

# Methane Investigation, Monitoring, and Mitigation Program

Petroglyph Energy Inc.  
Little Creek and Bear Creek  
Huerfano County, CO

[www.norwestcorp.com](http://www.norwestcorp.com)

**NORWEST**  
QUESTA ENGINEERING



# **Methane Investigation, Monitoring, and Mitigation Program (MIMMP)**

- Petroglyph voluntarily and temporarily shut in its wells in Huerfano County on July 20, 2007
- Petroglyph and through contract, Norwest Questa Engineering and Norwest Applied Hydrology (Norwest), have been actively reviewing, analyzing, and evaluating all available data to determine the origins of the methane found in the shallower ground water aquifers.
- Petroglyph and Norwest have also been creating a long-term ground water and gas seep monitoring program in addition to developing a field reactivation plan, which prevents significant adverse impacts to public health, safety, welfare, and environment while mitigating and providing remediation of methane in the impacted ground water.



# MIMMP Goals

- Supply detailed scientific and engineering data to provide framework for determining the extent of the methane impacted ground water, its potential origins, mitigation, and remediation strategies.
- Develop strategy for remediation of affected aquifers.
- Develop an ongoing strategy for continued CBM operations of Petroglyph's wells in Huerfano County.
- Develop strategy for de-gassing Vermejo coals in controlled manner for future public utilization of large fresh water aquifer.

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# MIMMP Data Gathering

- Data has been collected through a cooperative effort between Petroglyph and its contractors, the landowners, and the Colorado Oil and Gas Conservation Commission (COGCC).

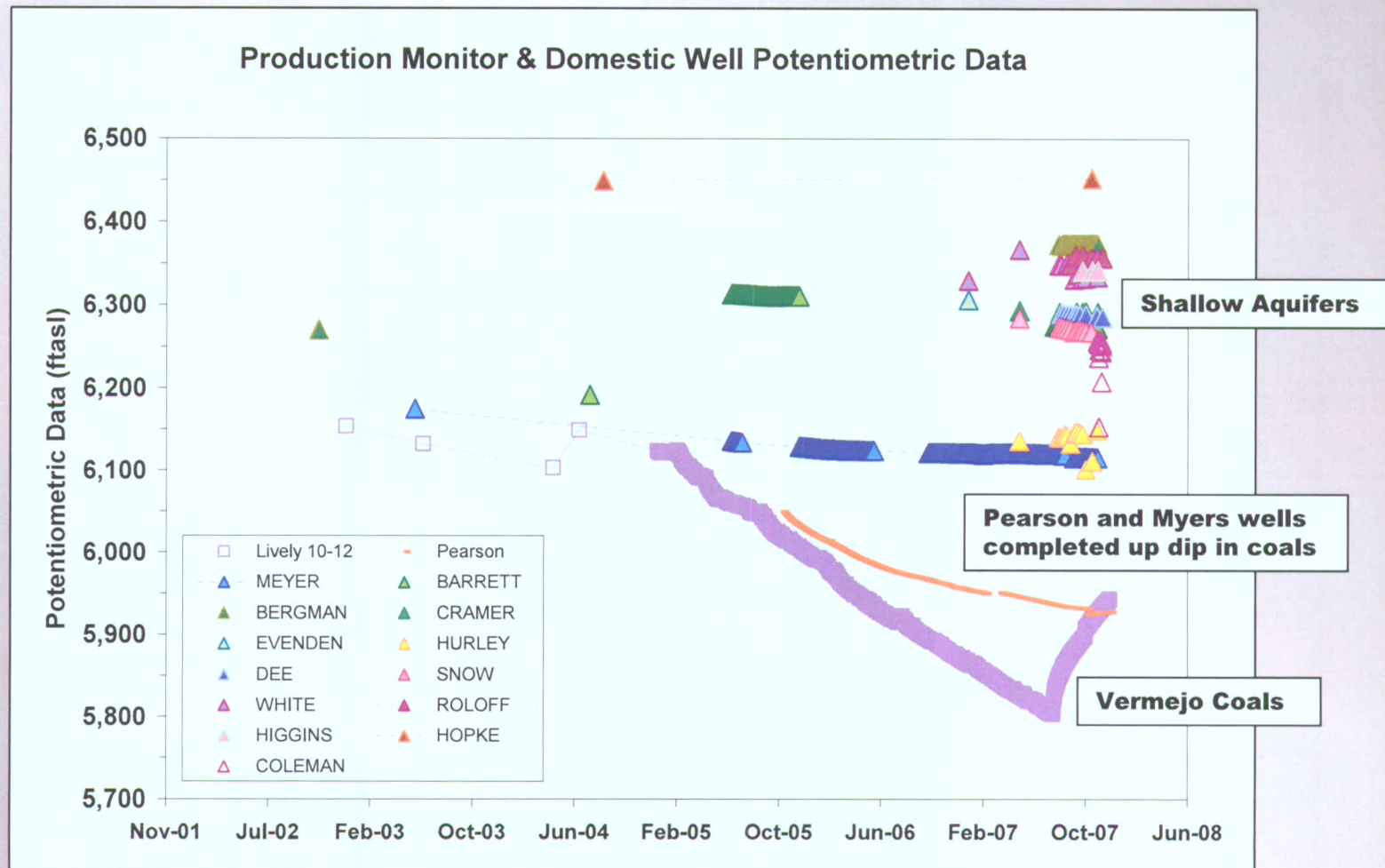


# MIMMP Data Gathering

- **Pressure and Water Level Measurements**
  - Water well pressure measurement of 10 water wells using sounding tubes or downhole transducers
  - CBM water well pressure measurement with downhole pressure transducers in 6 Vermejo coal wells, two of which are dedicated pressure monitoring wells
  - Fluid level measurements in from fluid level shots and casing pressure measurements in 11 Vermejo coal wells



# Pressure and Water Level Measurements





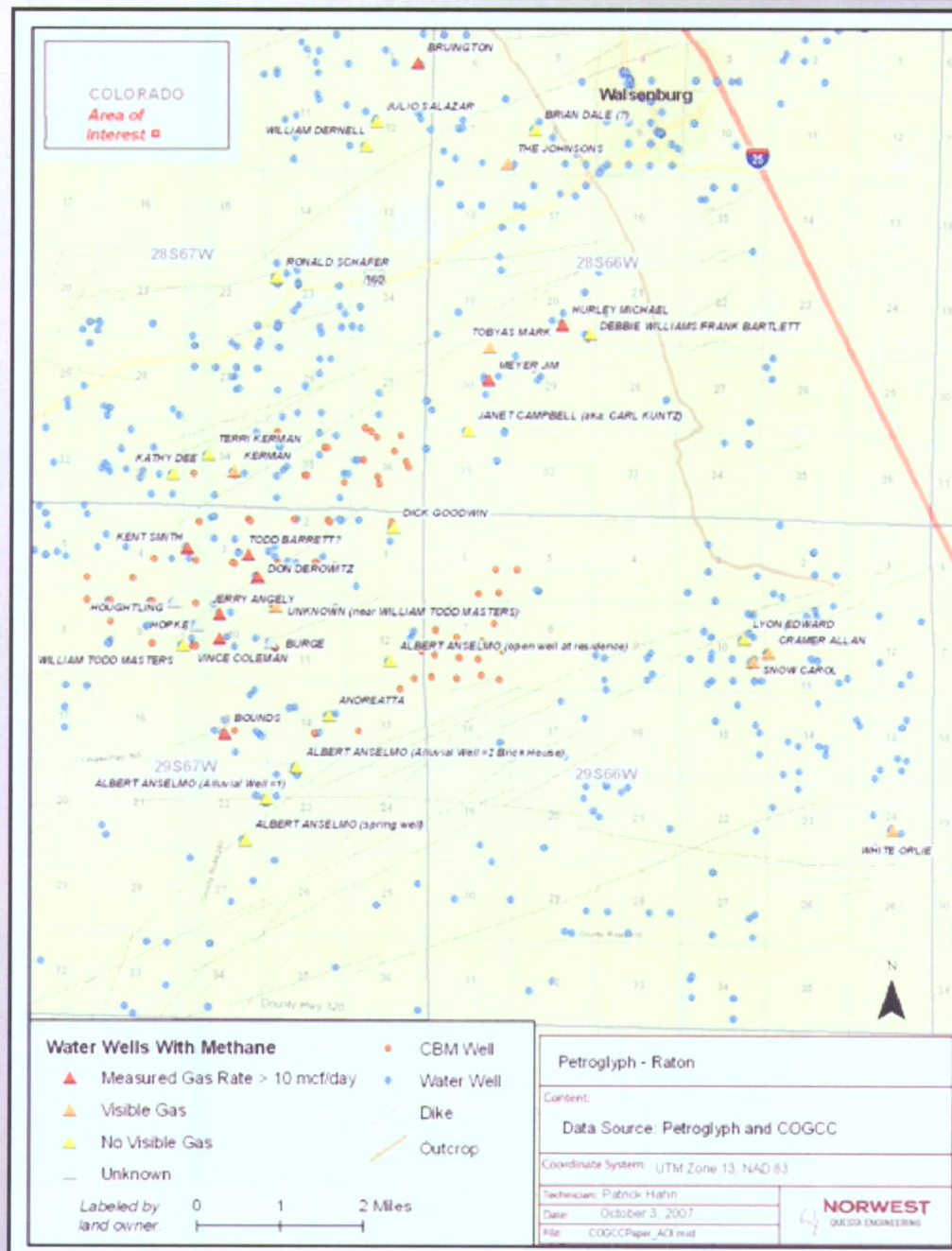
# MIMMP Data Gathering

- **Methane Identification and Monitoring of Water Wells**
  - Initial gas sampling for potential methane in 66 water wells
- Currently Monitoring 54 locations
  - 39 in near vicinity on bi-weekly schedule
  - 15 near outcrop/north on monthly schedule
- Gas flow rate measurement and monitoring in 5 shallow water wells
  - 2 wells measured continuously
  - 3 wells measured weekly

