Figures

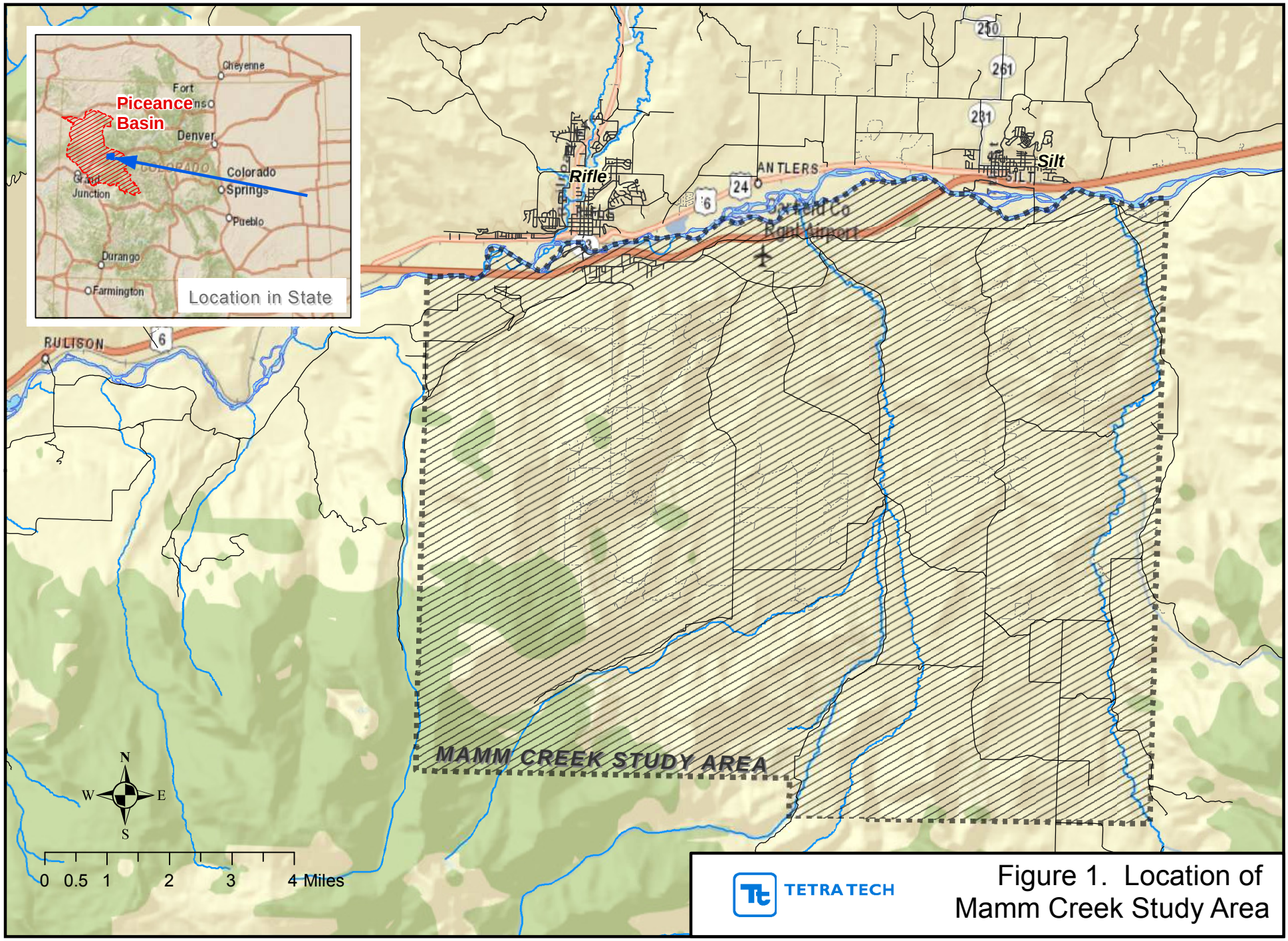
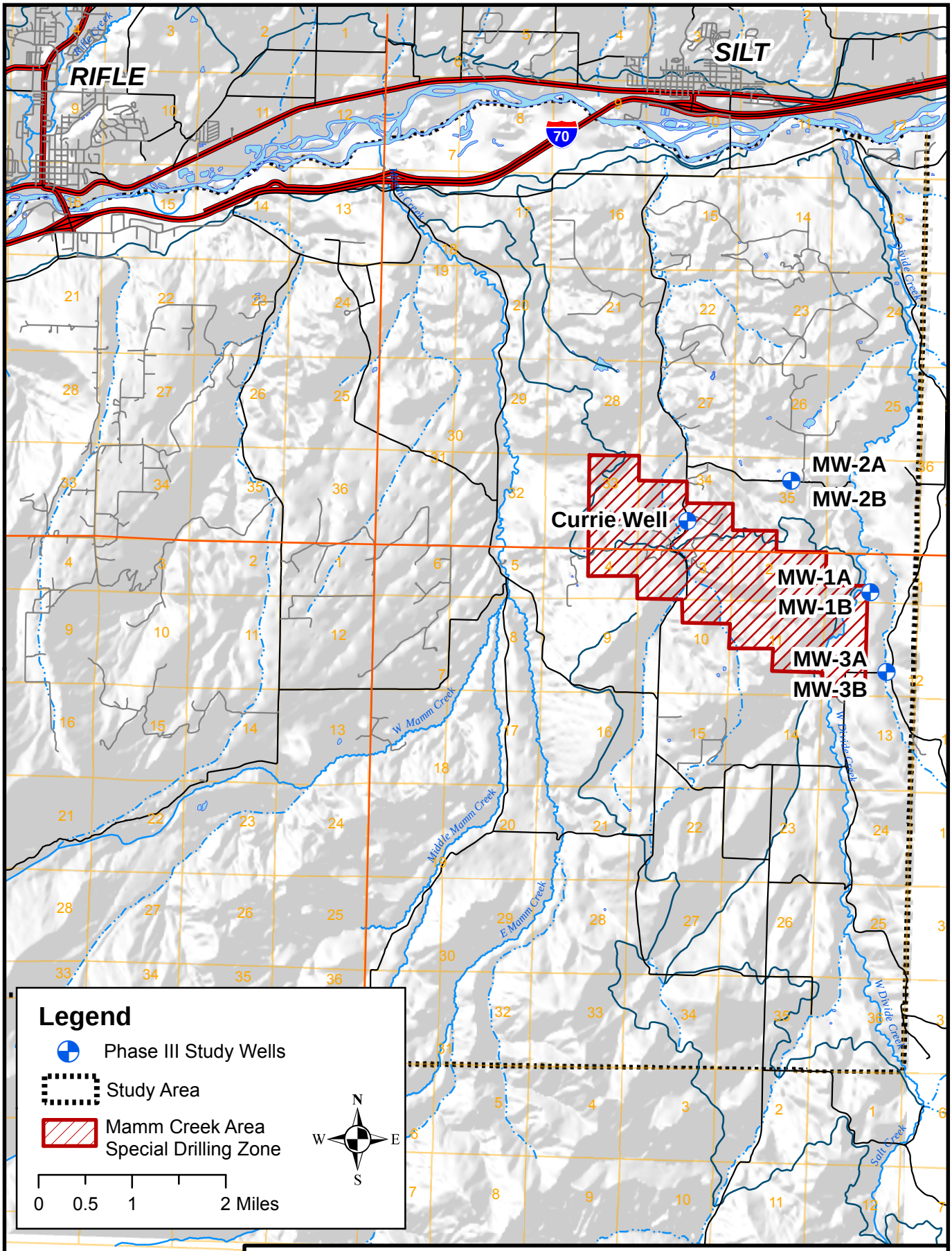
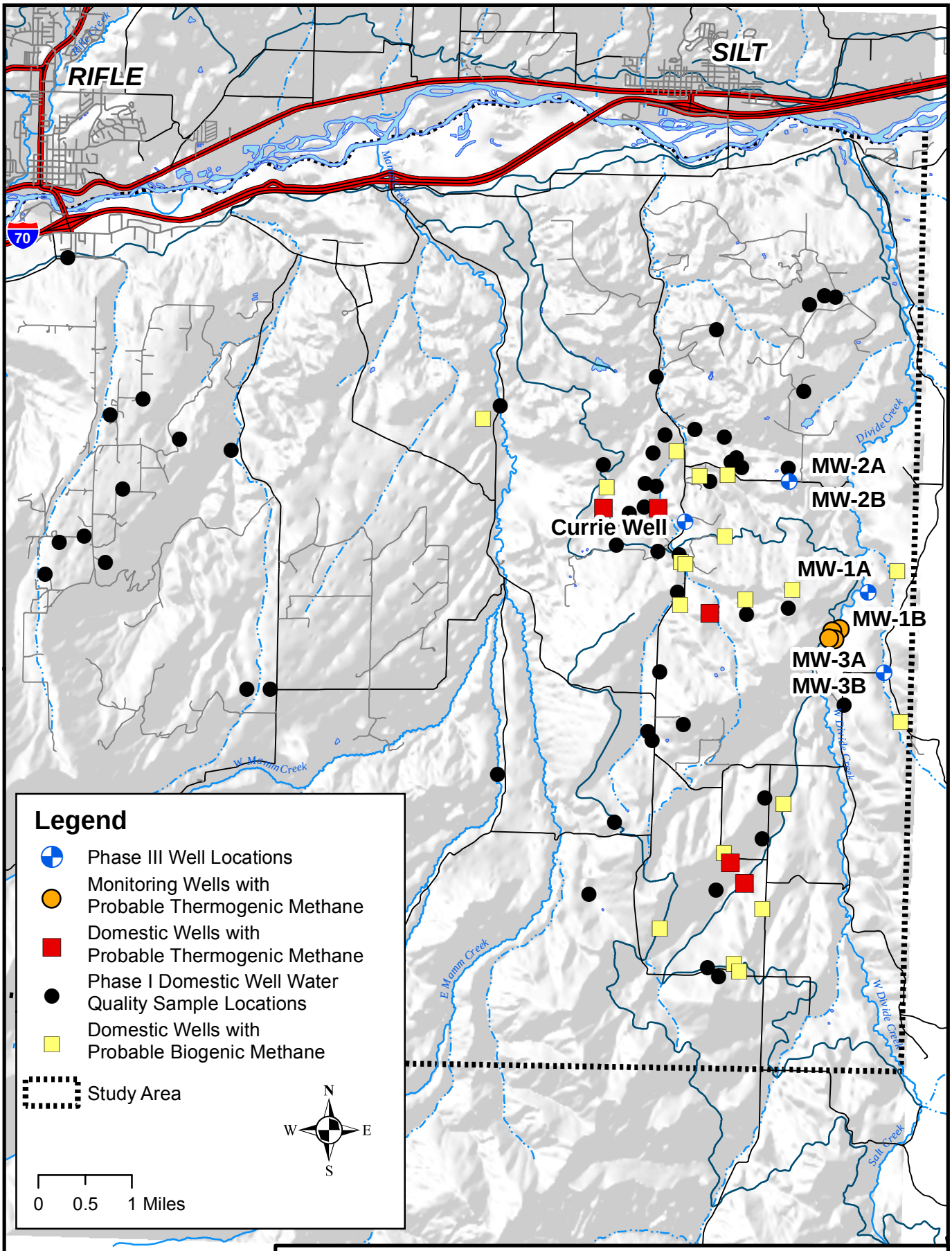


Figure 1. Location of Mamm Creek Study Area



TETRA TECH

Figure 2. Locations for Phase III Wells and Special Drilling Zone



TETRA TECH

Figure 3. Proximity to Methane-Bearing Wells

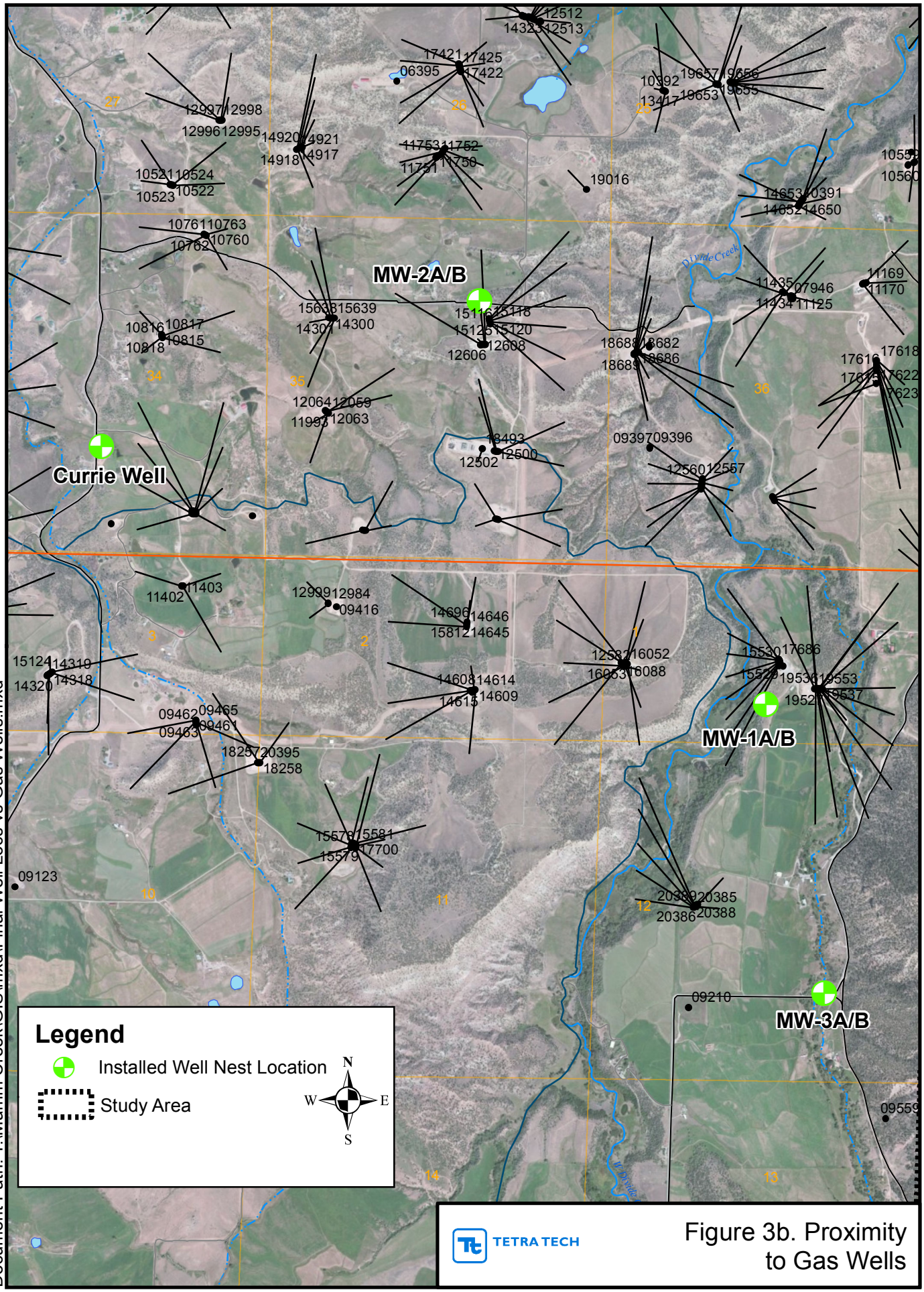
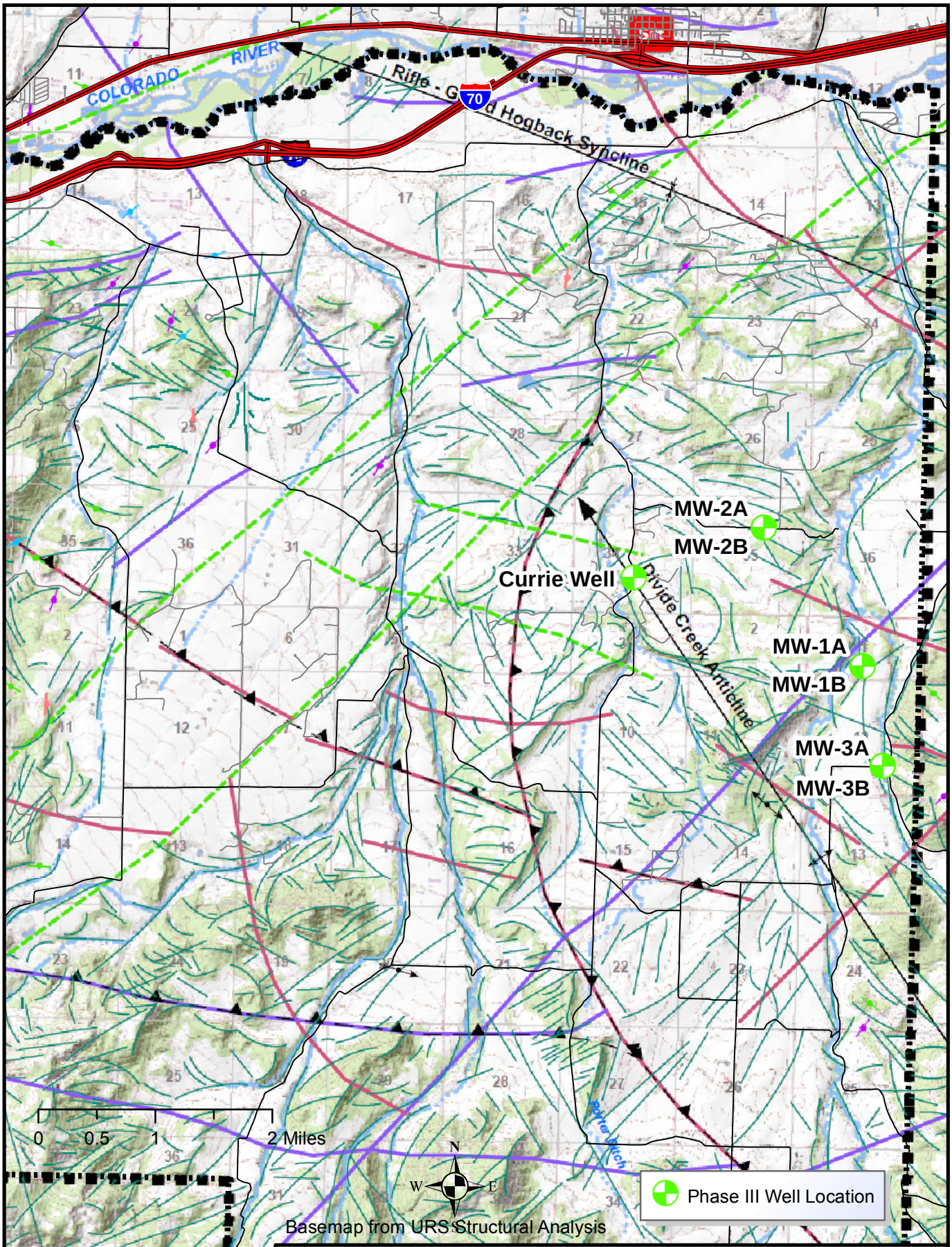


