Phase III Hydrogeologic Study of the Mamm Creek Area Garfield County, Colorado

November 12, 2013

Tetra Tech, Inc.
Louisville, CO

Project History

- Phase I Hydrogeologic Study (URS, 2006)
  - Broad review of historical data
- Phase II Hydrogeologic Study (S.S. Papadopulos & Assoc., 2008)
  - Sample collection and data evaluation

Project Objectives

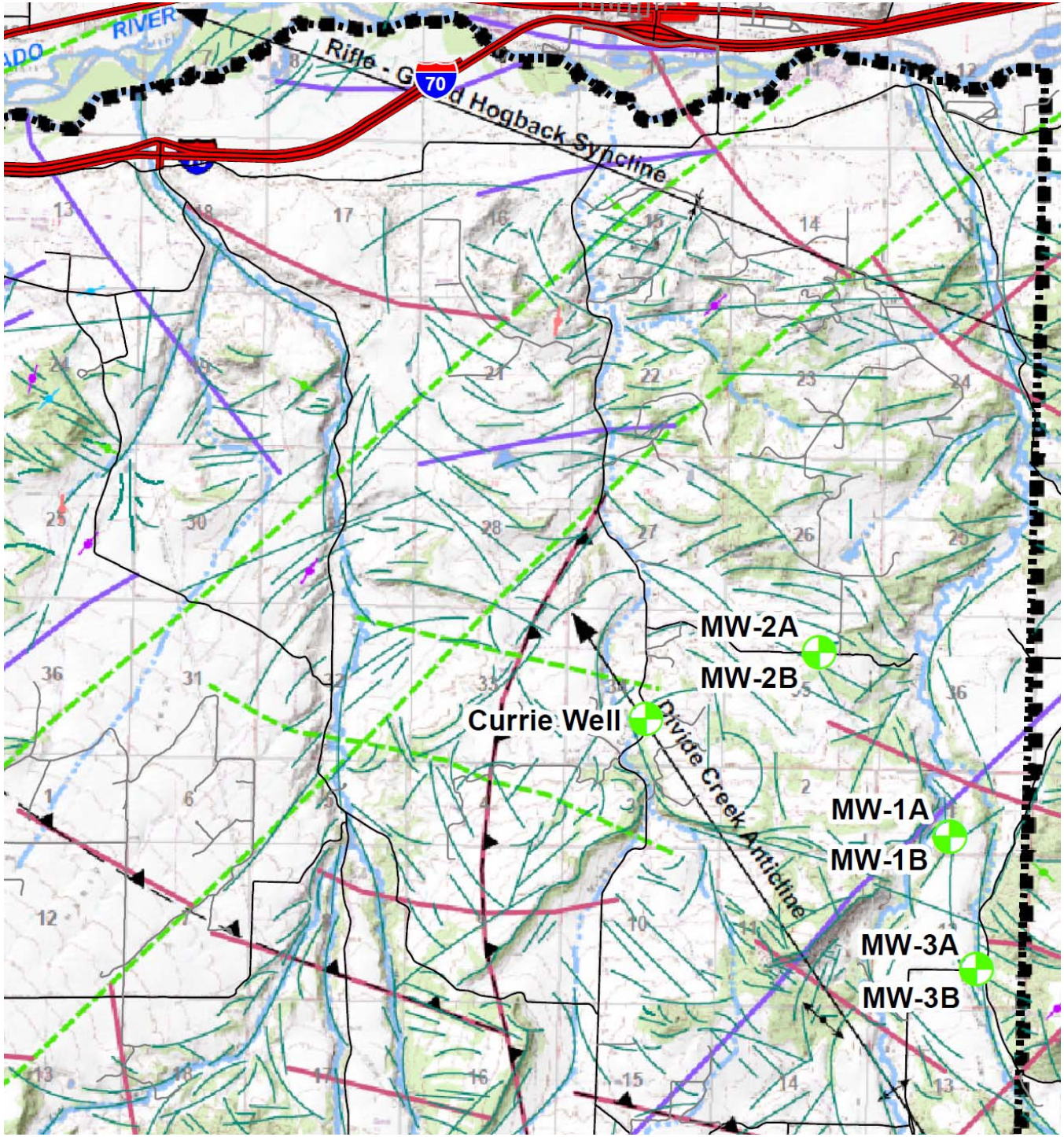
- Gather additional data through installation of nested monitoring wells
- Clarify the nature of the hydrologic flow system and water quality in the study area
- Evaluate the possible effects, if any, of oil and gas development on the Wasatch Formation water quality

Monitoring Wells

- Coordinated with Garfield County to locate three sets of nested wells
- Local water wells are generally 200 feet deep or less
- Wells installed during 2010 in Atwell Gulch member of Wasatch Formation
- Well Screens (bgs):
  - A: 390-405 feet
  - B: 590-605 feet

