33E-04	K Hazen (cm/sec	5.74E-04	K Hazen (cm/sec	4.31E-04	K Hazen (cm/sec	3.34E-04
		K (ft/day)	2.08	K (ft/day)	1.63	K (ft/day)	1.22	K (ft/day)	0.95
		K Hazen (cm/sec	3.78E-04	K Hazen (cm/sec	2.96E-04	K Hazen (cm/sec	2.22E-04	K Hazen (cm/sec	1.72E-04
		K (ft/day)	1.07	K (ft/day)	0.84	K (ft/day)	0.63	K (ft/day)	0.49
	Sand (%)	48.09		36.63		39.31		27.65	
	Silt (%)	48.95		59.98		56.30		67.34	
	Clay (%)	2.96		3.40		4.39		5.00	

		Brule		Brule		Brule		Brule	
	Porosity	0.35		0.35		0.35		0.35	
		M-1956C Run 5, Sample 1		M-1956C Run 5, Sample 2		M-2169C Run 3, Sample 1		M-2169C Run 4, Sample 1	
Sieves Size/Number	Sieve Size (mm)	Retained (%)		Retained (%)		Retained (%)		Retained (%)	
	6.35107	0.00		0.00		0.00		0.00	
	4.75683	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000
	3.36359	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000
	2.00000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000
Medium Sand	1.18921	0.00	0.000	0.30	0.185	0.00	0.000	0.00	0.000
	0.84090	0.00	0.000	0.96	0.929	0.00	0.000	0.05	0.046
	0.70711	0.00	0.000	0.36	0.459	0.00	0.000	0.15	0.191
	0.59460	0.00	0.000	0.50	0.758	0.00	0.000	0.28	0.425
	0.50000	0.00	0.000	0.75	1.352	0.00	0.000	0.33	0.595
	0.42045	0.00	0.000	0.89	1.908	0.00	0.000	0.24	0.514
Fine Sand	0.35355	0.00	0.000	0.81	2.064	0.00	0.000	0.18	0.459
	0.29730	0.00	0.000	1.32	4.000	0.00	0.000	0.40	1.212
	0.25000	0.00	0.006	1.42	5.116	0.00	0.000	0.69	2.486
	0.21022	0.07	0.283	1.86	7.968	0.00	0.021	1.21	5.184
	0.17678	0.48	2.445	2.47	12.582	0.13	0.662	1.91	9.729
	0.14865	1.31	7.933	3.17	19.199	0.79	4.785	2.69	16.292
	0.12500	1.85	13.320	3.67	26.428	1.80	12.963	3.29	23.692
	0.10511	2.13	18.234	4.09	35.019	2.90	24.833	3.88	33.221
#200	0.08839	2.72	27.686	4.65	47.339	4.30	43.781	4.70	47.848
	0.07433	3.98	48.168	5.35	64.759	6.04	73.119	5.72	69.238
Silt	0.06250	5.62	80.872	5.98	86.066	7.67	110.401	6.60	94.989
	0.05256	6.92	118.399	6.34	108.493	8.62	147.526	7.00	119.787
	0.04419	7.52	152.983	6.40	130.219	8.74	177.850	6.92	140.799
	0.03716	7.36	178.027	6.10	147.573	8.10	195.979	6.41	155.072
	0.03125	6.89	198.157	5.62	161.657	7.16	205.977	5.75	165.396
	0.02503	7.90	275.494	6.38	222.523	7.75	270.336	6.37	222.174
	0.02005	6.75	293.780	5.50	239.414	6.28	273.398	5.34	232.449
	0.01563	6.26	343.867	5.15	282.938	5.59	307.146	4.99	274.148
	0.01105	7.04	516.033	5.57	408.346	5.90	432.587	5.73	420.076
	0.00781	5.65	585.488	4.05	419.752	4.43	459.187	4.62	478.828
	0.00500	5.73	874.224	3.55	541.707	4.28	653.174	4.60	701.931
Clay	0.00195	8.38	2437.979	4.08	1187.174	5.97	1737.309	6.31	1836.046
	0.00098	3.76	2530.975	1.76	1184.898	2.52	1696.748	2.56	1723.487
	0.00049	1.56	2098.715	0.87	1170.621	0.94	1264.951	1.00	1345.541
	0.00038	0.14	316.435	0.08	185.369	0.08	171.825	0.08	189.891
			11119.503		6706.814		8264.558		8311.745
		Deff (mm)	0.0090	Deff (mm)	0.0149	Deff (mm)	0.0121	Deff (mm)	0.0120
		K (cm/sec)	**2.6E-05**	**K (cm/sec)**	**7.0E-05**	**K (cm/sec)**	**4.6E-05**	**K (cm/sec)**	**4.6E-05**
		K (ft/day)	0.07	K (ft/day)	0.20	K (ft/day)	0.13	K (ft/day)	0.13
		K (m/day)	0.02	K (m/day)	0.06	K (m/day)	0.04	K (m/day)	0.04
		D10 (mm)	0.0090	D10 (mm)	0.0149	D10 (mm)	0.0121	D10 (mm)	0.0120
		K Hazen (cm/sec	8.09E-05	K Hazen (cm/sec	2.22E-04	K Hazen (cm/sec	1.46E-04	K Hazen (cm/sec	1.45E-04
		K (ft/day)	0.23	K (ft/day)	0.63	K (ft/day)	0.42	K (ft/day)	0.41
		K Hazen (cm/sec	4.17E-05	K Hazen (cm/sec	1.15E-04	K Hazen (cm/sec	7.55E-05	K Hazen (cm/sec	7.47E-05
		K (ft/day)	0.12	K (ft/day)	0.33	K (ft/day)	0.21	K (ft/day)	0.21
	Sand (%)	12.54		32.57		15.97		25.72	
	Silt (%)	73.63		60.64		74.53		64.33	
	Clay (%)	13.84		6.79		9.51		9.95	

