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.

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.

[redacted]

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 / OF /

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 ☐
- 48 HOURS ☐
- 72 HOURS ☐
- 5 DAYS ☐
- NORMAL ☒
- 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				
[illegible]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
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Results of Kozeny-Carmen Grain Size Analysis of Core Samples					
Formation	Geomean of K (cm/sec)	STD	Coeff of Variation	# of Samples	
Arikaree	1.4E-04	9.3E-04	6.69	10	
Brule	8.9E-05	6.1E-05	0.69	13	
Upper Chadron	5.1E-05	8.2E-06	0.16	3	
Middle Chadron	2.2E-05	8.3E-06	0.37	2	
Upper + Middle Chadron	3.7E-05	1.7E-05	0.47	5	
Basal Sandstone	7.5E-05	NA	NA	1	Uses re-run sample only
Pierre	2.5E-06	1.3E-06	0.54	7	

Note:

While values have been calculated for the Pierre Shale using Kozeny-Carmen, those values are not valid due to high levels of clay present and have not been included in the application. K values presented for the Upper and Middle Chadron Formation represent primarily samples of the coarser-grained portion of the confining unit (e.g. significant silt and sand fraction). Representative K values for the Upper and Middle Chadron claystone was determined separately by laboratory falling-head permeameter.

Porosity	0.438
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)	5.5E-08
Rho (g/cm3)	1.03
Viscosity (dyne-sec/cm2)	0.016
Gravitational Const (cm/sec2)	980
Hydraulic Conductivity K (cm/sec)	3.5E-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)	Arikaree		Arikaree		Arikaree		Arikaree		Arikaree		Arikaree	
	Porosity	0.35		0.35		0.35		0.35		0.35		0.35	
		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		M-1912C Run 2, Sample 1	
Sieves Size/Number	Sieve Size (mm)	Retained (%)		Retained (%)		Retained (%)		Retained (%)		Retained (%)		Retained (%)	
	6.35107	0.00		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	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	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	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	0.74	0.457
	0.84090	2.47	2.389	0.00	0.000	0.00	0.000	0.00	0.000	0.69	0.668	2.75	2.661
	0.70711	1.42	1.810	0.00	0.000	0.00	0.000	0.00	0.000	0.32	0.408	0.96	1.224
	0.59460	2.07	3.137	0.00	0.000	0.00	0.000	0.00	0.000	0.35	0.531	0.89	1.350
	0.50000	3.50	6.307	0.00	0.000	0.00	0.000	0.00	0.000	0.56	1.010	1.17	2.109
	0.42045	5.55	11.892	0.00	0.000	0.00	0.000	0.00	0.000	1.11	2.381	1.33	2.851
Fine Sand	0.35355	6.39	16.280	0.00	0.007	0.00	0.000	0.00	0.000	1.76	4.488	0.98	2.498
	0.29730	11.20	33.927	0.11	0.333	0.00	0.000	0.00	0.000	4.49	13.615	1.10	3.334
	0.25000	10.90	39.258	0.41	1.477	0.00	0.005	0.00	0.004	6.17	22.245	1.17	4.216
	0.21022	10.80	46.250	0.83	3.555	0.08	0.343	0.09	0.377	8.16	34.937	2.13	9.126
	0.17678	9.65	49.136	1.24	6.315	0.67	3.413	0.88	4.485	9.53	48.523	3.87	19.714
	0.14865	7.85	47.525	1.75	10.597	1.98	11.993	2.96	17.936	10.31	62.421	6.15	37.250
	0.12500	5.92	42.614	2.41	17.351	3.41	24.558	5.43	39.122	10.51	75.660	8.05	57.974
	0.10511	4.21	36.033	3.35	28.677	5.23	44.785	8.03	68.789	10.00	85.591	9.01	77.152
#200	0.08839	2.94	29.919	4.59	46.718	7.43	75.648	10.41	105.930	8.75	89.034	8.83	89.901
	0.07433	2.12	25.652	5.84	70.675	9.08	109.920	11.81	142.906	6.87	83.211	7.73	93.576
Silt	0.06250	1.60	23.019	6.64	95.545	9.18	132.135	11.41	164.155	4.77	68.695	6.16	88.664
	0.05256	1.23	21.040	6.82	116.682	7.90	135.202	9.55	163.507	2.95	50.514	4.63	79.238
	0.04419	0.95	19.322	6.51	132.429	6.22	126.570	7.16	145.756	1.73	35.222	3.46	70.406
	0.03716	0.74	17.895	5.84	141.253	4.87	117.828	5.21	126.106	1.11	26.871	2.74	66.293
	0.03125	0.58	16.677	5.09	146.381	3.96	113.920	3.91	112.527	0.83	23.890	2.34	67.315
	0.02503	0.60	20.919	5.57	194.231	4.21	146.852	3.82	133.302	0.92	32.108	2.67	93.133
	0.02005	0.49	21.321	4.80	208.899	3.69	160.642	2.89	125.865	0.88	38.331	2.44	106.222
	0.01563	0.47	25.812	4.61	253.218	3.96	217.583	2.52	138.518	0.97	53.325	2.50	137.361
	0.01105	0.56	41.039	5.64	413.391	5.59	409.855	2.77	203.177	1.28	93.899	3.19	233.885
	0.00781	0.48	49.729	5.27	546.082	5.31	550.399	2.25	233.314	1.09	113.043	2.85	295.408
	0.00500	0.52	79.319	6.26	955.037	5.67	865.297	2.39	364.885	1.06	161.853	3.12	476.135
Clay	0.00195	0.80	232.691	10.50	3054.588	7.19	2092.322	3.82	1112.086	1.22	355.216	4.56	1326.961
	0.00098	0.39	262.463	4.34	2921.239	2.79	1878.529	1.80	1212.444	0.49	330.098	1.77	1191.737
	0.00049	0.20	269.006	1.49	2004.438	1.43	1924.326	0.80	1076.981	0.27	363.529	0.65	874.681
	0.00038	0.02	45.195	0.11	248.614	0.14	316.517	0.07	162.846	0.03	63.337	0.05	119.823
		Sum(fi/(dli^0.404*	1539.687		11617.733		9458.645		5855.019		2335.161		5632.654
		Deff (mm)	0.0649	Deff (mm)	0.0086	Deff (mm)	0.0106	Deff (mm)	0.0171	Deff (mm)	0.0428	Deff (mm)	0.0178
		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 (cm/sec)	1.0E-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 (ft/day)	0.28
		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	K (m/day)	0.09
		D10 (mm)	0.0649	D10 (mm)	0.0086	D10 (mm)	0.0106	D10 (mm)	0.0171	D10 (mm)	0.0428	D10 (mm)	0.0178
		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 Hazen (cm/sec)	3.15E-04
		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 (ft/day)	0.89
		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 Hazen (cm/sec)	1.63E-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	K (ft/day)	0.46
	Sand (%)	90.37		20.53		27.88		39.61		80.39		56.86	
	Silt (%)	8.22		63.04		60.57		53.90		17.60		36.10	
	Clay (%)	1.41		16.44		11.55		6.50		2.01		7.03	

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

Porosity	0.438
Kozeny-Carman Coeff	4.8
Shape Factor	6.5
Effective Grain Size (cm)	0.006494829
Intrinsic Permeability (cm2)	5.5E-08
Rho (g/cm3)	1.03
Viscosity (dyne-sec/cm2)	0.016
Gravitational Const (cm/sec2)	980
Hydraulic Conductivity K (cm/sec)	3.5E-03

		Arikaree		Arikaree		Arikaree		Arikaree	
	Porosity	0.35		0.35		0.35		0.35	
		M-1956C Run 1, Sample 1		M-1956C Run 3, Sample 1		M-2169C Run 1, Sample 1		M-2169C Run 2, Sample 3	
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	1.37	0.845	0.00	0.000	0.00	0.000	0.00	0.000
	0.84090	1.79	1.731	0.00	0.000	0.00	0.000	0.00	0.000
	0.70711	1.31	1.670	0.01	0.018	0.00	0.000	0.00	0.000
	0.59460	2.02	3.061	0.14	0.212	0.00	0.000	0.00	0.000
	0.50000	3.82	6.883	0.39	0.703	0.00	0.000	0.00	0.000
	0.42045	6.67	14.289	0.46	0.986	0.00	0.000	0.00	0.000
Fine Sand	0.35355	8.24	20.989	0.27	0.688	0.00	0.000	0.00	0.000
	0.29730	15.19	46.034	0.19	0.576	0.00	0.008	0.00	0.000
	0.25000	14.79	53.294	0.25	0.901	0.06	0.213	0.00	0.003
	0.21022	13.69	58.657	0.78	3.341	0.32	1.371	0.07	0.308
	0.17678	10.59	53.962	1.77	9.015	0.85	4.330	0.73	3.716
	0.14865	7.02	42.492	3.04	18.410	1.60	9.690	2.55	15.435
	0.12500	4.36	31.379	4.33	31.178	2.43	17.499	4.98	35.840
	0.10511	2.69	23.019	5.74	49.142	3.54	30.310	7.70	65.890
#200	0.08839	1.72	17.500	7.32	74.513	5.07	51.615	10.09	102.761
	0.07433	1.08	13.065	8.67	104.935	6.71	81.221	11.09	134.281
Silt	0.06250	0.62	8.918	9.27	133.403	7.79	112.116	10.19	146.715
	0.05256	0.34	5.815	8.89	152.114	7.92	135.531	8.29	141.949
	0.04419	0.22	4.474	7.85	159.705	7.37	149.956	6.38	129.735
	0.03716	0.18	4.352	6.58	159.169	6.51	157.492	5.02	121.373
	0.03125	0.15	4.312	5.41	155.600	5.65	162.520	4.11	118.153
	0.02503	0.17	5.926	5.49	191.461	6.07	211.711	4.26	148.493
	0.02005	0.18	7.831	4.19	182.371	4.94	215.038	3.36	146.174
	0.01563	0.19	10.432	3.60	197.762	4.56	250.525	3.06	168.016
	0.01105	0.23	16.852	3.74	274.158	5.32	390.020	3.52	257.905
	0.00781	0.21	21.752	2.78	288.097	4.59	475.721	2.95	305.565
	0.00500	0.26	39.651	2.64	402.806	5.01	764.497	3.15	480.387
Clay	0.00195	0.47	136.678	3.67	1067.766	8.07	2348.169	5.08	1477.277
	0.00098	0.32	215.311	1.71	1151.118	3.87	2605.438	2.41	1621.546
	0.00049	0.13	174.819	0.76	1022.507	1.61	2166.330	0.95	1277.512
	0.00038	0.00	0.000	0.07	153.705	0.14	316.486	0.08	176.223
			1045.993		5986.360		10657.807		7075.259
		Deff (mm)	0.0956	Deff (mm)	0.0167	Deff (mm)	0.0094	Deff (mm)	0.0141
		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)	8.18	K (ft/day)	0.25	K (ft/day)	0.08	K (ft/day)	0.18
		K (m/day)	2.49	K (m/day)	0.08	K (m/day)	0.02	K (m/day)	0.05
		D10 (mm)	0.0956	D10 (mm)	0.0167	D10 (mm)	0.0094	D10 (mm)	0.0141
		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)	25.91	K (ft/day)	0.79	K (ft/day)	0.25	K (ft/day)	0.57
		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)	13.37	K (ft/day)	0.41	K (ft/day)	0.13	K (ft/day)	0.29
	Sand (%)	96.33		33.36		20.58		37.21	
	Silt (%)	2.75		60.43		65.73		54.28	
	Clay (%)	0.92		6.21		13.69		8.51	

Analysis of K results	
Formation	**Geomean of K (cm/sec)**
Arikaree	1.4E-04

Porosity	0.438
Kozeny-Carman Coeff	4.8
Shape Factor	6.5
Effective Grain Size (cm)	0.00152912
Intrinsic Permeability (cm2)	3.1E-09
Rho (g/cm3)	1.03
Viscosity (dyne-sec/cm2)	0.016
Gravitational Const (cm/sec2)	980
Hydraulic Conductivity K (cm/sec)	1.9E-04

		Brule		Brule		Brule		Brule		Brule		Brule		Brule	
	Porosity	0.35		0.35		0.35		0.35		0.35		0.35		0.35	
		M-1956C Run 4, Sample 1		**M-1956C Run 4, Sample 2**		**M-1956C Run 5, Sample 1**		**M-1956C Run 5, Sample 2**		**M-2169C Run 3, Sample 1**		**M-2169C Run 4, Sample 1**		**M-2169C Run 5, Sample 1**	
Sieves Size/Number	Sieve Size (mm)	Retained (%)		Retained (%)		Retained (%)		Retained (%)		Retained (%)		Retained (%)		Retained (%)	
	6.35107	0.00		0.00		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	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	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	0.00	0.000	0.00	0.000
Medium Sand	1.18921	0.03	0.015	0.00	0.000	0.00	0.000	0.30	0.185	0.00	0.000	0.00	0.000	1.72	1.062
	0.84090	0.30	0.290	0.00	0.000	0.00	0.000	0.96	0.929	0.00	0.000	0.05	0.046	4.90	4.741
	0.70711	0.19	0.242	0.00	0.000	0.00	0.000	0.36	0.459	0.00	0.000	0.15	0.191	1.67	2.130
	0.59460	0.34	0.516	0.00	0.000	0.00	0.000	0.50	0.758	0.00	0.000	0.28	0.425	1.86	2.820
	0.50000	0.64	1.154	0.00	0.000	0.00	0.000	0.75	1.352	0.00	0.000	0.33	0.595	1.99	3.588
	0.42045	0.72	1.544	0.00	0.000	0.00	0.000	0.89	1.908	0.00	0.000	0.24	0.514	1.73	3.709
Fine Sand	0.35355	0.48	1.224	0.00	0.000	0.00	0.000	0.81	2.064	0.00	0.000	0.18	0.459	1.32	3.364
	0.29730	0.46	1.394	0.00	0.000	0.00	0.000	1.32	4.000	0.00	0.000	0.40	1.212	1.94	5.879
	0.25000	0.47	1.694	0.00	0.000	0.00	0.006	1.42	5.116	0.00	0.000	0.69	2.486	1.71	6.162
	0.21022	0.97	4.157	0.02	0.086	0.07	0.283	1.86	7.968	0.00	0.021	1.21	5.184	1.60	6.855
	0.17678	1.90	9.682	0.32	1.630	0.48	2.445	2.47	12.582	0.13	0.662	1.91	9.729	1.70	8.660
	0.14865	3.20	19.388	1.54	9.329	1.31	7.933	3.17	19.199	0.79	4.785	2.69	16.292	2.19	13.265
	0.12500	4.74	34.147	3.30	23.768	1.85	13.320	3.67	26.428	1.80	12.963	3.29	23.692	2.70	19.445
	0.10511	6.58	56.361	5.27	45.131	2.13	18.234	4.09	35.019	2.90	24.833	3.88	33.221	3.05	26.117
#200	0.08839	8.47	86.262	7.51	76.468	2.72	27.686	4.65	47.339	4.30	43.781	4.70	47.848	3.46	35.227
	0.07433	9.81	118.791	9.69	117.314	3.98	48.168	5.35	64.759	6.04	73.119	5.72	69.238	4.13	49.996
Silt	0.06250	10.00	143.979	10.90	156.904	5.62	80.872	5.98	86.066	7.67	110.401	6.60	94.989	4.92	70.816
	0.05256	9.08	155.441	10.80	184.847	6.92	118.399	6.34	108.493	8.62	147.526	7.00	119.787	5.52	94.468
	0.04419	7.55	153.677	9.50	193.328	7.52	152.983	6.40	130.219	8.74	177.850	6.92	140.799	5.73	116.596
	0.03716	6.03	145.936	7.74	187.281	7.36	178.027	6.10	147.573	8.10	195.979	6.41	155.072	5.41	130.890
	0.03125	4.83	138.987	6.13	176.358	6.89	198.157	5.62	161.657	7.16	205.977	5.75	165.396	4.83	138.944
	0.02503	4.86	169.574	5.99	208.957	7.90	275.494	6.38	222.523	7.75	270.336	6.37	222.174	5.28	184.171
	0.02005	3.68	160.252	4.42	192.436	6.75	293.780	5.50	239.414	6.28	273.398	5.34	232.449	4.42	192.417
	0.01563	3.10	170.379	3.66	201.114	6.26	343.867	5.15	282.938	5.59	307.146	4.99	274.148	4.14	227.468
	0.01105	3.08	225.888	3.57	261.770	7.04	516.033	5.57	408.346	5.90	432.587	5.73	420.076	4.75	348.258
	0.00781	2.15	222.918	2.46	255.006	5.65	585.488	4.05	419.752	4.43	459.187	4.62	478.828	3.88	402.165
	0.00500	1.92	293.094	2.16	329.661	5.73	874.224	3.55	541.707	4.28	653.174	4.60	701.931	3.98	607.371
Clay	0.00195	2.50	727.719	2.84	826.514	8.38	2437.979	4.08	1187.174	5.97	1737.309	6.31	1836.046	5.84	1699.424
	0.00098	1.22	821.670	1.41	949.435	3.76	2530.975	1.76	1184.898	2.52	1696.748	2.56	1723.487	2.54	1710.159
	0.00049	0.61	821.101	0.69	928.590	1.56	2098.715	0.87	1170.621	0.94	1264.951	1.00	1345.541	1.00	1345.649
	0.00038	0.06	131.166	0.06	144.704	0.14	316.435	0.08	185.369	0.08	171.825	0.08	189.891	0.08	189.906
			4818.643		5470.632		11119.503		6706.814		8264.558		8311.745		7651.720
		Deff (mm)	0.0208	Deff (mm)	0.0183	Deff (mm)	0.0090	Deff (mm)	0.0149	Deff (mm)	0.0121	Deff (mm)	0.0120	Deff (mm)	0.0131
		K (cm/sec)	**1.4E-04**	**K (cm/sec)**	**1.1E-04**	**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 (cm/sec)**	**5.4E-05**
		K (ft/day)	0.39	K (ft/day)	0.30	K (ft/day)	0.07	K (ft/day)	0.20	K (ft/day)	0.13	K (ft/day)	0.13	K (ft/day)	0.15
		K (m/day)	0.12	K (m/day)	0.09	K (m/day)	0.02	K (m/day)	0.06	K (m/day)	0.04	K (m/day)	0.04	K (m/day)	0.05
		D10 (mm)	0.0208	D10 (mm)	0.0183	D10 (mm)	0.0090	D10 (mm)	0.0149	D10 (mm)	0.0121	D10 (mm)	0.0120	D10 (mm)	0.0131
		K Hazen (cm/sec)	4.31E-04	K Hazen (cm/sec)	3.34E-04	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 Hazen (cm/sec)	1.71E-04
		K (ft/day)	1.22	K (ft/day)	0.95	K (ft/day)	0.23	K (ft/day)	0.63	K (ft/day)	0.42	K (ft/day)	0.41	K (ft/day)	0.48
		K Hazen (cm/sec)	2.22E-04	K Hazen (cm/sec)	1.72E-04	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 Hazen (cm/sec)	8.81E-05
		K (ft/day)	0.63	K (ft/day)	0.49	K (ft/day)	0.12	K (ft/day)	0.33	K (ft/day)	0.21	K (ft/day)	0.21	K (ft/day)	0.25
	Sand (%)	39.31		27.65		12.54		32.57		15.97		25.72		37.67	
	Silt (%)	56.30		67.34		73.63		60.64		74.53		64.33		52.86	
	Clay (%)	4.39		5.00		13.84		6.79		9.51		9.95		9.46	