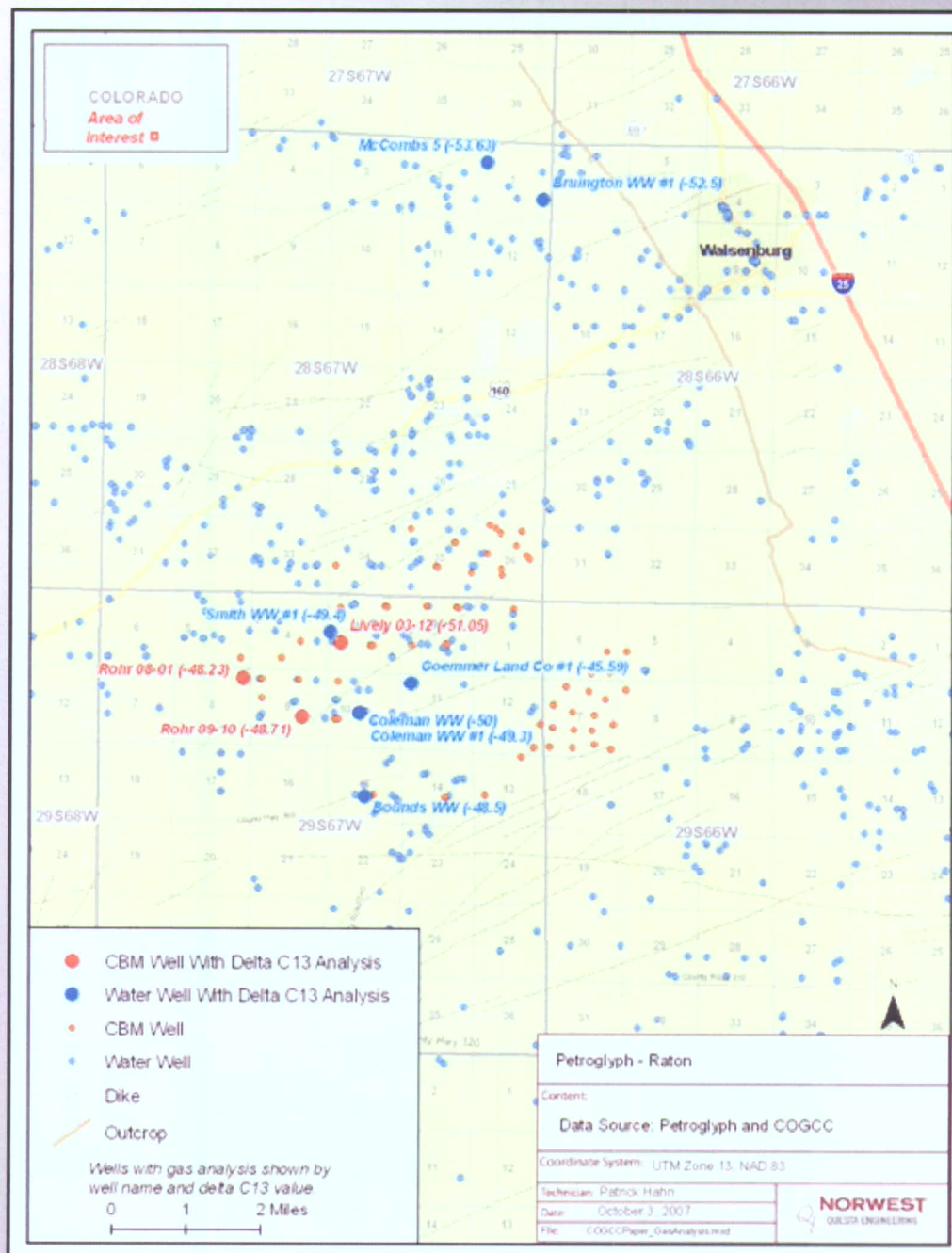


# Water Wells

## Methane and Flow Rates



# Carbon Isotope Analysis

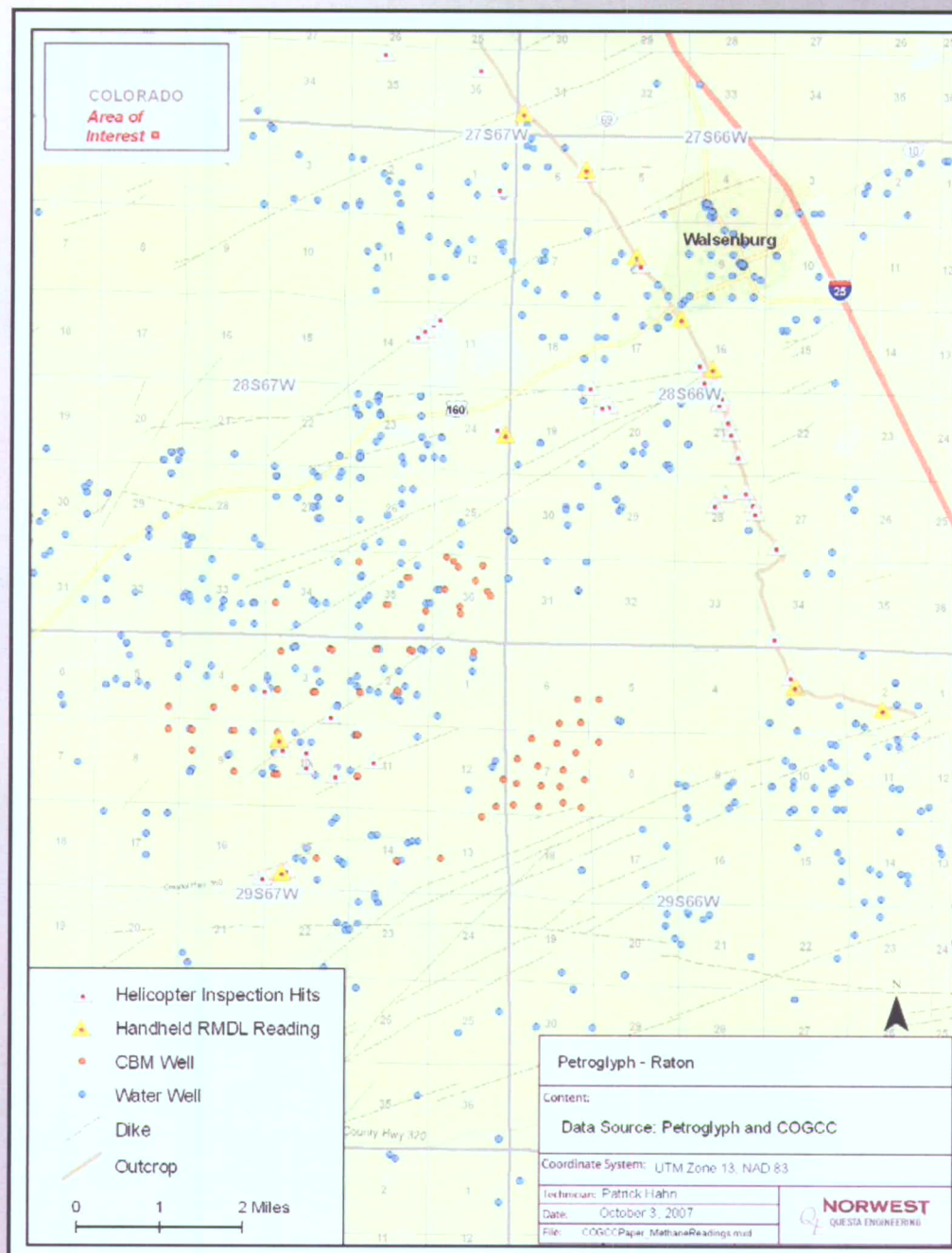




# MIMMP Data Gathering

- **Potential Vertical Pathways: Identification and Monitoring**
  - Braden head pressure monitoring of all 56 Vermejo CBM producers.
  - Successfully pressure tested casing in both the Lively 03-10 and Lively 03-12 from surface to approximately 30 feet above the coal perfs.
  - Ran camera surveys in four oil and gas wells which have been converted to water wells and tagged the PBTD in each well.
  - Re-entered two old P&A'd Oil and Gas wells (Lively 10-02 and the Dick Realty #1). No significant gas shows were noted during operations.
  - Re-plugged the Dick Realty #1 well and left the Lively 10-02 as a monitoring well per the COGCC.
  - Helicopter Survey of AOI using laser methane detector.
  - Ground based verification of several newly found positive laser methane shows using hand held RMLD

# Helicopter and RMLD Survey Results





# Current Mitigation Efforts

- Conduit for methane movement from the Vermejo coals to the shallow aquifers has not been located.
- Mitigation efforts have been focused at removing the methane from the produced water stream at the affected water wells.
- Installed and/or provided home methane monitors for 10 land owners.
- Petroglyph is supplying water to 7 land owners.
- Installed methane vent systems on 5 water wells.

# Vertical Pathways: Identification

- Dikes as vertical conduits?
  - Known to communicate deeper salt water in southern Raton to Vermjo coals.
  - Believed to be important for observed CBM gas performance in Petroglyph CBM wells.
  - Have been suggested as vertical conduits for observed methane migration.