Figure 3b. Proximity to Gas Wells

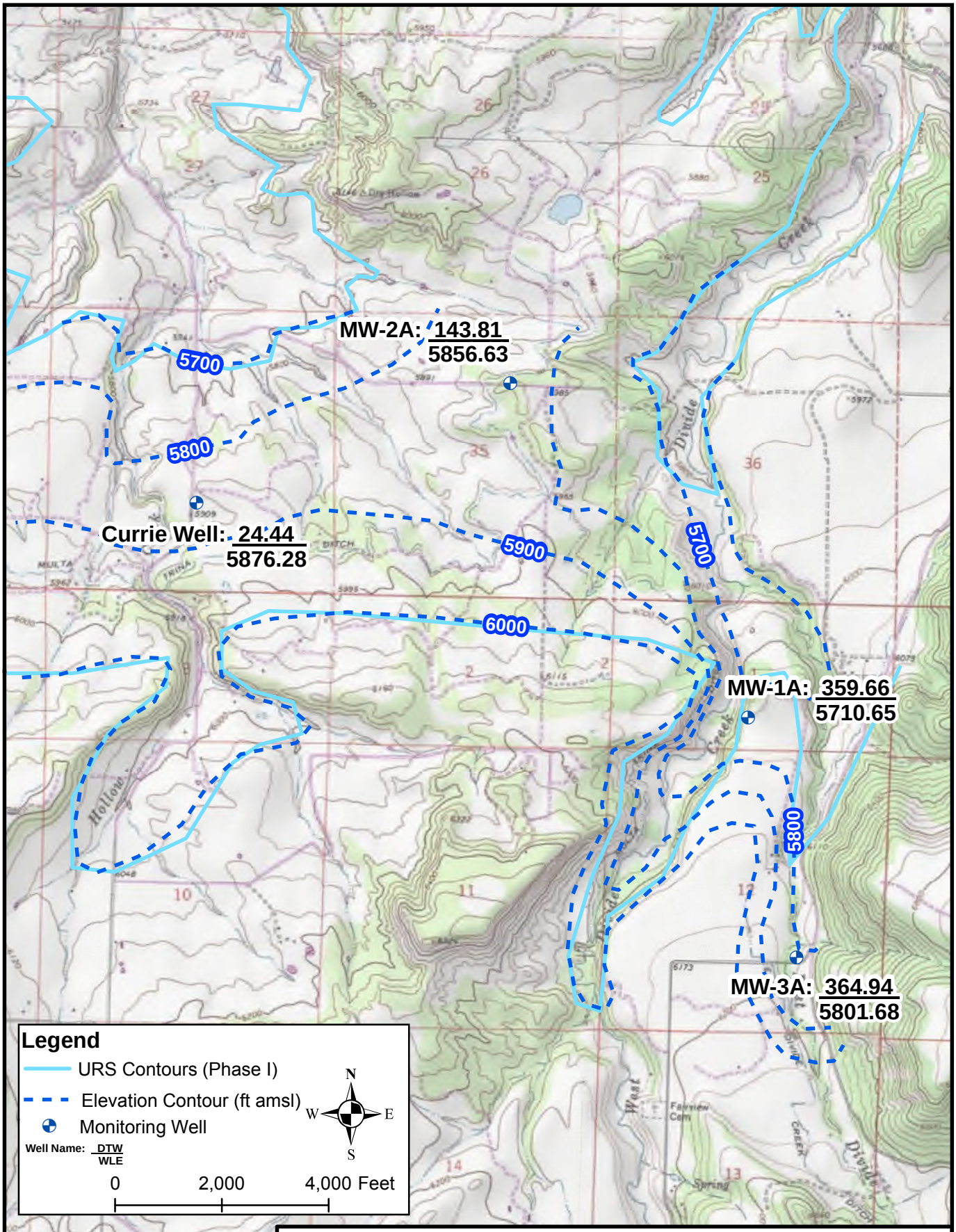
TETRA TECH

Document Path: T:\Mamm Creek\GIS\mxd\Final Well Locs vs Gas Wells.mxd



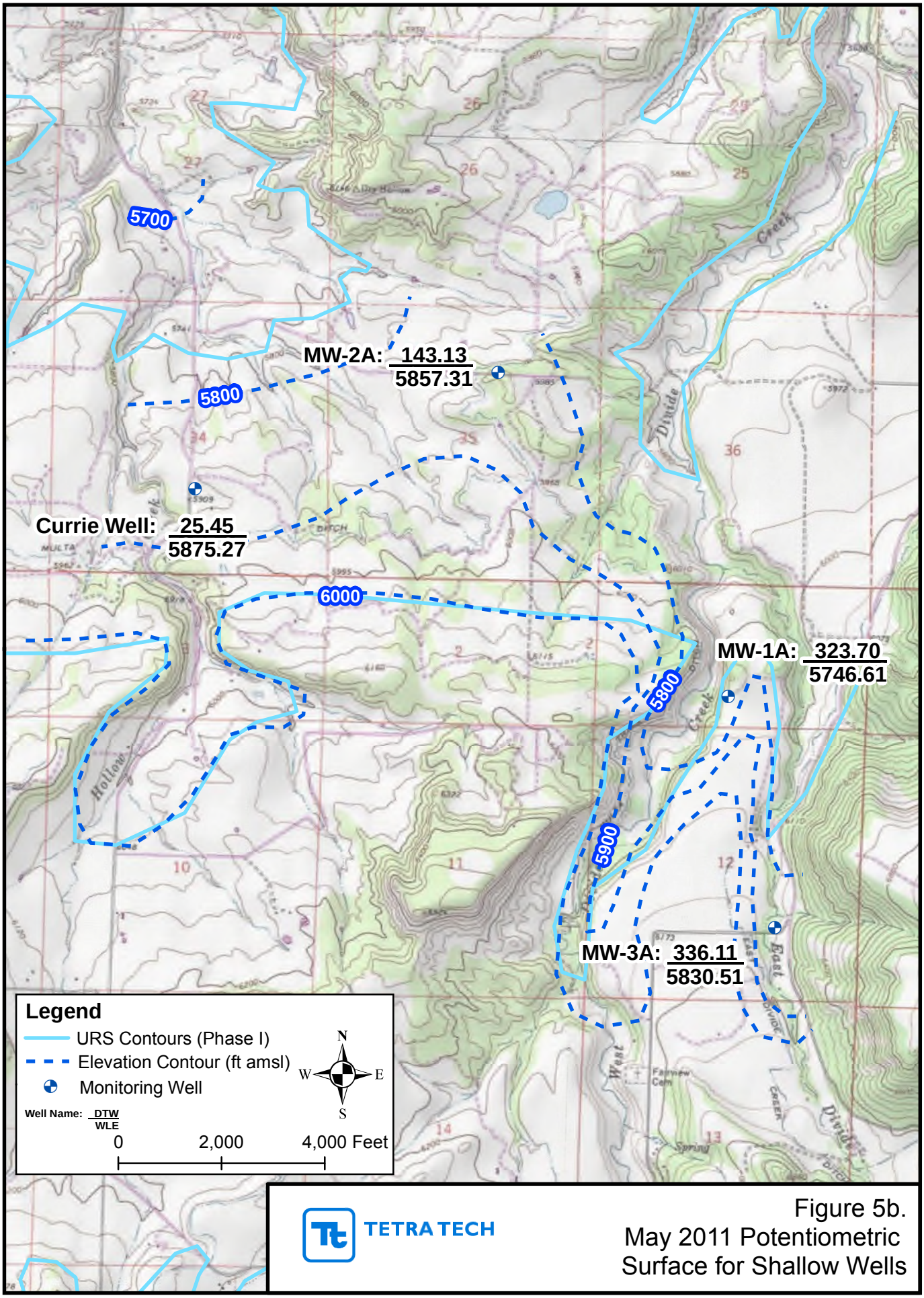
TETRA TECH

Figure 4. Structure and Observed Lineations



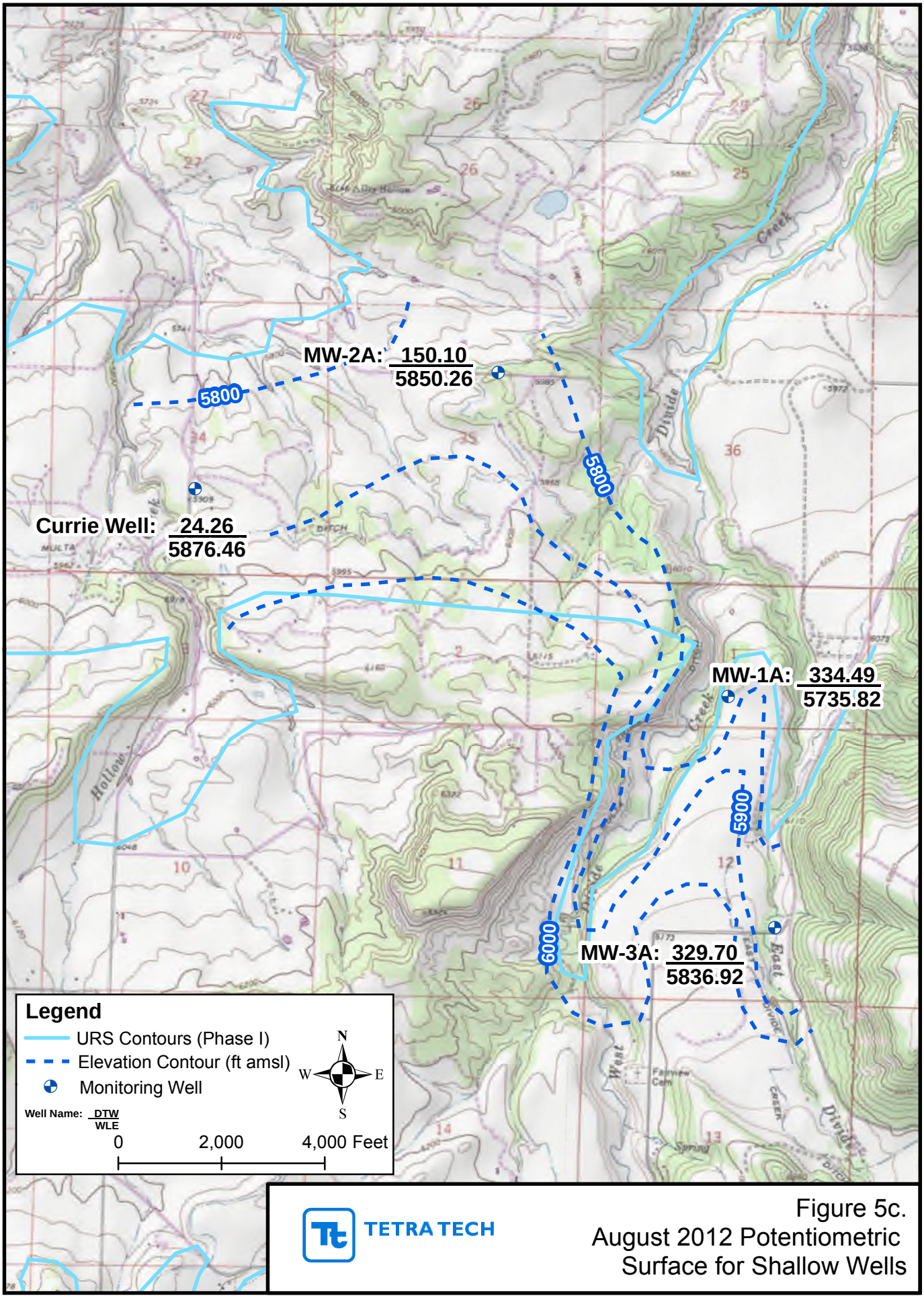
TETRA TECH

Figure 5a.
January 2011 Potentiometric Surface for Shallow Wells



TETRA TECH

Figure 5b.
May 2011 Potentiometric Surface for Shallow Wells



TETRA TECH

Figure 5c.
August 2012 Potentiometric Surface for Shallow Wells

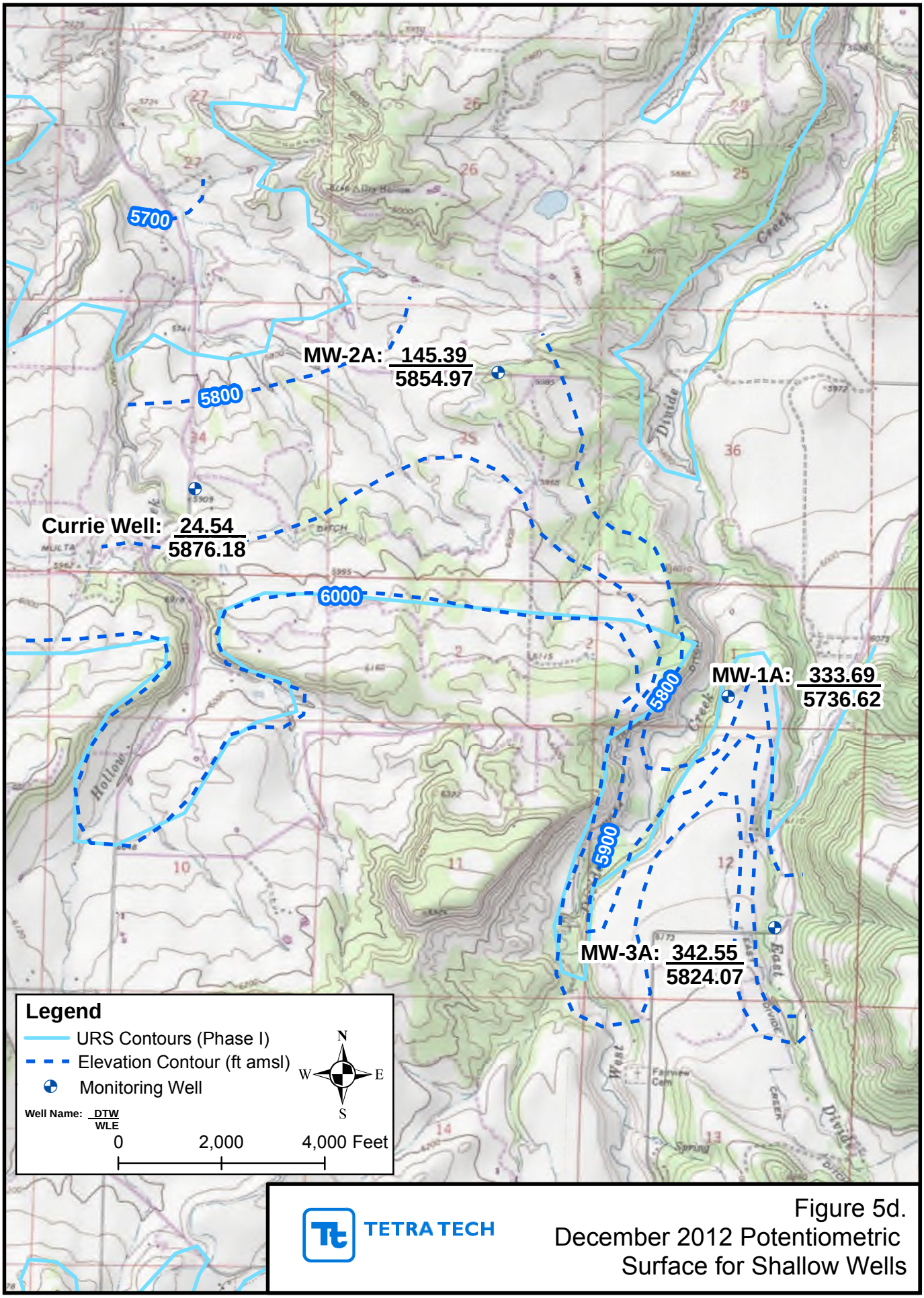