Analysis of K results			
Formation	**Geomean of K (cm/sec)**	**STD**	**# of Samples**
Brule	9.2E-05	6.2E-05	12

Porosity	0.35	
Kozeny-Carman Coeff	4.8	Range 4.5 to 5.1
Shape Factor	6.5	Range 6 to 8.4 — Rounded 6.1 - 6.6; Medium angular 7.4 - 7.5; Very Angular 7.7 - 8.4
Effective Grain Size (cm)	0.001164539	
Intrinsic Permeability (cm2)	6.8E-10	
Rho (g/cm3)	1.03	
Viscosity (dyne-sec/cm2)	0.016	
Gravitational Const (cm/sec2)	980	
Hydraulic Conductivity K (cm/sec)	4.3E-05	

$$\text{Intrinsic Permeability} = \frac{\text{Porosity}^3}{\left(\text{K-C coefficient} \times \left(\frac{\text{Shape Factor}}{\text{Effective Grain Size}}\right)^2 \times \left(1 - \text{Porosity}\right)^2\right)}$$

$$\text{Hydraulic Conductivity (K)} = \frac{\text{Intrinsic Permeability} \times \text{Density} \times \text{Gravity}}{\text{Viscosity}}$$

		Upper Chadron		Upper Chadron		Upper Chadron		Upper Chadron	
	Porosity	0.35		0.35		0.35		0.35	
		M-1635C Run 3, Sample 1		M-2169C Run 5, Sample 1		M-1451c Run 1		M-1624c Run 1	
Sieves Size/Number	Sieve Size (mm)	Retained (%)		Retained (%)		Retained (%)		Retained (%)	
	6.35107	0.00		0.00		0.00		0.00	
	4.75683	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000
	3.36359	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000
	2.00000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000
Medium Sand	1.18921	0.00	0.000	1.72	1.062	3.58	2.211	0.81	0.500
	0.84090	0.17	0.164	4.90	4.741	11.00	10.646	2.66	2.573
	0.70711	0.40	0.510	1.67	2.130	3.31	4.223	0.89	1.135
	0.59460	0.56	0.849	1.86	2.820	2.42	3.671	0.81	1.228
	0.50000	0.77	1.388	1.99	3.588	2.14	3.860	1.05	1.892
	0.42045	0.93	1.993	1.73	3.709	1.85	3.967	1.28	2.743
Fine Sand	0.35355	0.79	2.013	1.32	3.364	1.22	3.111	1.16	2.956
	0.29730	1.07	3.243	1.94	5.879	1.34	4.062	1.72	5.211
	0.25000	1.05	3.783	1.71	6.162	1.13	4.073	1.76	6.340
	0.21022	1.53	6.555	1.60	6.855	1.36	5.829	2.25	9.636
	0.17678	2.36	12.021	1.70	8.660	1.63	8.306	2.84	14.462
	0.14865	3.19	19.320	2.19	13.265	1.89	11.451	3.32	20.102
	0.12500	3.54	25.492	2.70	19.445	2.06	14.841	3.52	25.341
	0.10511	3.66	31.338	3.05	26.117	2.23	19.102	3.69	31.586
#200	0.08839	4.02	40.926	3.46	35.227	2.62	26.684	4.10	41.728
	0.07433	4.75	57.498	4.13	49.996	3.31	40.083	4.77	57.723
Silt	0.06250	5.53	79.591	4.92	70.816	4.09	58.889	5.44	78.273
	0.05256	5.99	102.505	5.52	94.468	4.59	78.579	5.83	99.738
	0.04419	6.12	124.524	5.73	116.596	4.73	96.280	5.87	119.403