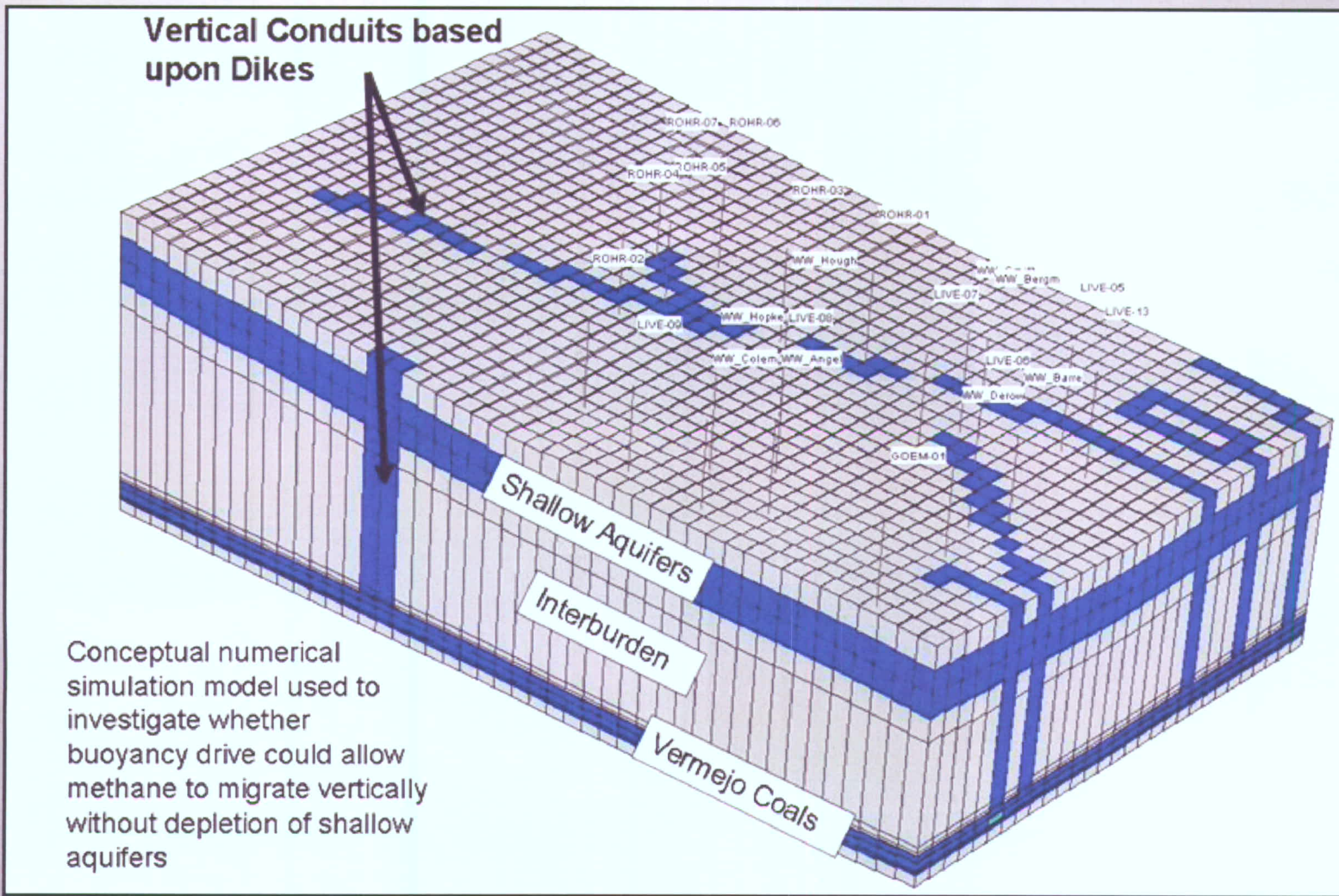


# Vertical Pathways: Identification

- Dikes as vertical conduits?
  - Observed P head differences between shallow aquifers and Vermejo coal aquifer indicates no hydraulic connectivity.
  - Numerous studies have discounted large scale hydraulic communication between shallow aquifers and Vermejo Coal.
  - Used conceptual numerical simulation to study gas migration by buoyancy as possible mechanism for gas migration.