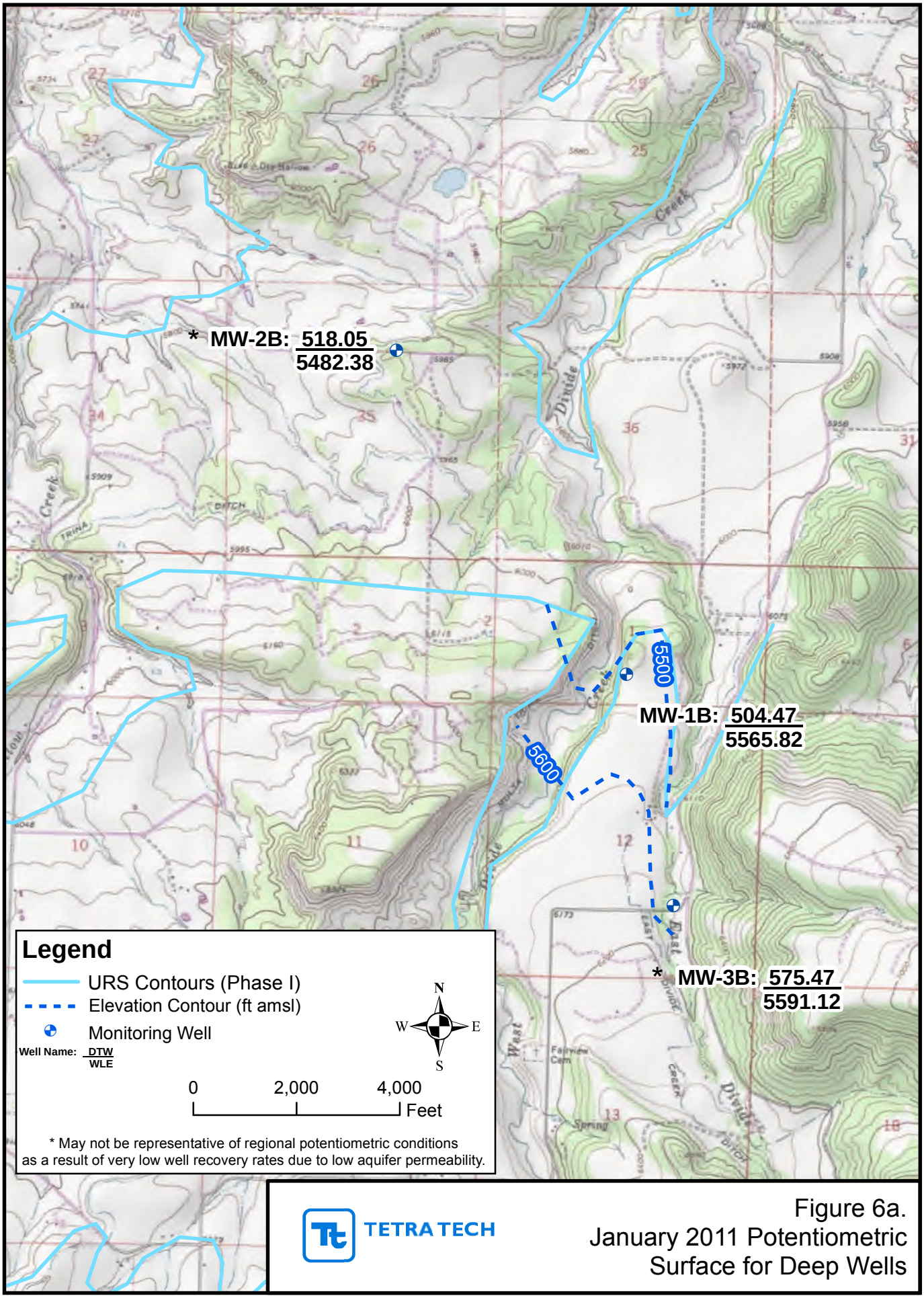
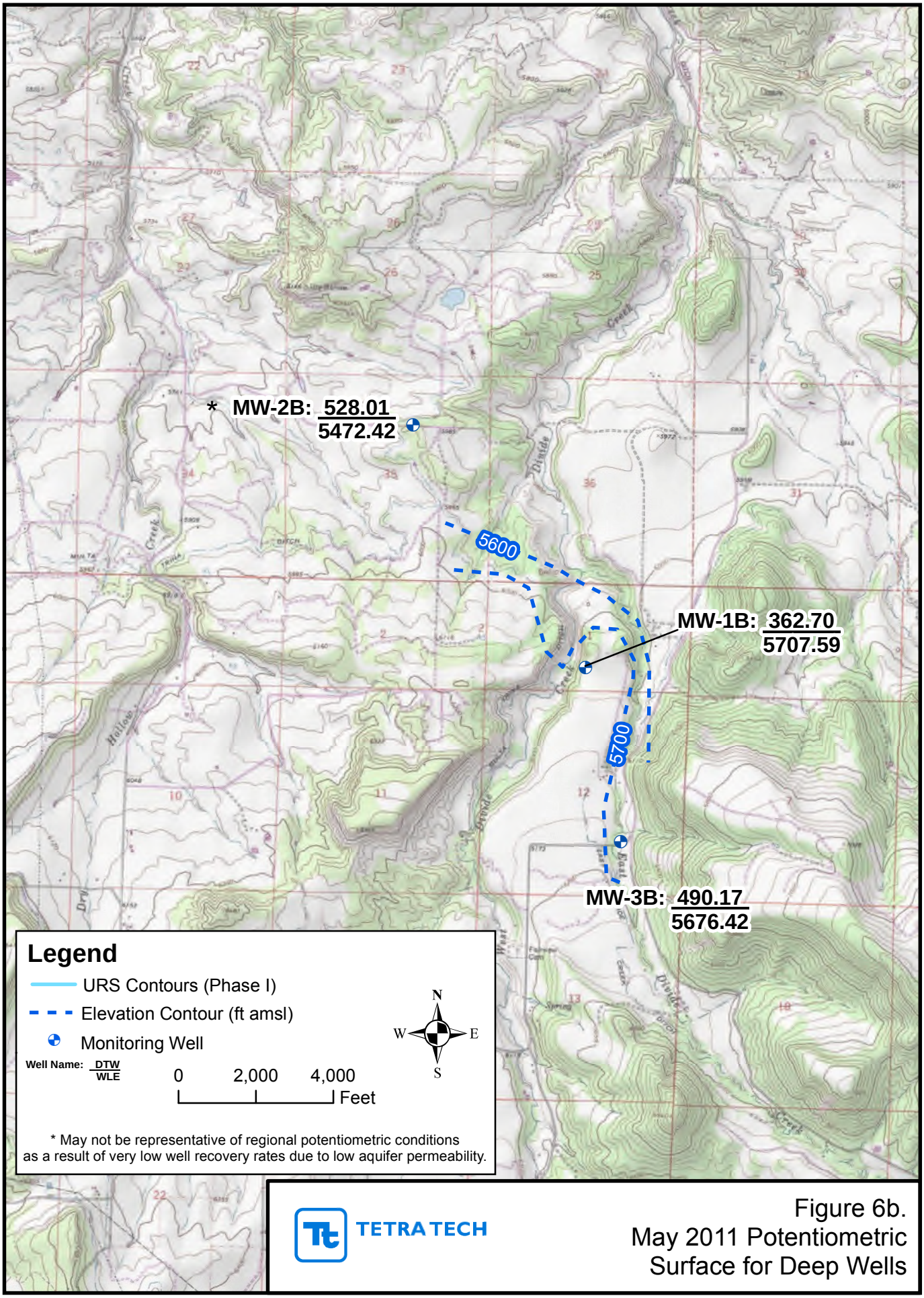


Figure 5d.
December 2012 Potentiometric Surface for Shallow Wells



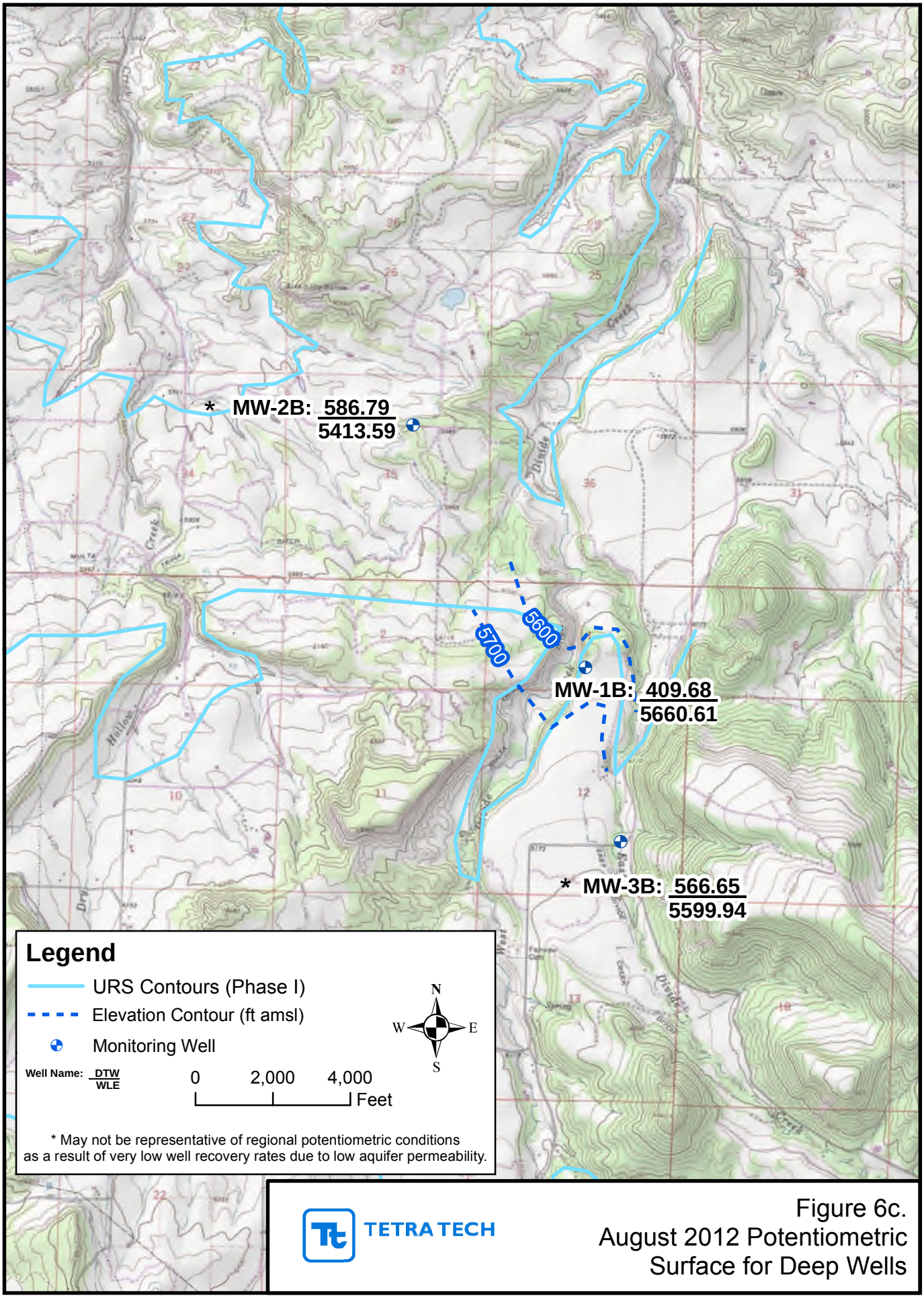
TETRA TECH

Figure 6a.
January 2011 Potentiometric Surface for Deep Wells



TETRA TECH

Figure 6b.
May 2011 Potentiometric Surface for Deep Wells



TETRA TECH

Figure 6c.
August 2012 Potentiometric Surface for Deep Wells

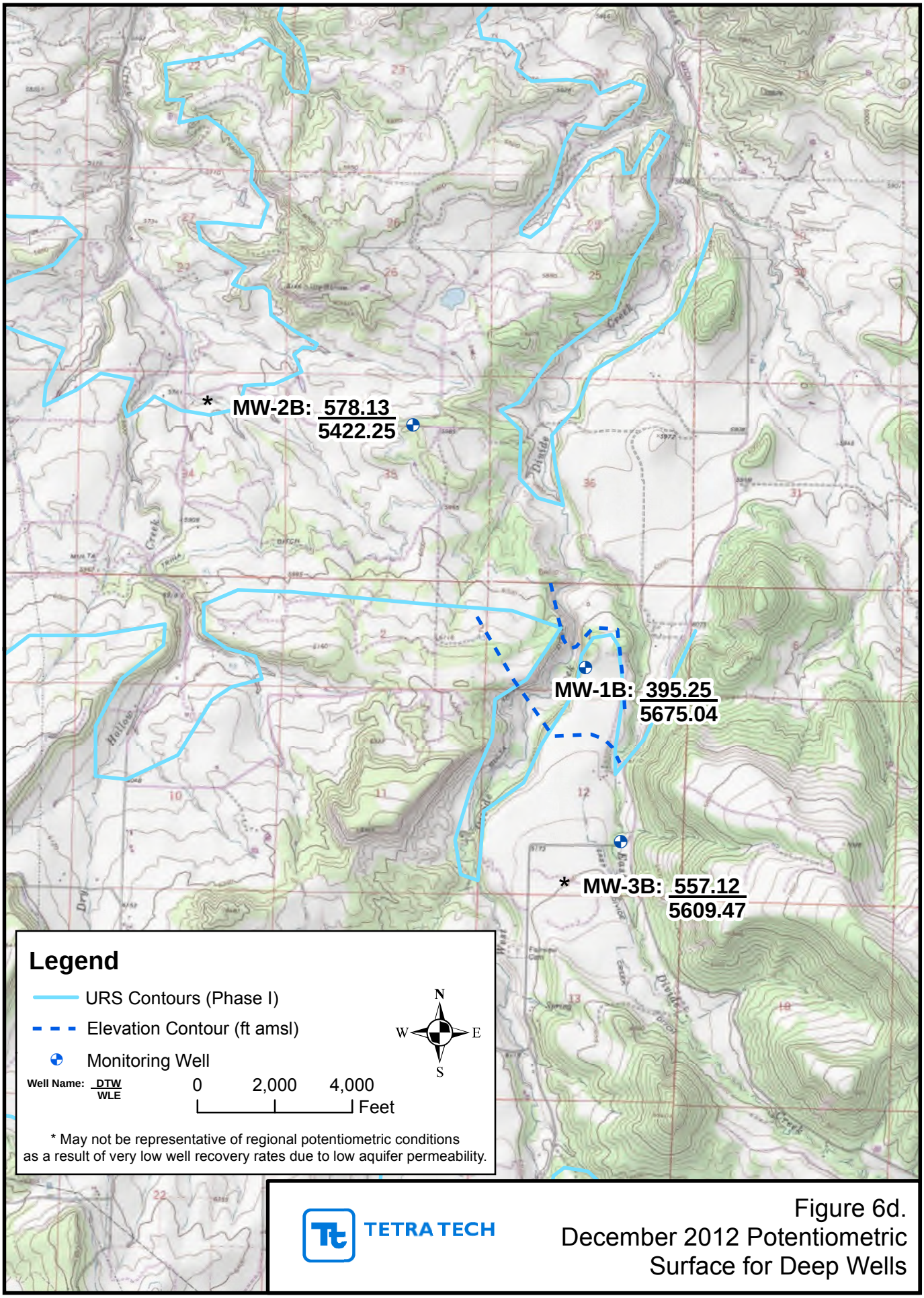
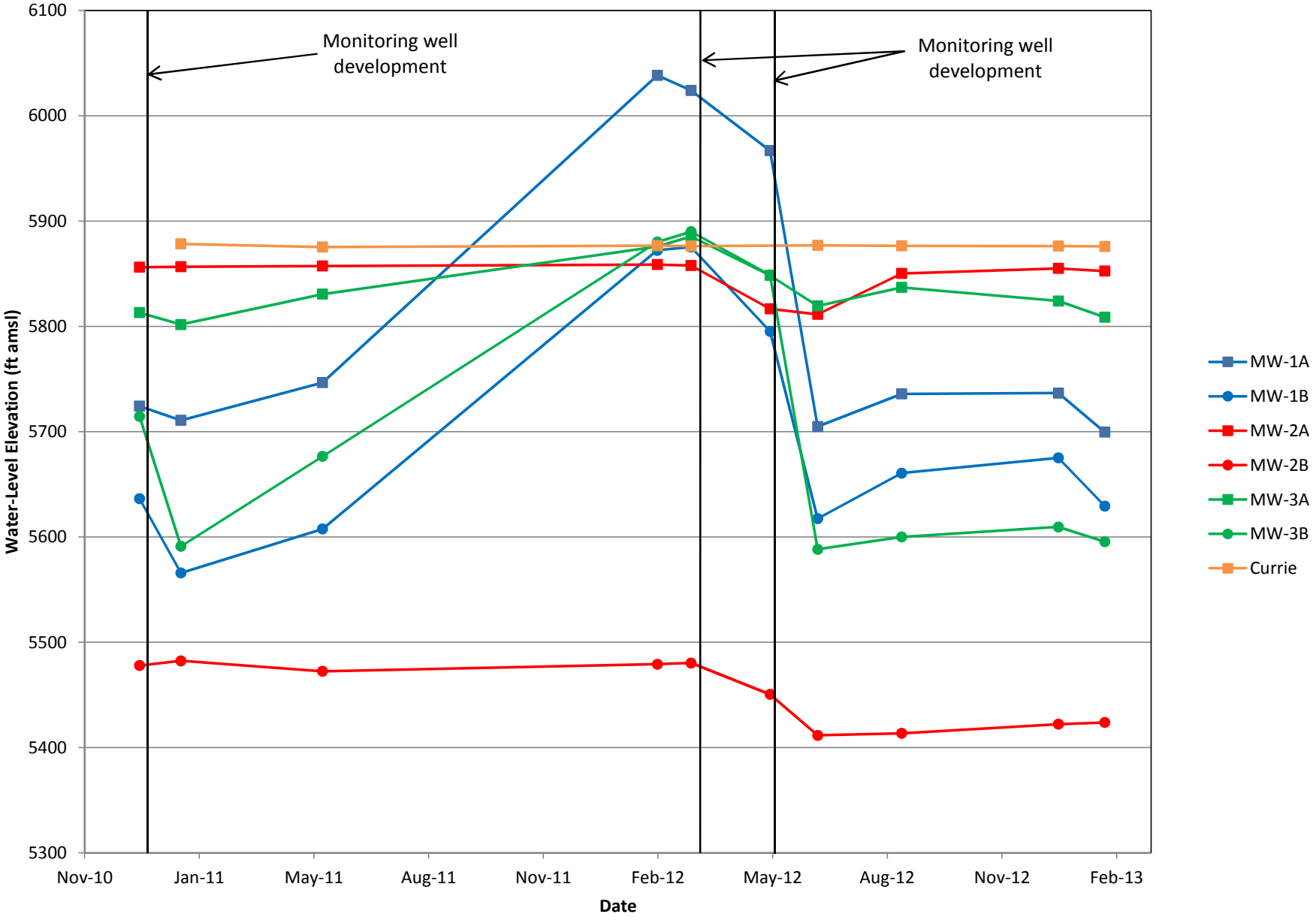
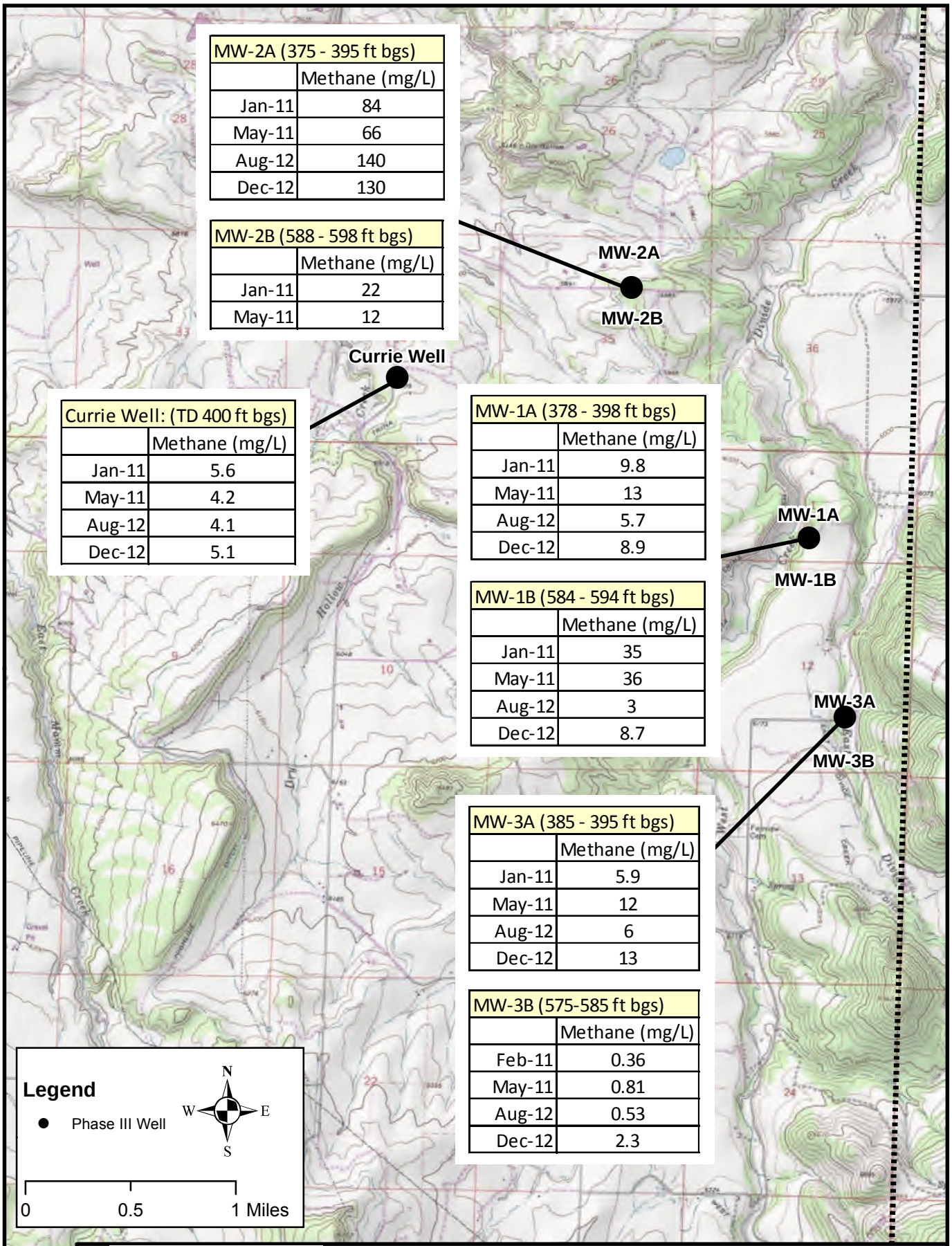