Analysis of K results	
Formation	**Geomean of K (cm/sec)**
Brule	8.9E-05

Porosity	0.438			
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)	1.8E-09			
Rho (g/cm3)	1.03			
Viscosity (dyne-sec/cm2)	0.016			
Gravitational Const (cm/sec2)	980			
Hydraulic Conductivity K (cm/sec)	1.1E-04			

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

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

		Upper Chadron		Upper Chadron		Upper Chadron	
	Porosity	0.35		0.35		0.35	
		M-1635C Run 3, Sample 1		**M-1454c Run 1**		**M-1624c Run 1**	
Sieves Size/Number	Sieve Size (mm)	Retained (%)		Retained (%)		Retained (%)	
	6.35107	0.00		0.00		0.00	
	4.75683	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
	2.00000	0.00	0.000	0.00	0.000	0.00	0.000
Medium Sand	1.18921	0.00	0.000	3.58	2.211	0.81	0.500
	0.84090	0.17	0.164	11.00	10.646	2.66	2.573
	0.70711	0.40	0.510	3.31	4.223	0.89	1.135
	0.59460	0.56	0.849	2.42	3.671	0.81	1.228
	0.50000	0.77	1.388	2.14	3.860	1.05	1.892
	0.42045	0.93	1.993	1.85	3.967	1.28	2.743
Fine Sand	0.35355	0.79	2.013	1.22	3.111	1.16	2.956
	0.29730	1.07	3.243	1.34	4.062	1.72	5.211
	0.25000	1.05	3.783	1.13	4.073	1.76	6.340
	0.21022	1.53	6.555	1.36	5.829	2.25	9.636
	0.17678	2.36	12.021	1.63	8.306	2.84	14.462
	0.14865	3.19	19.320	1.89	11.451	3.32	20.102
	0.12500	3.54	25.492	2.06	14.841	3.52	25.341
	0.10511	3.66	31.338	2.23	19.102	3.69	31.586
#200	0.08839	4.02	40.926	2.62	26.684	4.10	41.728
	0.07433	4.75	57.498	3.31	40.083	4.77	57.723
Silt	0.06250	5.53	79.591	4.09	58.889	5.44	78.273
	0.05256	5.99	102.505	4.59	78.579	5.83	99.738
	0.04419	6.12	124.524	4.73	96.280	5.87	119.403
	0.03716	5.98	144.672	4.54	109.879	5.54	133.989
	0.03125	5.68	163.386	4.23	121.725	5.02	144.359
	0.02503	6.54	228.108	4.87	169.928	5.58	194.567
	0.02005	5.53	240.725	4.23	184.208	4.69	204.100
	0.01563	5.10	280.197	3.98	218.751	4.33	237.824
	0.01105	5.70	417.885	4.53	332.241	4.81	352.534
	0.00781	4.47	463.291	3.67	380.528	3.79	392.699
	0.00500	4.37	666.848	3.77	575.520	3.77	575.123
Clay	0.00195	6.15	1789.526	5.78	1682.536	5.38	1565.017
	0.00098	2.77	1864.904	2.69	1811.769	2.34	1574.950
	0.00049	1.18	1587.771	1.08	1453.795	0.93	1251.016
	0.00038	0.10	226.065	0.09	203.540	0.08	178.539
			8587.092	Sum(fi/(dli^0.404'	7644.287		7327.286
		Deff (mm)	0.0116	Deff (mm)	0.0131	Deff (mm)	0.0136
		K (cm/sec)	**4.3E-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)	0.17
		K (m/day)	0.04	K (m/day)	0.05	K (m/day)	0.05
		D10 (mm)	0.0116	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	1.86E-04
		K (ft/day)	0.38	K (ft/day)	0.49	K (ft/day)	0.53
		K Hazen (cm/sec	7.00E-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)	0.27
	Sand (%)	28.79		43.11		36.62	
	Silt (%)	61.01		47.25		54.65	
	Clay (%)	10.20		9.64		8.73	

Analysis of K results

Formation	**Geomean of K (cm/sec)**	**STD**	**# of Samples**
Upper Chadron	5.1E-05	8.2E-06	3

Porosity	0.438
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

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

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

Effective Grain Size (cm)	0.0007421
Intrinsic Permeability (cm2)	7.2E-10
Rho (g/cm3)	1.03
Viscosity (dyne-sec/cm2)	0.016
Gravitational Const (cm/sec2)	980
Hydraulic Conductivity K (cm/sec)	4.6E-05

		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

	M-1451c Run 2	M-1624c Run 2
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

Avg K
#DIV/0!

Vertical Permeability Calculations, Upper/Middle Chadron Confining Unit

Lithology	Formation	Number of Samples	Method	K (cm/s)
Claystone	Upper/Middle Chadron	1	Falling-Head Permeameter	1.32E-07
Siltstone +/- Sandstone	Upper/Middle Chadron	5	Grain-Size, Kozeny-Carmen	3.70E-05
			Harmonic Mean*	**1.47E-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 - 2.56×10^{-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.

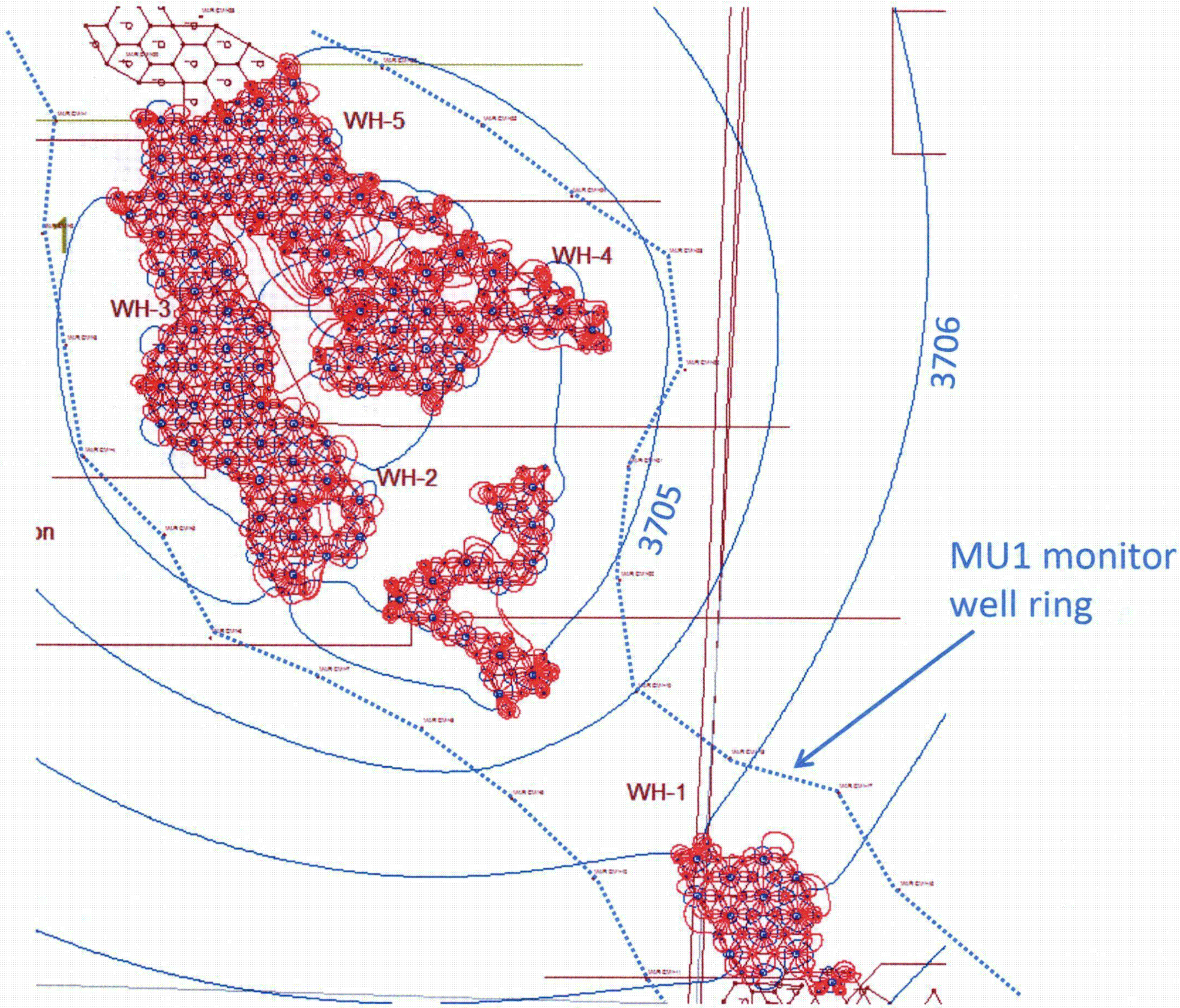

Figure B-1. Groundwater flow model simulation showing hydraulic containment in MU1 at MEA. Capture zone defined by red particle traces and inward hydraulic gradient illustrated by blue water level elevation contours.

Appendix BB

MEA Baseline Radiological Investigation Report – Tetra Tech

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Marsland Expansion Area Baseline Radiological Investigation Report Revision 2

PROJECT NO. 114-910141

APRIL 27, 2015

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1.0 INTRODUCTION

This *Baseline Radiological Investigation Report* supports an amendment application for a U.S. Nuclear Regulatory Commission (NRC) uranium recovery permit to construct and operate the proposed Marsland Expansion Area in situ recovery (ISR) uranium project (Marsland Expansion Area). The NRC source and byproduct license is required to recover uranium by ISR extraction techniques under the provisions of Title 10, U.S. Code of Federal Regulations, Part 40 (10 CFR Part 40), "Domestic Licensing of Source Material." This report summarizes the results of the baseline radiological investigation performed by Tetra Tech Inc. under contract to Crow Butte Resources, Inc. (CBR), at the Marsland Expansion Area. The proposed site is located within the southern portion of Dawes County, which is within the Nebraska-South Dakota-Wyoming Uranium Milling Region (NRC 2009). Figure 1 shows a site location map.

1.1 PURPOSE

This document presents the results of the baseline radiological investigation at the Marsland Expansion Area. The investigation provides site-specific preoperational radiological data for the proposed uranium project, as specified in Section 2.9 of Regulatory Guide 3.46 (RG 3.46) *Standard Format and Content of License Applications, Including Environmental Reports, for In-situ Uranium Solution Mining* (NRC 1982). As specified in 10 CFR Part 40, Appendix A, Criterion 7: *at least one full year prior to any major site construction, a preoperational monitoring program must be conducted to provide complete baseline data on a milling site and its environs.* The baseline radiological investigation is part of CBR's preoperational monitoring program for the Marsland Expansion Area. The data presented in this report can be used quantitatively in support of the Technical Report to be completed by CBR as part of the license application process. Additionally, the data can be compared with operational data to note any changes in surface radiation characteristics and may also be referenced during development of site reclamation and decommissioning plans. The site-specific radiological data collected as part of the Marsland Expansion Area baseline radiological investigation include two components: (1) the preoperational soil sampling program, and (2) the preoperational gamma radiation survey program.

The purpose of the preoperational soil sampling program was to collect baseline data to meet the soil sampling (radial grid, air particulate monitoring) specifications provided by NRC in Section 1.1.4 of Regulatory Guide 4.14 (RG 4.14), Revision 1, *Radiological Effluent and Environmental Monitoring at Uranium Mills*, issued in April 1980 (NRC 1980). A secondary purpose was to collect data to provide information during eventual site decommissioning. The specifications in RG 4.14 are limited to conventional mills (OARU 2014); they do not provide certain monitoring details directly applicable to ISR mining.

In 1999, 64 Federal Register (FR) 17506 (Final Rule), *Radiological Criteria for License Termination of Uranium Recovery Facilities*, was established to amend the NRC regulations regarding decommissioning of licensed uranium recovery facilities to provide specific radiological criteria for decommissioning lands and structures. Release criteria for a site are developed based on background levels; it is therefore important to establish background radiological concentrations for a site such as the Marsland Expansion Area. The objective of the baseline radiological investigation was to establish background soil radionuclide (uranium and radium) data within the proposed disturbed area. Tetra Tech applied a radiation scanning and soil sampling methodology to (1) meet the requirements of RG 4.14 and other applicable guidance, and (2) to develop additional exposure rate and soil concentration data to more completely characterize the site, looking ahead to decommissioning data needs. Tetra Tech performed (1) soil sampling and radiation exposure rate studies conforming to RG 4.14 specifications, and also performed (2) a background surface exposure rate scanning and soil sampling study to quantify the existing radionuclide soil concentrations.

To summarize: Tetra Tech performed a grid-based gamma radiation study and developed other data as specified in Section 1.1.5 of RG 4.14 (NRC, 1980). Tetra Tech also performed a separate, continuous gamma radiation scanning survey (the scanning survey) and collected other data, going beyond the specifications in RG 4.14 (NRC, 1980) and other guidance, because the RG 4.14 grid-based guidance does not provide a complete characterization of the site. This continuous scanning and sampling procedure is not required by RG 4.14, but was performed to better detail the site's existing conditions. The continuous exposure rate survey developed a large data set characterizing the entire site.

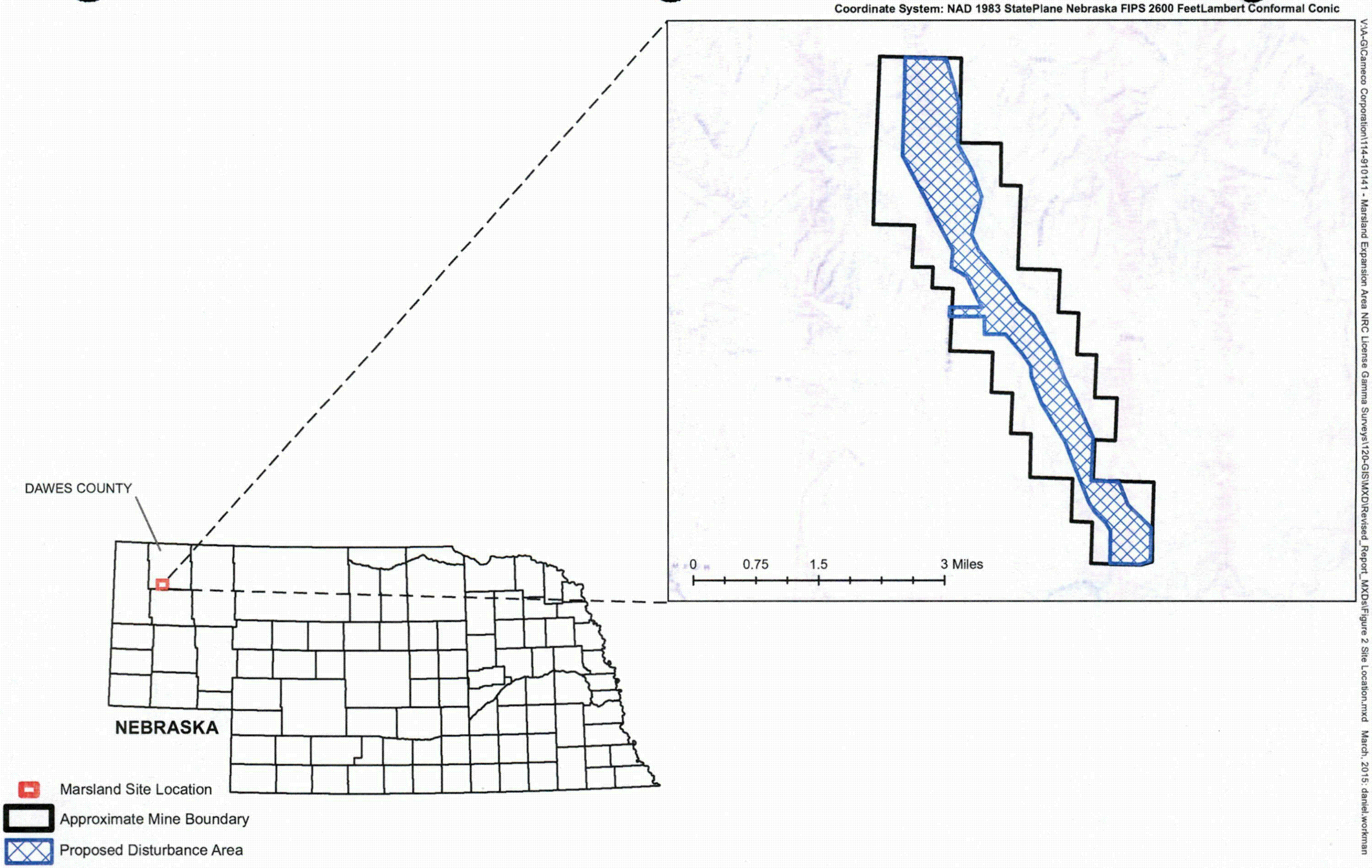
The purpose of the second, scanning survey was to provide a more complete data set, looking ahead toward eventual site reclamation. A comparison between existing surface radiation conditions and post-operation conditions will be useful to determine whether remedial actions are required at site closure.