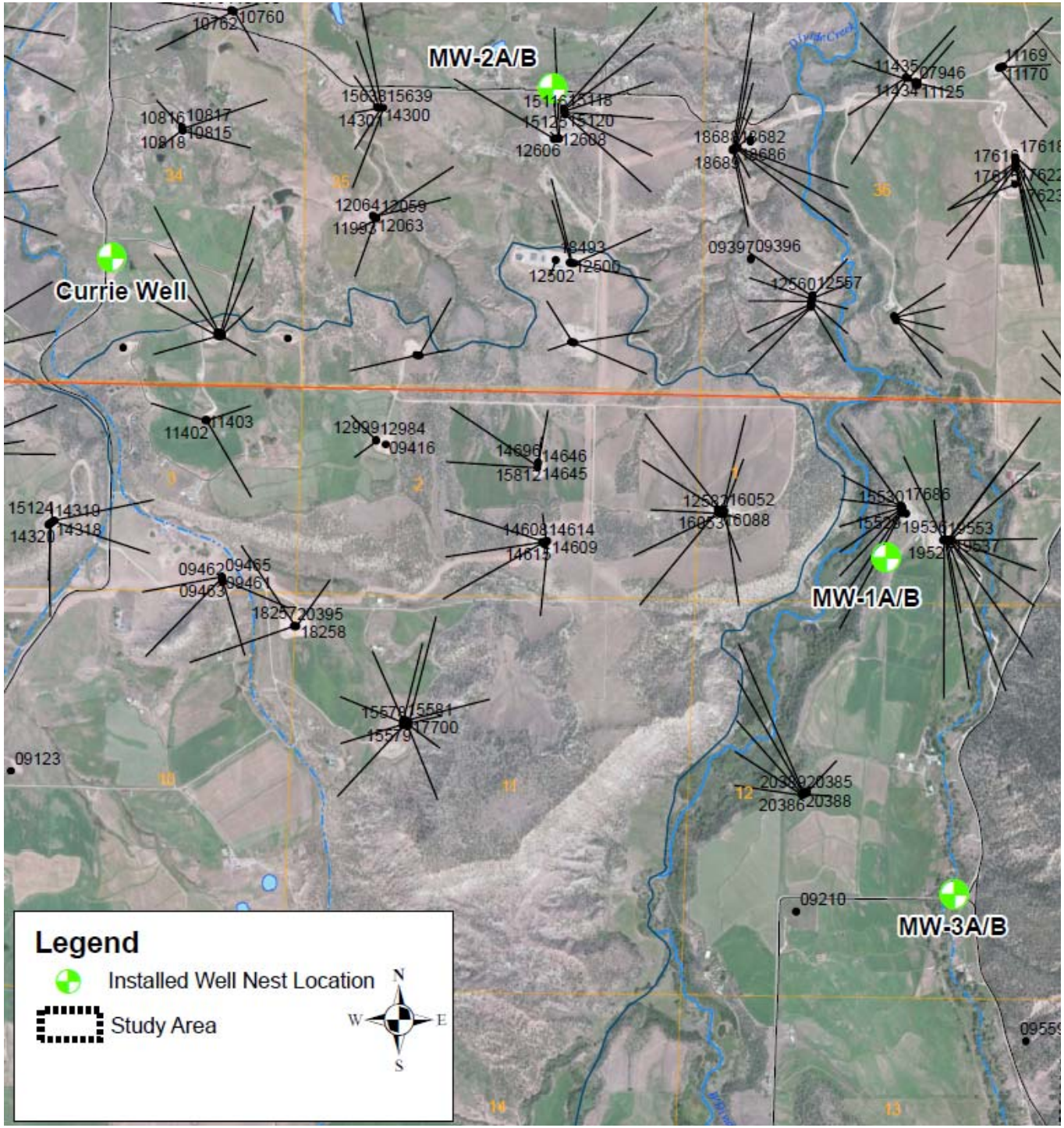

Rifle
ANTLERS
24
6
Garfield Co
Rural Airport
Silt
SILT
MW-2A/B
Currie Well
MW-1A/B
MW-3A/B
MAMM CREEK STUDY AREA

Monitoring Wells in Geologic Context



Basemap from URS Phase I Study Report

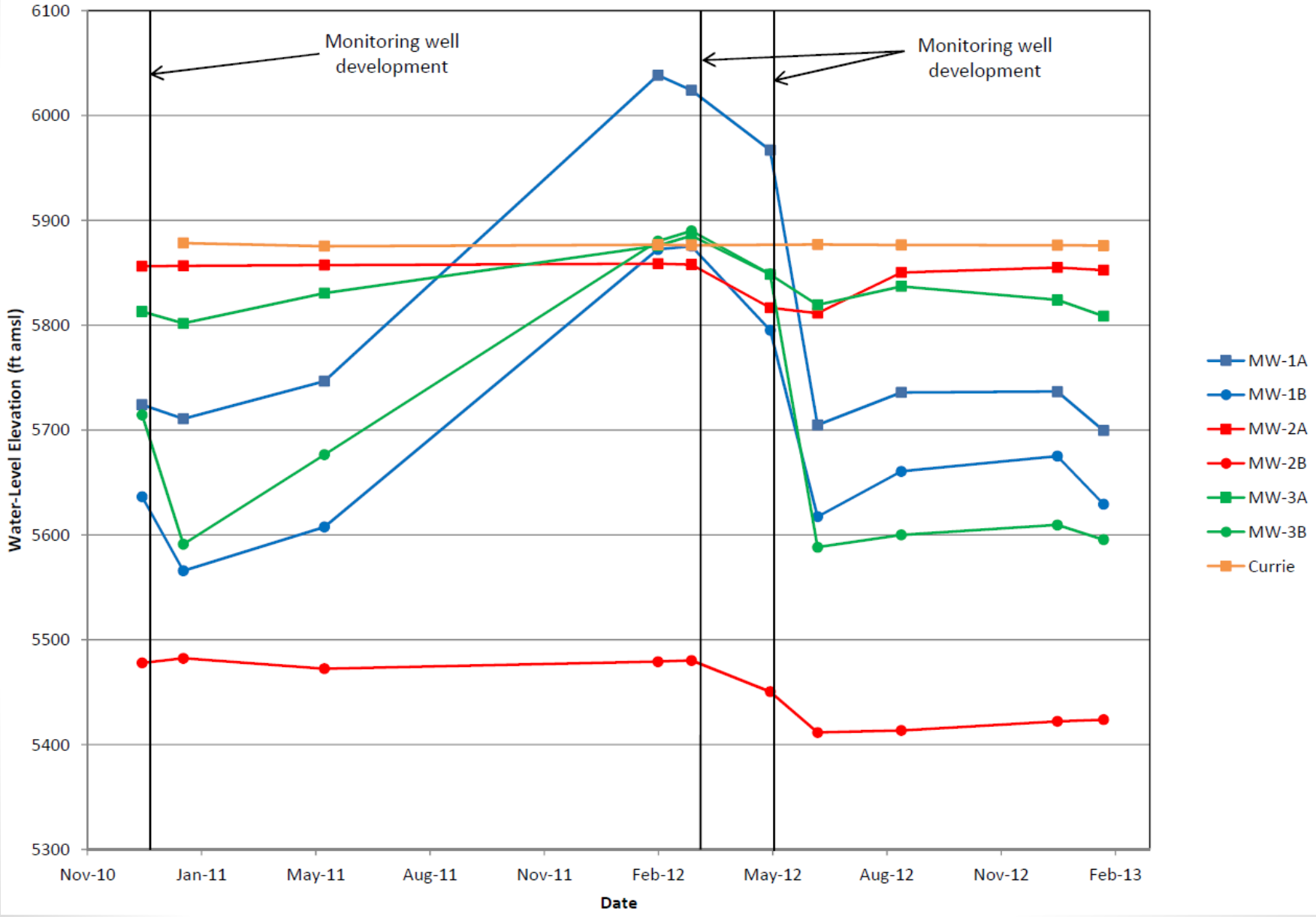
Natural Gas Wells in Vicinity of Monitoring Wells