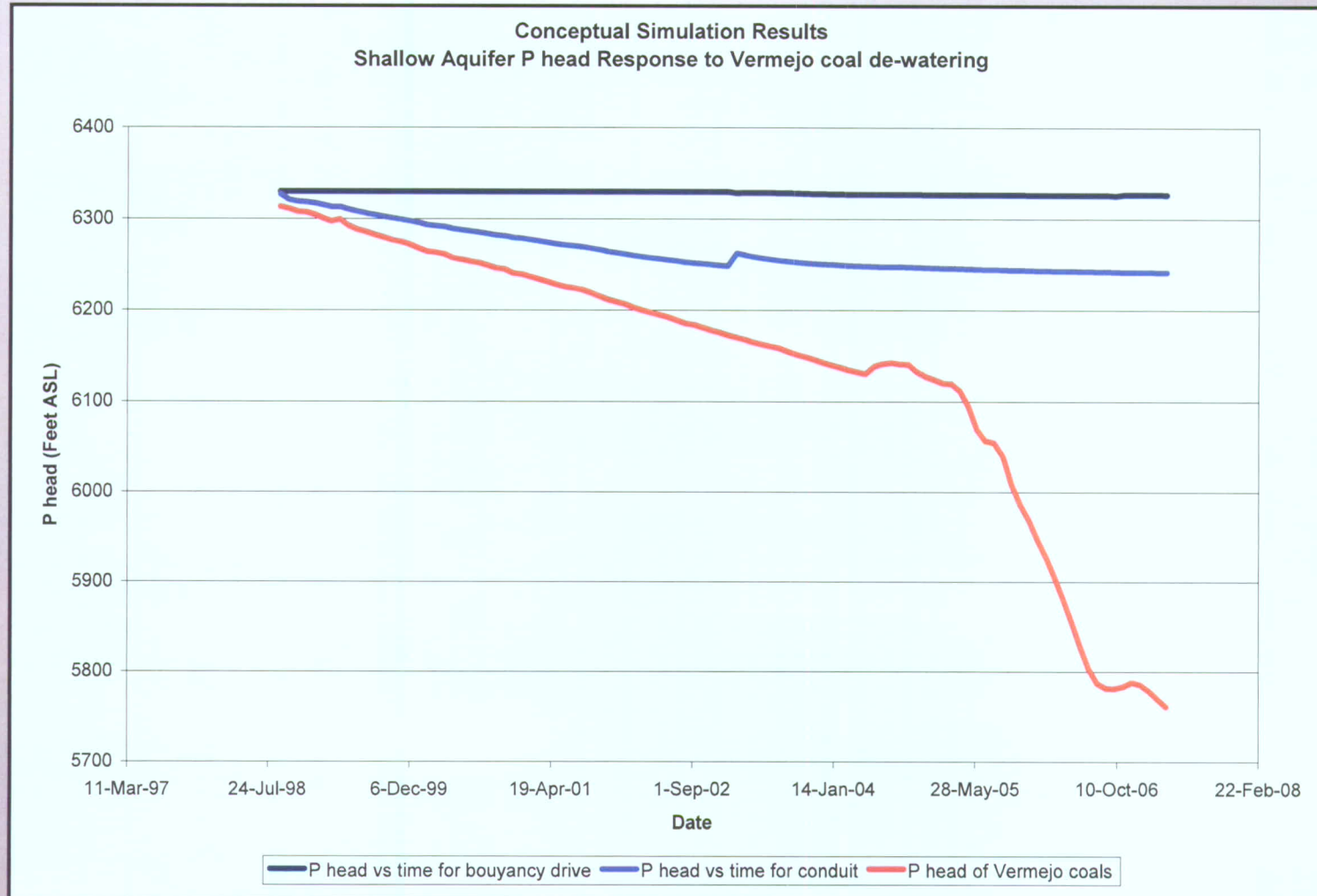


# Methane Buoyancy through Dikes

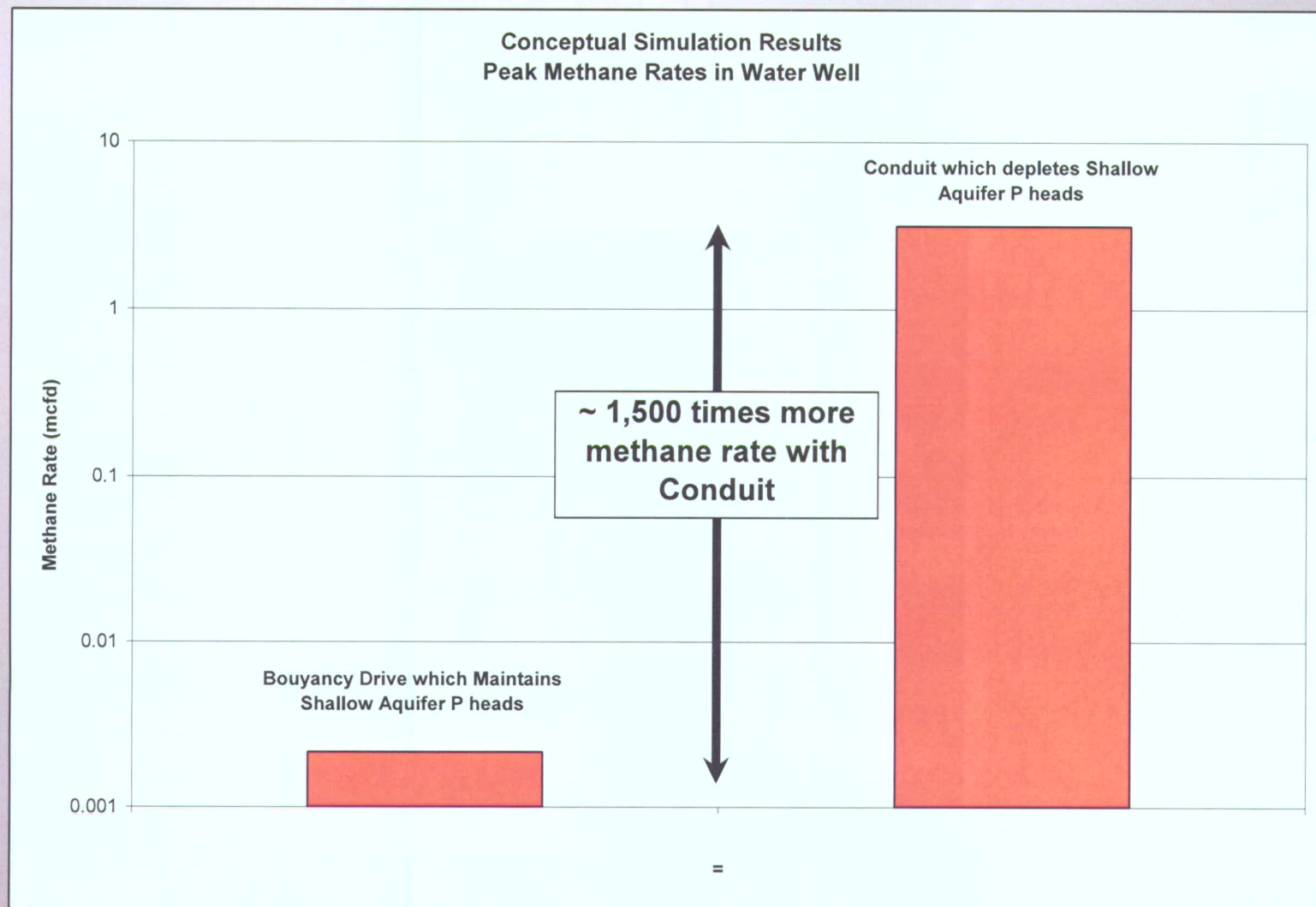




# Methane Buoyancy through Dikes



# Methane Buoyancy through Dikes





# Vertical Pathways: Identification

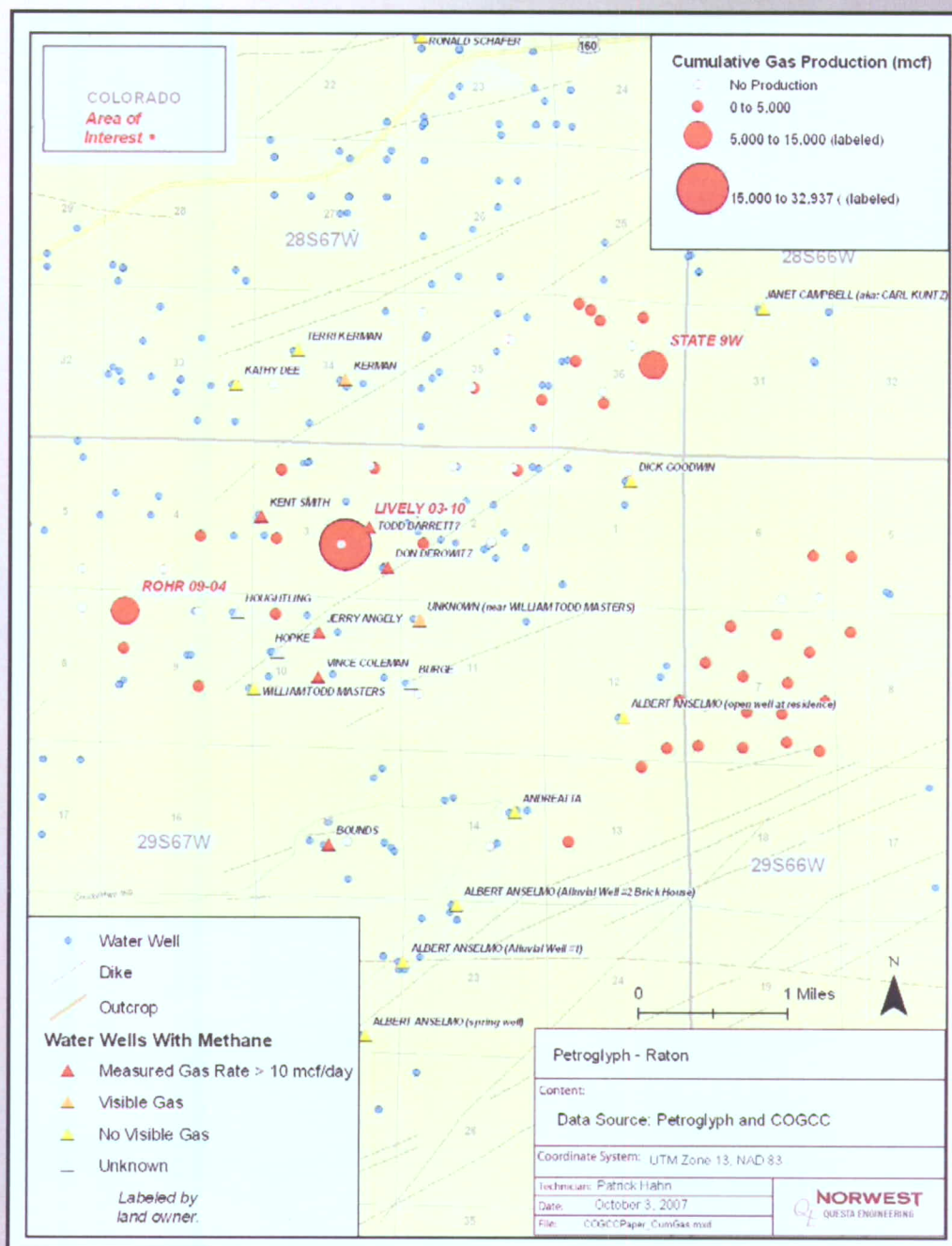
- Dikes as vertical conduits?
  - Results of simulation imply that the Dikes may be pathway for low volume methane migration via buoyancy.
  - Low volume methane migration could be showing up in the helicopter surveys due to sensitivity of measurement.
  - High probability that high rate methane migration requires hydraulic connectivity.

# Vertical Pathways: Identification

- Data suggests that conduit exists in vicinity of Lively 03-10
  - Lively 03-10 has highest gas cumulative.
  - Impacted wells with high methane concentrations and flow rates are massed around Lively 03-10.
  - Conduit could be man-made or natural, more investigation is required.



# CBM Gas Cumulative and Shallow Water Methane



# **Recommended Methane Monitoring Program**

- **The goals of the monitoring program are as follows:**
  - **Develop base line data of the extent of methane migration.**
  - **Determine whether the mitigation program is working through reductions in the amounts and concentrations of migrated methane in the shallow aquifers.**
  - **Prevent impacts to public health, safety, and welfare.**
  - **Provide additional data for use in determination and possible plugging of the conduit.**



# Recommended Baseline Monitoring Program

- Continued Monitoring 54 locations
  - 39 in near vicinity on bi-weekly schedule
  - 15 near outcrop/north on monthly schedule
- Continued Gas flow rate measurement and monitoring in 5 shallow water wells
  - 2 wells measured continuously
  - 3 wells measured weekly
- **Semi-annual monitoring of known, accessible gas seeps at dikes.**
- **Monthly monitoring of known, accessible gas seeps along the outcrop.**
- **Semi-annual monitoring of inaccessible gas seeps with helicopter survey.**
- **Water sampling of all 52 Vermejo CBM wells for analysis of tracer elements such as Boron and/or Chlorofluorocarbons (CFCs) used in determining the mixing of newer waters with older waters.**

# Proposed Mitigation Program

- The goals of the mitigation program are as follows:
  - Provide for resource development in a safe and environmental responsible manner of both methane and water.
  - Limit the extent of the affected shallow aquifers.
  - Remove significant volumes of methane from aquifers.
  - Re-charge the shallow aquifers to help prevent future methane migration.
  - Locate and if possible, plug conduit.
  - Controlled degassing of Vermejo coal aquifer.



# Surface Mitigation Program

- Providing adequate well ventilation systems along with methane monitors has been shown to be effective.
- Water should be provided to land owners whose wells run dry or produce significant volumes of methane during pumping.

# Shallow Aquifer Mitigation Program

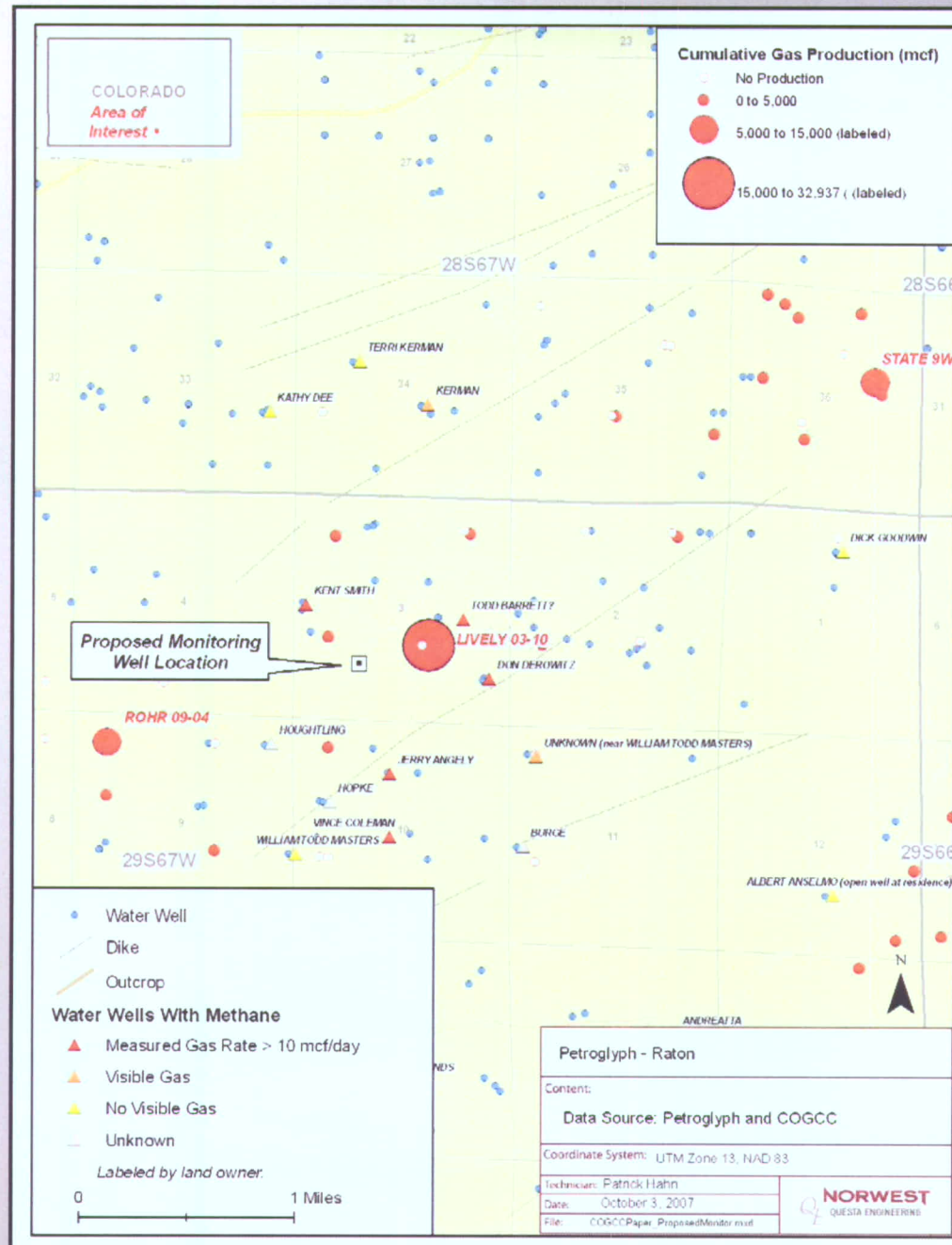
- Three phased program has been proposed
  - Phase I - Aquifer Data Acquisition, Aquifer Characterization And Baseline Data Monitoring
  - Phase II - Initiation of hydraulic barrier and methane removal
  - Phase III - Long term methane removal from Vermejo coals, remediation of aquifer, and potential methane conduit identification and plugging