During the scanning survey, a cross-calibration was also performed between the portable scintillators and a pressurized ion chamber to correct for the energy dependence of the portable gamma detectors used for the scanning survey. The ion chamber data allow field correlation of a different set of portable survey instruments, if necessary, to be used during eventual final site scanning surveys. This cross-calibration is not required by NRC guidance.

Soil samples were also collected as part of the scanning survey to assess whether a useful correlation could be developed between exposure rate and laboratory-measured soil radium-226 (Ra-226) concentrations. This correlation could be useful during eventual site closure planning. Development of such a correlation is not required by existing NRC guidance. Exposure rate conditions at Marsland were too uniform to develop such a correlation, however. The correlation analysis is not included in this report.

The detailed gamma measurements developed during the scanning survey also allow preoperational evaluation of exposure rates that workers and the public may be exposed to at the site. In this case, these exposure rates are uniform and low across the site.

This report describes sampling and laboratory methods, results, and quality assurance and quality control procedures implemented by Tetra Tech at the Marsland Expansion Area. The report also presents maps of sampling and scanning locations. The sampling methods are described in detail in Section 2.0. The high pressurized ionization chamber cross-calibration objective, methods, and results are outlined in Section 3.0. The results of the baseline investigations are presented in Section 4.0. Conclusions are presented in Section 5.0. References are provided in Section 6.0.



N	NAD_1983_STATEPLANE_NEBRASKA FIPS_2600_FEET	PREPARED FOR: Cameco	PREPARED BY: TETRA TECH 3801 Automation Way Suite 100 Fort Collins, Colorado 80525 (970) 223-9600 (970) 223-7171 fax	**MARSLAND SITE LOCATION**	A REVISION
				PROJECT: MARSLAND EXPANSION / PROJECT NO.: 114-91022X	**Figure 1**
				LOCATION: DAWES COUNTY, NE / DATE: 03/2015	

1.2 Scope of Work

The sampling generally followed the site work agreement established between Tetra Tech and CBR. The scope of work consisted of two primary elements: soil sampling and gamma radiation surveys. The baseline radiological investigation includes the following framework shown below. An organizational flowchart is provided in Figure 2.

1. Preoperational Soil Sampling Program:

   a. *Regulatory Guide 4.14 Soil Sampling Field Investigation* - Performed soil sampling to satisfy the requirements in Section 1.1.4 of RG 4.14 (NRC 1980).

   b. *Background Soil Sampling Field Investigation* – Collected background soil samples within the Marsland Expansion Area proposed disturbed area.

2. Preoperational Gamma Radiation Survey Program:

   a. *Regulatory Guide 4.14 Direct Gamma Measurement and Soil Sampling Field Investigation:* Recorded direct gamma measurements and soil samples on a radial grid to meet the requirements in Section 1.1.5 of RG 4.14 (NRC 1980).

   b. *Continuous Gamma Survey Field Investigation:* Conducted a continuous gamma radiation survey using mobile scanning systems on 50-m grid transects within the site area; collected correlation soil samples. An in-field cross-correlation of the portable instruments vs. a pressurized ion chamber was also performed.

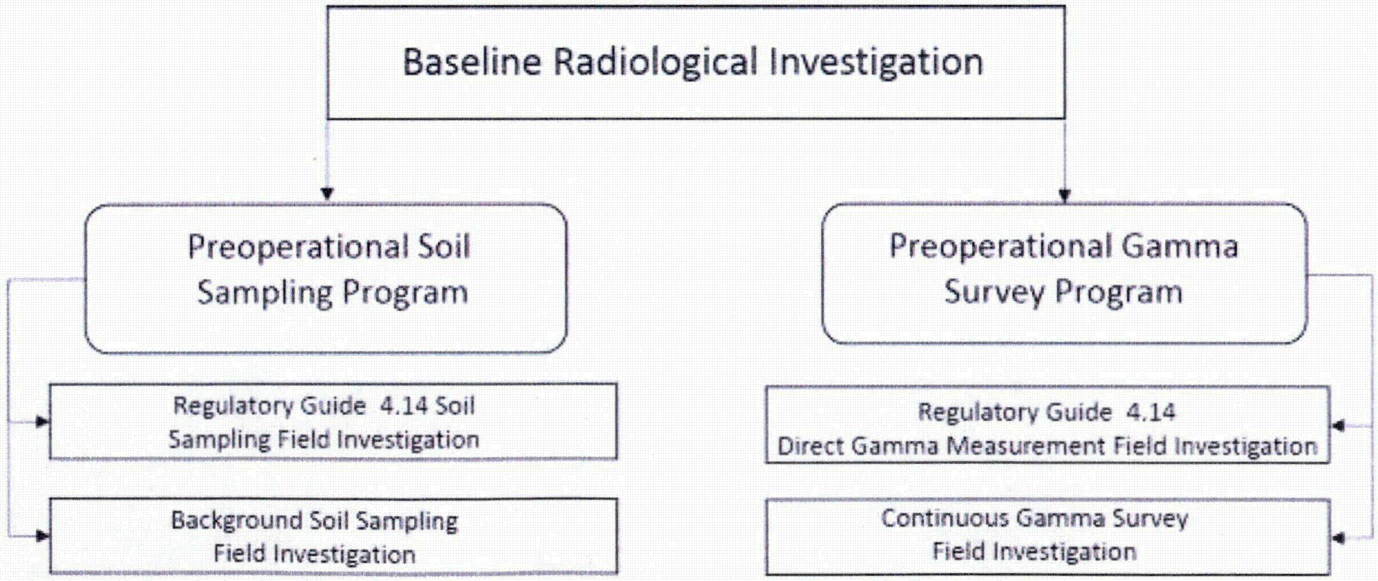


Figure 2 Baseline Radiological Investigation Organizational Flowchart

2.0 METHODS

This section presents the objectives, methods, and quality assurance/quality control (QA/QC) protocol for the sampling.

2.1 Preoperational Soil Sampling Program

2.1.1 Objective

Two sampling approaches were followed as part of the preoperational soil sampling program: (1) a *RG 4.14 soil sampling field investigation,* and (2) a *background soil sampling field investigation*. The following discussion provides the objectives and basis for each sampling approach.

RG 4.14 Soil Sampling Field Investigation:

The first approach to the preoperational soil sampling program was the RG 4.14 soil sampling field investigation. The objective of the RG 4.14 soil sampling field investigation is to meet the requirements of the RG 4.14 (NRC 1980).

Section 1.1.4(a) of RG 4.14 (NRC 1980) specifies that 40 surface soil samples should be collected to a depth of 5-cm below ground surface [bgs] at 300-m intervals in each of the eight compass directions (N, S, E, W, NW, NE, SW, SE), out to a distance of 1500-m from the center of the milling area (in the case of an ISR, the central processing plant [CPP] location). In contrast, NRC's Regulatory Guide (NUREG) Guidance Document 1569 (NUREG-1569) Acceptance Criteria 2.9.3(2) (NRC 2003) specifies that soil sampling be conducted at both a 5-cm depth as described in RG 4.14 (NRC 1980) and 15-cm for background decommissioning data.

Section 1.1.4(c) of RG 4.14 (NRC 1980) further specifies that subsurface samples collected to a depth of 1-m bgs in three equal intervals be collected out to a distance of 750-m from the center of the CPP and at the center of the CPP.

Section 1.1.4(b) of RG 4.14 (NRC 1980) specifies that surface soil samples (5-cm bgs) should also be collected at each of the locations chosen for air particulate monitoring stations.

The RG 4.14 soil sampling field investigation performed by Tetra Tech met the requirements of RG 4.1.4 (NRC 1980). The RG 4.14 soil sampling field investigation method is presented in Section 2.1.2.1.

Background Soil Sampling Field Investigation:

The second segment of the preoperational soil sampling program was the background soil sampling field investigation. The purpose of this investigation was to establish the background natural uranium (U-nat) and Ra-226 radionuclide concentrations within the proposed disturbed area for the Marsland Expansion Area. Appendix A of 10 CFR Part 40 Criterion 6(6) says that *the design requirements in this criterion for longevity and control of radon releases apply to any portion of a licensed and/or disposal site unless such portion contains a concentration of radium in land, averaged over 100 square meters, which as result of byproduct material, does not exceed the background level by more than: (i) 5 picocuries per gram (pCi/g) of radium-226, and (ii) 15 pCi/g of radium-226 averaged over 15-cm thick layers more than 15-cm below the surface.* On July 21, 1997, the NRC amended the regulations in 10 CFR Part 20 to include explicit radiological criteria for decommissioning (62 FR 139, pp. 39057 – 39092). Subpart E of the amended regulation contains dose-based radiological criteria for restricted and unrestricted release, including a total effective dose equivalent (TEDE) limit for residual radioactivity above background.

The release criteria are stated in terms of background concentrations; it is important to identify how the background levels were established for the site (Abelquist 2000). Establishing background concentrations that describe a distribution of measurement data is necessary to later identify and evaluate contributions attributable to site operations. Establishing background concentrations for comparison with the conditions determined in specific survey units (during decommissioning) entails conducting surveys in one or more reference areas to define the radiological conditions of the site (NRC 2000). There are several sources of information concerning the selection of background reference areas, including NUREG-CR-5849 *Manual for Conducting Radiological Surveys in Support of License Termination* (NRC 1992), NUREG-1501 *Background as a Residual Radioactivity Criterion for Decommissioning* (NRC 1994), and *Multi-Agency Radiation Survey and Site Investigation Manual* (MARRSIM) (NRC 2000). Considerations for selecting background reference areas can be expressed as follows: (1) the background location should be representative of the survey unit location, and (2) the background location should be non-impacted from site operations (Abelquist 2000). The objective is to select non-impacted background reference areas where the distribution of measurements should be the same as those that would be expected in the survey unit if that survey unit had never been contaminated. Since the entire disturbed area at the Marsland Expansion Area has not yet been impacted, the potentially disturbed area itself was selected to represent the background reference area. MARSSIM recognizes the possibility that a survey unit can serve as its own reference area (NRC 2000).

The objective of the surface soils characterization is to collect a sufficient number of soil samples within the background reference area, using a strategic sampling design, to confidently show that the data are representative of the entire survey unit. Tetra Tech considered multiple factors in designing the background soil sampling strategy, including: (1) variability of soil type, (2) the range of gamma radiation observed at the site, (3) use of the NUREG/CR-5849 (NRC 1992) equation for estimating the number of background samples needed, and (4) locating samples in a manner representative of the disturbed area. Applying these factors, the resulting data can be considered representative of the site. The background soil sampling field investigation methods are presented in Section 2.1.2.2.

2.1.2 Methods

This section presents the methods for the preoperational soil sampling program.

2.1.2.1 Regulatory Guide 4.14 Soil Sampling Field Investigation Methods

Tetra Tech conducted the RG 4.14 soil sampling field investigation in May and June 2014. The field investigation included collection of the following: (1) surface radial grid soil samples, (2) subsurface radial grid soil samples, and (3) air particulate monitoring station soil samples. Table 1 provides a summary of the soil sampling types, number of samples collected for each type, sample depth, and analytes tested. Tetra Tech collected 41 surface radial grid soil samples (5-cm bgs) and five subsurface radial grid soil samples (0-cm to 33-cm bgs, 33-cm to 66 -cm bgs, and 66-cm to 100-cm bgs). Tetra Tech collected three separate soil samples to a depth of 5-cm at each air particulate monitoring station. Additional samples were collected to a depth of 0-cm to 15-cm bgs and 15-cm to 30-cm bgs at each air particulate monitoring station.

Table 1 Summary of Regulatory Guide 4.14 Soil Sampling Field Investigation

Soil Sampling Type	# of Sample Locations	# of Samples Collected[1]	Sample Depth[2]	Analytes Tested			
				Radium-226	Natural Uranium	Thorium-230	Lead-210
Surface Radial Grid	41	41	0-cm to 5-cm	41	17	4	4
Subsurface Radial Grid	5	15	0-m to 1-m	15	3	3	3
Air Particulate Monitoring	5	15	0-cm to 5-cm	15	15	15	15
	5	5	0-cm to 15-cm	5	5	5	5
	5	5	15-cm to 30-cm	5	5	5	5

[1]This includes primary samples only, it does not include field QC samples

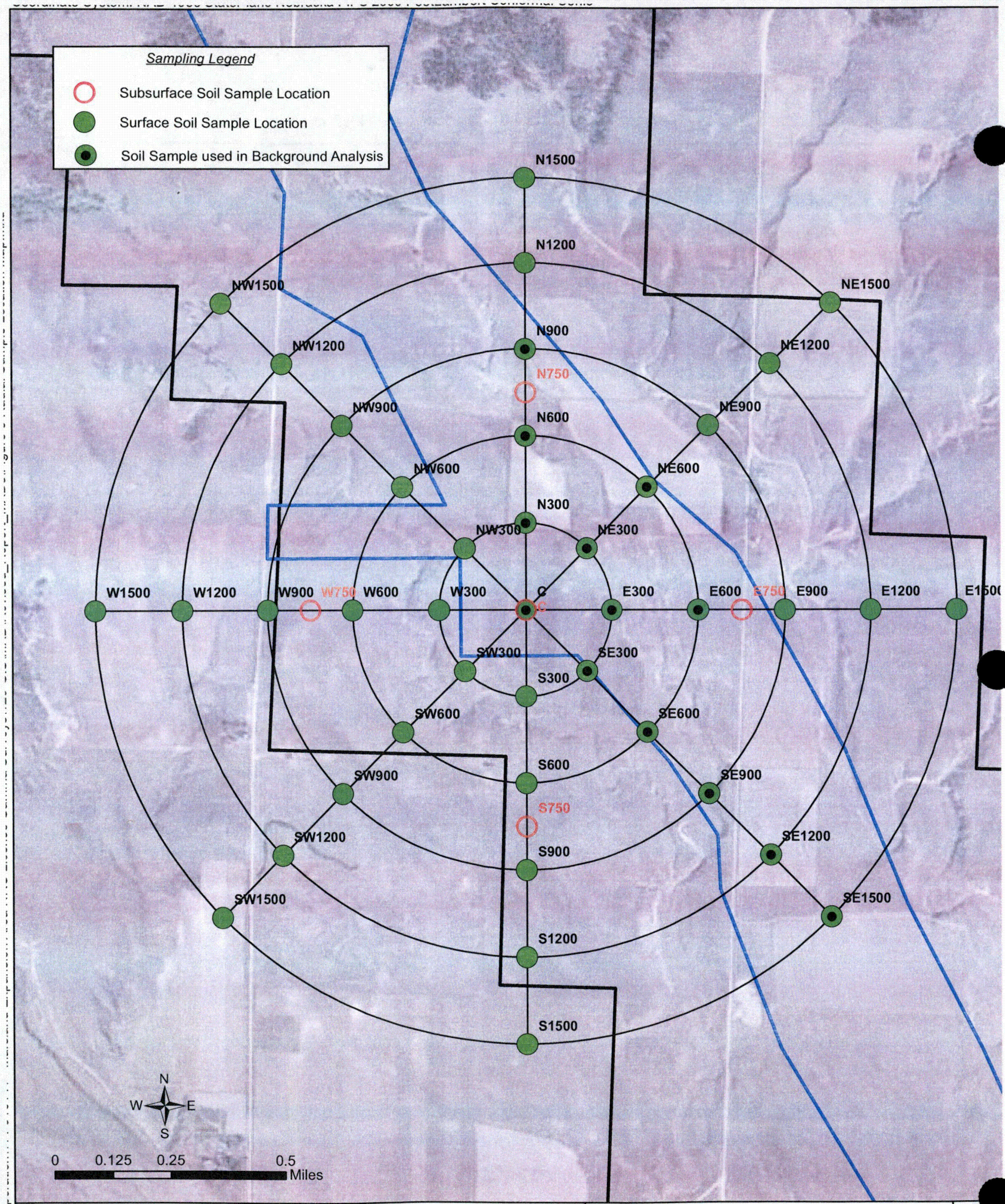
[2]The radial grid subsurface samples were collected to a depth of 1-m subsamples (0-cm to 33-cm, 33-cm to 66-cm, and 66-cm to 100-cm)

The soil samples were collected and submitted for analysis to Inter-mountain Laboratories (IML) in Sheridan, Wyoming (Table 1). Table 2 provides a summary of the laboratory analytical methods. The laboratory testing frequency and reporting limits used in this investigation meet the requirements of Section 2.2 of RG 4.14 (NRC 1980). The surface radial grid soil samples were all analyzed for Ra-226; 10 percent (four samples) were also analyzed for lead-210 (Pb-210), U-nat, and thorium-230 (Th-230). An additional 13 surface radial grid soil samples, located within the boundary of the proposed disturbed area, were analyzed for U-nat, results to be used in the background analysis. The air particulate monitoring soil samples were analyzed for Ra-226, Pb-210, Th-230, and U-nat. Subsurface radial grid soil samples were all analyzed for Ra-226; one set was analyzed for Ra-226, Pb-210, Th-230, and U-nat.