	0.03716	5.98	144.672	5.41	130.890	4.54	109.879	5.54	133.989
	0.03125	5.68	163.386	4.83	138.944	4.23	121.725	5.02	144.359
	0.02503	6.54	228.108	5.28	184.171	4.87	169.928	5.58	194.567
	0.02005	5.53	240.725	4.42	192.417	4.23	184.208	4.69	204.100
	0.01563	5.10	280.197	4.14	227.468	3.98	218.751	4.33	237.824
	0.01105	5.70	417.885	4.75	348.258	4.53	332.241	4.81	352.534
	0.00781	4.47	463.291	3.88	402.165	3.67	380.528	3.79	392.699
	0.00500	4.37	666.848	3.98	607.371	3.77	575.520	3.77	575.123
Clay	0.00195	6.15	1789.526	5.84	1699.424	5.78	1682.536	5.38	1565.017
	0.00098	2.77	1864.904	2.54	1710.159	2.69	1811.769	2.34	1574.950
	0.00049	1.18	1587.771	1.00	1345.649	1.08	1453.795	0.93	1251.016
	0.00038	0.10	226.065	0.08	189.906	0.09	203.540	0.08	178.539
			8587.092		7651.720	Sum(fi/(dli^0.404*	7644.287		7327.286
		Deff (mm)	0.0116	Deff (mm)	0.0131	Deff (mm)	0.0131	Deff (mm)	0.0136
		K (cm/sec)	**4.3E-05**	**K (cm/sec)**	**5.4E-05**	**K (cm/sec)**	**5.4E-05**	**K (cm/sec)**	**5.9E-05**
		K (ft/day)	0.12	K (ft/day)	0.15	K (ft/day)	0.15	K (ft/day)	0.17
		K (m/day)	0.04	K (m/day)	0.05	K (m/day)	0.05	K (m/day)	0.05
		D10 (mm)	0.0116	D10 (mm)	0.0131	D10 (mm)	0.0131	D10 (mm)	0.0136
		K Hazen (cm/sec)	1.36E-04	K Hazen (cm/sec)	1.71E-04	K Hazen (cm/sec)	1.71E-04	K Hazen (cm/sec)	1.86E-04
		K (ft/day)	0.38	K (ft/day)	0.48	K (ft/day)	0.49	K (ft/day)	0.53
		K Hazen (cm/sec)	7.00E-05	K Hazen (cm/sec)	8.81E-05	K Hazen (cm/sec)	8.83E-05	K Hazen (cm/sec)	9.61E-05
		K (ft/day)	0.20	K (ft/day)	0.25	K (ft/day)	0.25	K (ft/day)	0.27
	Sand (%)	28.79		37.67		43.11		36.62	
	Silt (%)	61.01		52.86		47.25		54.65	
	Clay (%)	10.20		9.46		9.64		8.73	

Analysis of K results

Formation	Geomean of K (cm/sec)	STD	# of Samples
Upper Chadron	5.2E-05	6.8E-06	4

Porosity	0.35	
Kozeny-Carman Coeff	4.8	Range 4.5 to 5.1
Shape Factor	6.5	Range 6 to 8.4 — Rounded 6.1 - 6.6; Medium angular 7.4 - 7.5; Very Angular 7.7 - 8.4
Effective Grain Size (cm)	0.0007421	
Intrinsic Permeability (cm2)	2.8E-10	
Rho (g/cm3)	1.03	
Viscosity (dyne-sec/cm2)	0.016	
Gravitational Const (cm/sec2)	980	
Hydraulic Conductivity K (cm/sec)	1.7E-05	

$$\text{Intrinsic Permeability} = \frac{\text{Porosity}^3}{\left(\text{K-C coefficient} \times \left(\frac{\text{Shape Factor}}{\text{Effective Grain Size}}\right)^2 \times (1 - \text{Porosity})^2\right)}$$

$$\text{Hydraulic Conductivity (K)} = \frac{\text{Intrinsic Permeability} \times \text{Density} \times \text{Gravity}}{\text{Viscosity}}$$