# Phase I Shallow Aquifer Mitigation Program

- Aquifer Data Acquisition, Aquifer Characterization and Baseline Data Monitoring
  - Data gathered from drilling, completion, testing and operation of:
  - Monitor well in NW SE SW Sec 3 29S 67W, Lot 55
  - Three or four methane removal wells
  - Approximately eight injection wells designed to create a hydraulic barrier to methane migration in the shallow aquifer
  - Utilization of data acquired to create geologic and numerical models to refine design of aquifer remediation program
  - Continued baseline monitoring

# Proposed Shallow Aquifer Monitoring Well Location

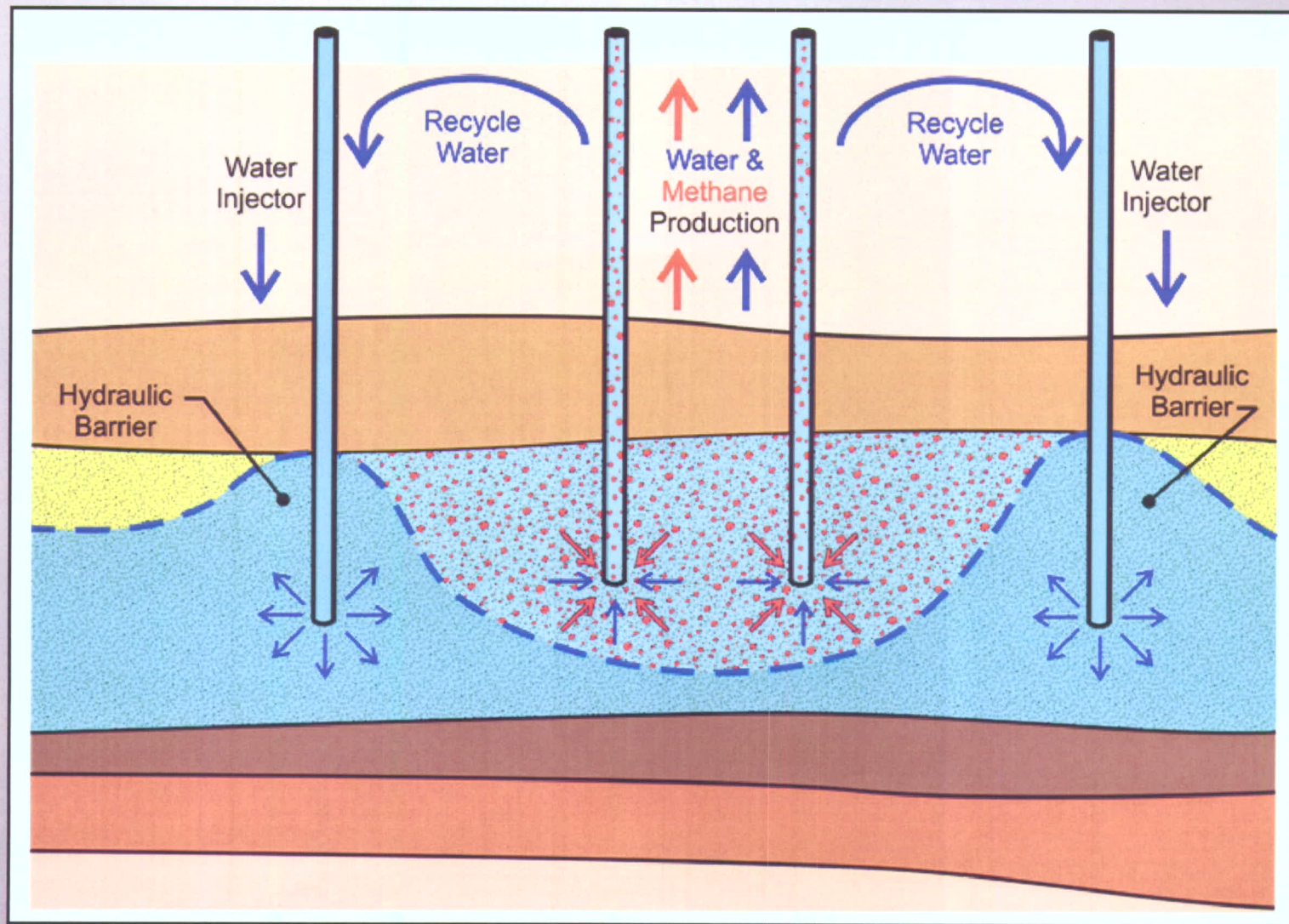




# Phase II Shallow Aquifer Mitigation Program

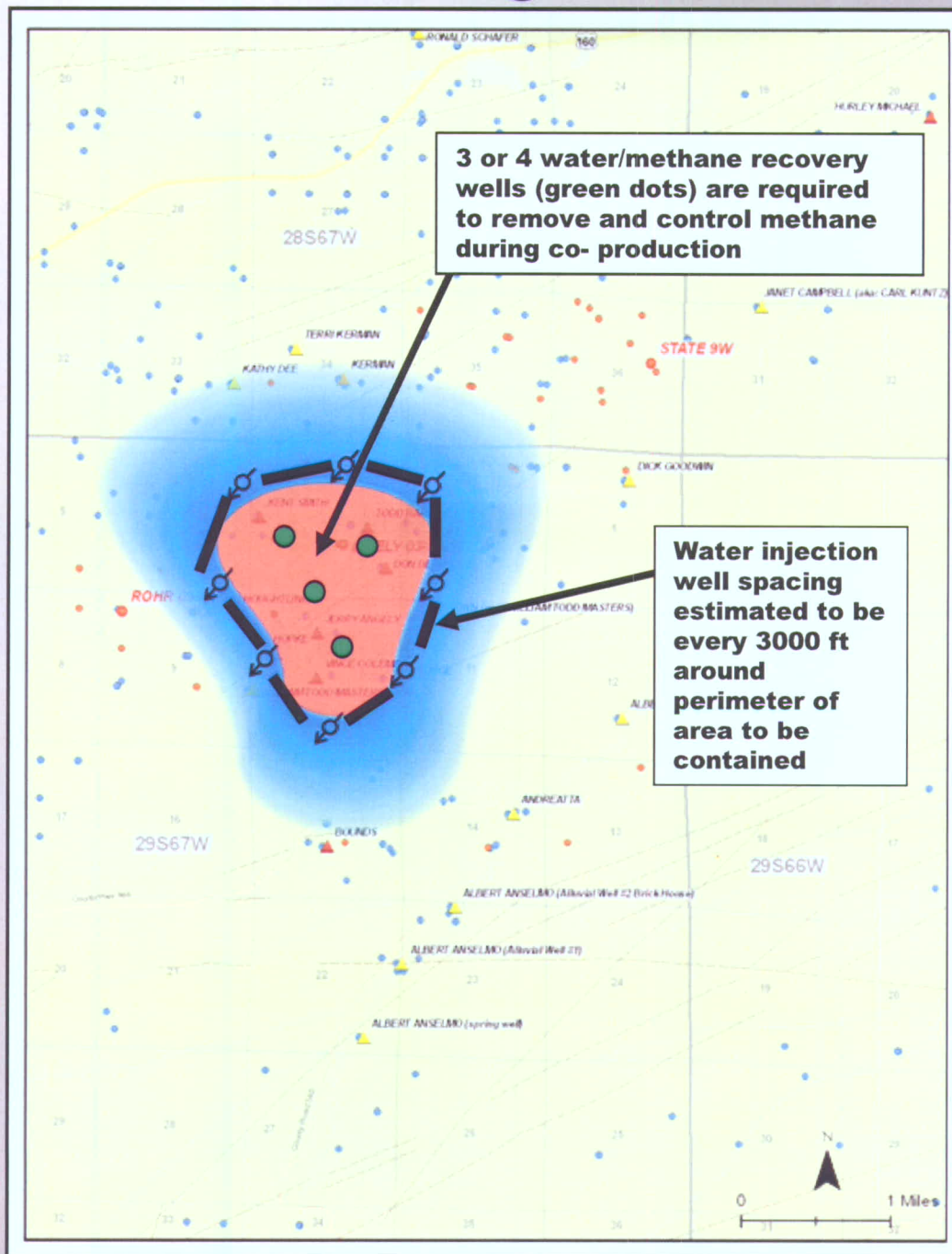
- Initiation of hydraulic barrier and methane removal
  - Hydraulic barriers would be created through a circle of injection wells surrounding production wells located in the migration hot spot neighboring Live 03-10.
  - Continuous or near continuous monitoring of pressures, gas and water rates, and methane concentrations in hydraulic barrier / remediation wells
  - Continued baseline monitoring
  - Dissolved methane monitoring in select wells
  - Continual updating and calibration of geologic and numerical models to refine design and optimize aquifer remediation program