Figure 6d.
December 2012 Potentiometric Surface for Deep Wells

Figure 7. Water-Level Elevation Time Series Plot for Phase III Wells





MW-2A (375 - 395 ft bgs)	
	Methane (mg/L)
Jan-11	84
May-11	66
Aug-12	140
Dec-12	130

MW-2B (588 - 598 ft bgs)	
	Methane (mg/L)
Jan-11	22
May-11	12

Currie Well: (TD 400 ft bgs)	
	Methane (mg/L)
Jan-11	5.6
May-11	4.2
Aug-12	4.1
Dec-12	5.1

MW-1A (378 - 398 ft bgs)	
	Methane (mg/L)
Jan-11	9.8
May-11	13
Aug-12	5.7
Dec-12	8.9

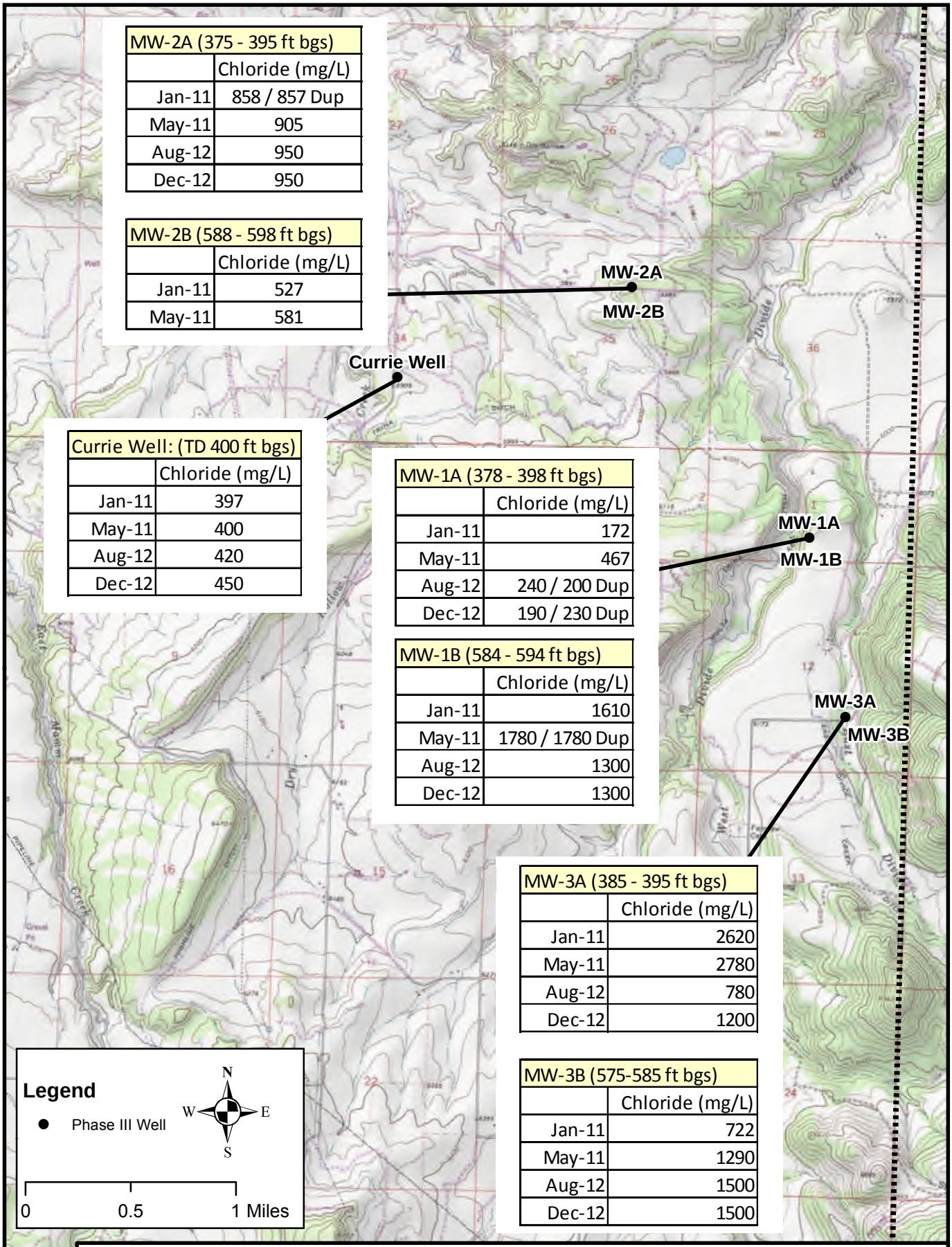
MW-1B (584 - 594 ft bgs)	
	Methane (mg/L)
Jan-11	35
May-11	36
Aug-12	3
Dec-12	8.7

MW-3A (385 - 395 ft bgs)	
	Methane (mg/L)
Jan-11	5.9
May-11	12
Aug-12	6
Dec-12	13

MW-3B (575-585 ft bgs)	
	Methane (mg/L)
Feb-11	0.36
May-11	0.81
Aug-12	0.53
Dec-12	2.3

TETRA TECH

Figure 8. Methane in Phase III Monitoring Wells Map



MW-2A (375 - 395 ft bgs)	
	Chloride (mg/L)
Jan-11	858 / 857 Dup
May-11	905
Aug-12	950
Dec-12	950

MW-2B (588 - 598 ft bgs)	
	Chloride (mg/L)
Jan-11	527
May-11	581

Currie Well: (TD 400 ft bgs)	
	Chloride (mg/L)
Jan-11	397
May-11	400
Aug-12	420
Dec-12	450

MW-1A (378 - 398 ft bgs)	
	Chloride (mg/L)
Jan-11	172
May-11	467
Aug-12	240 / 200 Dup
Dec-12	190 / 230 Dup

MW-1B (584 - 594 ft bgs)	
	Chloride (mg/L)
Jan-11	1610
May-11	1780 / 1780 Dup
Aug-12	1300
Dec-12	1300

MW-3A (385 - 395 ft bgs)	
	Chloride (mg/L)
Jan-11	2620
May-11	2780
Aug-12	780
Dec-12	1200

MW-3B (575-585 ft bgs)	
	Chloride (mg/L)
Jan-11	722
May-11	1290
Aug-12	1500
Dec-12	1500

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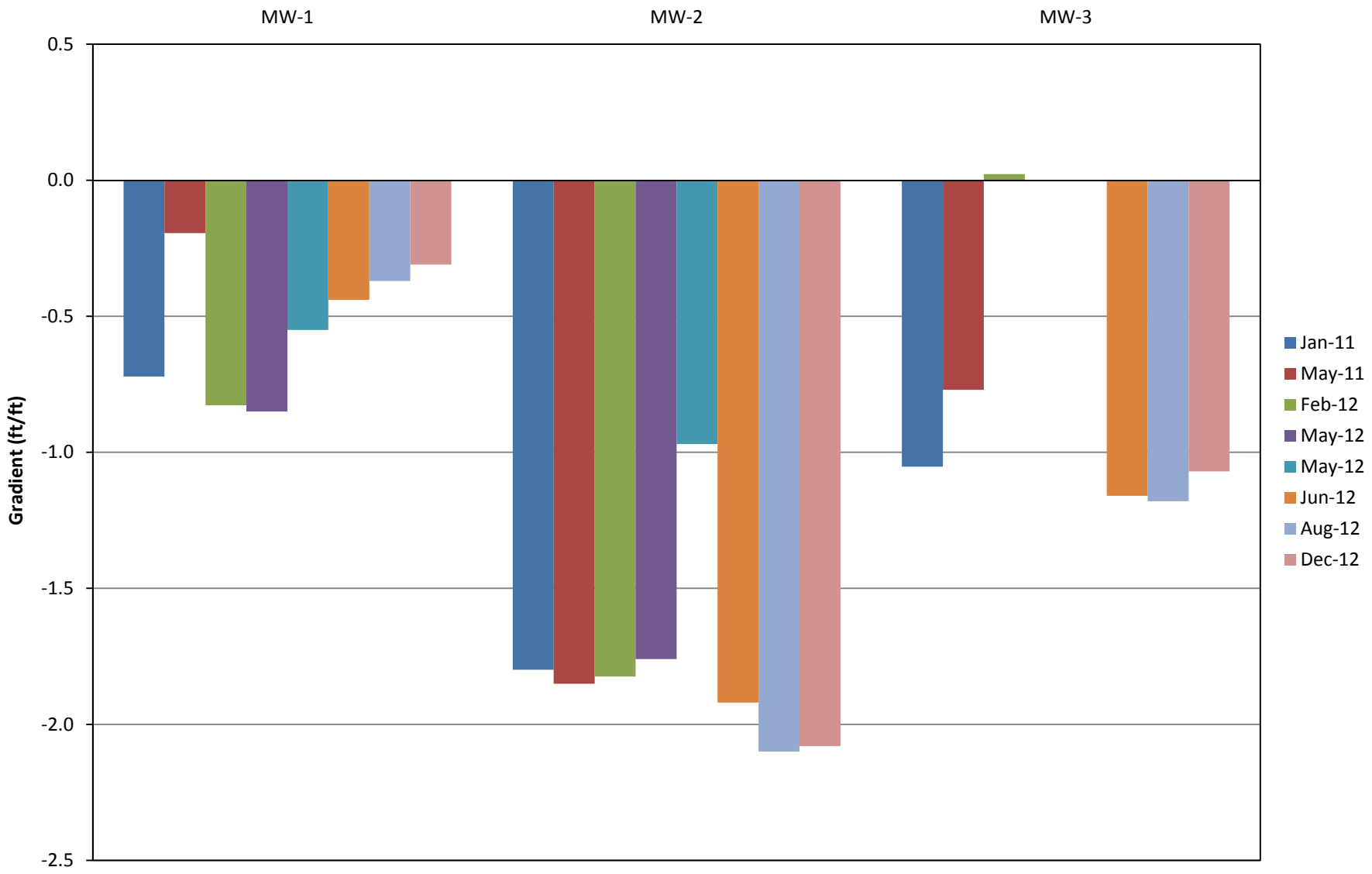
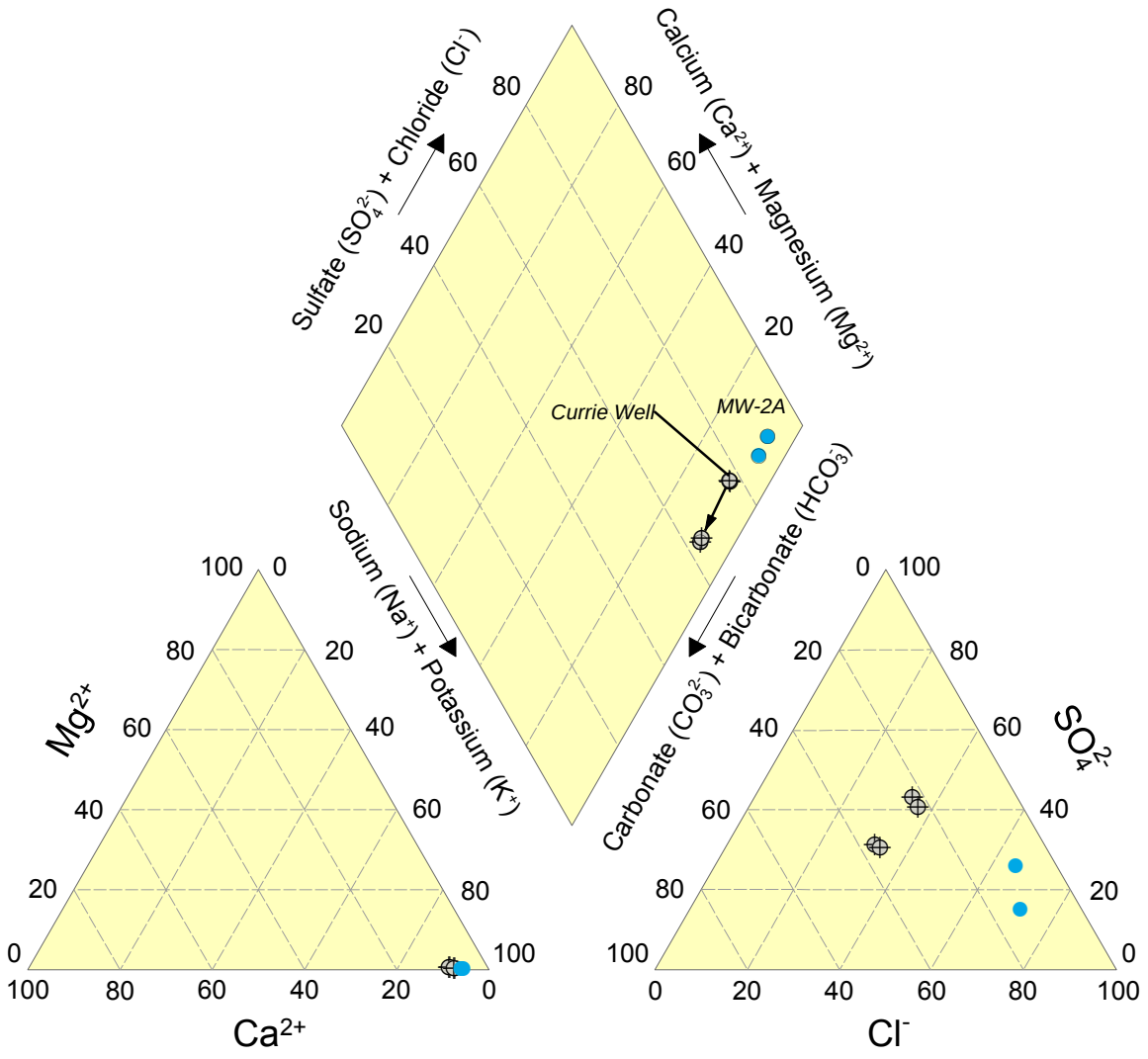
Figure 9. Chloride Concentration Map, Phase III Wells 2011 and 2012



Notes:
Gradients are calculated relative to vertical distance between center of screened intervals.