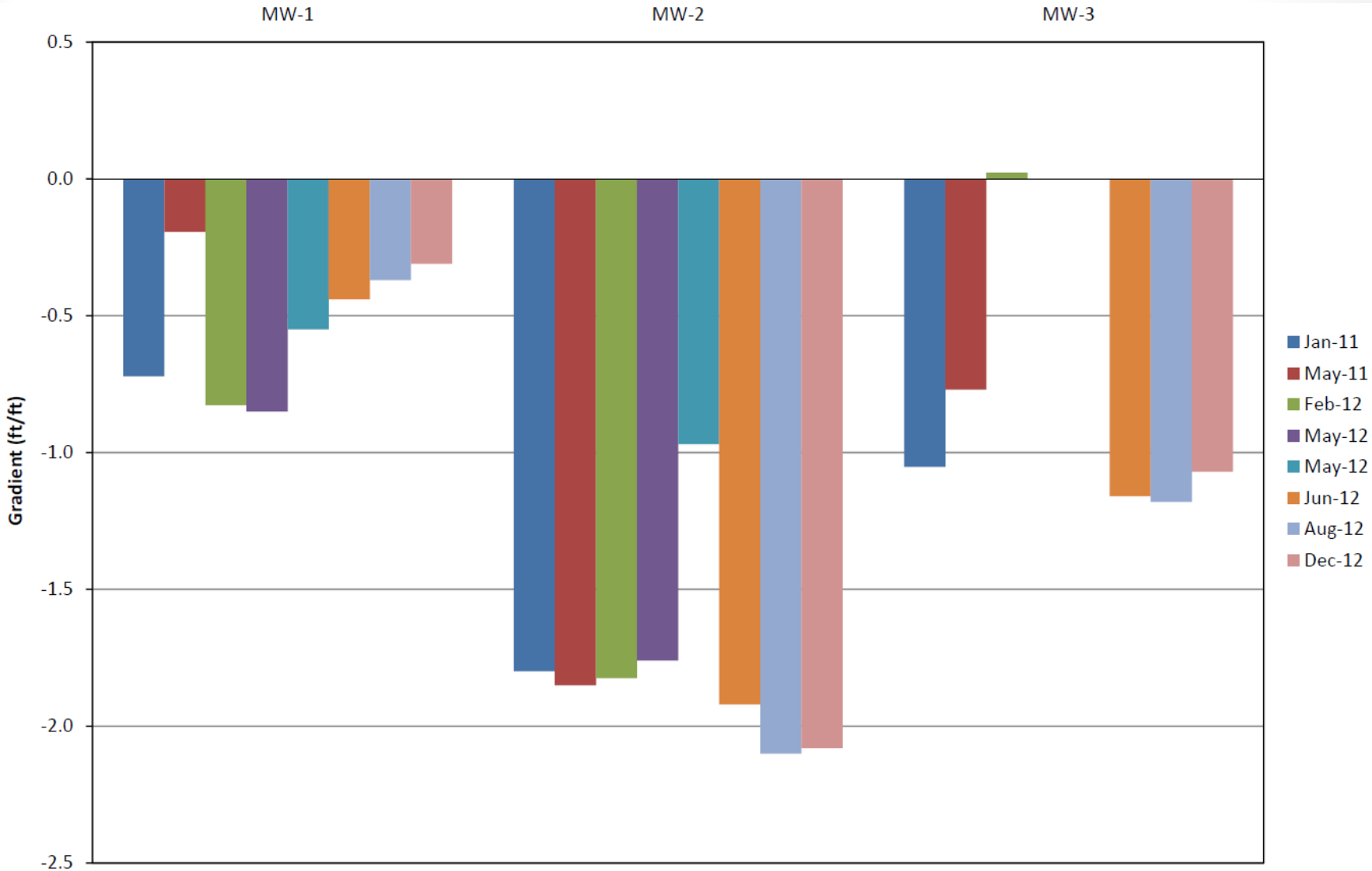
Water-Level Measurements

- Slow rates of recharge indicate tight matrix
- Rapid water-level rise after spring indicates fracture contributions
- Stable lower water levels indicate deeper potentiometric equilibrium