Table 2 Soil Sampling Laboratory Analytical Methods

Parameter	Method	Detection Limit	Reported Units
Radium-226	E901.1 Mod.	0.2	pCi/g
Lead-210	OTW01	0.2	pCi/g
Thorium-230	ACW10	0.2	pCi/g
Natural Uranium	EPA 200.8	0.2	pCi/g

The RG 4.14 soil sampling was performed in accordance with Standard Operating Procedure (SOP) 1 (Appendix A). The results of the RG 4.14 soil sampling field investigation are presented in Section 4.1.1. The radial grid soil sampling locations are provided in Figure 3. The soil sampling locations for the air particulate monitoring station are provided in Figure 4. A scanned copy of the field logbook is provided in Appendix B. A photographic log of the field sampling is provided in Appendix C. The final laboratory reports are provided in Appendix D. Location coordinates for all soil samples are provided in Appendix E.



Legend:

Radial Grid Transect

Disturbed Area

Marsland Permit Boundary

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3801 Automation Way, Suite 100
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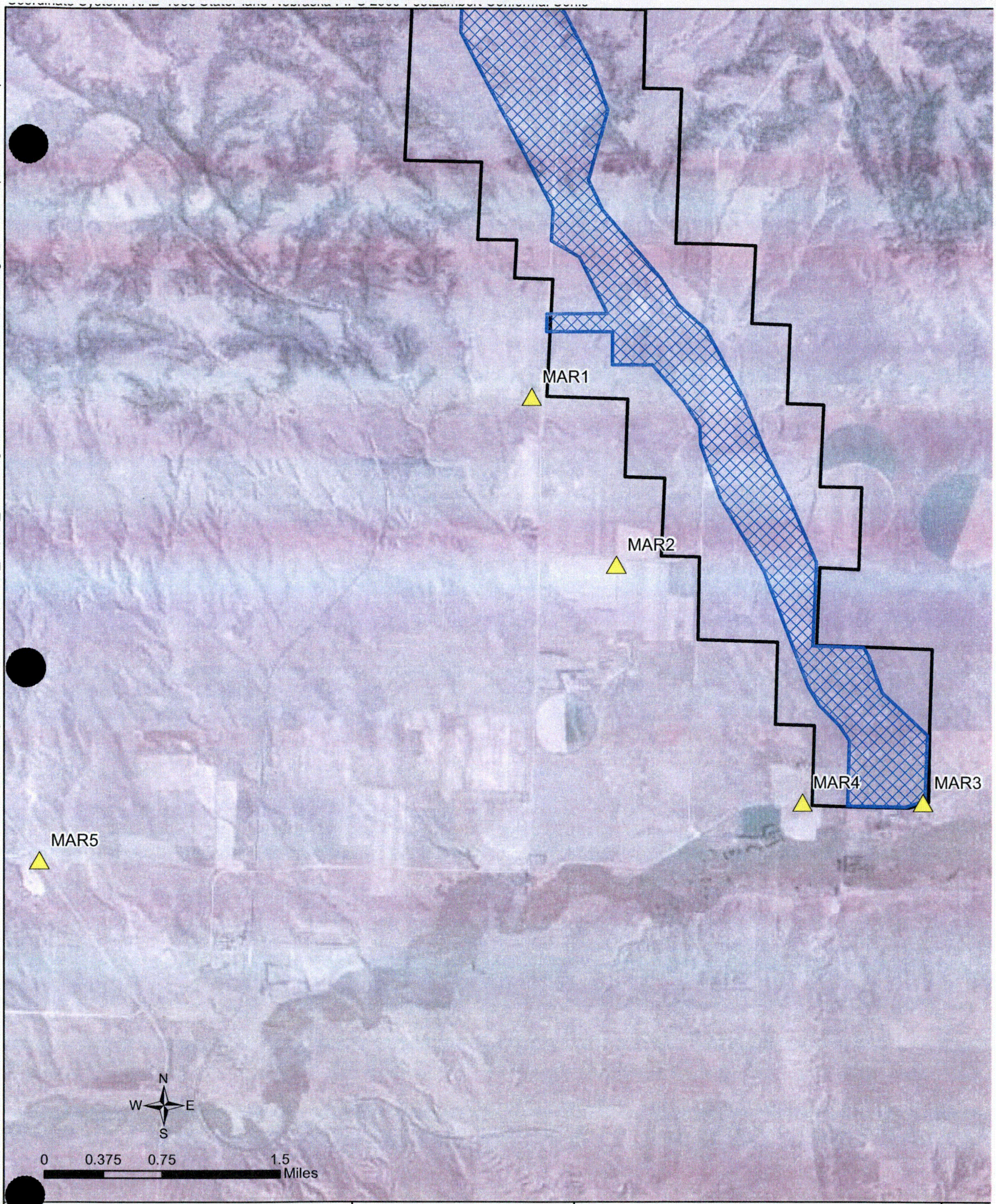
Reg. Guide 4.14
Radial Grid Soil Sample Location Map

2
Revision

Project:	MARSLAND EXPANSION	Project no.: 114-910141	Figure 3
Location:	DAWES COUNTY, NE	3/17/2015	



Legend:

- Air Particulate Monitoring Station Location
- Proposed Disturbed Area
- Marsland Permit Boundary

Issued by:

TETRA TECH
3801 Automation Way, Suite 100
Fort Collins, Colorado 80525
(970) 223-9600 (970) 223-7171 fax

Air Particulate Monitoring Station Sample Location Map

Revision 1

Project: MARSLAND EXPANSION	Project no.: 114-910141		Figure 4
Location: DAWES COUNTY, NE	3/17/2015		

2.1.2.2 Background Soil Sampling Field Investigation Methods

The second portion of the preoperational soil sampling program involved the background soil sampling field investigation. The objectives of this field investigation are described in Section 2.1.1.

The proposed disturbed area was used as a background reference area. An approach provided by NRC was used to determine the number of soil samples required. Guidance in NUREG-5849 (NRC 1992) provides a statistical approach to estimating the total number of samples that are needed to accurately estimate, within ± 20 percent, the true average background at a 95 percent confidence level. The total number of background measurements needed to satisfy the objective is calculated by the following equation presented in section 8.6 of NUREG 5849 (NRC 1992):

Equation 1

$$n_B = \left[\frac{t_{95.5\%,df} * S_x}{0.2 * \overline{X_B}}\right]^2$$

Where

n_B	=	number of background measurements required
$\overline{X_B}$	=	mean of initial background measurements
S_x	=	standard deviation of initial background measurements
df	=	n-1 degrees of freedom, where n is number of initial background data points
$t_{95\%,df}$	=	t statistic for 95% confidence at df

An initial set of samples must be collected and evaluated to use Equation 1 to calculate the number of samples needed. Tetra Tech collected 10 background soil samples (soil correlation samples) at a depth of 0-cm to 15-cm bgs in conjunction with the gamma survey performed in May 2014. The laboratory results of these background samples were used in Equation 1 to determine whether additional background samples were required. The results of the additional sampling analysis, and the parameters used in Equation 1, are presented in Table 3. Appendix F presents the details of the calculations and the statistical tables used.

Table 3 Estimate of Required Number of Supplemental Background Samples, Parameters and Results

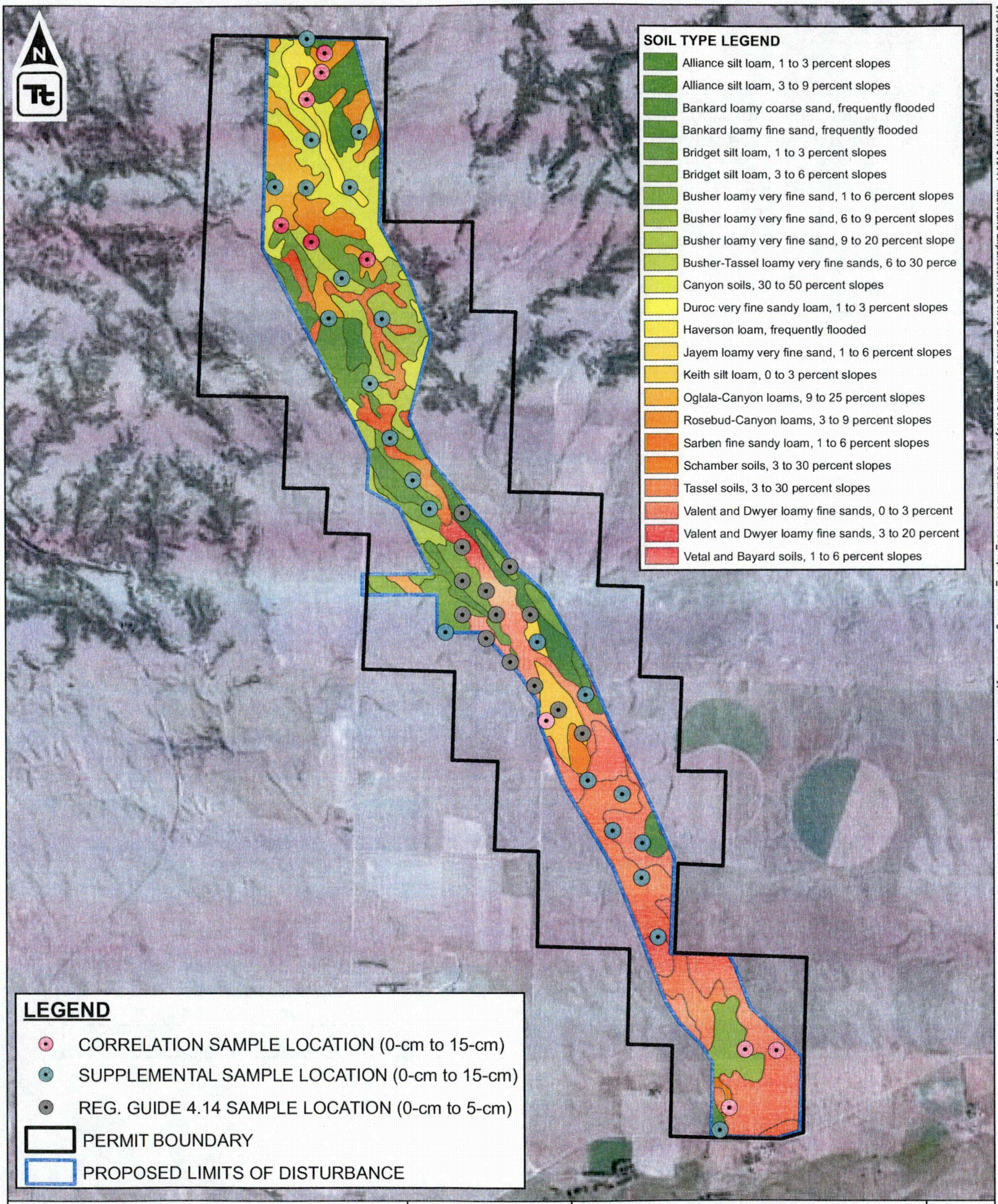
Analyte	n_B	X_B (pCi/g)	S_x (pCi/g)	$t_{95\%,df}$	d_f
U-nat	11	0.41	0.12	2.262	9
Ra-226	24	0.69	0.30	2.262	9

Based on the analysis using Equation 1, it was determined that 14 additional Ra-226 samples (24 total) and one additional natural uranium (11 total) soil sample were needed to accurately estimate, within ± 20 percent, the true average background at a 95 percent confidence level. Tetra Tech selected the soil sample locations based on the following factors: (1) variability of soil type, (2) the range of gamma radiation observed at the site, and (3) the location of samples to be representative of the disturbed area.

Data from the United States Department of Agriculture (USDA) Web Soil Survey program (USDA 2015) were downloaded for the disturbed area to sample based on the variability of soil types found within the boundary of the proposed disturbed area. Soil sample locations were then selected based on the soil types of the site. A total of 23 soil types are found within the proposed disturbed area. Table 4 provides a summary of the number of soil samples collected within each soil type. Figure 5 displays the soil types within the Marsland Expansion Area proposed disturbance boundary and soil sampling locations. Soil types representing 99 percent of the total proposed disturbed area were sampled at the site.

Table 4 Number of Background Soil Samples in Each Soil Type

Soil Type	Number of Soil Samples	Area (ac)	Percent of Disturbed Area
Alliance silt loam, 1 to 3 percent slopes	2	138	7%
Alliance silt loam, 3 to 9 percent slopes	1	23	1%
Bankard loamy coarse sand, frequently flooded	1	8	0%
Bankard loamy fine sand, frequently flooded	1	48	3%
Bridget silt loam, 1 to 3 percent slopes	2	96	5%
Bridget silt loam, 3 to 6 percent slopes	1	57	3%
Busher loamy very fine sand, 1 to 6 percent slopes	4	145	8%
Busher loamy very fine sand, 6 to 9 percent slopes	2	69	4%
Busher loamy very fine sand, 9 to 20 percent slope	1	59	3%
Busher-Tassel loamy very fine sands, 6 to 30 percent	3	95	5%
Canyon soils, 30 to 50 percent slopes	2	187	10%
Duroc very fine sandy loam, 1 to 3 percent slopes	1	0	0%
Haverson loam, frequently flooded	2	50	3%
Jayem loamy very fine sand, 1 to 6 percent slopes	2	11	1%
Keith silt loam, 0 to 3 percent slopes	3	48	2%
Oglala-Canyon loams, 9 to 25 percent slopes	2	92	5%
Rosebud-Canyon loams, 3 to 9 percent slopes	1	92	5%
Sarben fine sandy loam, 1 to 6 percent slopes	0	15	1%
Schamber soils, 3 to 30 percent slopes	1	5	0%
Tassel soils, 3 to 30 percent slopes	1	115	6%
Valent and Dwyer loamy fine sands, 0 to 3 percent	3	176	9%
Valent and Dwyer loamy fine sands, 3 to 20 percent	7	362	19%
Vetal and Bayard soils, 1 to 6 percent slopes	3	45	2%



V:\A-G\Cameco Corpor[illegible]\114-910141 - Marsland Expansion Area NRC License Gamma Surveys\120-GIS\MXD\Revised_Report_MXDs\Figure 5 Soil Typ[illegible] and Sample Location.mxd March, 2015: aaron.orechwa

SCALE IN FEET 0 1,000 2,000	1 INCH = 4,000 FEET (SCALE AT 8.5" X 11")	NOTES: NAD 1983 STATE PLANE NEBRASKA FIPS 2600 FEET	TITLE: **BACKGROUND SOIL SAMPLING LOCATIONS AND SOIL TYPES** A REVISION
PREPARED FOR: Cameco	PREPARED BY: TETRA TECH 3801 Automation Way, Suite 100 Fort Collins, Colorado 80525 (970) 223-9600		PROJECT: MARSLAND EXPANSION LOCATION: DAWES COUNTY, NE PROJECT NO.: 114-910141 DATE: 3/2015 FIGURE: **Figure 5**

Another criterion for selecting soil sample locations was to choose a set that represents the range of gamma exposure rates observed within the proposed disturbed area for the Marsland Expansion Area. On open ground, about two-thirds of the gamma radiation dose comes from radionuclides contained in the top 15-cm of soil (NRC 1994); therefore, it is important to select soil samples over the range of gamma radiation doses to assess the variability in background natural occurring radionuclides in the surface soils. Based on gamma survey data, sample locations selected above were modified, where possible, to allow for sampling throughout the range of gamma exposure rates observed at the site. A box plot in Figure 6 shows the gamma exposure rates (HPIC-converted) measured at each background soil sample location compared with the gamma exposure rates measured during the continuous gamma survey at the site. It was concluded that the background soil samples were collected within the range of gamma radiation observed at the site.