# Hydraulic Barrier in Shallow Aquifer





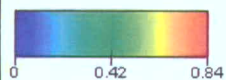
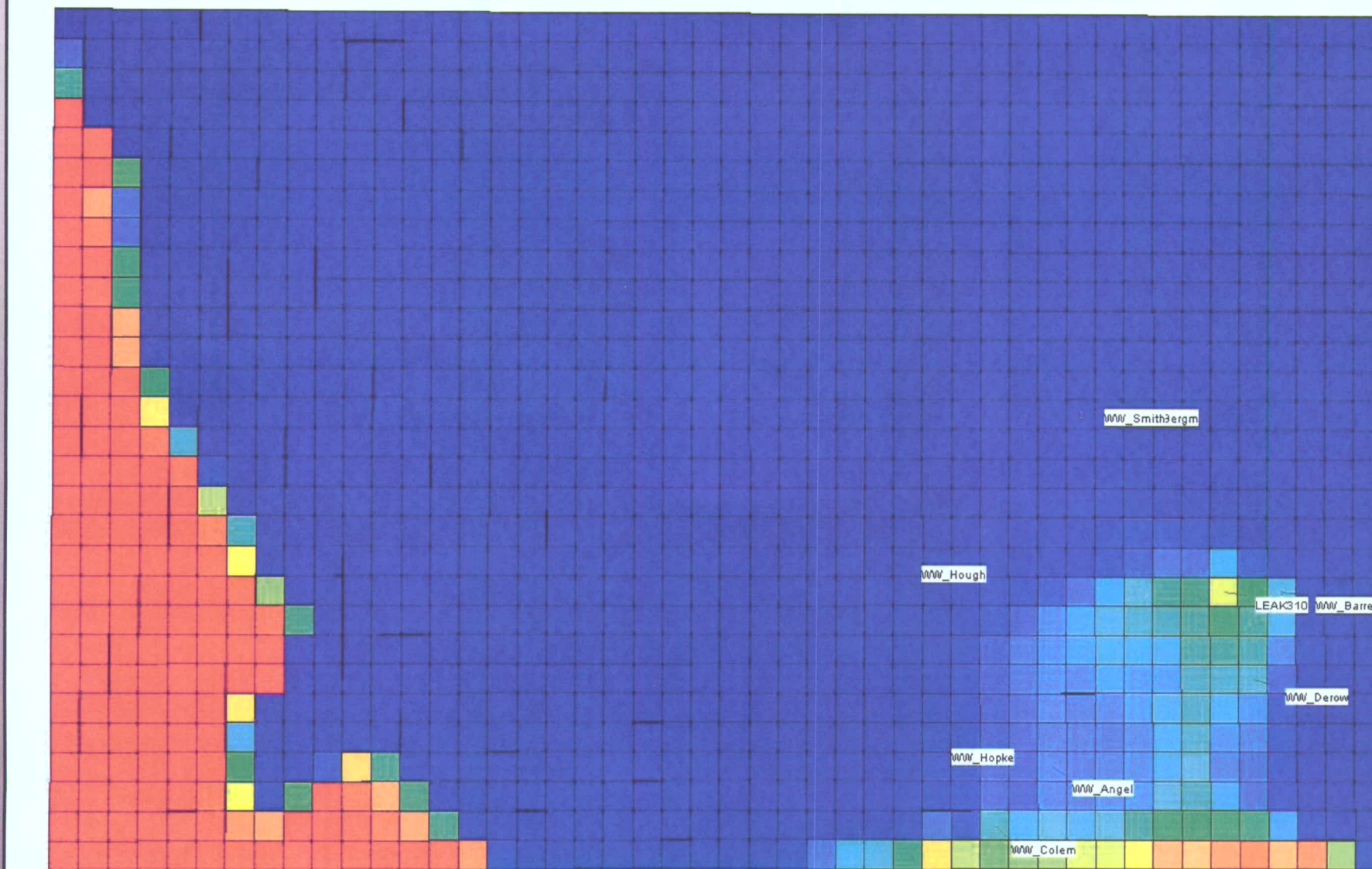
# Hydraulic Barrier in Shallow Aquifers



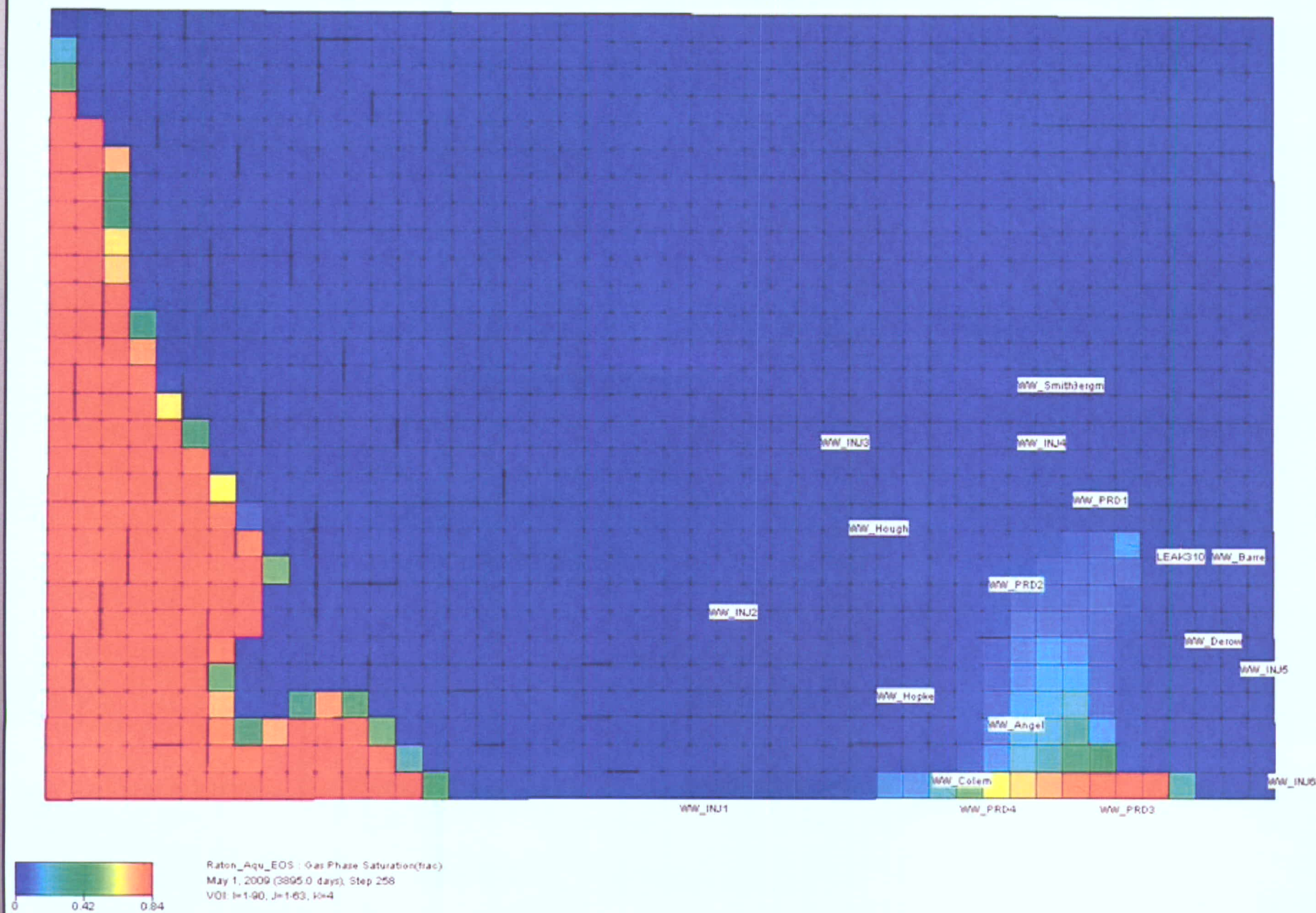
# Aquifer Model Description for Hydraulic Barrier Proof of Concept

- Average Depth from Surface = 350 ft
- Average Permeability = 100 md (NAH estimated perm average 268 md)
- Average Thickness = 120 ft (NAH estimated 114 ft of sat. zone)
- Average porosity 1% required to spread out gas plume
- Maximum water injection pressure observed 167.5 psia (0.49 psi/ft at 350 ft)
- Production wells pumped off initially