Water-Level Elevations



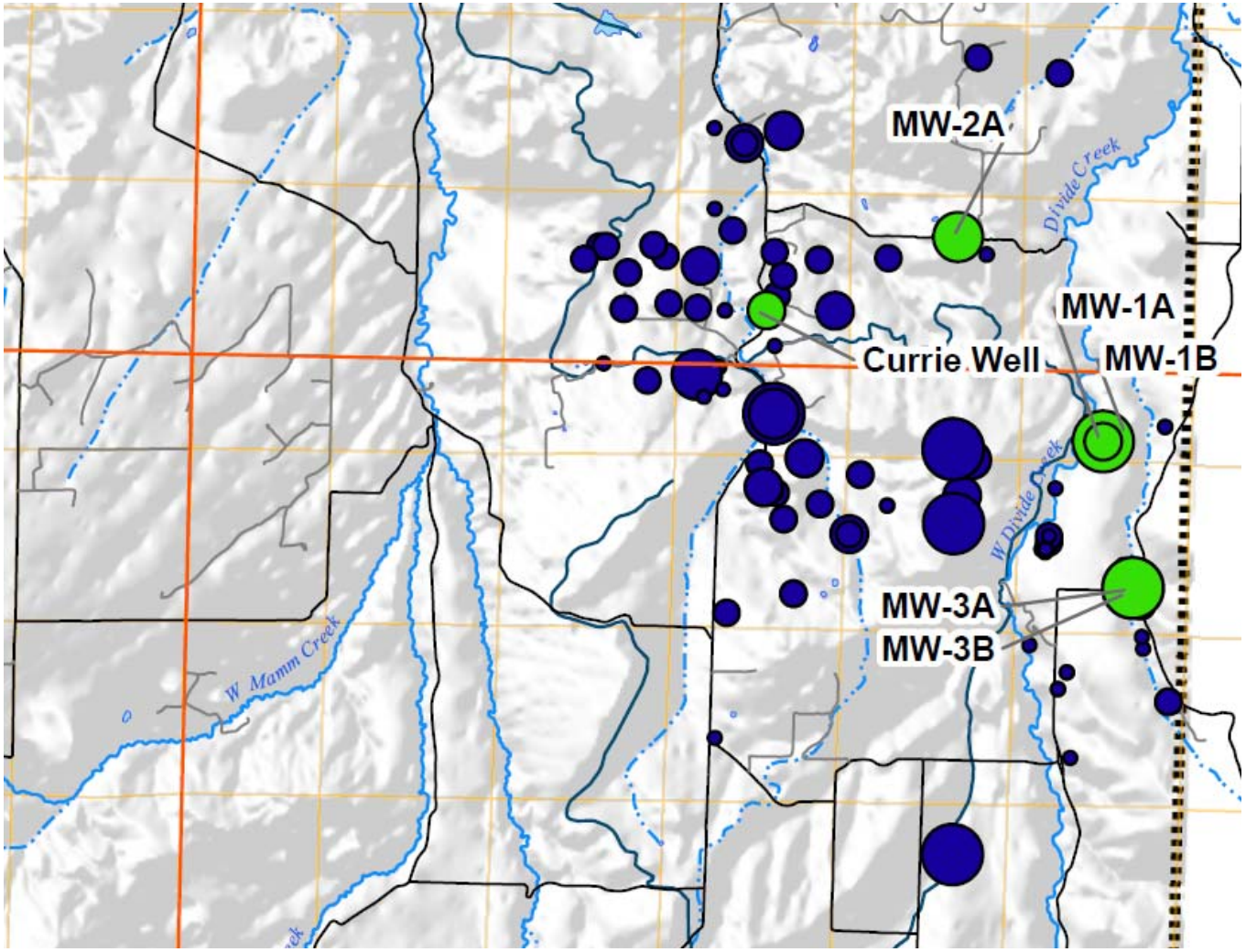
Vertical Hydraulic Gradients



Water-Quality Sampling

- Four sampling events:
  - January 2011
  - May 2011
  - August 2012
  - December 2012

Chloride Distribution



Legend

Data from Prior Studies

- 0 - 50
- 50 - 175
- 175 - 500
- 500 - 1000
- 1000 - 2000

Concentrations are an average of data from years 2004 and 2005 in mg/L.