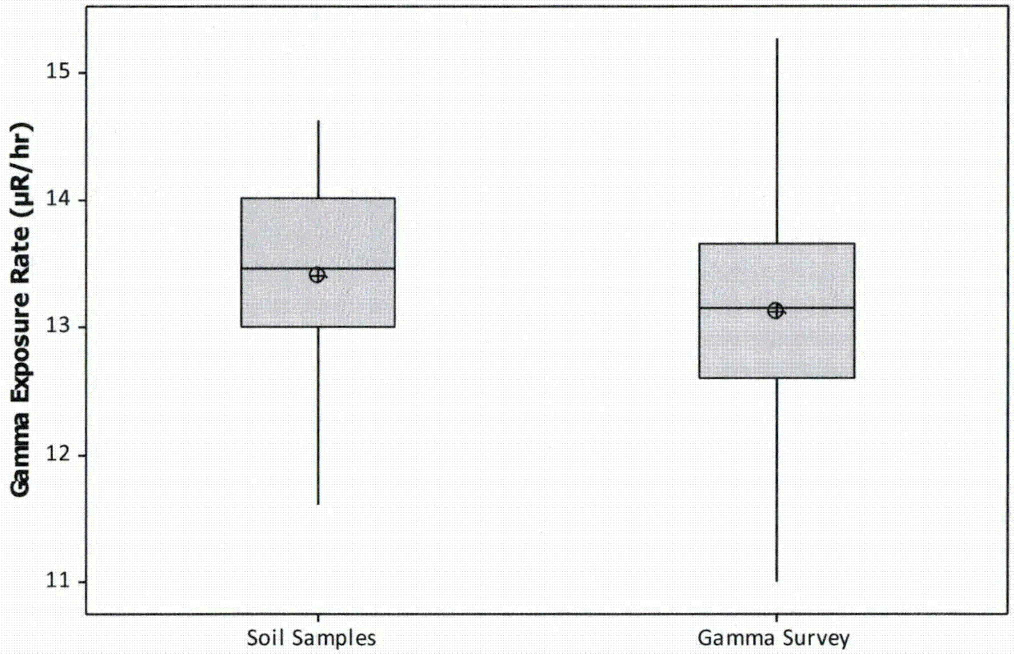


Figure 6 Boxplot of Gamma at Background Soil Sample Locations and Gamma Survey

The final criterion for selection of background soil samples was to cover a spatial extent representative of the disturbed area. As can be seen in Figure 5, the soil samples represent the spatial expanse of site.

Tetra Tech collected 23 soil samples as part of the supplemental background soil sampling field investigation in November 2014. More soil samples were collected than the estimate calculated above to ensure that the data represent the site. Table 5 provides a summary of the soil sampling types, number of samples collected for each type, sample depth, and analytes tested. Ten samples (0-cm to 15 cm bgs) were collected following the methods outlined in SOP 2 in Appendix A. An additional 23 supplemental samples (0-cm to 15-cm bgs) were collected following the methods outlined in SOP 1 (Appendix A).

Table 5 Summary of Background Soil Sampling Field Investigation

Soil Sampling Type	# of Sample Locations	# of Samples Collected[1]	Sample Depth (bgs[2])	Analytes Tested			
				Ra-226	U-nat	Th-230	Pb-210
RG 4.14	13	13	0-cm to 5-cm	13	13	-	-
Soil Correlation	10	10	0-cm to 15-cm	10	10	10	10
Supplemental Background	23	23	0-cm to 15-cm	23	23	-	-

[1]This number includes primary samples only, it does not include field QC duplicate samples
[2]bgs= below ground surface

The factors noted above were considered in selecting background soil sample locations. The background soil data collected within the Marsland Expansion Area proposed disturbed area can be considered representative of the site.

2.1.3 QA/QC

Tetra Tech developed and applied specific QA/QC requirements as part of the preoperational soil sampling program. Tetra Tech applied the QA/QC planning recommendations presented in the Multi-Agency Radiological Laboratory Analytical Protocols (MARLAP) Manual (NRC 2004) and in MARSSIM (NRC 2000). MARLAP provides guidance for planning, implementation, and assessment phases of projects that require the laboratory analysis of radionuclides. Tetra Tech established QA/QC requirements for both field soil sampling and laboratory activities. The field QC requirements involved collection of field QC duplicate samples and evaluation of the precision of the results. The laboratory QA/QC methods involved the review and evaluation of the analytical QC summary reports included in the IML final laboratory reports.

Precision was analyzed by collecting field QC duplicate samples and evaluating the laboratory data between primary and duplicate samples. Field QC duplicates are samples obtained from one location, homogenized, and divided into separate containers and treated as separate samples throughout the sample handling and analytical process. Field QC duplicates were collected and submitted to the analytical laboratory at a minimum frequency of one per 20 primary soil samples. Field QC duplicate samples were sent blind to the laboratory, along with the primary soil samples. The soil sampling QA/QC methods are presented in SOP 1 of Appendix A.

Table 1 and Table 5 summarize the numbers of RG 4.14 and background primary soil samples collected. Table 6 summarizes, by type, the number of primary and field QC duplicate samples collected. A total of 114 primary samples and eight field duplicates were submitted for laboratory analysis. The frequency of field QC duplicates met the project QC requirements. A detailed summary, including the QA/QC methods, project QC acceptance criteria, and data validation results, is provided in Appendix G.

Table 6 Summary of Field QC Primary and Duplicate Soil Samples

Soil Sample Type	Purpose	# of Primary Samples Collected	# of Field QC Duplicates
Surface Radial Grid	RG 4.14	41	2
Subsurface Radial Grid	RG 4.14	15	1
Air Particulate Monitoring	RG 4.14	25	2
Soil Correlation	Background Determination	10	1
Supplemental Background	Background Determination	23	2
Total		**114**	**8**

2.2 PREOPERATIONAL GAMMA SURVEY FIELD INVESTIGATION

2.2.1 Objective

Tetra Tech performed two gamma survey approaches: (1) RG 4.14 *direct gamma field investigation,* and (2) *continuous gamma survey field investigation.* Both of these approaches used NRC guidance documents for ISR uranium projects. Background radiation, as described in NUREG-1757 Vol. 1, Rev. 2 *Consolidated Decommission Guidance* (NRC 2006a) and NUREG-1757 Vol. 2, Rev. 1 *Characterization, Survey, and Determination of Radiological Criteria* (NRC 2006b), is radiation from cosmic sources, naturally occurring radioactive material (including radon), and global fallout. The following discussion provides the objectives and basis for each sampling approach.

Regulatory Guide 4.14 Direct Gamma Measurement Field Investigation

Section 1.1.5 of RG 4.14 (NRC 1980) specifies that before mining can begin, the gamma exposure rate should be measured at 150-m intervals in each of the eight compass directions out to a distance of 1500-m from the center of the milling area (in the case of ISR mining, the CPP location). It also states that direct gamma measurements should be collected at the air particulate monitoring stations. Direct gamma measurements can be accomplished using passive integration devices, pressurized ionization chambers, or properly calibrated portable survey instruments (NRC 1980). Tetra Tech's methods for the direct gamma measurements are presented in Section 2.2.2.1.

Continuous Gamma Survey Field Investigation

The gamma measurement procedures described in Section 1.1.5 of RG 4.14 (NRC 1980) do not consider technologies available beyond 1980. More recent radiological survey guidelines found in MARSSIM (NRC 2000) specify the use of mobile systems with integrated positioning systems that can acquire data over large land areas. In some cases, gamma scanning can be used to augment soil sampling over a large land area (Whicker et al. 2006). Abelquist (2000) states that scanning can be used as an indicator when it is necessary to collect soil samples during decommissioning (One example where this condition is satisfied is at sites where windblown tailings are present). A soil correlation analysis was performed at the Marsland site in May 2014; however, the correlation was not useable since the variability of natural soil radionuclides is small at this site. Still, the results of the preoperational gamma survey may be used to compare preoperational, operational, and post-operational survey results to identify changes (ORAU 2014).

A continuous gamma radiation survey using global positioning system (GPS) equipment was performed at Marsland. The purpose of the continuous gamma radiation survey was to characterize the spatial distribution of gamma radiation emanating from surface soils on the site. The survey was consistent with ISR permit recovery application guidelines in Regulatory Guide 3.46 (NRC 1982) and NUREG-1569 (NRC 2003), as well as radiological survey guidelines outlined in MARSSIM (NRC 2000).

2.2.2 Methods

2.2.2.1 Regulatory Guide 4.14 Direct Gamma Measurement Field Investigation Methods

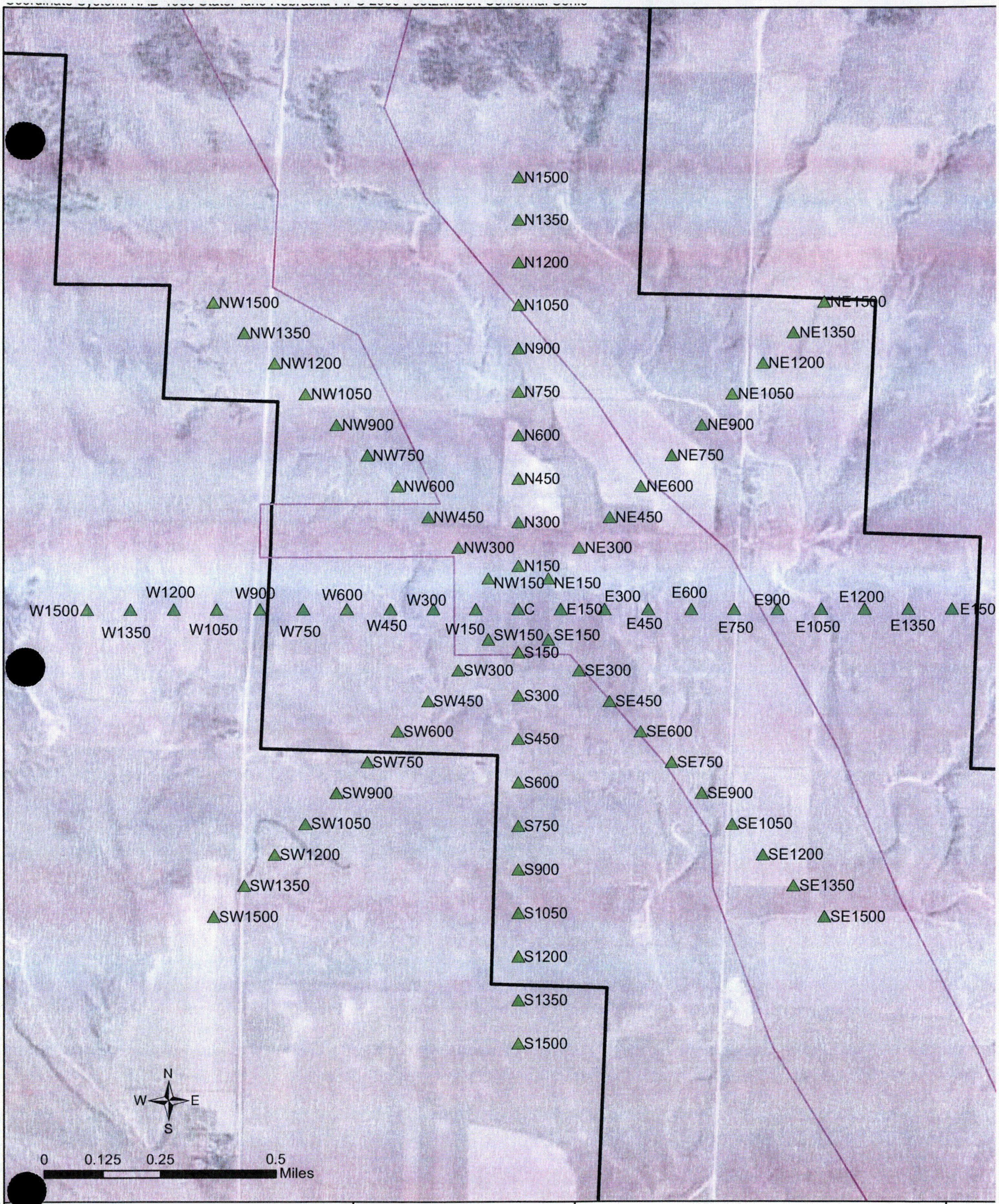
The first portion of the preoperational gamma survey program was the RG 4.14 direct gamma field investigation. The objectives of this field investigation are described in Section 2.2.1. Tetra Tech conducted the RG 4.14 direct gamma field investigation in June 2014. Tetra Tech field engineers measured the gamma exposure rates at pre-determined locations using a factory-calibrated 2-inch by 2-inch unshielded sodium iodide (NaI) detector (Ludlum Model 44-10) coupled to a Ludlum Model 2350-1 data logger. RG 4.14 (NRC 1980) does not specify a detector height to be used for the direct gamma radiation measurements. As a result, Tetra Tech field engineers collected measurements using a detector height of 1-m above the ground surface. This height is considered standard practice (EPA 1999; OSD 2012; NRC 1992) for the detection of gamma-emitting radionuclides in surface soils.

The radial grid direct gamma measurement sampling locations are shown on Figure 7 and the geographic coordinates for the direct gamma measurement locations are provided in Appendix E. Direct gamma measurements were also collected at the air particulate monitoring stations shown in Figure 4. A scanned copy of the field logbook is included in Appendix B. A photographic log of the field sampling is included in Appendix C. The gamma radiation survey QA/QC methods are described in Section 2.2.3. The results of the direct gamma survey are presented in Section 4.2.1.

2.2.2.2 Continuous Gamma Survey Field Investigation Methods

The second portion of the preoperational gamma survey program performed at the Marsland Expansion Area was the continuous gamma survey field investigation. The objectives of this field investigation are described in Section 2.2.1. Tetra Tech field engineers, in conjunction with CBR's radiation technicians, performed the continuous gamma survey field investigation in May 2014. Each member of the gamma survey field crew was trained and experienced in use of the systems. The continuous gamma survey field investigation was carried out in accordance with the methods outlined in SOP 2 (Appendix A). Field engineers used backpack-mounted survey systems. The systems consisted of GPS receivers and radiation detectors, and used proprietary software developed by Tetra Tech (Tetra Tech 2006). The survey system allows for rapid gamma scanning with simultaneous geospatial data acquisition. The GPS units utilize the Wide Area Augmentation System (WAAS), providing GPS signal correction. The Ludlum gamma detector system was, with the GPS unit, linked to a portable computer to record location/exposure rate data pairs once per second.

A scanned copy of the field logbook is included in Appendix B. A photographic log of the field sampling is included in Appendix C. The gamma radiation survey QA/QC methods are described in Section 2.2.3. The results of the continuous gamma survey field investigation are presented in Section 4.2.2.



Legend:

▲ **1.3** -- Gamma Exposure Rate (µR/hr)

Proposed Disturbed Area

Marsland Permit Boundary

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TETRA TECH

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Fort Collins, Colorado 80525
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Direct Gamma Measurement Locations

1 Revision

Project:	MARSLAND EXPANSION	Project no.: 114-910141	Figure 7
Location:	DAWES COUNTY, NE	MARCH 2015	

2.2.2.3 Geospatial Interpolation Methods

Geostatistical methods are powerful tools for mapping spatial data and providing interpolation between existing data points. Geostatistical methods are commonly used in geographic, geological, and environmental sciences as outlined in Journel et al. (1978), David (1977), and Verly et al. (1984). More specifically, geospatial analysis kriging techniques applied to radiological survey data are discussed in Whicker et al. (2008). This study used kriging to interpolate the gamma radiation point data. There are two primary types of spatial interpolation methods: deterministic and geostatistical.

Kriging is a method of interpolation that has become an important tool in the field of geostatistics and earth sciences. The technique was named after Daniel G. Krige (Krige 1982), a South African mining engineer who developed the tool in an attempt to more accurately predict ore reserves and mineral resources. There are three types of kriging: ordinary, simple, and universal. The kriging results are displayed on a grid or mesh and provide characterizations of parameters across an entire site. The process was applied to the gamma radiation survey data, the radionuclide soil concentrations, and the dose rate data collected at the site.

Tetra Tech used *ArcGIS Geostatistical Analyst* for all analyses on the gamma radiation data. The exploratory spatial data analysis tools contained within *ArcGIS Geostatistical Analyst* allow the engineer to visualize and explore the data sets, using statistical methods, to best determine which model and parameters most accurately represent the data. In addition to prediction mapping, *ArcGIS Geostatistical Analyst* allows for mapping of prediction uncertainties and errors, along with providing for validation and cross-validation tools that allow the analyst to evaluate the model and the corresponding predictions. Multiple kriging scenarios were evaluated for the site, and the best method was selected based on a number of criteria.

2.2.3 QA/QC

All radiological characterization projects conducted by Tetra Tech incorporate QA/QC protocols. In general, QA includes qualitative factors that provide confidence in the results, while QC involves quantitative, field evidence that supports the validity of results. The gamma survey QA/QC procedures used in this investigation are widely used and represent accepted techniques for characterization of gamma radiation in the uranium and health physics industry. All instruments utilized during the gamma radiation surveys were factory calibrated within the past 12 months, per the manufacturer's recommendation. Two types of QC measurements were performed for this project: (1) daily background and check source (cesium-137) QC measurements conducted in the field, and (2) pre-survey and post-survey background and cesium-137 QC measurements performed at a location off site (the Tetra Tech office in Fort Collins, Colorado). A detailed summary of the gamma survey QA/QC methods and results is provided in Appendix G. A scanned copy of the field logbook is included in Appendix B. Scanned copies of the calibration documentation for the gamma radiation instruments are included in Appendix H. The following section discusses the HPIC cross-calibration objectives, methods, QA/QC, and results.