		Middle Chadron		Middle Chadron	
	Porosity	0.35		0.35	
		M-1451c Run 2		M-1624c Run 2	
Sieves Size/Number	Sieve Size (mm)	Retained (%)		Retained (%)	
	6.35107	0.00		0.00	
	4.75683	0.00	0.000	0.00	0.000
	3.36359	0.00	0.000	0.00	0.000
	2.00000	0.00	0.000	0.00	0.000
Medium Sand	1.18921	0.00	0.000	2.23	1.377
	0.84090	1.24	1.200	8.51	8.234
	0.70711	2.40	3.061	4.07	5.191
	0.59460	1.92	2.911	4.04	6.126
	0.50000	1.42	2.560	3.97	7.158
	0.42045	1.60	3.430	3.55	7.611
Fine Sand	0.35355	1.64	4.180	2.54	6.474
	0.29730	2.63	7.970	3.04	9.214
	0.25000	2.46	8.864	2.40	8.649
	0.21022	2.67	11.439	2.31	9.898
	0.17678	2.82	14.365	2.24	11.412
	0.14865	2.77	16.777	2.14	12.963
	0.12500	2.49	17.931	1.98	14.260
	0.10511	2.26	19.351	1.83	15.671
#200	0.08839	2.26	23.008	1.79	18.226
	0.07433	2.41	29.172	1.85	22.397
Silt	0.06250	2.55	36.701	1.93	27.781
	0.05256	2.63	45.007	2.00	34.230
	0.04419	2.80	56.972	2.13	43.345
	0.03716	3.04	73.546	2.28	55.167
	0.03125	3.28	94.350	2.43	69.908
	0.02503	4.40	153.467	3.22	112.324
	0.02005	4.43	192.841	3.24	141.058
	0.01563	4.61	253.276	3.39	186.273
	0.01105	5.86	429.615	4.36	319.687
	0.00781	5.69	589.737	4.35	450.912
	0.00500	7.07	1078.859	5.63	859.231
Clay	0.00195	13.10	3811.835	10.80	3142.990
	0.00098	5.63	3790.401	4.44	2989.622
	0.00049	1.79	2408.567	1.22	1641.807
	0.00038	0.13	293.884	0.08	174.092
			13475.274	Sum(fi/(dli^0.404*	10413.286
		Deff (mm)	0.0074	Deff (mm)	0.0096
		K (cm/sec)	**1.7E-05**	**K (cm/sec)**	**2.9E-05**
		K (ft/day)	0.05	K (ft/day)	0.08
		K (m/day)	0.02	K (m/day)	0.03
		D10 (mm)	0.0074	D10 (mm)	0.0096
		K Hazen (cm/sec)	5.51E-05	K Hazen (cm/sec)	9.22E-05
		K (ft/day)	0.16	K (ft/day)	0.26
		K Hazen (cm/sec)	2.84E-05	K Hazen (cm/sec)	4.76E-05
		K (ft/day)	0.08	K (ft/day)	0.13
	Sand (%)	32.99		48.50	
	Silt (%)	46.36		34.96	
	Clay (%)	20.65		16.54	

Analysis of K results

Formation	**Geomean of K (cm/sec)**	**STD**	**# of Samples**
Middle Chadron	2.2E-05	8.29E-06	2

Vertical Permeability Calculations, Upper/Middle Chadron Confining Unit

Lithology	Formation	Number of Samples	Method	K (cm/s)
Claystone	Upper/Middle Chadron	2	Falling-Head Permeameter	1.31E-07
Siltstone +/- Sandstone	Upper/Middle Chadron	6	Grain-Size, Kozeny-Carmen	3.90E-05
			Harmonic Mean*	**1.5E-07**

*Assumes Upper/Middle Chadron Formation consists of 90 percent claystone, 10 percent coarser material.

ATTACHMENT B

MODEL HYDRAULIC CONTAINMENT SIMULATION

GROUNDWATER FLOW MODEL SIMULATION OF HYDRAULIC CONTAINMENT

A groundwater modeling simulation was performed to demonstrate hydraulic containment of mining solutions at the MEA under typical operating conditions. The operation of Mine Unit 1 (MU1) at the MEA was simulated for this purpose. A total production flow rate of 1600 gpm and 1580.8 gpm injection (1.2 percent bleed) was assumed per the MEA water balance and TR report. Representative hydraulic parameters for the Basal Chadron aquifer were established from baseline water level monitoring and aquifer testing as follows:

Transmissivity - 1012 ft^2/day (average from aquifer testing)

Storage Coefficient - 2.56 x 10^{-4} (average from aquifer testing)

Hydraulic Gradient – 0.0003 bearing 324 degrees (NW)

Porosity - 0.2

Groundwater flow was simulated using WinFlow®, an analytical element flow model developed by Environmental Simulations, Inc. The flow model simulation was run for a period of 3 years, equivalent to the approximate production schedule for MU1. Particle tracking techniques were utilized to illustrate groundwater flow paths from injection wells toward production wells. Results of the simulation are provided in **Figure B-1**.