Phase III Well Data

- 0 - 50
- 50 - 175
- 175 - 500
- 500 - 1000
- 1000 - 2000

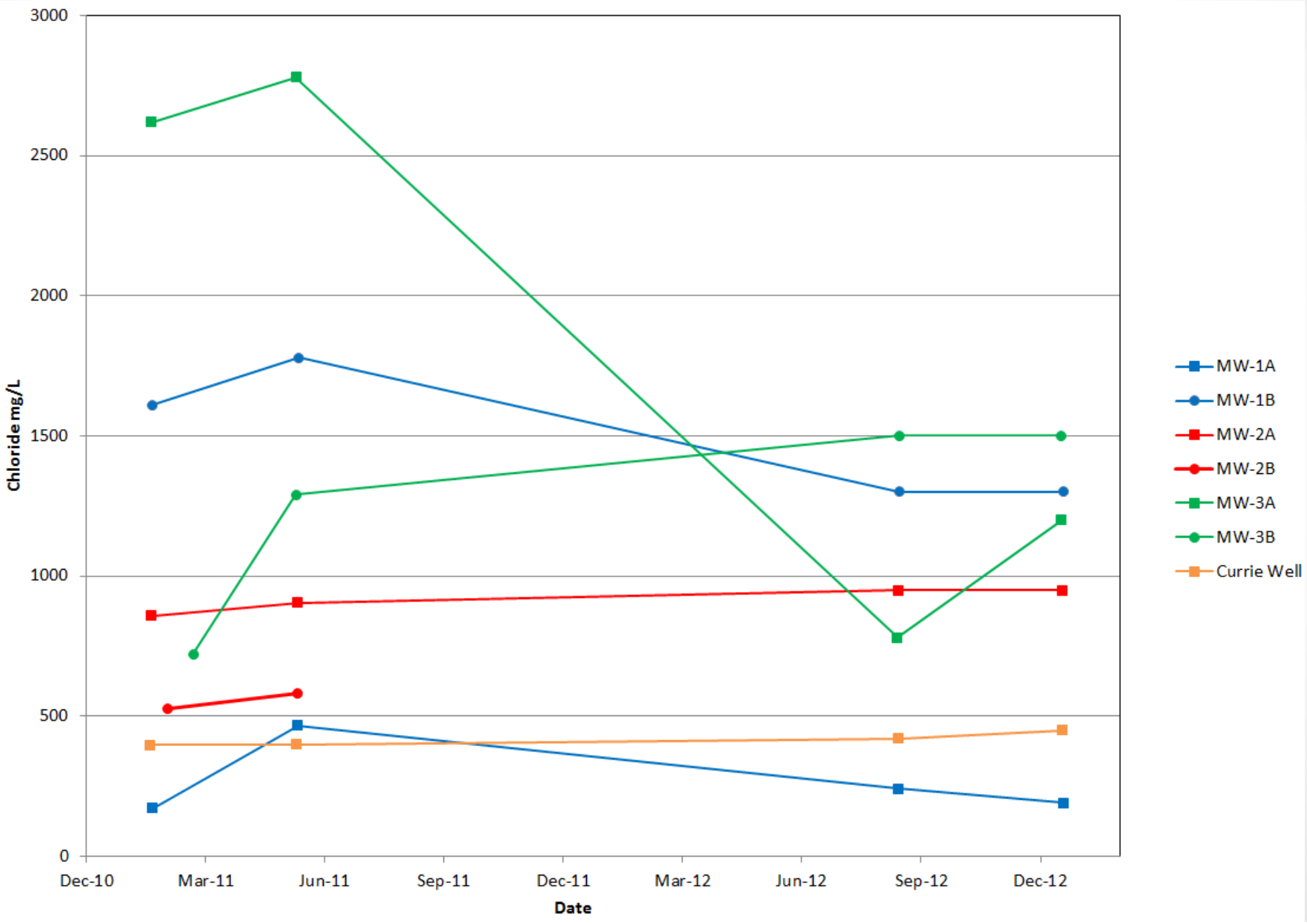
Concentrations are from December 2012 data in mg/L.