3.0 HPIC CROSS-CALIBRATION

3.1 Objectives

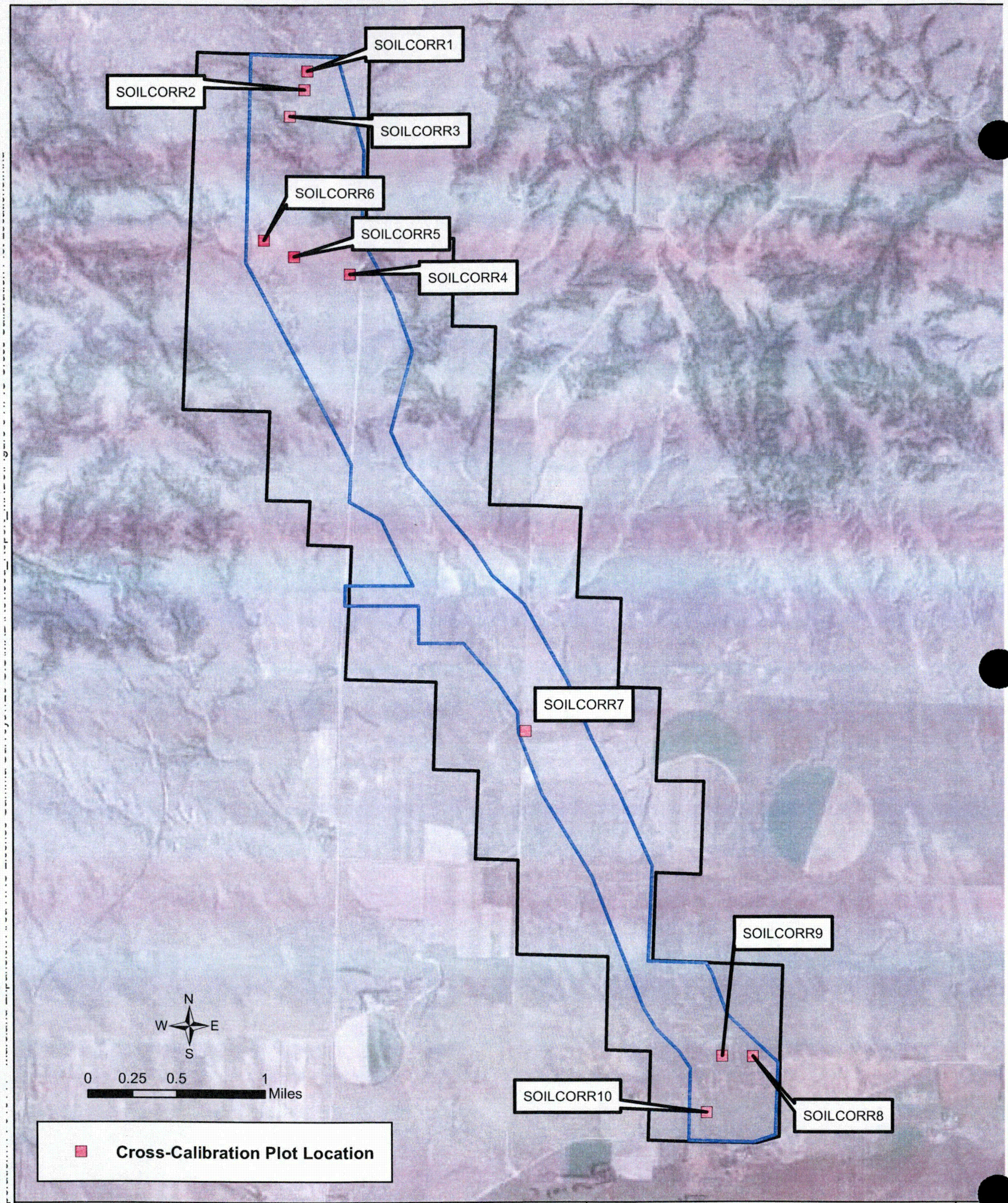
MARRSIM specifies that NaI scintillation detectors may be used for direct gamma measurements if they are cross-calibrated to an HPIC for the energy range of interest (NRC 2000). The HPIC is widely recognized as the industry standard for measurement of exposure rates (Abelquist 2001). The HPICs exhibit a reasonably flat energy response across a wide gamma energy range, compared with the NaI scintillation detectors. By developing a cross-calibration model, the sturdier and more sensitive NaI scintillation detector is more appropriate for field gamma exposure rate measurements. Tetra Tech quantified the measurement relationship between the HPIC and the NaI detection systems for the site. The methods are presented below.

3.2 Methods

A cross-calibration was performed using a RSS-131 Environmental Radiation Monitor HPIC from GE Energy and the Ludlum 44-10 NaI portable scintillation detectors. Tetra Tech performed the cross-calibration analysis in accordance with SOP 3 (Appendix A). Static measurements were taken at various locations covering a range of exposure rates representative of the proposed disturbed area at the Marsland Expansion Area to perform HPIC/NaI cross-calibrations. The cross-calibration measurements were performed at the same times and locations as those were for the gamma/radium-226 correlation plot measurements in May 2014. The center of the sensitive volume of the HPIC was positioned 1-m above the ground surface at each cross-calibration location, and 5 minutes of readings (approximately 300 data points) were logged and averaged from the HPIC. The location directly below the HPIC was marked, and personnel equipped with a backpack-mounted NaI system positioned the detector above the marked location. A minimum of 30 readings from the static NaI system were logged and averaged. The HPIC/NaI cross-calibration plot locations are shown in Figure 8. These data pairs were then used to establish the cross-correlation; the results are presented in Section 3.4. A scanned copy of the field logbook is included in Appendix B. A photographic log is included in Appendix C.

3.3 QA/QC

The RSS-131 Environmental Radiation Monitor HPIC from GE Energy used for this project was rented from the Environmental Restoration Group of Albuquerque, New Mexico. The QA protocol for using this instrument consists of following the factory-recommended calibration frequency (12-month frequency). A copy of the calibration certificate for the HPIC is provided in Appendix H.



Legend:

Disturbed Area

Marsland Permit Boundary

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3801 Automation Way, Suite 100
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HPIC/NaI Cross-Calibration Plot Locations

1 Revision

Project: MARSLAND EXPANSION	Project no.: 114-910141	Figure 8	
Location: DAWES COUNTY, NE	3/2015		

3.4 RESULTS

Tetra Tech performed a cross-calibration analysis between the HPIC and NaI radiation detectors in accordance with SOP 2 (Appendix A) and per Section 3.2, above. Gamma measurements were collected at the center of the soil correlation plot using the HPIC low-level radiation detector and the NaI scintillation detector. A summary table providing the average HPIC and average NaI readings at each plot is provided in Table 7. The ratio between the average NaI and HPIC readings ranged between 0.81 and 1.0.

Table 7 Summary of HPIC and NaI Measurement Data

Plot Location	Average HPIC[1] Reading (μR/hr[2])	Average NaI[3] Static Reading (μR/hr)	Ratio (NaI/HPIC)
SOILCORR1	13.9	13.9	1.00
SOILCORR2	14.2	14.0	0.99
SOILCORR3	13.4	13.1	0.98
SOILCORR4	14.0	13.7	0.98
SOILCORR5	11.6	9.38	0.81
SOILCORR6	12.2	10.5	0.86
SOILCORR7	13.2	11.6	0.87
SOILCORR8	13.5	12.8	0.95
SOILCORR9	13.1	12.2	0.94
SOILCORR10	11.7	10.0	0.86

[1]*HPIC = high pressurized ionization chamber*
[2]*μR/hr = microroentgen per hour*
[3]*NaI = sodium iodide scintillator*

A linear regression was performed on the average HPIC and NaI gamma exposure rates recorded at the plot locations. Figure 9 shows the results of the cross-calibration linear regression analysis. The Pearson's correlation coefficient (R) calculated for this analysis is 0.98, indicating a strong correlation between the readings. The residuals of the linear regression were analyzed as shown in Figure 10. The standardized residuals follow the normal probability plot; the model shows a strong statistical relationship. Equation 2 was used to best relate the NaI measured gamma exposure rates to HPIC-measured gamma exposure rates for the site. The results of the gamma survey are presented in terms of *HPIC* measurements using this relationship, and are described in Section 4.2.2.

Equation 2:
$$HPIC\left[{}^{\mu R}/_{hour}\right] = 0.5406\,NaI\left[{}^{\mu R}/_{hour}\right] + 6.519$$

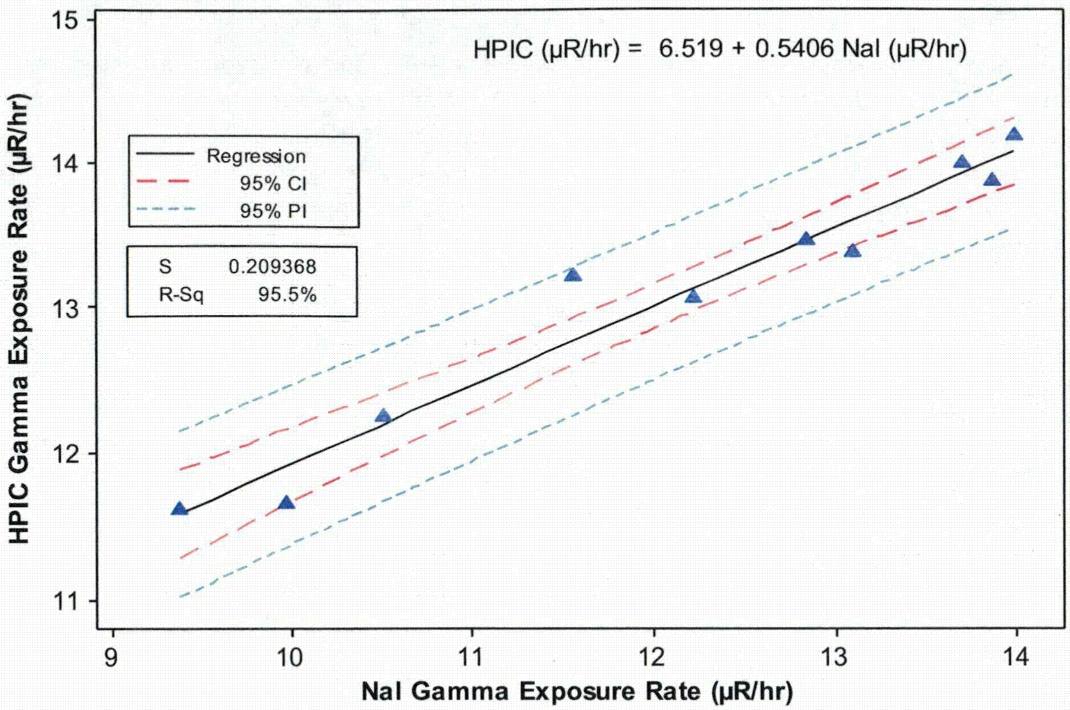


Figure 9 HPIC vs. NaI Cross-Calibration Analysis Linear Regression

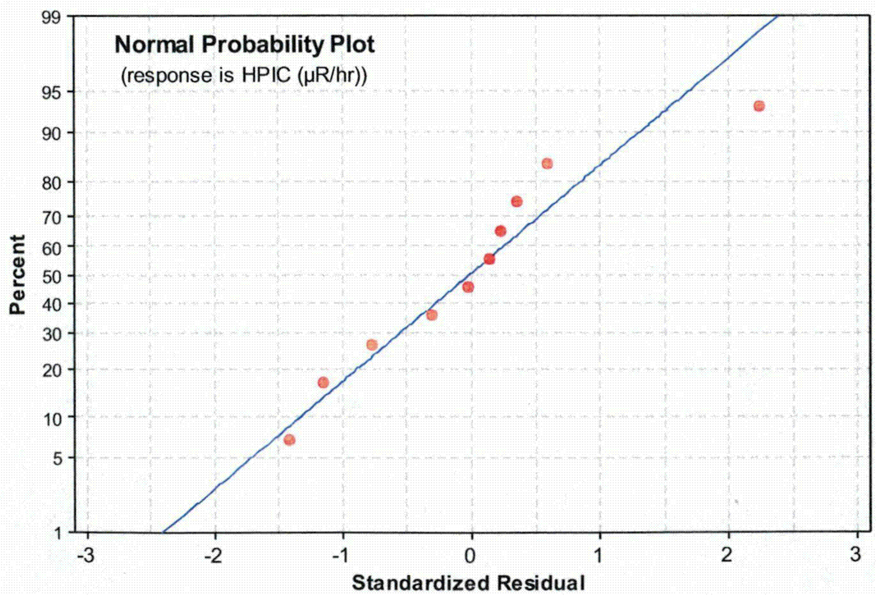


Figure 10 Normal Probability Plot of Standardized Residuals of HPIC/NaI Linear Regression

4.0 RESULTS

4.1 PREOPERATIONAL SOIL SAMPLING PROGRAM

The preoperational soil sampling program was conducted according to the methods described in Section 2.1 and consisted of (1) an *RG 4.14 soil sampling field investigation*, and (2) a *background soil sampling field investigation*. The results of both field investigations are presented in this section.

4.1.1 RG 4.14 Soil Sampling Field Investigation

Soil samples were collected in accordance with SOP 1 of Appendix A, and Section 2.1.2.1. The field investigation consisted of collecting surface radial grid soil samples, subsurface radial grid samples, and air particulate monitoring station soil samples. The following sections present the results for each of these soil sampling types.

4.1.1.1 Surface Radial Grid Soil Sampling

Table 1 provides a summary of the number of samples collected for each type, sample depth, and analytes tested for the surface radial grid soil sampling. Tetra Tech collected 41 radial grid surface soil samples (5-cm bgs) at 300-m increments in the eight compass directions (N, S, E, W, NW, NE, SW, SE) originating from the center of the CPP location, and a sample was collected at the center location. The surface radial grid soil sample locations are shown in Figure 3, and the geographic coordinates are provided in Appendix E. The laboratory analytical methods and reporting limits are shown in Table 2. The summary statistics for the surface radial grid soil samples are provided in Table 8. The laboratory results for the surface radial grid soil samples are provided in Table 9.

Table 8 Summary Statistics of Surface Radial Grid Soil Sampling (0-cm to 5-cm bgs)

Analyte	Total # of Samples Analyzed	# of Non-Detects[1]	Average (pCi/g[2])	Minimum (pCi/g)	Maximum (pCi/g)	Standard Deviation (pCi/g)	Median (pCi/g)
Radium-226	41	2	0.7	0.2	1.2	0.3	0.6
Lead-210	4	0	1.4	1.1	2.0	0.4	1.3
Thorium-230	4	0	0.4	0.3	0.6	0.1	0.4
Uranium	17[3]	0	0.5	0.4	1.6	0.1	0.6

[1]All non-detects data points were set to the value of the reporting limit prior to performing statistical analysis.
[2]pCi/g = picocuries per gram
[3]13 surface radial grid soil samples were used in the background analysis

Table 9 Laboratory Results for Surface Radial Grid Soil Samples (0-cm to 5-cm bgs)

Sample ID	Radium-226		Lead-210		Thorium-230		Natural Uranium
	Reported Value (pCi/g[1])	Precision +/- (pCi/g)	Reported Value (pCi/g)	Precision +/- (pCi/g)	Reported Value (pCi/g)	Precision +/- (pCi/g)	Reported Value (pCi/g)
CENTER	0.5	0.4					0.6
N300	0.8	0.3					1.1
N600	0.5	0.3					1.4
N900	0.7	0.4					0.6
N1200	1.1	0.4					
N1500	0.5	0.2					
NE300	0.5	0.3					0.5
NE600	0.4	0.1					0.4
NE900	0.5	0.3					
NE1200	0.4	0.3	1.3	0.5	0.4	0.1	0.5
NE1500	0.6	0.4					
E300	1.0	0.5					1.6
E600	0.5	0.4					0.7
E900	0.9	0.4					
E1200	0.8	0.3					

[1]pCi/g = picocuries per gram

Table 9 Cont. Laboratory Results for Radial Grid Soil Samples (0-cm to 5-cm bgs)

Sample ID	Radium-226		Lead-210		Thorium-230		Natural Uranium
	Reported Value (pCi/g)	Precision +/- (pCi/g)	Reported Value (pCi/g)	Precision +/- (pCi/g)	Reported Value (pCi/g)	Precision +/- (pCi/g)	Reported Value (pCi/g)
E1500	1.0	0.4					
SE300	0.9	0.4					0.6
SE600	0.9	0.3					0.5
SE900	0.5	0.3					0.6
SE1200	0.7	0.3					1.5
SE1500	0.5	0.3					0.4
S300	0.8	0.3					
S600	< 0.2	-					
S900	0.6	0.4					
S1200	0.6	0.3					
S1500	1.2	0.4					
SW300	0.6	0.3	2.0	0.5	0.4	0.2	0.4
SW600	0.6	0.4					
SW900	1.1	0.4					
SW1200	1.0	0.4	1.3	0.5	0.6	0.2	0.6
SW1500	0.8	0.4					
W300	0.6	0.3					
W600	0.5	0.4					
W900	1.2	0.4					
W1200	1.1	0.4					
W1500	<0.2	-					
NW300	1.1	0.4					
NW600	0.7	0.3					
NW900	0.3	0.3	1.1	0.4	0.3	0.1	0.4
NW1200	0.5	0.3					
NW1500	0.5	0.3					

[1]pCi/g = picocuries per gram

4.1.1.2 Subsurface Radial Grid Soil Sampling

Table 1 provides a summary of the number of samples collected for each type, sample depth, and analytes tested for the subsurface radial grid soil sampling. Tetra Tech collected subsurface radial grid soil samples (0-cm to 33-cm bgs, 33-cm to 66-cm bgs, and 66-cm to 100-cm bgs), at 750-m increments in the four primary compass directions originating from the center of the CPP location. A set of samples was also collected at grid center. The radial grid soil sample locations are shown in Figure 3, and the geographic coordinates are provided in Appendix E. The laboratory analytical methods and reporting limits are shown in Table 2. The summary statistics for the surface radial grid soil samples are provided in Table 10. The laboratory results for the subsurface radial grid soil samples are provided in Table 11.