Results of the simulation demonstrate mining solutions at the MEA will be fully contained under normal operating conditions with minimal wellfield flare, as evidenced by the particle capture zone and inward hydraulic gradient across MU1.

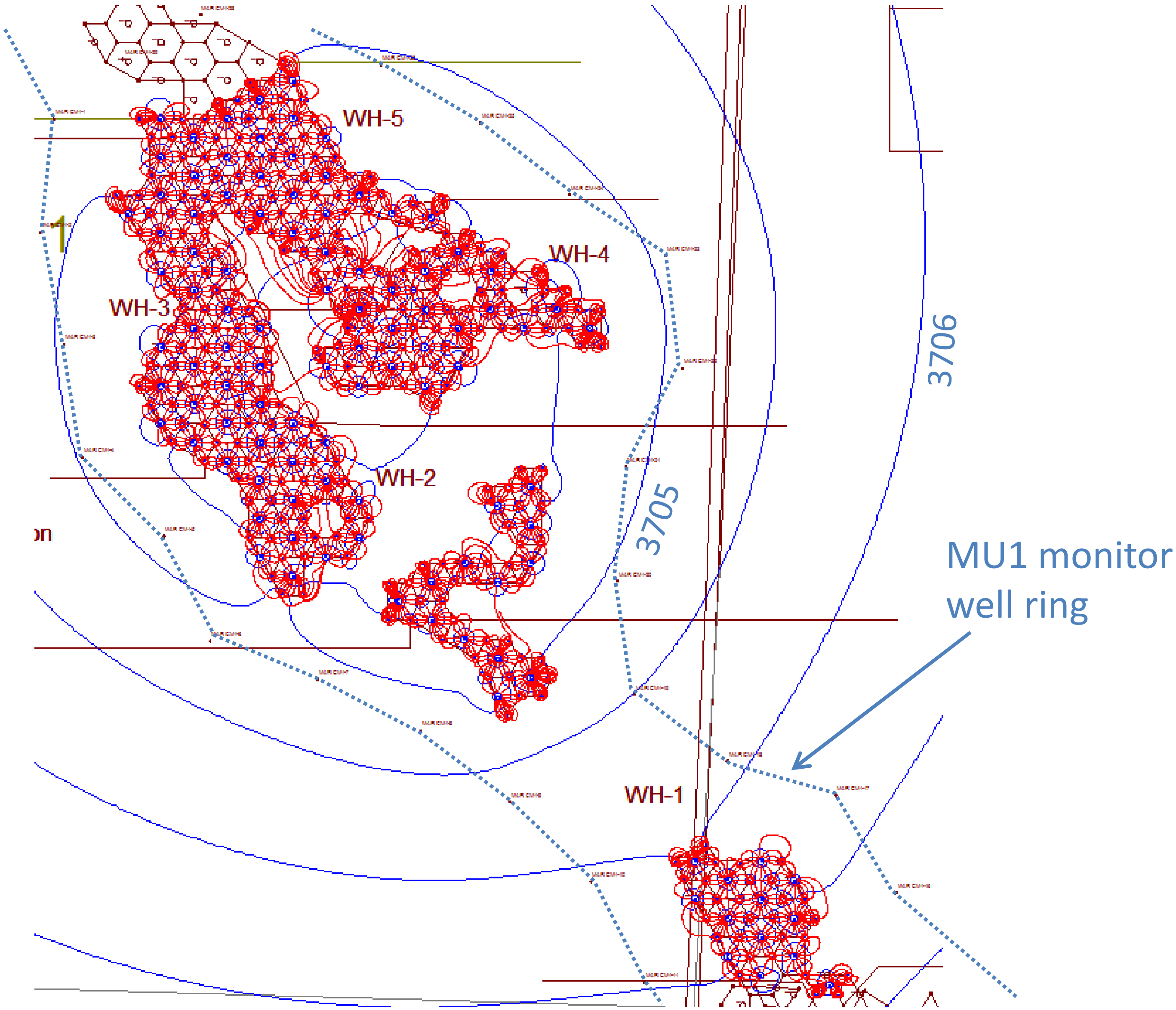

Figure B-1. Groundwater flow model simulation showing hydraulic containment in MU1 at MEA. Capture zone defined by red particle traces and inward hydraulic gradient illustrated by blue water level elevation contours.