Study Area

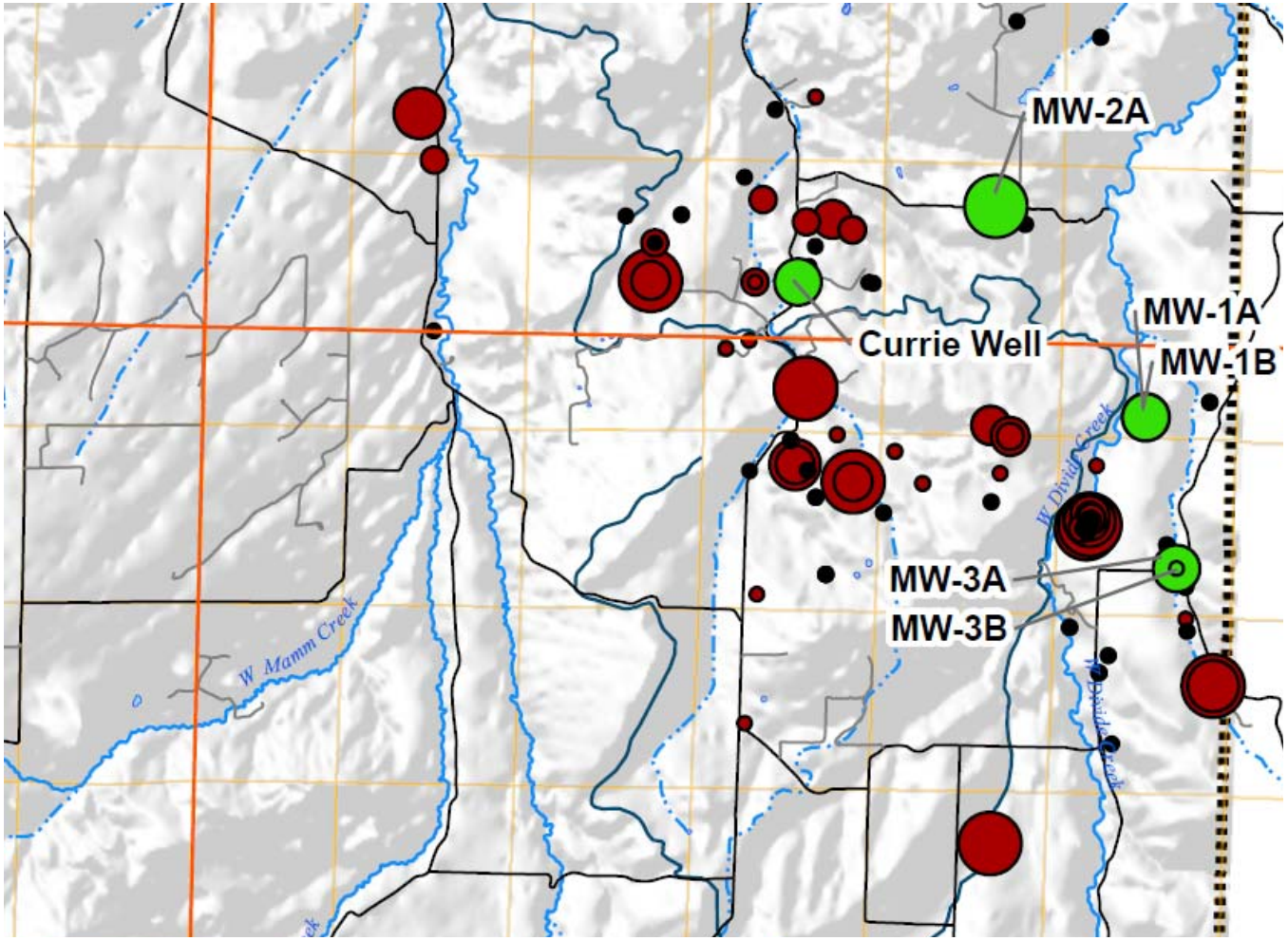
0 0.5 1 2 Miles

N W E S

Chloride Time-Series Data



Methane Distribution



Legend

Data from Prior Studies

- 0.000820 - 0.5
- 0.5 - 3
- 3 - 5
- 5 - 7
- 7 - 15
- ND

ND (non-detect values are reported at half the detection limit)

Concentrations are an average of data from years 2004 and 2005 in mg/L.

Phase III Well Data

- 0 - 3
- 3 - 5
- 5 - 13
- 130

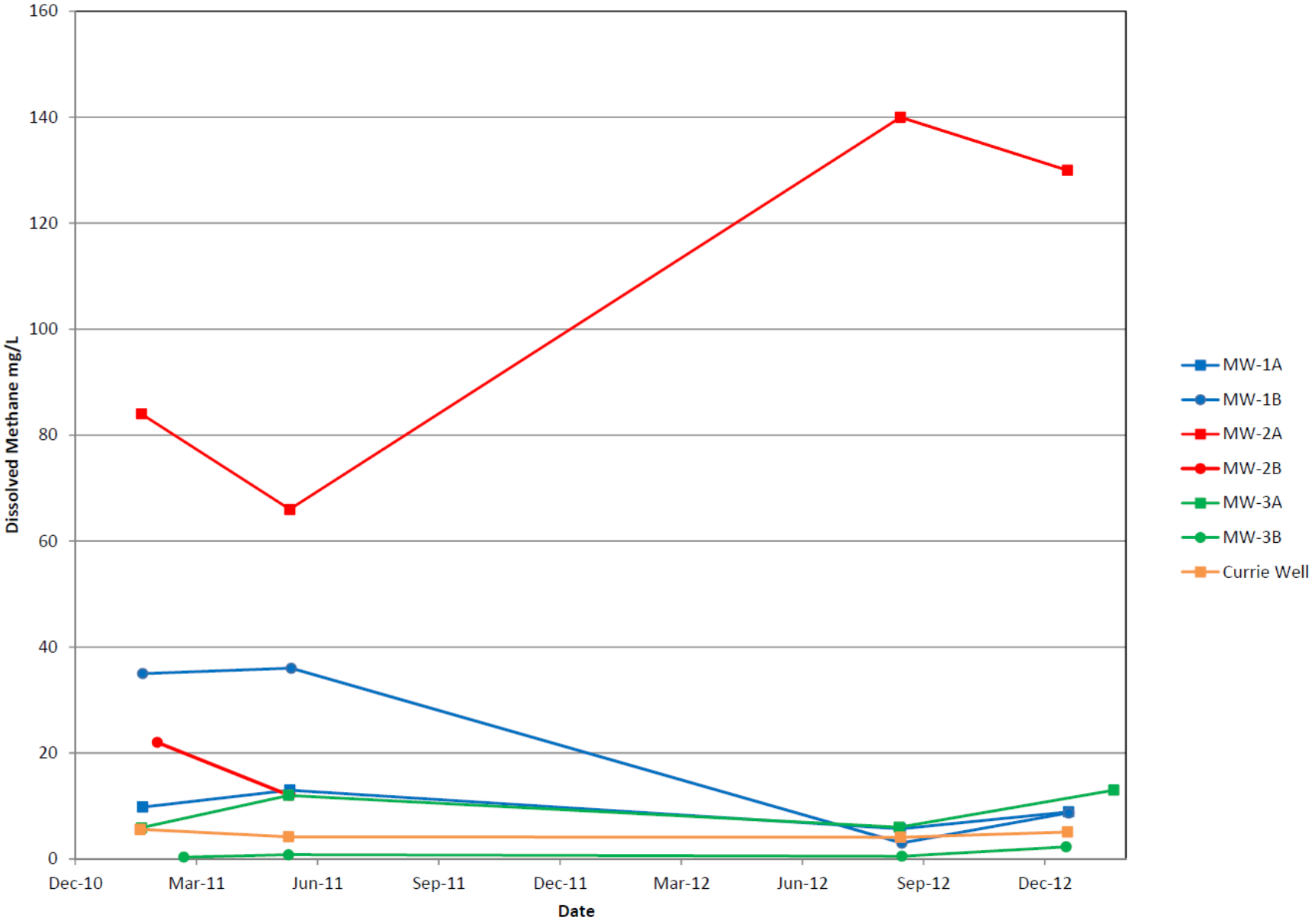
Concentrations are from December 2012 data in mg/L.