Table 10 Summary Statistics for Subsurface Radial Grid Soil Sampling

Analyte	Total # of Samples Analyzed[1]	# of Non-Detects	Average (pCi/g[2])	Minimum (pCi/g)	Maximum (pCi/g)	Standard Deviation (pCi/g)	Median (pCi/g)
0-cm to 33-cm Sample Statistics							
Radium-226	5	0	0.7	0.3	1.3	0.4	0.6
Lead-210	1	0	1.5	1.5	1.5	-	-
Thorium-230	1	0	0.5	0.5	0.5	-	-
Natural Uranium	1	0	0.5	0.5	0.5	-	-
33-cm to 66-cm Sample Statistics							
Radium-226	5	0	0.8	0.5	1.2	0.3	0.8
Lead-210	1	1	1.0	1.0	1.0	-	-
Thorium-230	1	0	0.8	0.8	0.8	-	-
Uranium	1	0	0.5	0.5	0.5	-	-
66-cm to 100-cm Sample Statistics							
Radium-226	5	1	0.6	0.2	0.8	0.3	0.7
Lead-210	1	0	1.4	1.4	1.4	-	-
Thorium-230	1	0	0.5	0.5	0.5	-	-
Natural Uranium	1	0	0.5	0.5	0.5	-	-
All Subsurface Sample Statistics							
Radium-226	15	1	0.7	0.2	1.3	0.3	0.7
Lead-210	3	1	1.3	1.0	1.5	0.3	1.4
Thorium-230	3	0	0.6	0.5	0.8	0.2	0.5
Natural Uranium	3	0	0.5	0.5	0.5	0.0	0.5

[1]All non-detects data points were set to the value of the reporting limit prior to performing statistical analysis.
[2]pCi/g = picocuries per gram

Table 11 Laboratory Results for Subsurface Radial Grid Soil Samples

Sample ID	Sample Depth	Radium-226		Lead-210		Thorium-230		Natural Uranium
		Reported Value (pCi/g[1])	Precision +/- (pCi/g)	Reported Value (pCi/g)	Precision +/- (pCi/g)	Reported Value (pCi/g)	Precision +/- (pCi/g)	Reported Value (pCi/g)
CENTER	0-cm to 33-cm	0.6	0.4	1.5	0.5	0.5	0.2	0.5
	33-cm to 66-cm	1.2	0.4	< 0.2	-	0.8	0.2	0.5
	66-cm to 100-cm	0.7	0.3	1.4	0.5	0.5	0.2	0.5
N750	0-cm to 33-cm	1.3	0.5					
	33-cm to 66-cm	0.8	0.3					
	66-cm to 100-cm	0.8	0.3					
W750	0-cm to 33-cm	0.3	0.3					
	33-cm to 66-cm	0.7	0.3					
	66-cm to 100-cm	< 0.2	-					
E750	0-cm to 33-cm	0.7	0.4					
	33-cm to 66-cm	0.9	0.4					
	66-cm to 100-cm	0.7	0.3					
S750	0-cm to 33-cm	0.5	0.3					
	33-cm to 66-cm	0.5	0.3					
	66-cm to 100-cm	0.4	0.3					

[1]pCi/g = picocuries per gram

4.1.1.3 Air Particulate Monitoring Station Soil Sampling

Table 1 provides a summary of the number of samples collected for each type, sample depth, and analytes tested for the air particulate station monitoring soil sampling. Tetra Tech collected three separate soil samples to a depth of 5-cm at each air particulate monitoring station. Additional samples were collected to a depth of 0-cm to 15-cm bgs and 15-cm to 30-cm bgs at each air particulate monitoring station. A map showing the locations of the air monitoring stations is provided in Figure 4, and the geographic coordinates are provided in Appendix E. A total of 25 samples were collected and submitted for laboratory analysis. Table 12 provides the laboratory results for the air particulate monitoring station soil samples.

Table 12 Laboratory Results for Air Particulate Monitoring Station Soil Samples

Air Monitoring Station ID	Sample ID	Sampling Depth (bgs)	Radium-226		Lead-210		Thorium-230		Natural Uranium
			Reported Value (pCi/g)	Precision +/- (pCi/g)	Reported Value (pCi/g)	Precision +/- (pCi/g)	Reported Value (pCi/g)	Precision +/- (pCi/g)	Reported Value (pCi/g)
MAR1	MAR1SOILA-01-5	0-cm to 5-cm	1.8	1.0	3.9	0.5	0.2	0.1	0.4
	MAR1SOILB-01-5	0-cm to 5-cm	0.4	0.5	3.1	0.4	0.4	0.2	0.4
	MAR1SOILC-01-5	0-cm to 5-cm	0.3	0.4	2.4	0.4	0.2	0.1	0.4
	MAR1SOIL-01-15	0-cm to 15-cm	0.2	0.5	3.4	0.6	0.3	0.2	0.5
	MAR1SOIL-01-30	15-cm to 30-cm	0.7	0.5	6.3	0.5	0.5	0.2	0.5
MAR2	MAR2SOILA-01-5	0-cm to 5-cm	1.1	0.4	2.2	0.5	0.4	0.1	0.4
	MAR2SOILB-01-5	0-cm to 5-cm	1.1	0.5	1.8	0.3	0.5	0.1	0.5
	MAR2SOILC-01-5	0-cm to 5-cm	0.9	0.4	1.3	0.3	0.4	0.1	0.5
	MAR2SOIL-01-15	0-cm to 15-cm	1.0	0.4	2.1	0.6	0.3	0.1	0.5
	MAR2SOIL-01-30	15-cm to 30-cm	1.5	0.4	< 0.2	-	0.4	0.1	0.5
MAR3	MAR3SOILA-01-5	0-cm to 5-cm	0.3	0.3	2.2	0.4	0.3	0.1	0.3
	MAR3SOILB-01-5	0-cm to 5-cm	0.3	0.3	1.5	0.5	< 0.2	-	< 0.2
	MAR3SOILC-01-5	0-cm to 5-cm	0.5	0.3	1.8	0.3	< 0.2	-	0.3
	MAR3SOIL-01-15	0-cm to 15-cm	0.4	0.4	2.5	0.4	< 0.2	-	0.3
	MAR3SOIL-01-30	15-cm to 30-cm	0.5	0.3	1.7	0.3	0.3	0.1	0.4
MAR4	MAR4SOILA-01-5	0-cm to 5-cm	0.9	0.3	1.5	0.3	0.3	0.2	0.4
	MAR4SOILB-01-5	0-cm to 5-cm	0.8	0.4	1.8	0.3	0.4	0.1	0.6
	MAR4SOILC-01-5	0-cm to 5-cm	0.9	0.3	1.8	0.3	0.4	0.1	0.4
	MAR4SOIL-01-15	0-cm to 15-cm	1.0	0.4	1.7	0.3	0.4	0.1	0.4
	MAR4SOIL-01-30	15-cm to 30-cm	0.7	0.3	1.8	0.3	0.5	0.2	0.6
MAR5	MAR5SOILA-01-5	0-cm to 5-cm	0.2	0.3	1.5	0.5	0.2	0.1	0.4
	MAR5SOILB-01-5	0-cm to 5-cm	0.4	0.2	< 0.2	-	0.3	0.1	0.3
	MAR5SOILC-01-5	0-cm to 5-cm	0.4	0.2	< 0.2	-	< 0.2	-	0.3
	MAR5SOIL-01-15	0-cm to 15-cm	0.6	0.3	1.3	0.5	0.2	0.1	0.4
	MAR5SOIL-01-30	15-cm to 30-cm	0.5	0.3	< 0.2	-	< 0.2	-	0.3

4.1.2 Background Soil Sampling Field Investigation

The methods for the background soil sampling field investigation are presented in Section 2.1.2.2. Tetra Tech collected 13 RG 4.14 surface radial grid soil samples (0-cm to 5-cm bgs), 10 soil correlation samples (0-cm to 15-cm bgs), and 23 supplemental background soil samples (0-cm to 15-cm bgs) to be used as part of the background analysis. The supplemental background soil sample locations were located based on criteria described in Section 2.1.2.2 (soil type, range of gamma, and spatial extent). The locations of the background soil samples are shown in Figure 5, and the geographic coordinates are presented in Appendix E. A total of 46 soil samples were used for background determination for Ra-226 and U-nat concentrations in soil. The average value represents the true background value to within ± 20 percent at a 95 percent confidence level, per NRC 1992 discussions. The summary statistics for the background soil samples are provided in Table 13. The laboratory results for the background soil samples are shown in Table 14 through Table 16.

Table 13 Final Background Soil Analysis for Radium-226 and Natural Uranium

Analyte	Total # of Samples Analyzed	# of Non-Detects[1]	Average (pCi/g[2])	Minimum (pCi/g)	Maximum (pCi/g)	Median (pCi/g)	Standard Deviation (pCi/g)
RG 4.14 Surface Radial Grid Samples Used in Background Analysis (0-cm to 5-cm)							
Radium-226	13	0	0.6	0.4	1.0	0.5	0.2
Uranium	13	0	0.8	0.4	1.6	0.6	0.4
Soil Correlation Samples Used in Background Analysis (0-cm to 15-cm)							
Radium-226	10	0	0.7	0.2	1.2	0.7	0.3
Uranium	10	0	0.4	0.3	0.6	0.4	0.1
Supplemental Background Soil Samples Used in Background Analysis (0-cm to 15-cm)							
Radium-226	23	1	0.7	0.2	1.1	0.7	0.3
Uranium	23	0	0.6	0.3	1.7	0.5	0.3
Final Background Analysis							
Radium-226	46	1	0.7	0.2	1.2	0.7	0.3
Uranium	46	0	0.6	0.3	1.7	0.5	0.4

[1]All non-detects data points were set to the value of the reporting limit prior to performing statistical analysis.
[2]pCi/g = picocuries per gram

The average Ra-226 and U-nat concentrations within the Marsland Expansion Area proposed disturbance area are 0.7 pCi/g Ra-226 and 0.6 pCi/g U-nat. As shown in Section 2.1.2.2, these average levels represent the true background average to within ± 20 percent at a 95 percent confidence level. The final laboratory reports are provided in Appendix D. A scanned copy of the field logbook is provided in Appendix B. A photographic log is presented in Appendix C. A detailed data validation and QC review, included in Appendix G, was performed and indicated that the soil sampling for this project met the project QC acceptance criteria.

Table 14 RG 4.14 Surface Radial Grid Soil Samples Used in Background Analysis (0-cm to 5-cm bgs)

Sample ID	Radium-226		Uranium
	Reported Value (pCi/g[1])	Margin Error +/- (pCi/g)	Reported Value (pCi/g)
CENTER	0.5	0.4	0.6
N300	0.8	0.3	1.1
N600	0.5	0.3	1.4
N900	0.7	0.4	0.6
NE300	0.5	0.3	0.5
NE600	0.4	0.1	0.4
E300	1.0	0.5	1.6
E600	0.5	0.4	0.7
SE300	0.9	0.4	0.6
SE600	0.9	0.3	0.5
SE900	0.5	0.3	0.6
SE1200	0.7	0.3	1.5
SE1500	0.5	0.3	0.4

[1]pCi/g = picocuries per gram

Table 15 Soil Correlation Samples Used in Background Analysis (0-cm to 15-cm bgs)

Sample ID	Radium-226		Uranium
	Reported Value (pCi/g[1])	Margin of Error +/- (pCi/g)	Reported Value (pCi/g)
SOILCORR1	1.0	0.3	0.6
SOILCORR2	0.7	0.4	0.5
SOILCORR3	1.2	0.4	0.5
SOILCORR4	1.0	0.4	0.5
SOILCORR5	0.2	0.2	0.3
SOILCORR6	0.6	0.3	0.3
SOILCORR7	0.5	0.3	0.3
SOILCORR8	0.5	0.3	0.5
SOILCORR9	0.7	0.3	0.3
SOILCORR10	0.5	0.2	0.3

[1]pCi/g = picocuries per gram

Table 16 Supplemental Background Soil Samples Used in Background Analysis (0-cm to 15-cm bgs)

Sample ID	Radium-226 Reported Value (pCi/g[1])	Radium-226 Margin Error +/- (pCi/g)	Uranium Reported Value (pCi/g)
MARSS-01	0.8	0.4	0.6
MARSS-02	1.0	0.3	1.7
MARSS-03	0.4	0.4	0.7
MARSS-04	0.9	0.4	0.5
MARSS-05	0.3	0.4	0.4
MARSS-06	1.0	0.4	0.6
MARSS-07	< 0.2	-	0.5
MARSS-08	0.8	0.4	0.6
MARSS-09	0.4	0.2	0.3
MARSS-10	0.5	0.4	0.5
MARSS-11	1.1	0.4	0.7
MARSS-12	0.7	0.4	0.4
MARSS-13	0.6	0.4	0.6
MARSS-14	0.4	0.3	0.4
MARSS-15	1.1	0.4	0.4
MARSS-16	0.5	0.3	0.3
MARSS-17	0.7	0.4	0.5
MARSS-18	0.7	0.4	0.4
MARSS-19	0.7	0.3	0.5
MARSS-20	0.6	0.3	1.3
MARSS-21	0.4	0.2	0.4
MARSS-22	1.0	0.3	0.5
MARSS-23	0.9	0.4	0.4

[1]pCi/g = picocuries per gram

4.2 Preoperational Gamma Survey Program

4.2.1 RG 4.14 Direct Gamma Measurement Field Investigation

Field personnel collected direct gamma measurements using portable NaI scintillation detectors in accordance with the methods outlined in Section 2.2.2.1. The values measured were then converted to HPIC equivalent gamma exposure rates using Equation 2 in Section 3.4. A map showing the results of the radial grid direct gamma measurement is provided in Figure 11. A total of 81 direct gamma measurements were collected as part of the baseline radiological site investigation. The direct gamma measurements (HPIC converted) ranged between 11.8 microroentgen per hour (µR/hr) and 14.2 µR/hr, with average and median gamma exposure rates of 13.2 µR/hr and 14.2 µR/hr. Table 17 provides the summary statistics for the direct gamma measurements. The direct gamma measurements were collected solely to satisfy the requirements of RG 4.14 (NRC 1980), and these values are not used in calculating the background radiation levels within the proposed disturbed area for the Marsland Expansion Area; however, the average value is nearly identical to the calculated average in the continuous gamma survey.

Table 17 Summary Statistics for Radial Grid Direct Gamma Measurements

Total # of Direct Gamma Measurements	Average (µR/hr[1])	Minimum (µR/hr)	Maximum (µR/hr)	Median (µR/hr)
81	13.2	11.8	14.2	13.3

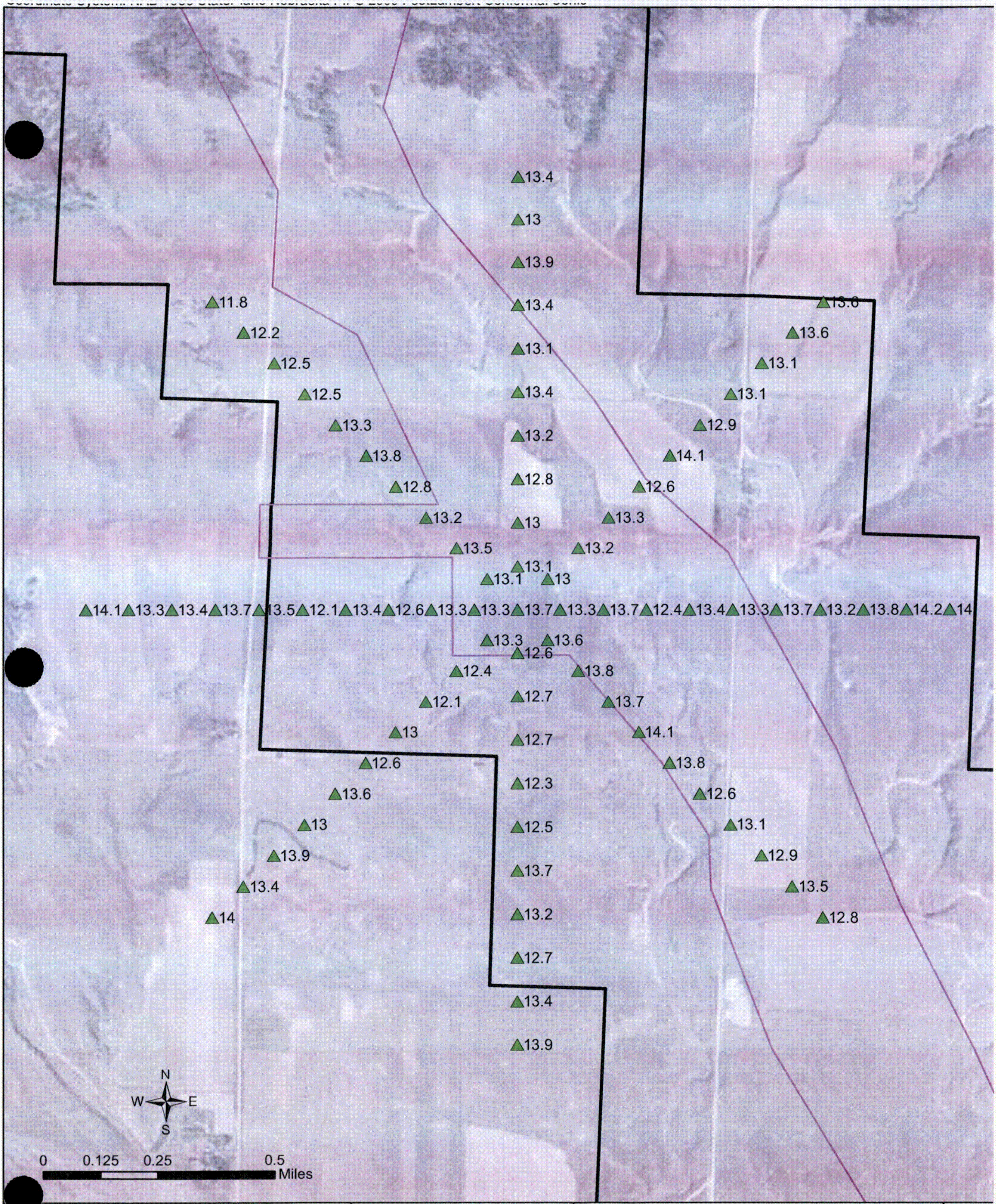
[1]µR/hr = microroentgen per hour

Additionally, direct gamma radiation measurements and HPIC measurements were collected at the air particulate monitoring stations per RG 4.14 (NRC 1980). A summary of the direct gamma measurements (HPIC and NaI) collected at the air particulate monitoring stations is provided in Table 18.