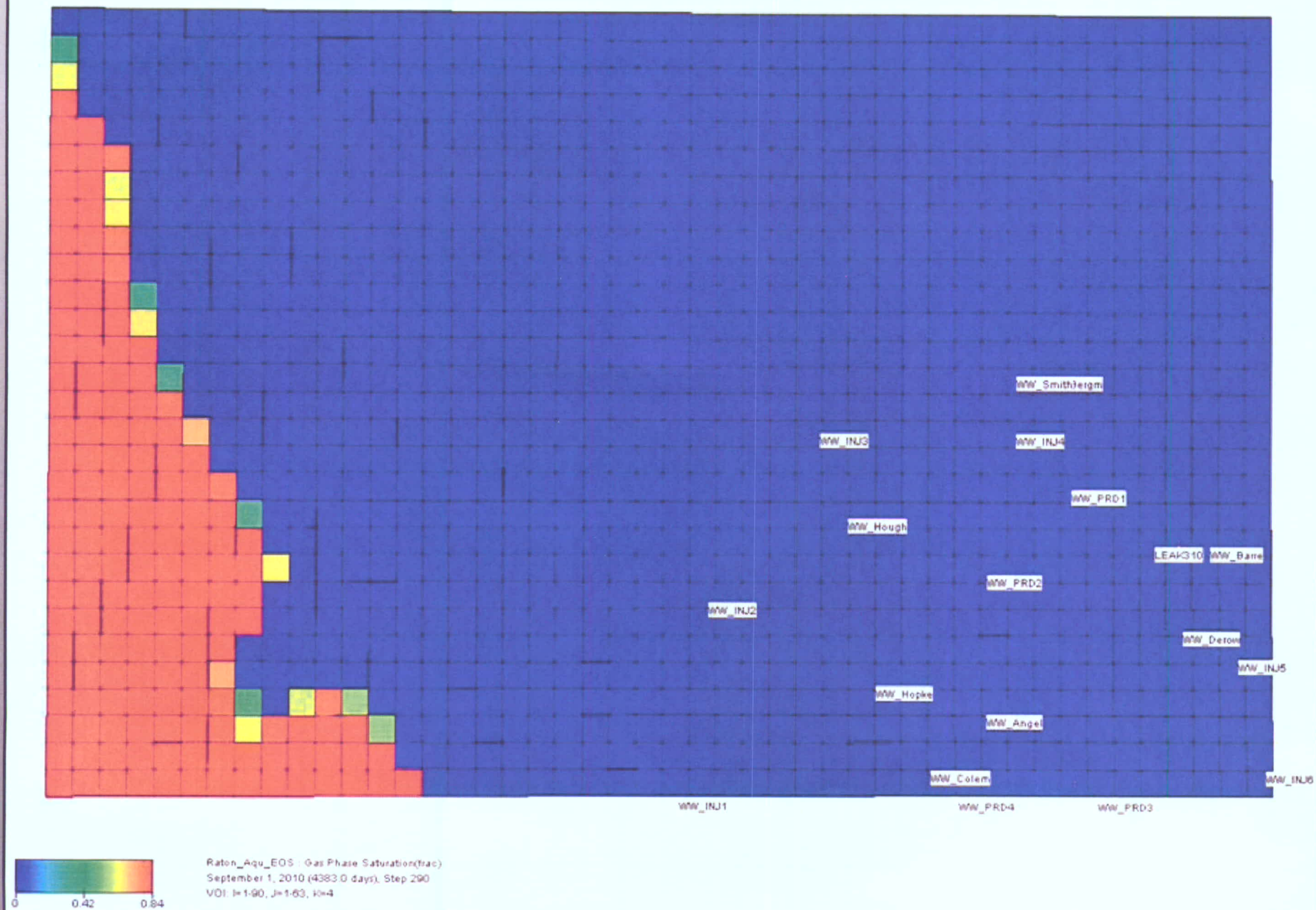




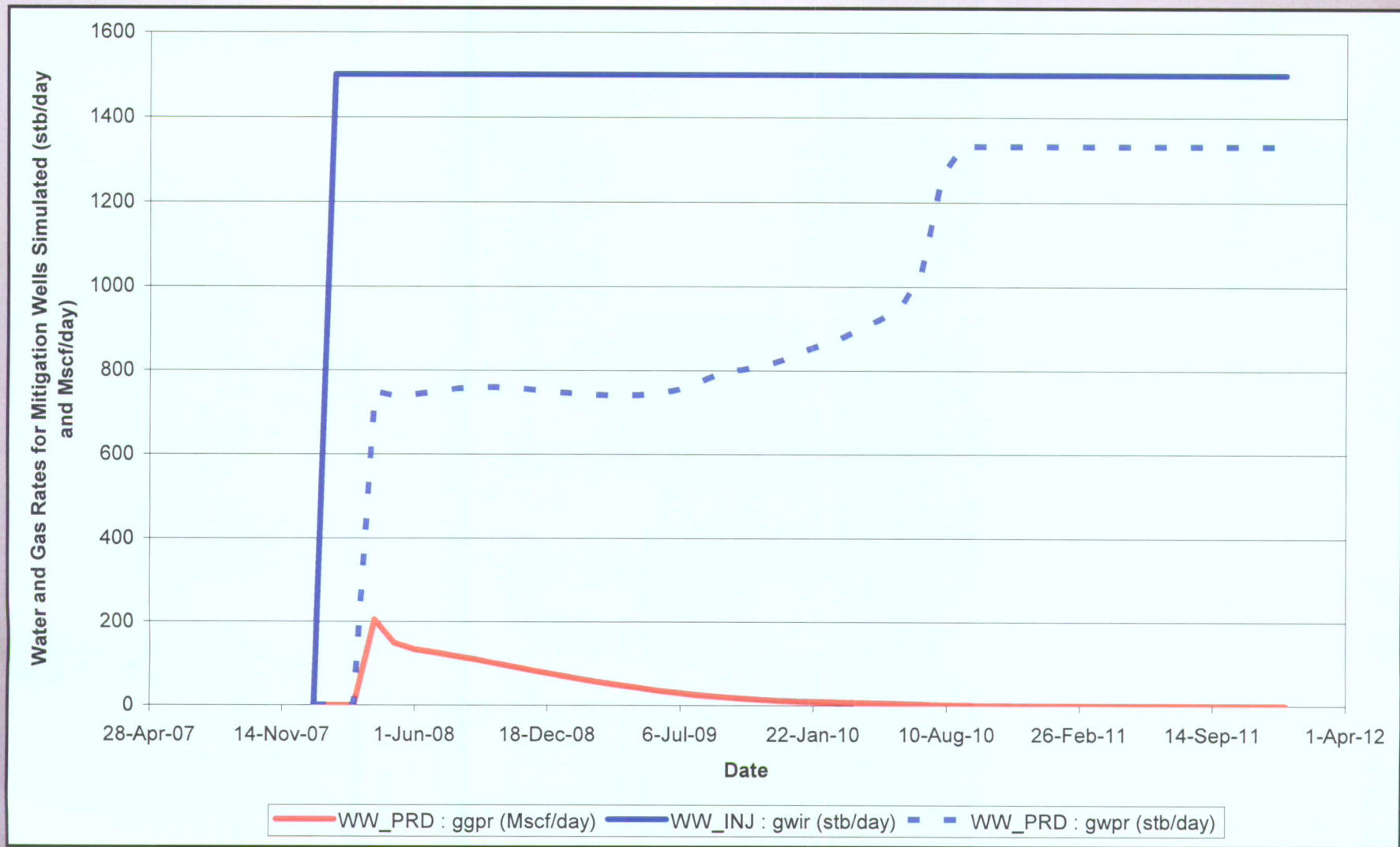
Raton\_Aqu\_EOS : Gas Phase Saturation(frac)  
 December 1, 2007 (3378.0 days), Step 224  
 VOI: I=1-90, J=1-63, K=4







# HM60 Tank Leak EOS Aqua2a Run





# Phase III Shallow Aquifer Mitigation Program

- Long Term Methane Removal from Vermejo Coals, Remediation Of Aquifer, Potential Methane Conduit Identification and Plugging
  - Reactivation of CBM wells for controlled removal of methane
  - Prevent impacts to public health, safety, and welfare.
  - Provide additional data for use in determination and possible plugging of the conduit

# Phase III Long Term Methane Removal from Vermejo Coals

- Vermejo coals are part of a very large fresh water aquifer system.
- Simulation estimates that the aquifer size is 300 billion barrels of water equivalent.
- Pressure communication between Little Creek has been observed 2 miles away.
- Water quality is high with low TDS (~850).
- Sometime in future this large fresh water aquifer most likely will be developed for public use.
- Development miles away from current CBM wells will cause P head decline and reactivation of methane desorption.
- Methane will again be moving through conduit to shallow aquifer, this time without obvious “cause and effect”.
- Infrastructure will not be in place to monitor and mitigate the methane migration.



# Phase III Long Term Methane Removal from Vermejo Coals

- Conduit can not be isolated, studied, or plugged without continued CBM production.
- Recovery in Vermejo aquifer has shut down current methane desorption but methane is still present for potential future migration.
- Controlled degassing of Vermejo coals through continue CBM production at Little Creek and Bear Creek lessen future migration of methane.

# MIMMP Summary

- Petroglyph and Norwest have created a long-term ground water and gas seep monitoring program which prevents significant adverse impacts to public health, safety, welfare, and environment while mitigating and providing remediation of methane in the impacted ground water.
- Program allows for resource development in a safe and environmentally responsible manner for both methane and fresh water.



# MIMMP Summary

- Program includes:
  - Continued monitoring of methane and aquifers.
  - Surface mitigation for public safety.
  - Long term shallow aquifer mitigation and protection.
  - Continued investigation of nature of methane conduit.
  - Potential for plugging methane conduit.
  - Protection of shallow aquifer from future development of the large fresh water aquifer connected to the Vermejo coals in this area.



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# Methane Investigation, Monitoring, and Mitigation Program