Study Area

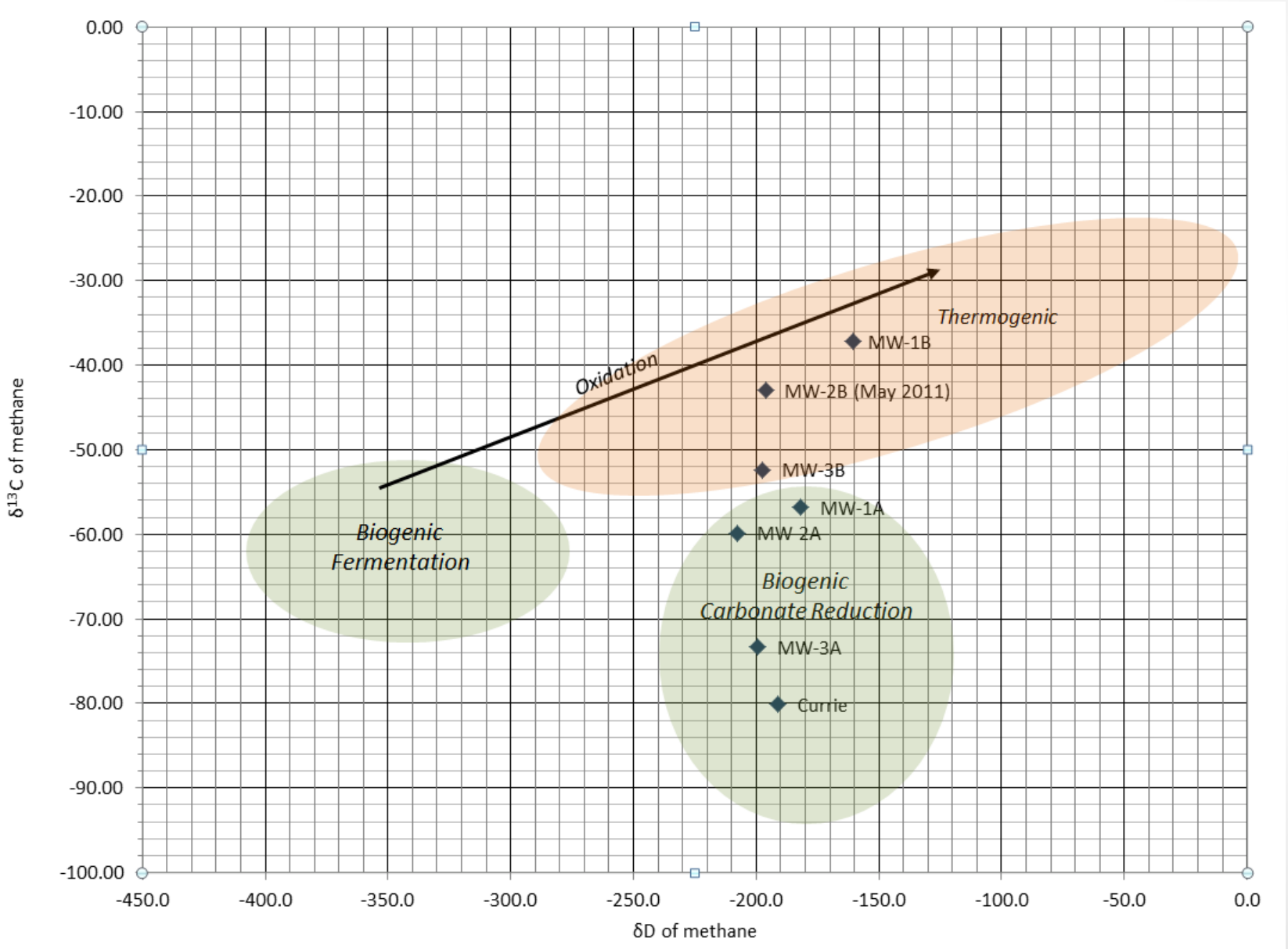
0 0.5 1 2 Miles

N W E S

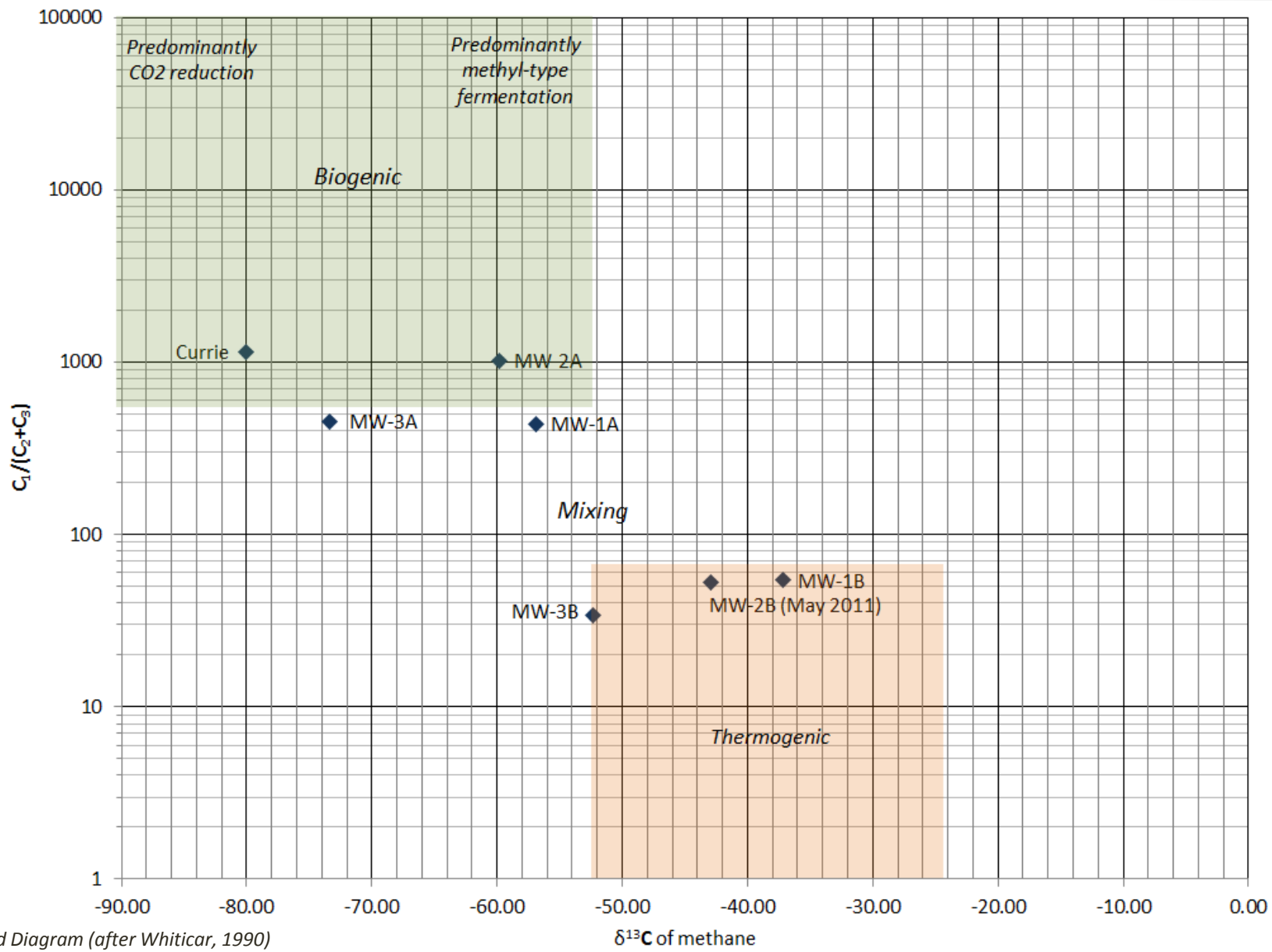
Methane Time-Series Data



December 2012 Methane Isotopes



December 2012 Wet-Gas Analysis



Bernard Diagram (after Whiticar, 1990)

Elevated Methane in MW-2A

- Methane concentrations in MW-2A:
  - 66 – 140 mg/L
  - Isotopes consistently indicate biogenic source
- As observed in Currie Well with similar isotopic signature, indications of carbonate-reduction environment:
  - Reducing groundwater chemistry
    - Oxidation-reduction chemistry measured during sampling
    - “Rotten-Egg” odor observed during sampling at MW-2A and Currie Well

Elevated Methane in MW-2A

- Likely source of methane in subsurface is carbon dioxide being reduced via microbial processes to methane

$$CO_2 + 4H_2 = CH_4 + 2H_2O$$

- Carbon dioxide origin is unknown, may be naturally occurring in Wasatch Formation

Benzene Concentrations

- Not detected conclusively in MW-1A, MW-2A, MW-3A
- MW-1B concentrations ranged from ND to 5.3 ug/L
- MW-2B concentrations ranged from 1.4 to 3.4 ug/L
- MW-3B concentrations ranged from ND to 1.5 ug/L
- Currie Well concentrations ranged from 1.3 to 1.8 ug/L
- Benzene concentrations greater with depth

Summary of Groundwater Flow Interpretation

- Bedrock is combination of low-permeability siltstones and sandstones
- Significant fractures exist, probably associated with structural anticline feature
- Water flows within this “dual-porosity” geology
- Water levels in wells may vary seasonally due to infiltration of snowmelt or rain into fracture network

Summary of Water Quality Interpretation

- Chloride is locally elevated in concentration
  - Consistent with concentrations in domestic wells near Phase III study