Table 18 Summary: Direct Gamma (HPIC and NaI) Measurements at Air Particulate Monitoring Stations

Sampling Location	Average HPIC Reading (µR/hr)	Average NaI Static Reading (µR/hr)	Ratio (NaI/HPIC)
MAR1	12.3	11.8	0.96
MAR2	13.7	13.6	0.99
MAR3	12.1	10.5	0.87
MAR4	13.1	12.4	0.94
MAR5	12.4	11.2	0.90

HPIC = high pressurized ionization chamber
NaI = sodium iodide scintillator



Legend:

▲ **1.3** -- Gamma Exposure Rate (μR/hr)

Proposed Disturbed Area

Marsland Permit Boundary

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Direct Gamma Measurement Results Map

1 Revision

Project:	MARSLAND EXPANSION	Project no.: 114-910141	Figure 11
Location:	DAWES COUNTY, NE	MARCH 2015	

4.2.2 Continuous Gamma Survey Field Investigation

Tetra Tech performed a continuous gamma radiation survey in May 2014 and June 2014 in accordance with SOP 2 (Appendix A) and with Section 2.2.2.2. A cross-calibration analysis was performed between the HPIC and the portable NaI scintillation detectors that were used for the continuous gamma survey. A strong correlation was found between the HPIC and the mobile NaI systems, and a model (Equation 2) was developed to convert the measurements collected with the NaI systems to HPIC-equivalent gamma exposure rates. The results presented here show the HPIC-equivalent gamma exposure rates.

The GPS-integrated mobile radiation detection systems were used to collect gamma exposure rate data over the expanse of the 1,938-acre disturbed area contained within the Marsland Expansion Area. The gamma surveys were generally performed at an approximate scan transect width of 50 meters. A smaller scan transect width (higher density) was applied in areas where elevated readings were observed. A total of 122,795 useable gamma exposure rate measurements were collected during the survey. The gamma exposure rates ranged between 10.9 µR/hr and 18.2 µR/hr. The average and median gamma exposure rates were 13.1 µR/hr and 13.1 µR/hr. Table 19 provides the summary statistics for the HPIC-equivalent gamma exposure rate data.

The average background gamma exposure rate within the proposed disturbed area for the Marsland Expansion Area is 13.1 µR/hr. The results of the preoperational gamma survey may be used for comparison with operational and post-operational survey results to identify any potential changes during the life of the mine. The gamma exposure rate data at the site exhibit Gaussian trends and may be classified as originating from a normal distribution. A relative frequency histogram of the data set fitted to a normal distribution is shown in Figure 12. A map showing the raw continuous NaI gamma exposure rate data is provided in Figure 13. The geospatial technique, kriging, was applied to the data set and provides a continuous surface averaged in a grid, as shown in Figure 14.

Table 19 Summary Statistics for Continuous Gamma Survey (HPIC-Equivalent)

Summary Statistic	Value
# of Samples	122,795
Average (µR/hr[1])	13.1
Standard Deviation (µR/hr)	0.75
Median (µR/hr)	13.1
Minimum (µR/hr)	10.9
Maximum (µR/hr)	18.2
90th Percentile (µR/hr)	14.1
95th Percentile (µR/hr)	14.3
99th percentile (µR/hr)	14.8

[1]µR/hr = microroentgen per hour

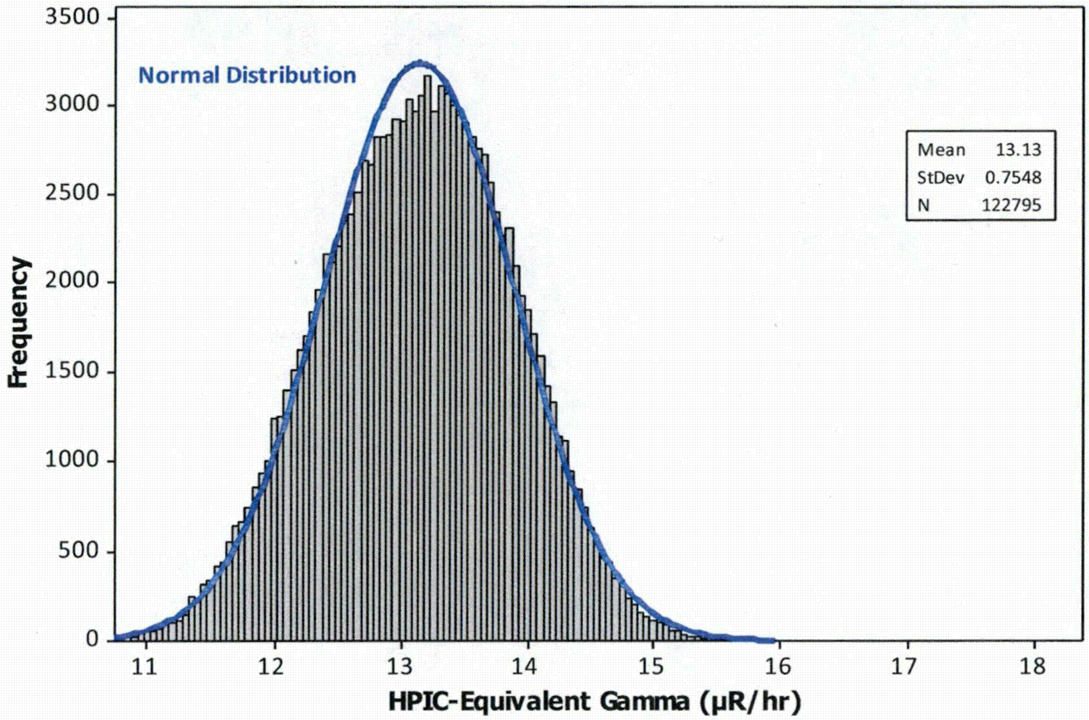
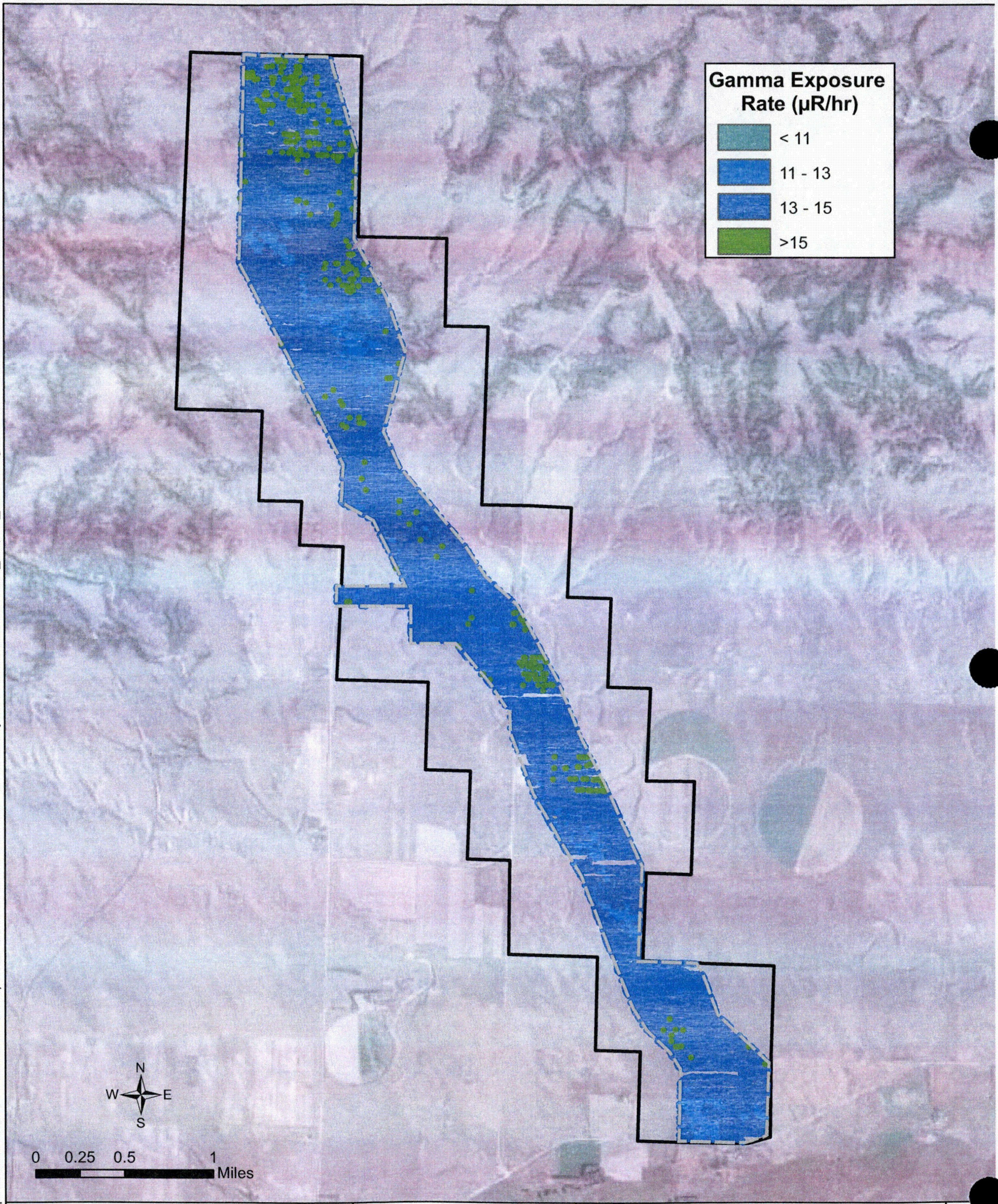


Figure 12 Frequency Histogram of HPIC Gamma Exposure Rate at Marsland Expansion Area



Legend:

Proposed Limits of Disturbance

Marsland Permit Boundary

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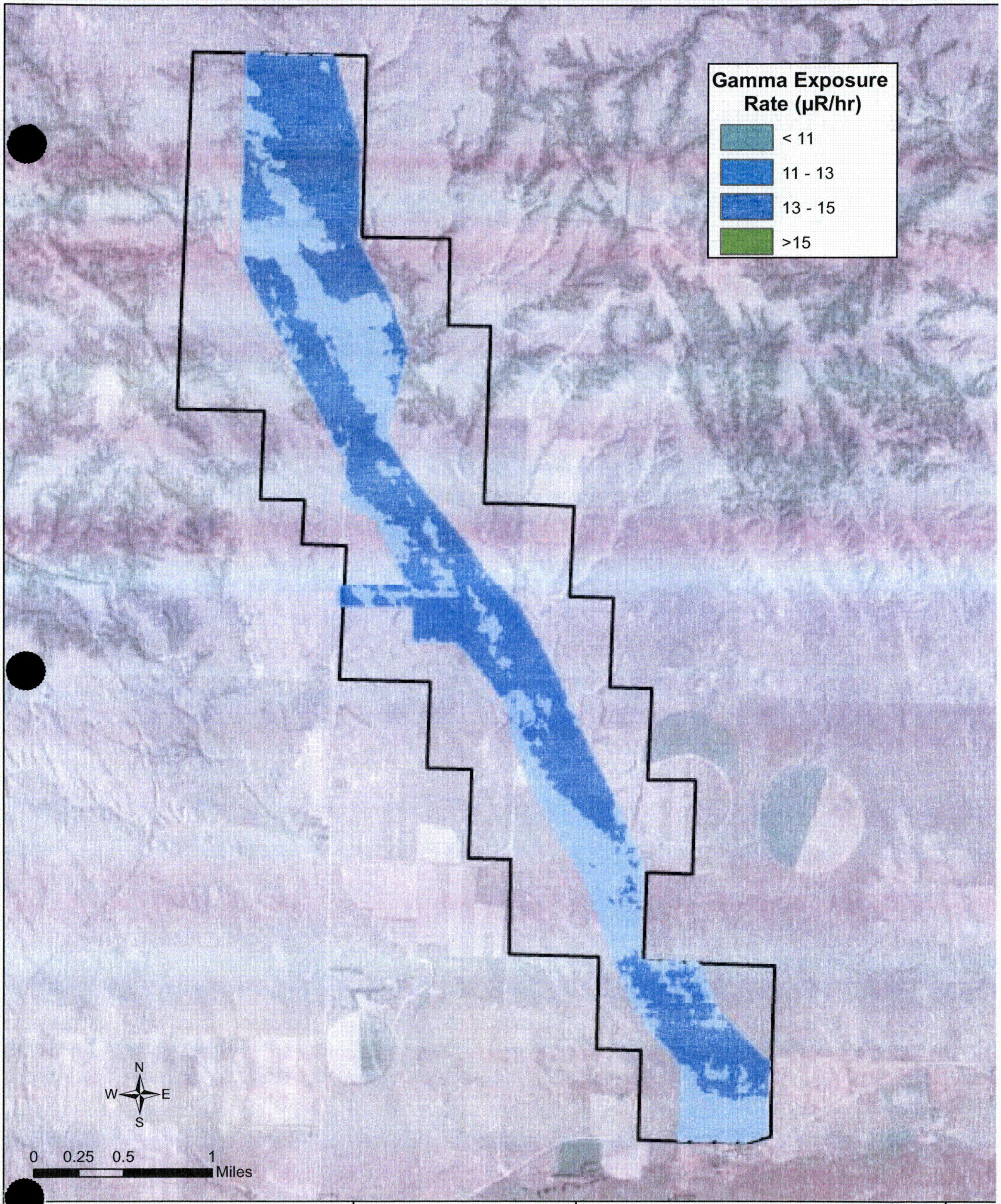
HPIC-Equivalent Gamma Exposure Rate Map

1 Revision

Project:	MARSLAND EXPANSION	Project no.: 114-910141	Figure 13
Location:	DAWES COUNTY, NE	3/2014	



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Proposed Limits of Disturbance

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HPIC-Equivalent Kriged Gamma Exposure Rate Map

Revision 1

Project: MARSLAND EXPANSION	Project no.: 114-910141	Figure 14
Location: DAWES COUNTY, NE	3/2014	

5.0 CONCLUSIONS

Tetra Tech performed a baseline radiological investigation Tetra Tech at Crowe Butte Resource's Marsland Expansion Area in situ recovery uranium project located in Dawes County, Nebraska. The purpose of the investigation was to collect site-specific preoperational radiological data to assist in development of the technical report to be submitted to the U.S. Nuclear Regulatory Commission.

The baseline radiological investigation presented in this report included preoperational soil sampling and preoperational gamma surveys. Both of these programs were designed to collect sufficient information to establish background radiological characteristics of the proposed disturbed area for the Marsland Expansion Area using the sampling frequency, methods, locations, and density found in various NRC guidance documents. The studies were aimed at satisfying the requirements set forth in Regulatory Guide 4.14 (NRC, 1980) for preoperational monitoring at proposed uranium mines in the United States, as well as other guidance. The studies were designed to address Final Rule, Regulatory Guide 3.46, and other applicable regulations. An alternative approach was also followed to supplement existing guidance.

The field investigations consisted of soil sampling and gamma surveys within the Marsland Expansion Area proposed disturbed area, to establish background levels for radiological parameters. The results of the background soil sampling radionuclide analysis indicate that the average background radium-226 and natural uranium average concentrations are 0.7 pCi/g and 0.6 pCi/g. These concentrations accurately represent true background values to within ± 20 percent at a 95 percent confidence level, per the analysis provided in this document. The soil sampling data collected at the site can be considered to represent the site based on the criteria used in development of the sampling strategy. The average background gamma exposure rate representative of the proposed disturbed area at the Marsland Expansion Area is 13.1 µR/hr. The gamma survey also provides a detailed spatial characterization of the gamma levels at the site.

The data presented in this report can be used quantitatively in support of the technical report that will be submitted by Crowe Butte Resources as part of the license application process. Additionally, this information can later be compared with operational data and may also be used during development of site decommissioning plans.

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