Negative vertical gradients indicate downward flow from the shallow well to the deeper well, and positive vertical gradients indicate upward flow from the deeper well to the shallow well.

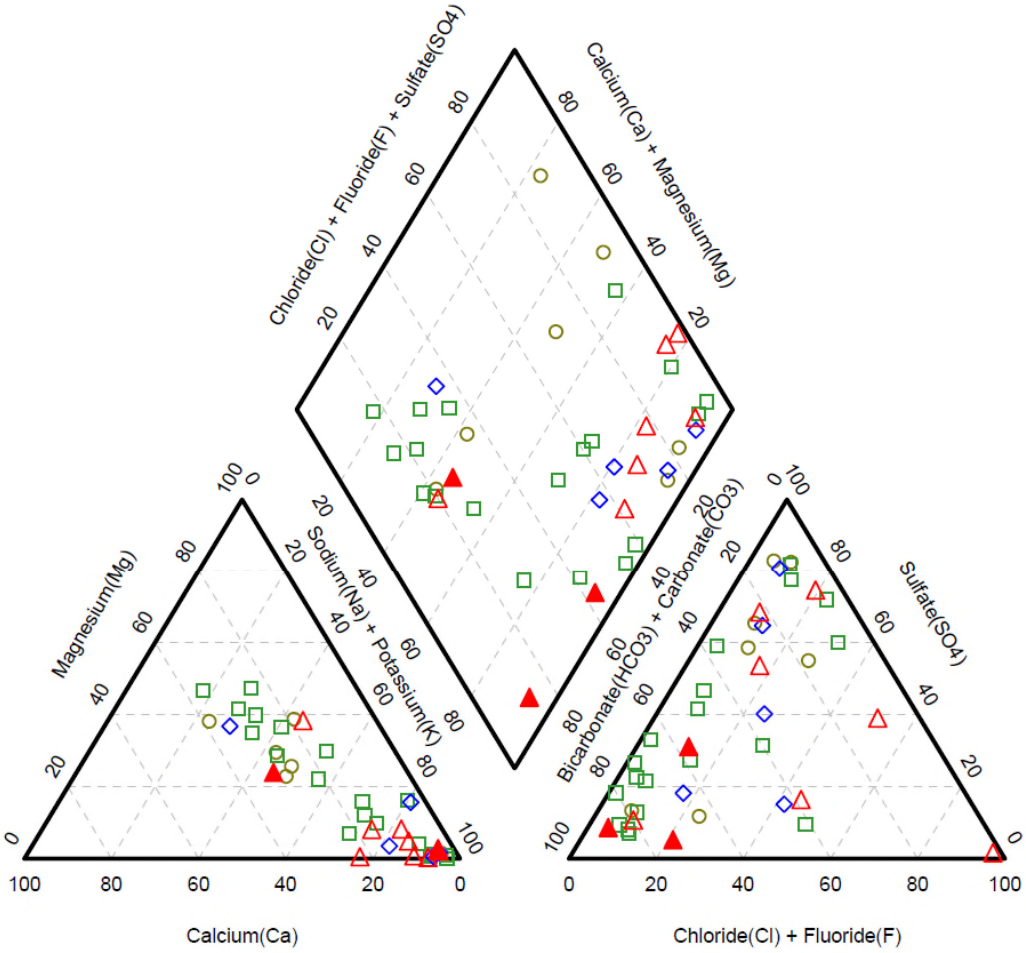
Vertical Hydraulic Gradient in Nested Wells	DATE:	5/6/2013
	DESIGNED:	DJB
	CHECKED:	DJB
	APPROVED:	DJB
	DRAWN:	DJB
	PROJECT: 117-7050003	
TETRA TECH	FIGURE:	10



Circle sizes on Piper diamond are proportional to TDS concentrations.
Arrows indicate evolution between sampling events.

TITLE: **Piper Diagram for Phase III Groundwater Samples**			
LOCATION: **Garfield County, Colorado**			
TETRA TECH	CHECKED	CG	FIGURE
	DRAFTED	ES	**11**
	PROJECT	7050003	
	DATE	5/16/2013	

T:\Mamm Creek\GIS\mxd\Fig15_Piper_new calcs_rev052313.mxd

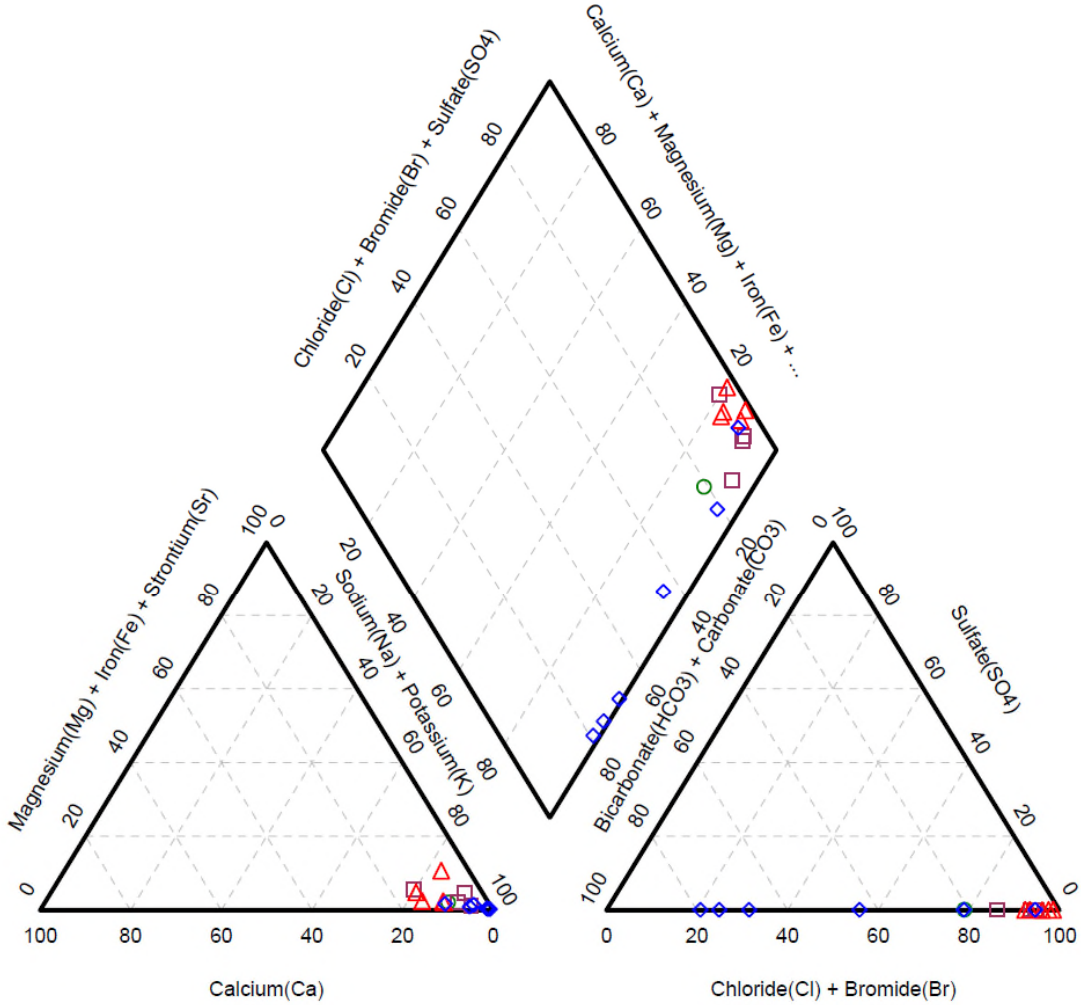


Divisions according to well Depth

0-100 ft
101-200 ft
201-300 ft
301-400 ft
401-495 ft

Reproduced from Figure 4.11 of:
Phase II Hydrogeologic Characterization of the
Mamm Creek Field Area, Garfield County, Colorado
S.S. Papadopulos & Assoc., September 2008

Piper Diagram for Phase II Domestic Well Groundwater Samples	DATE:	Sep2011
	DESIGNED:	
	CHECKED:	
	APPROVED:	
	DRAWN:	
	PROJECT: 117-7050002	
TETRA TECH	FIGURE: 12	



Produced Water Samples - Grouped by TDS ranges
Less than 1,000 mg/L
5,000 - 10,000 mg/L
10,000 - 15,000 mg/L
Greater than 15,000 mg/L

Reproduced from Figure 4.15 of:
Phase II Hydrogeologic Characterization of the
Mamm Creek Field Area, Garfield County, Colorado
S.S. Papadopulos & Assoc., September 2008

Piper Diagram for Phase II Produced Water Samples	DATE:	Sep2011
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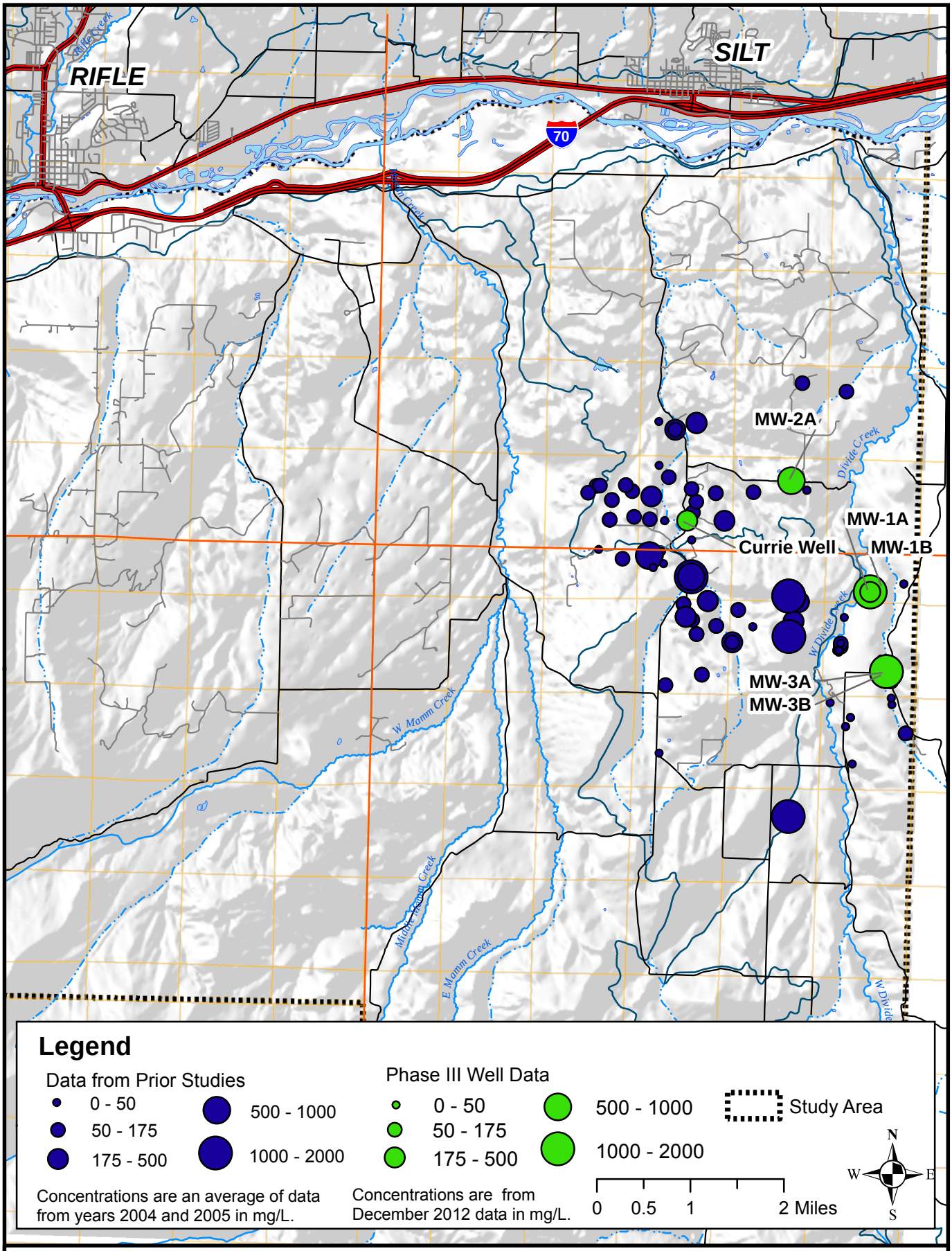
	CHECKED:	
	APPROVED:	
	DRAWN:	
	PROJECT: 117-7050002	
TETRA TECH	FIGURE: 13	



TETRA TECH

Figure 14. Chloride Concentration Map, Groundwater for Phase III Study Area 2004 - 2012

Figure 15a. Chloride Concentration Time Series in Groundwater in Phase III Study Area 2004 to 2005