  - In general, concentrations appear to increase with depth
    - Exception is MW-2 well nest
- TDS, pH, alkalinity not useful in water quality interpretation
  - Grout-fluid intrusion into adjacent fractures
  - Piper diagrams used for evaluation of other wells not appropriate evaluation tool because of high alkalinity

Summary of Water Quality Interpretation, cont.

- Benzene present in low concentrations (ND to 5.3 µg/L)
  - Consistency of detected concentrations suggests benzene is not derived from localized source, but likely naturally occurring within Wasatch Formation
- Methane in shallow wells possesses biogenic signature different from that of Williams Fork Formation
- Methane in deep wells possesses thermogenic signature

Summary of Water Quality Interpretation, cont.

- Higher concentrations of methane in initial samples at certain wells
- After multiple rounds of development and sampling, methane concentrations are more consistent from well to well
  - Suggests that methane is typically present in groundwater
  - Methane concentrations do not specifically point to gas production source, instead likely naturally occurring
    - Higher concentration and biogenic at surface
    - Lower concentration and thermogenic signature in deeper interval
    - Methane may be moving to wells through fractures, or trapped in intercepted isolated pockets in the Wasatch Formation

Conclusion

- The Phase III Study provided a understanding of groundwater chemistry in the hydrogeologic layers located about 200 feet deeper than those typically utilized for domestic purposes
- The Phase III Study did not show clear evidence of oil and gas impacts on Wasatch Formation water quality