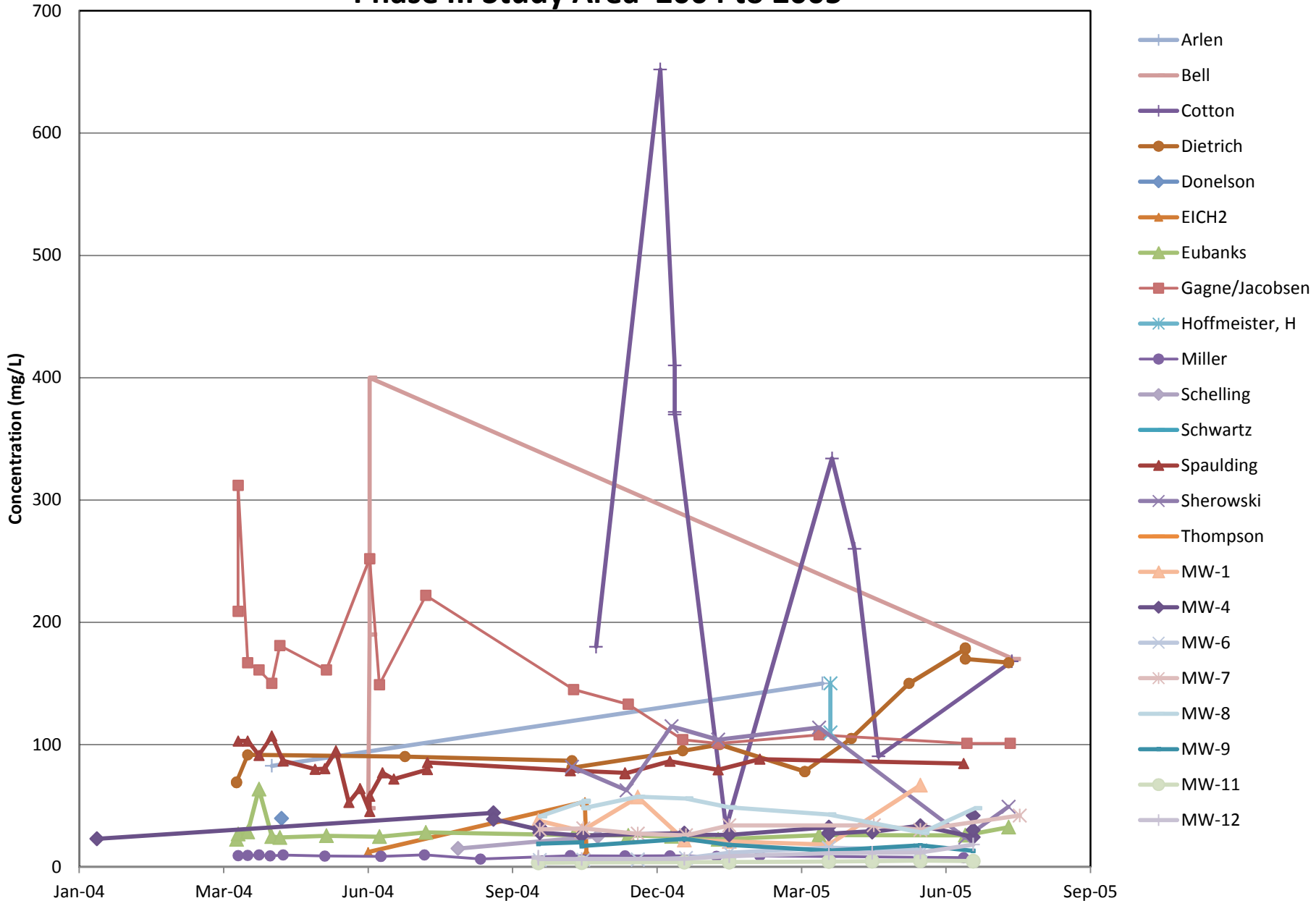
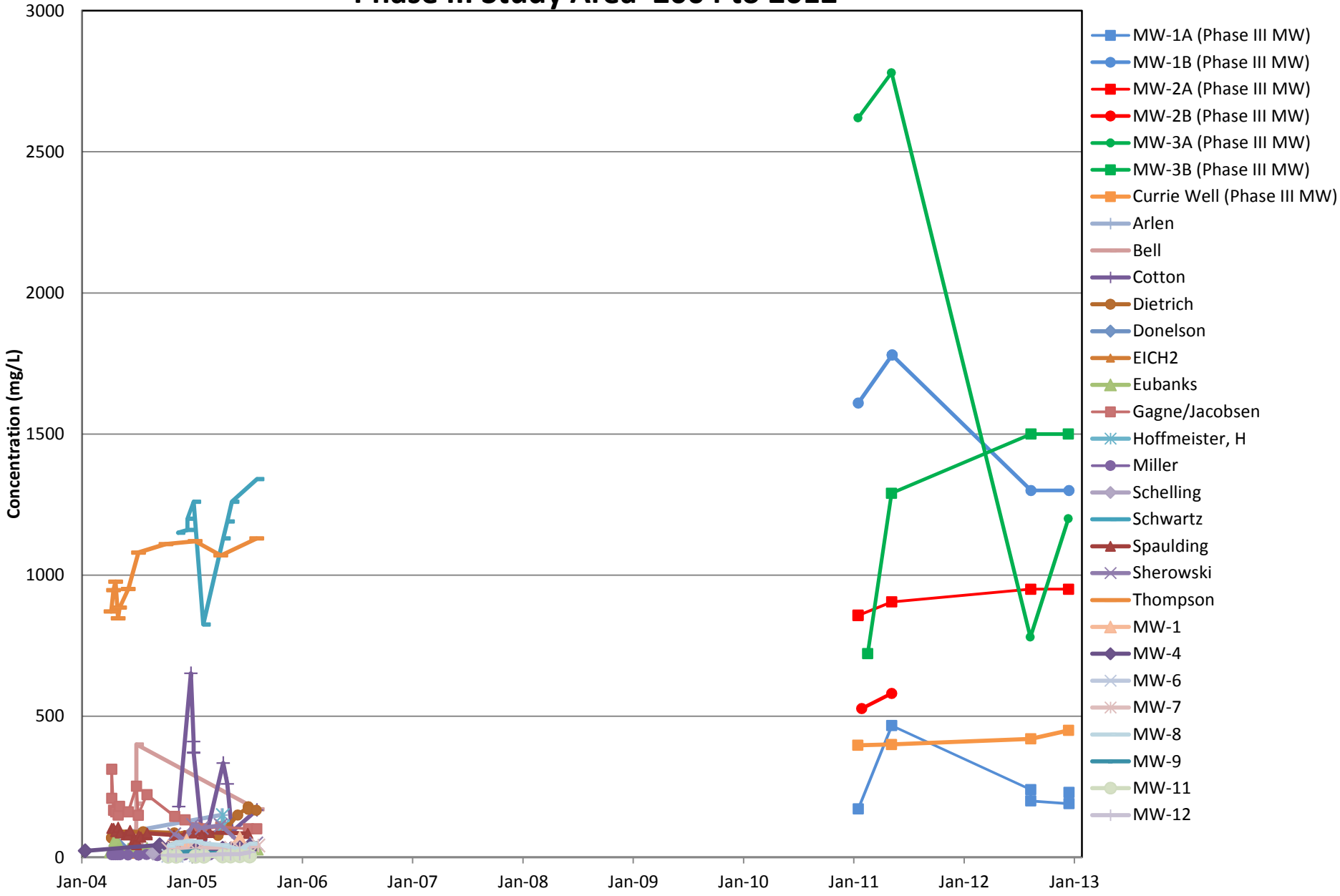
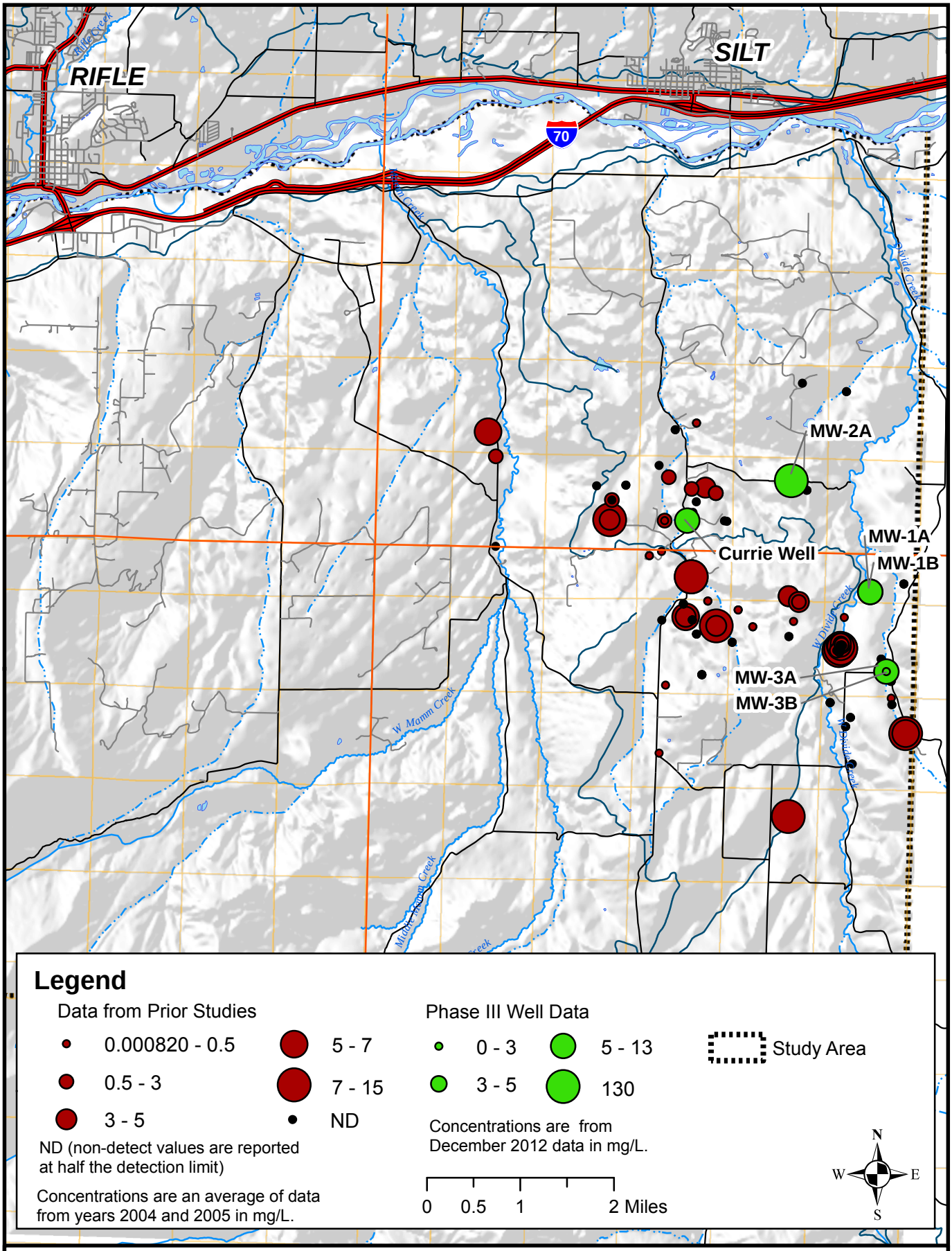


Figure 15b. Chloride Concentration Time Series in Groundwater in Phase III Study Area 2004 to 2012





TETRA TECH

Figure 16. Methane Concentration Map, Groundwater in and Around Phase III Study Area 2004 - 2012

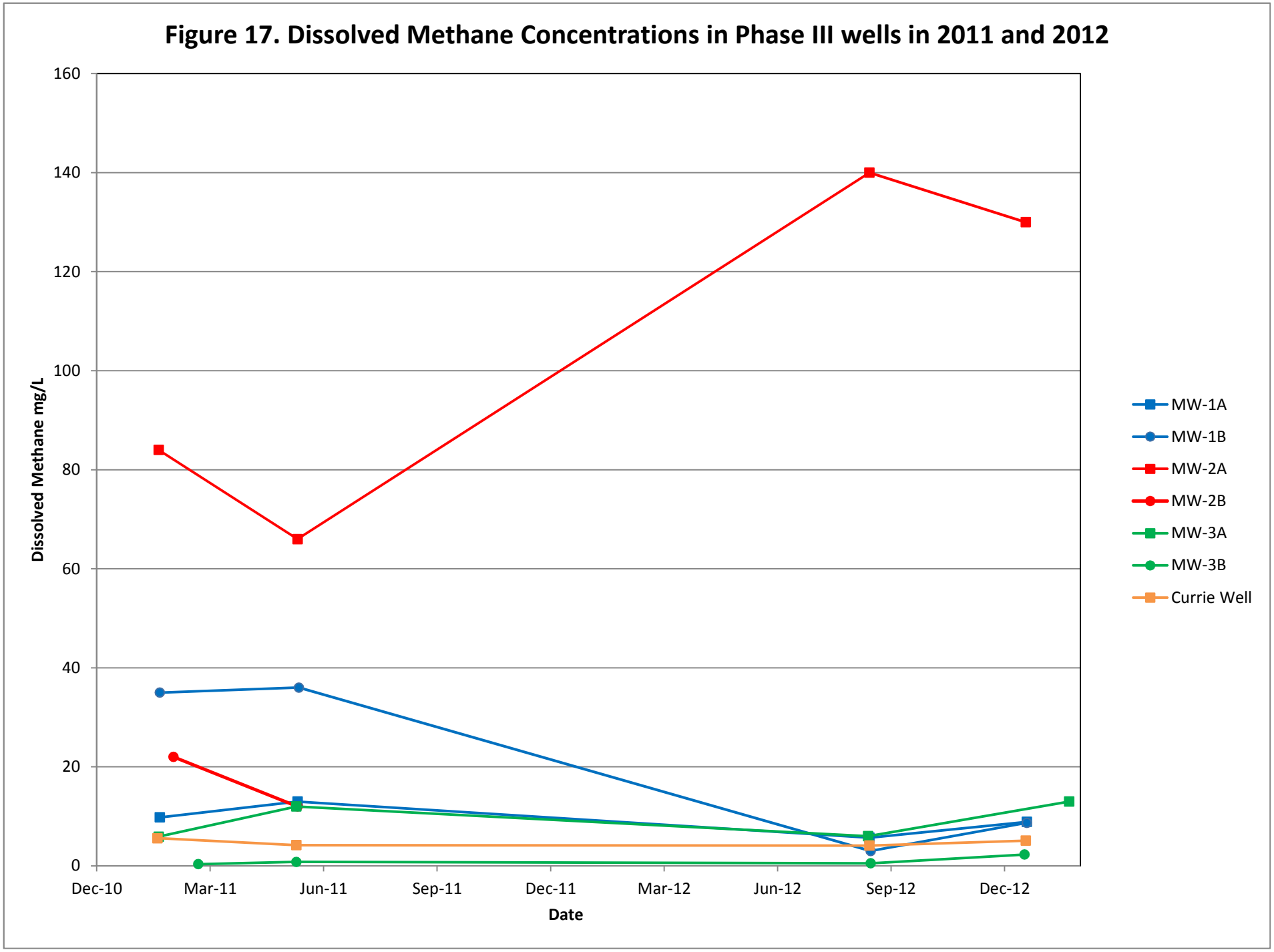
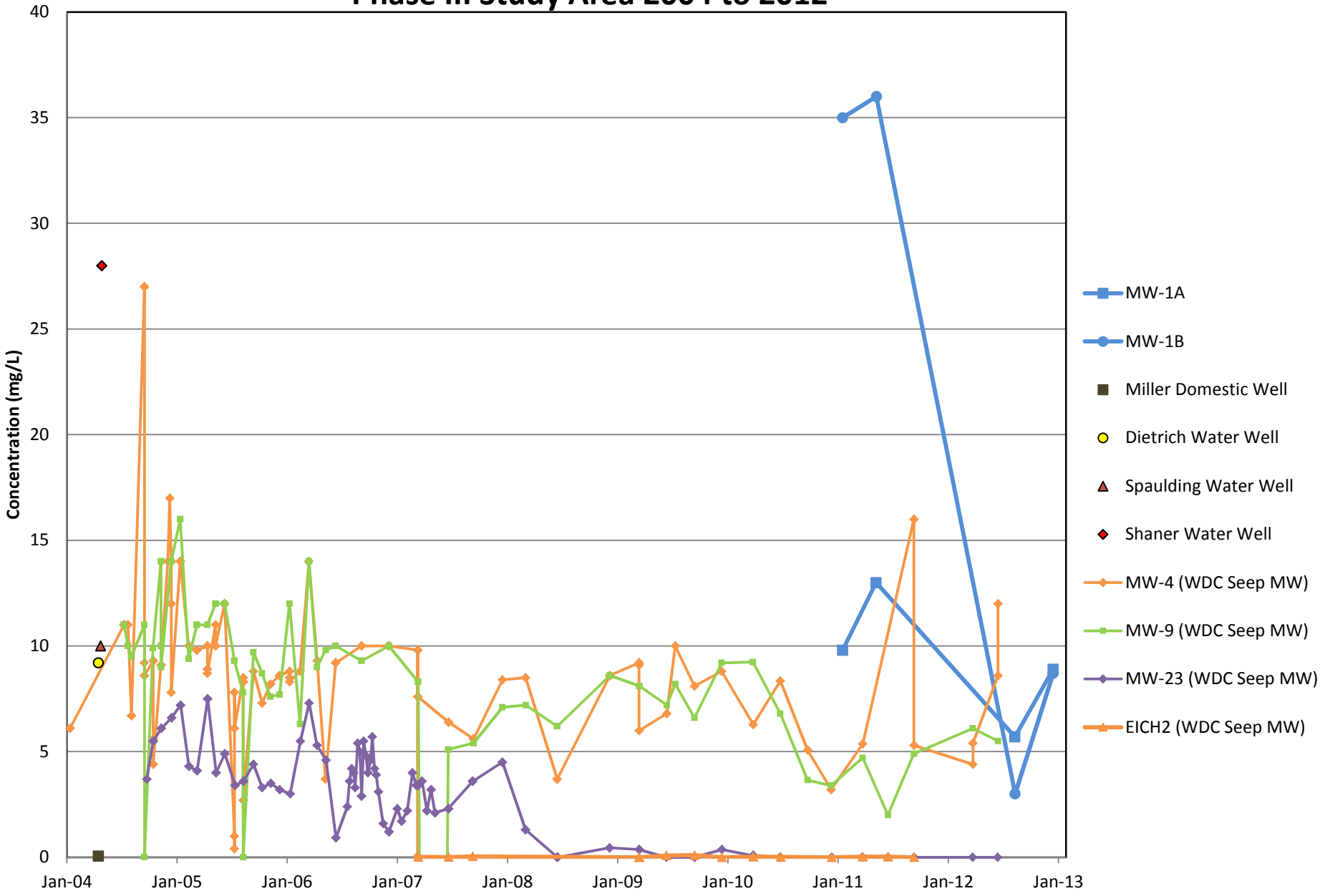


Figure 17. Dissolved Methane Concentrations in Phase III wells in 2011 and 2012
Dissolved Methane mg/L
160
140
120
100
80
60
40
20
0
Dec-10
Mar-11
Jun-11
Sep-11
Dec-11
Mar-12
Jun-12
Sep-12
Dec-12
Date
MW-1A
MW-1B
MW-2A
MW-2B
MW-3A
MW-3B
Currie Well

Figure 18. Methane Concentration Time Series in Groundwater in Phase III Study Area 2004 to 2012



Note: Non-detect values are plotted at 1/2 the detection limit

Figure 19a. January 2011 - Carbon and Hydrogen Isotopes of Methane for Phase III Wells

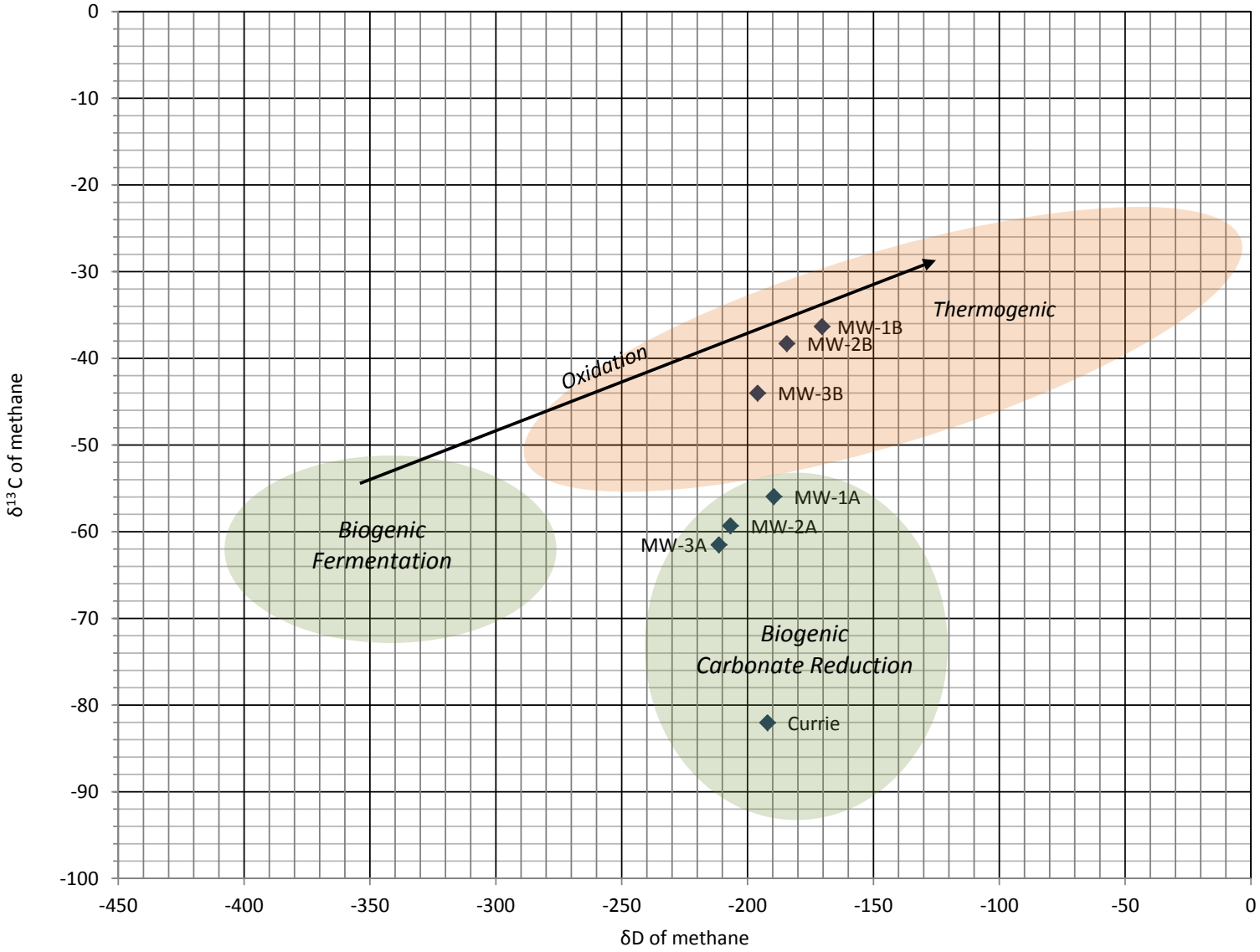
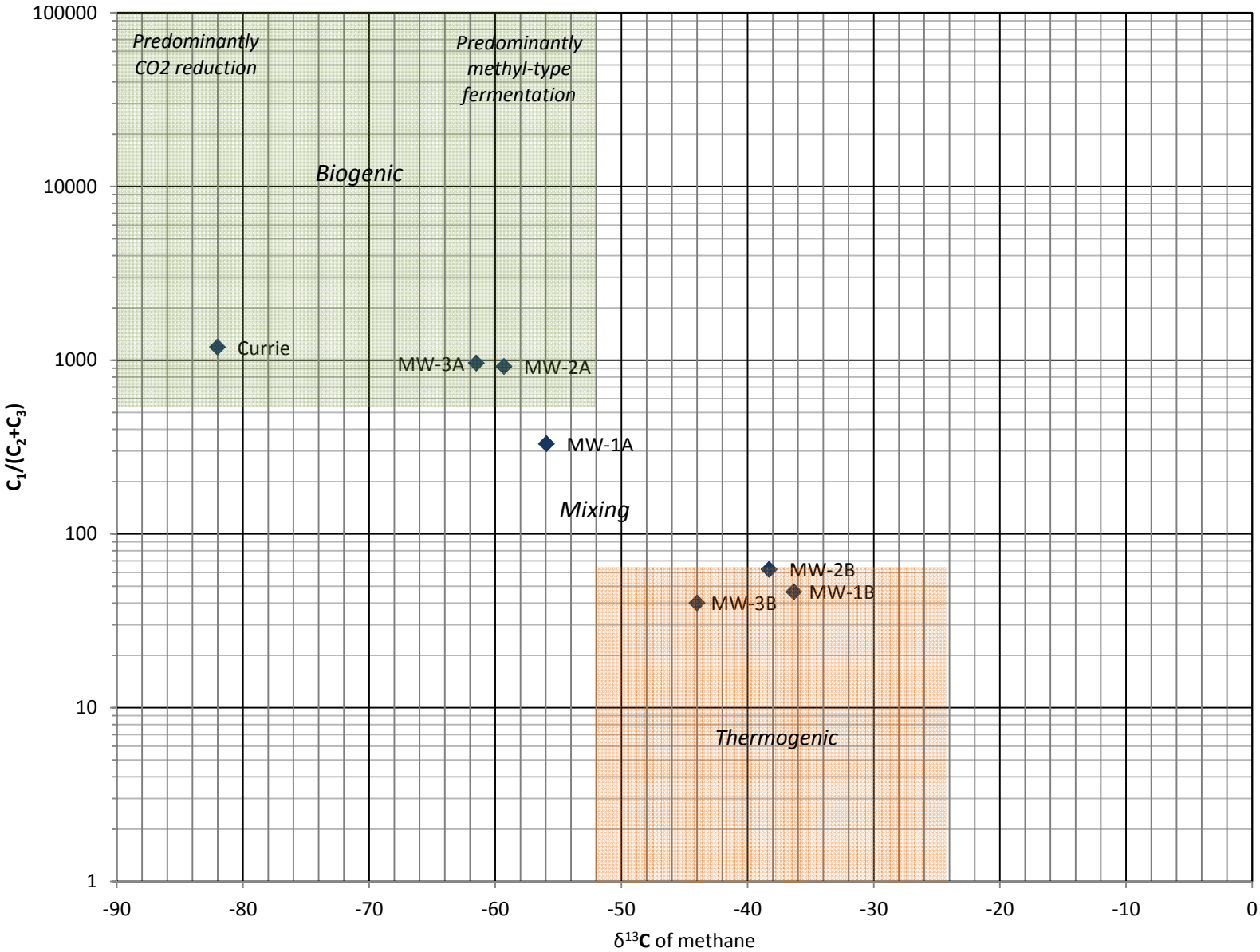


Figure 19b. January 2011 - Comparative Molecular and Isotopic Compositions of Biogenic and Thermogenic Gas for Phase III Wells



Bernard Diagram (after Whiticar, 1990)

Figure 20a. May 2011 - Carbon and Hydrogen Isotopes of Methane for Phase III Wells

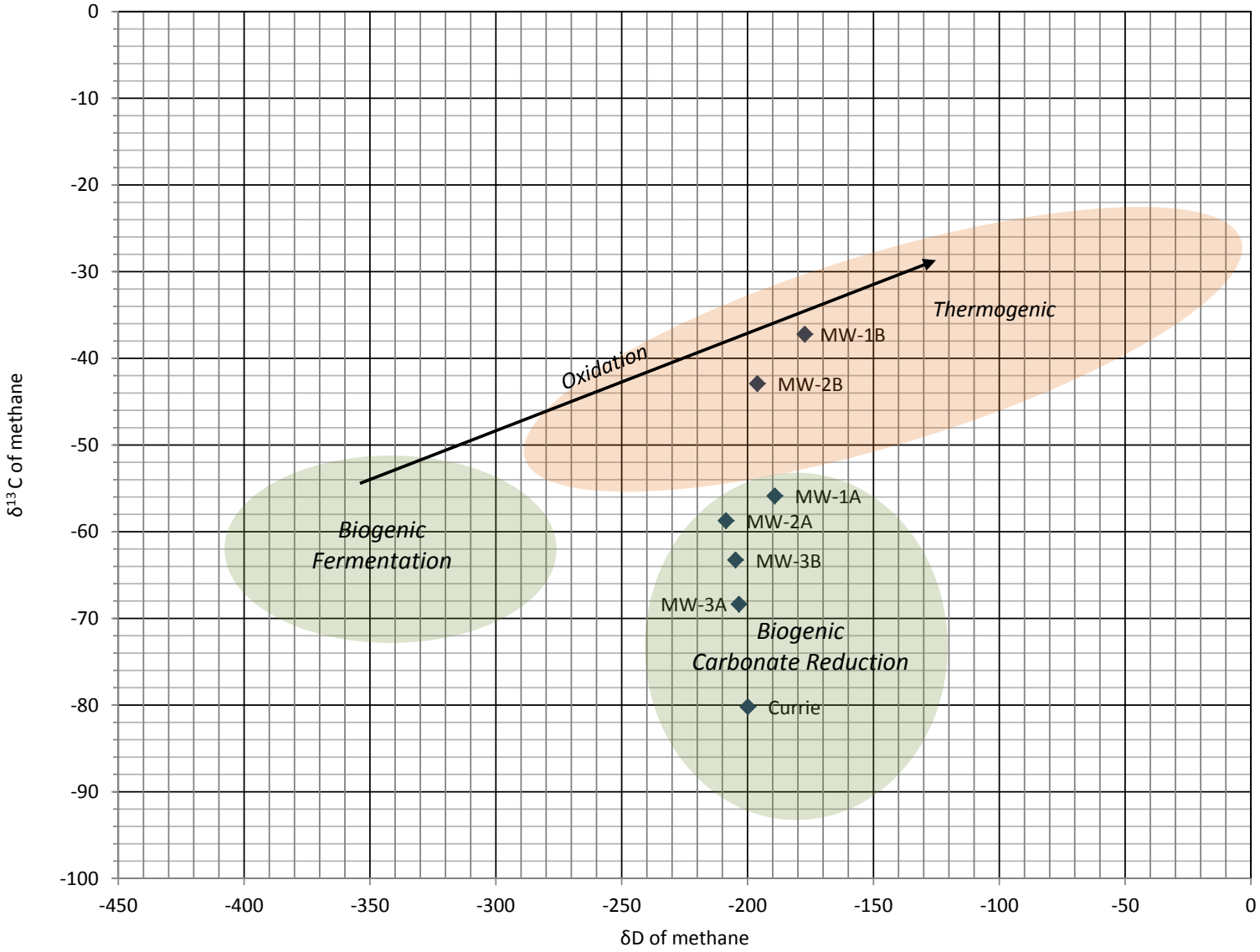
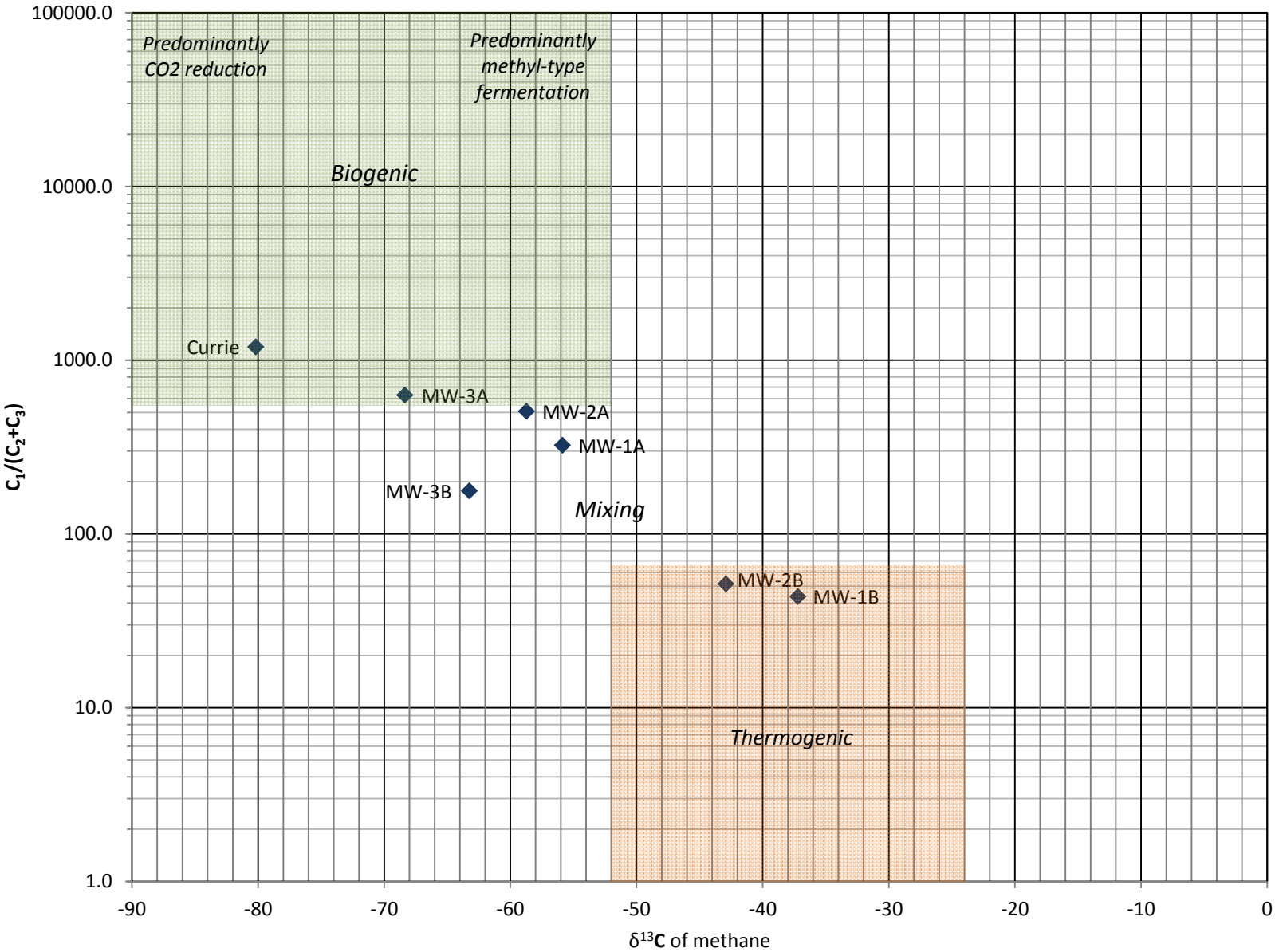


Figure 20b. May 2011 - Comparative Molecular and Isotopic Compositions of Biogenic and Thermogenic Gas for Phase III Wells



Bernard Diagram (after Whiticar, 1990)

Figure 21a. August 2012 - Carbon and Hydrogen Isotopes of Methane for Phase III Wells

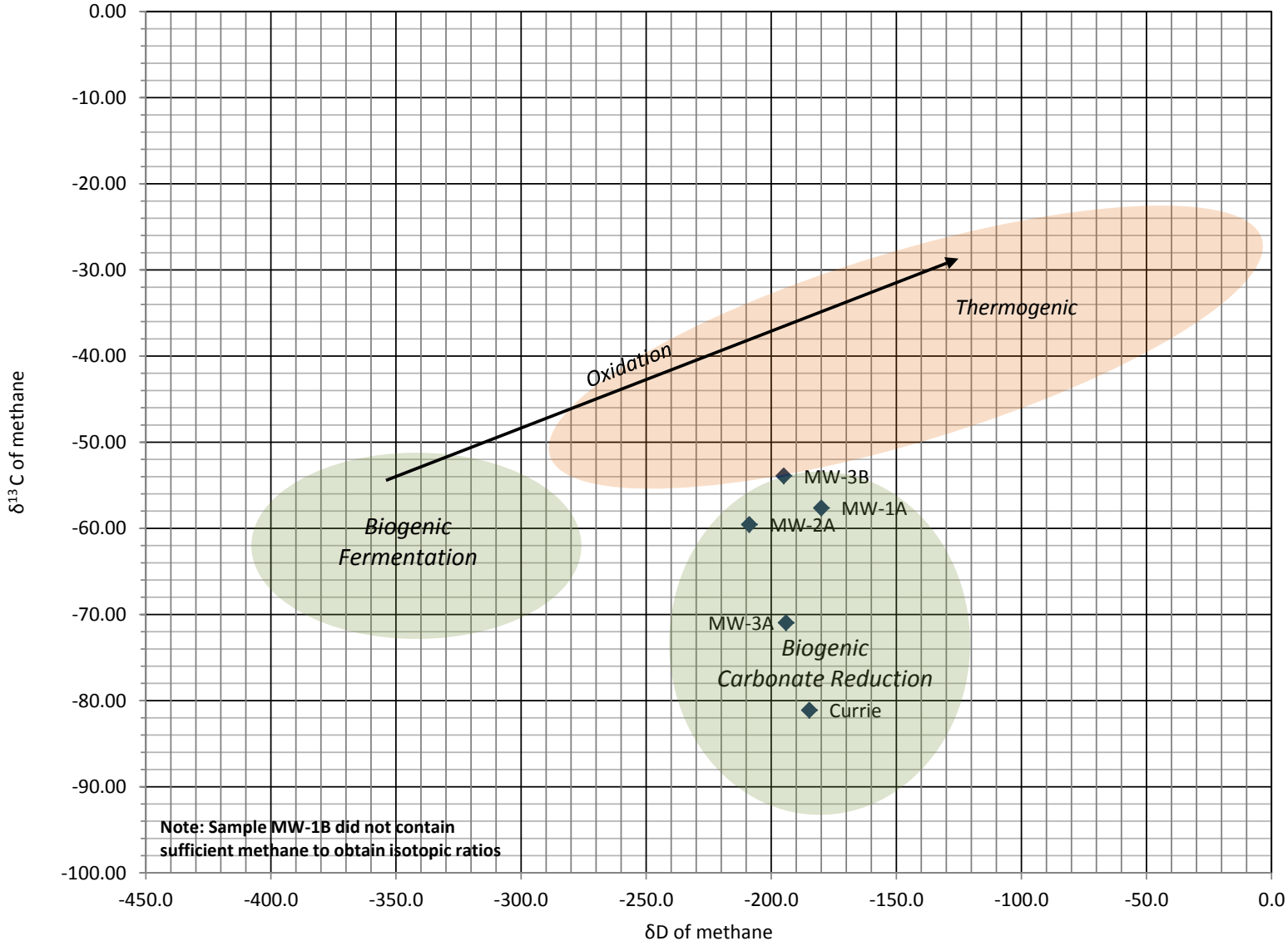
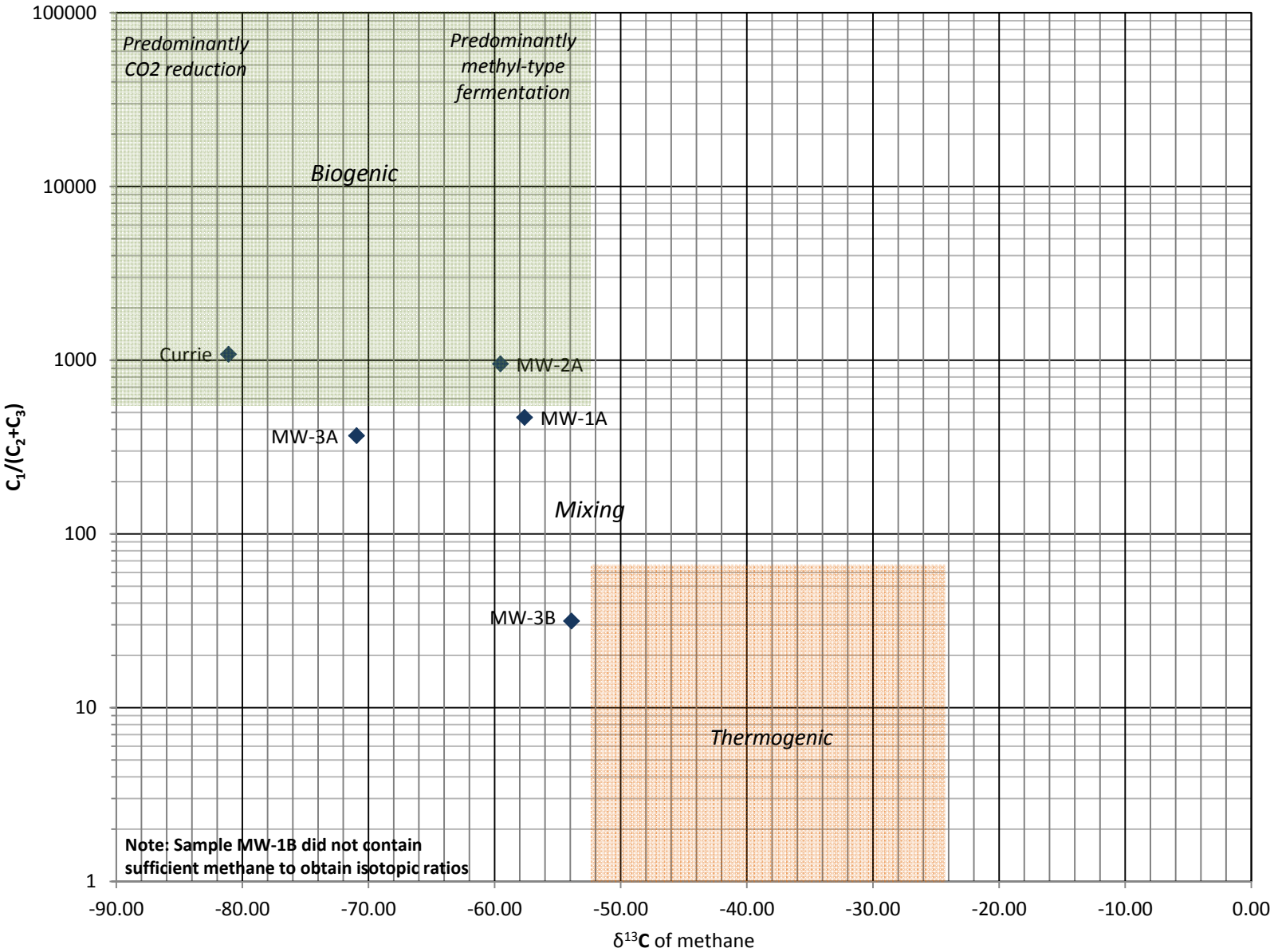


Figure 21b. August 2012 - Comparative Molecular and Isotopic Compositions of Biogenic and Thermogenic Gas for Phase III Wells



Bernard Diagram (after Whiticar, 1990)

Figure 22a. December 2012 - Carbon and Hydrogen Isotopes of Methane for Phase III Wells

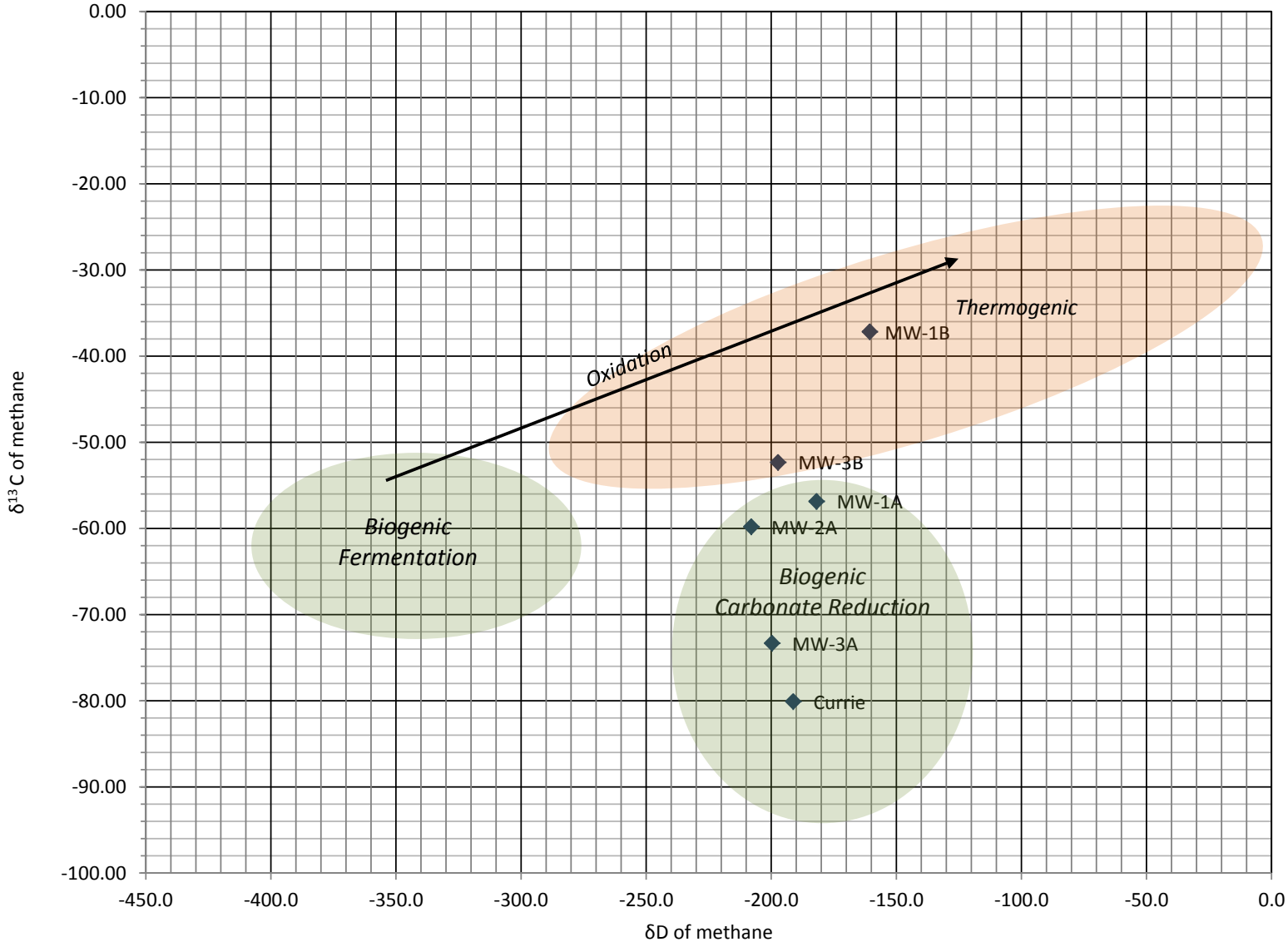
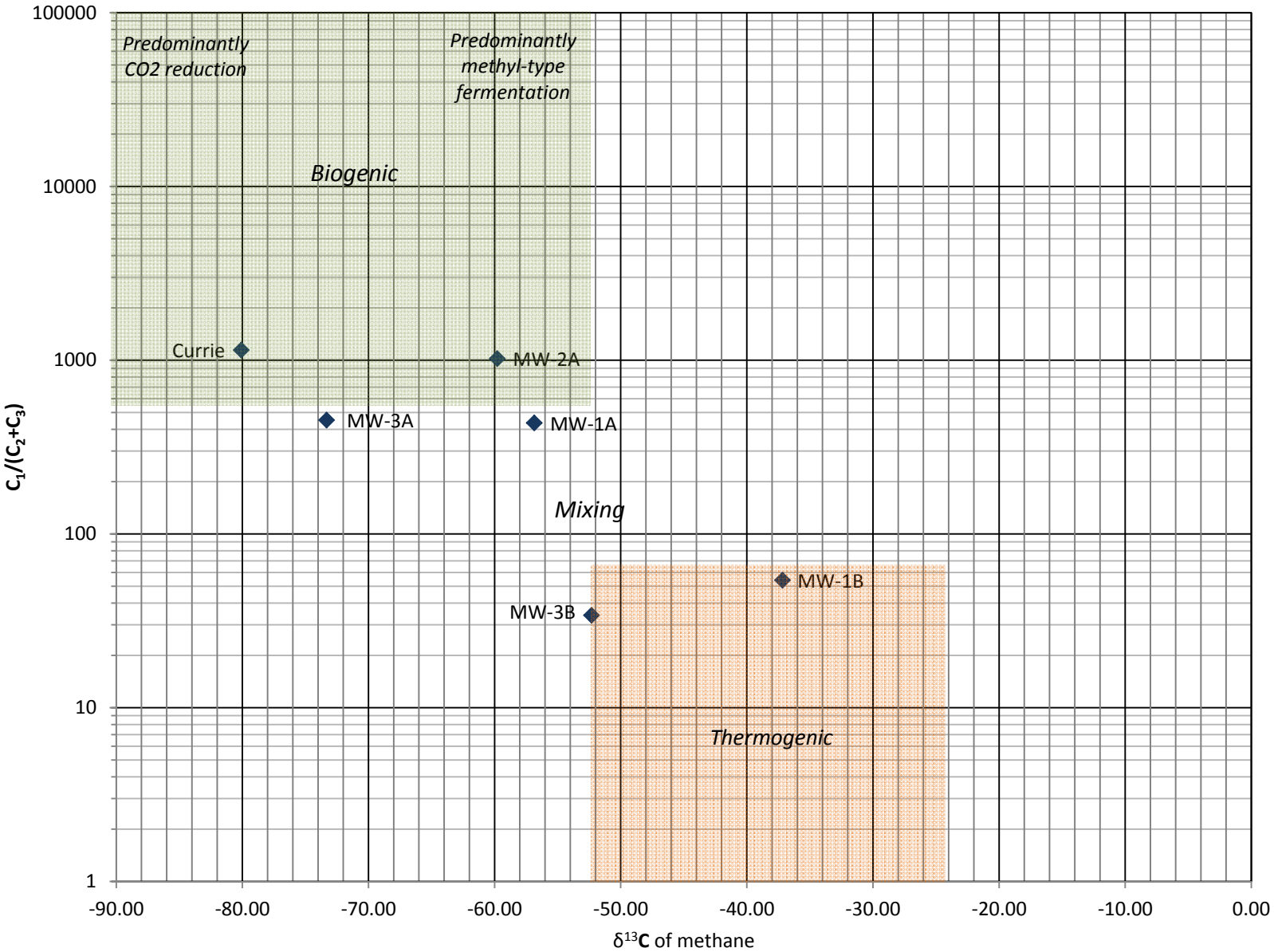
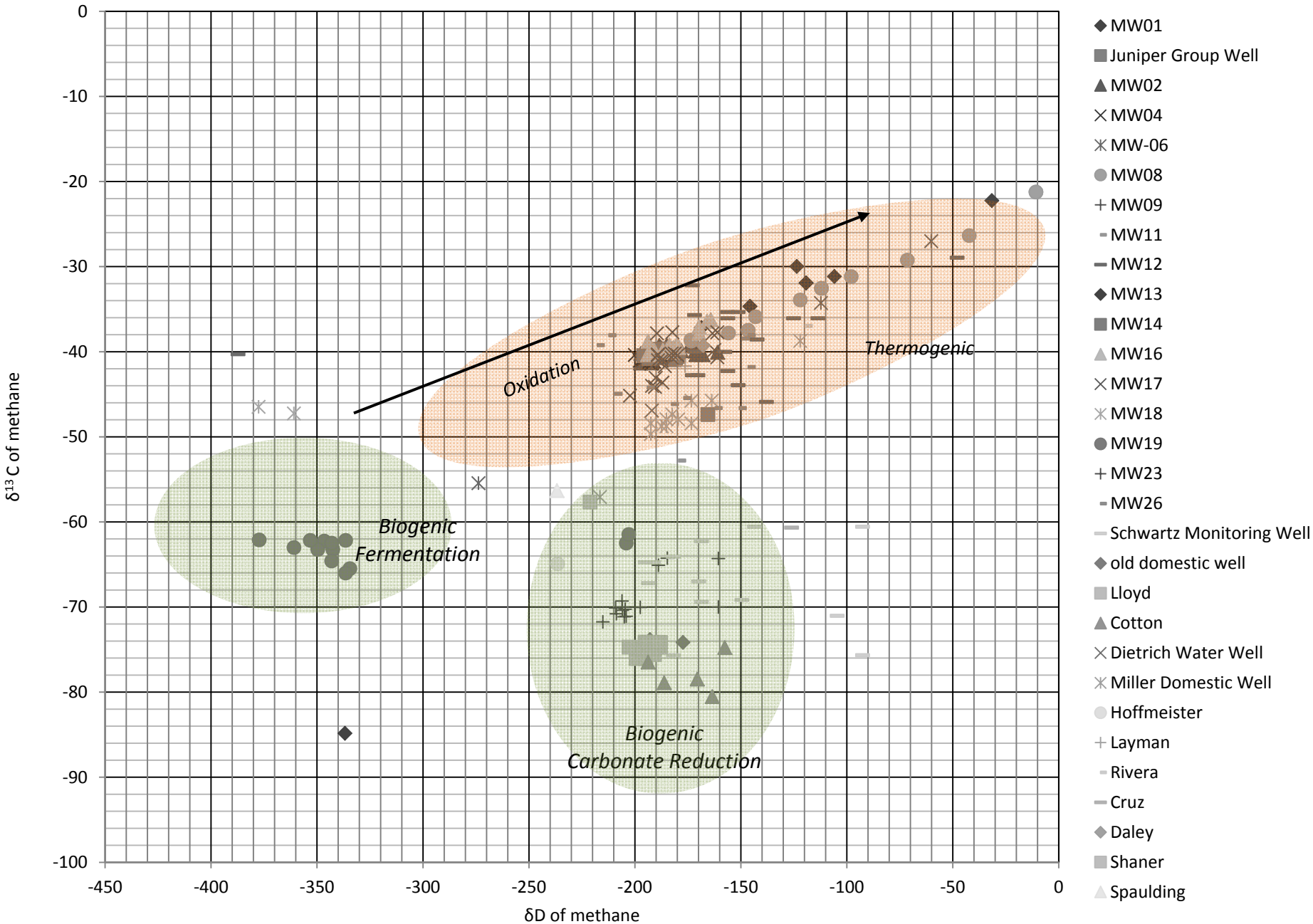


Figure 22b. December 2012 - Comparative Molecular and Isotopic Compositions of Biogenic and Thermogenic Gas for Phase III Wells



Bernard Diagram (after Whiticar, 1990)

Figure 23. Carbon and Hydrogen Isotopes of Methane in West Divide Creek Seep Study Data



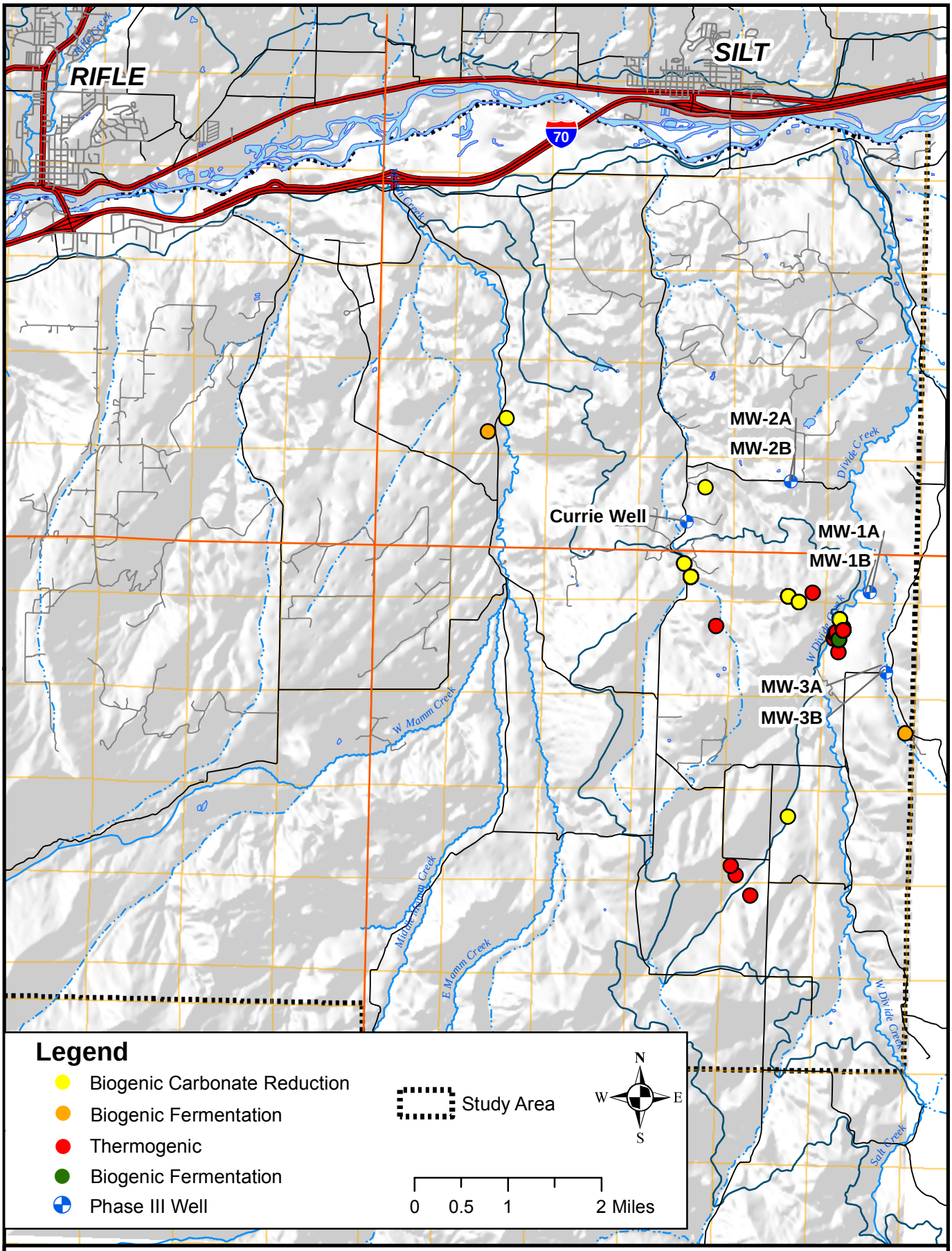


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Figure 24. WDS Seep Isotopic Methane Signature Wells