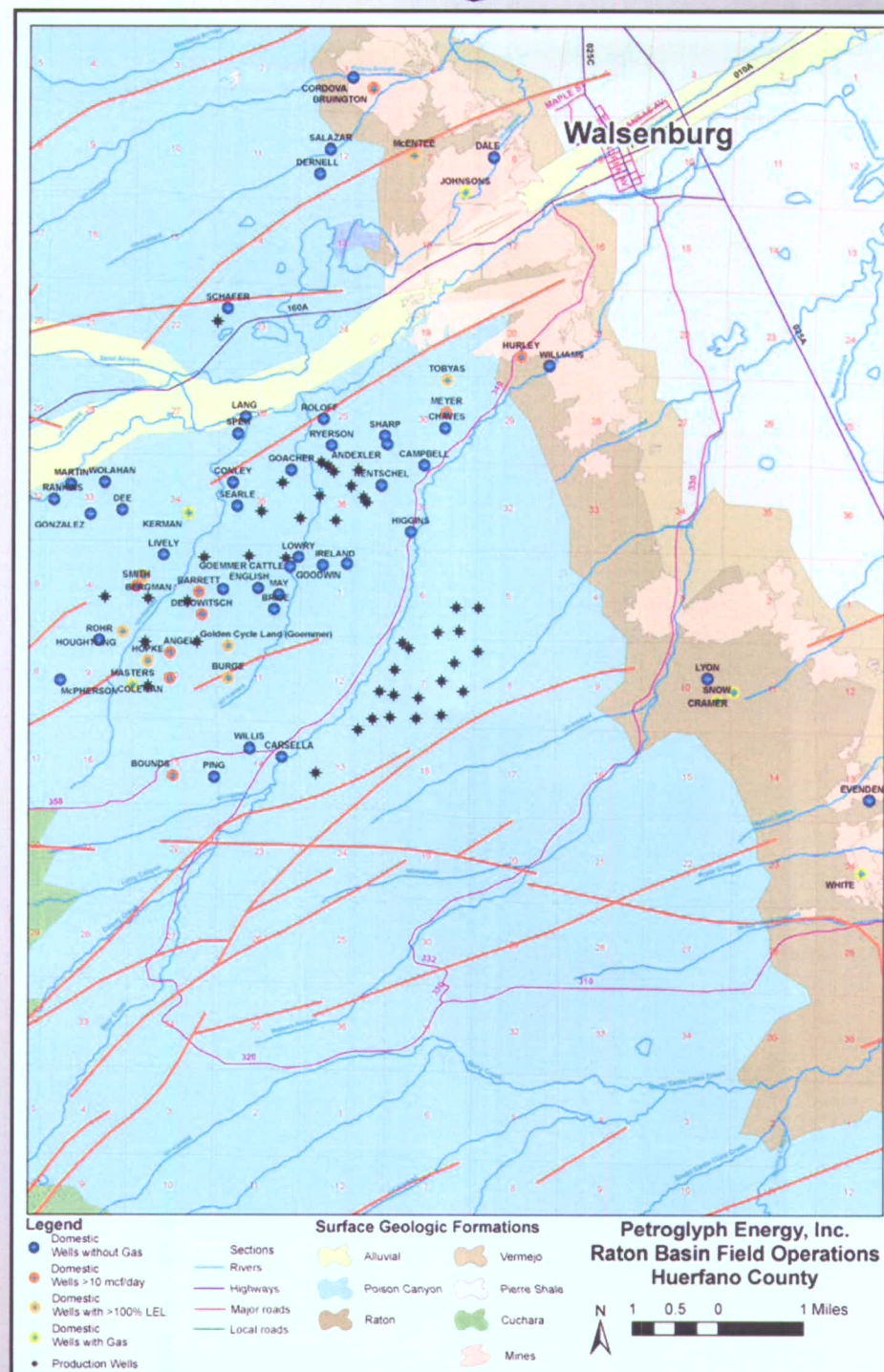
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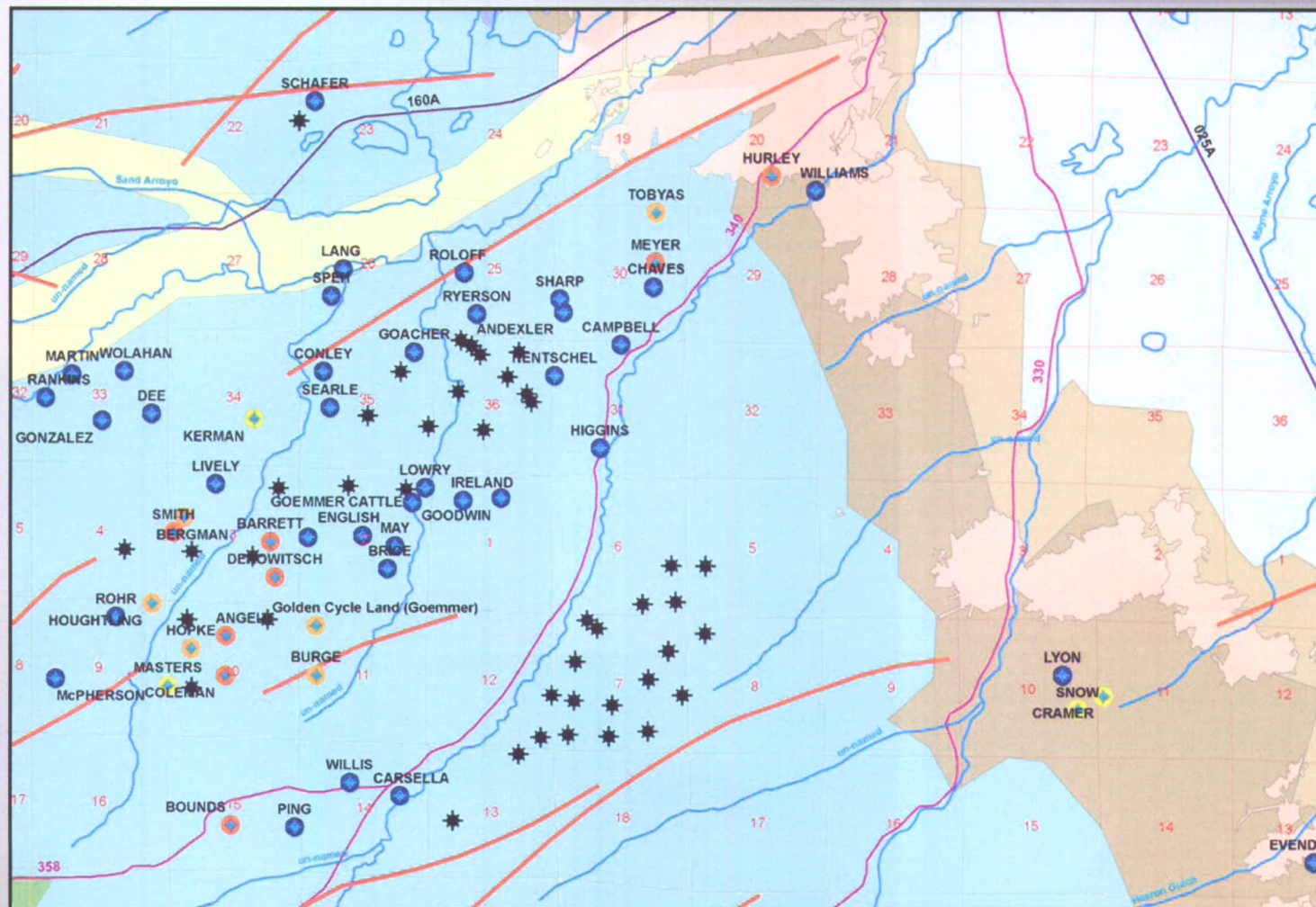


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# Current Monitoring

- Currently Monitoring 54 locations
  - 39 in near vicinity on bi-weekly schedule
  - 15 near outcrop/north on monthly schedule
  - 10 monitored for water levels
  - 4 have pressure transducers
    - Meyer, Barrett, Coleman, Bergman



# Additional Future Monitoring

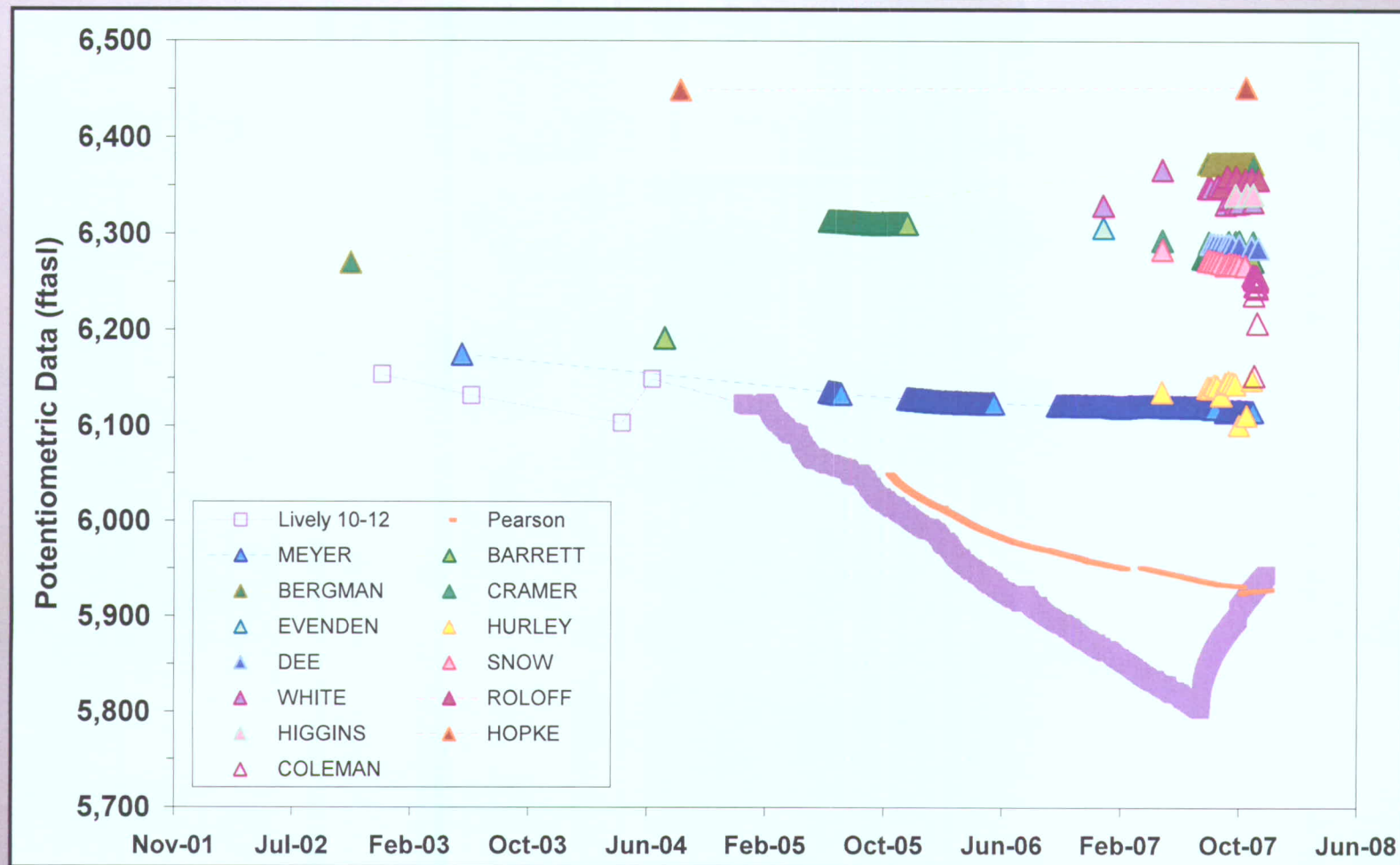
- Continue Monitoring 54 locations
- Helicopter survey of area including outcrop
  - Semi-annually
- Methane flow monitoring for:
  - Smith, Coleman (continuous)
  - Bounds, Bruington, and Angley (Weekly)
- Continuous monitoring of production and monitor wells

# Production Monitor & Domestic Well Potentiometric Data

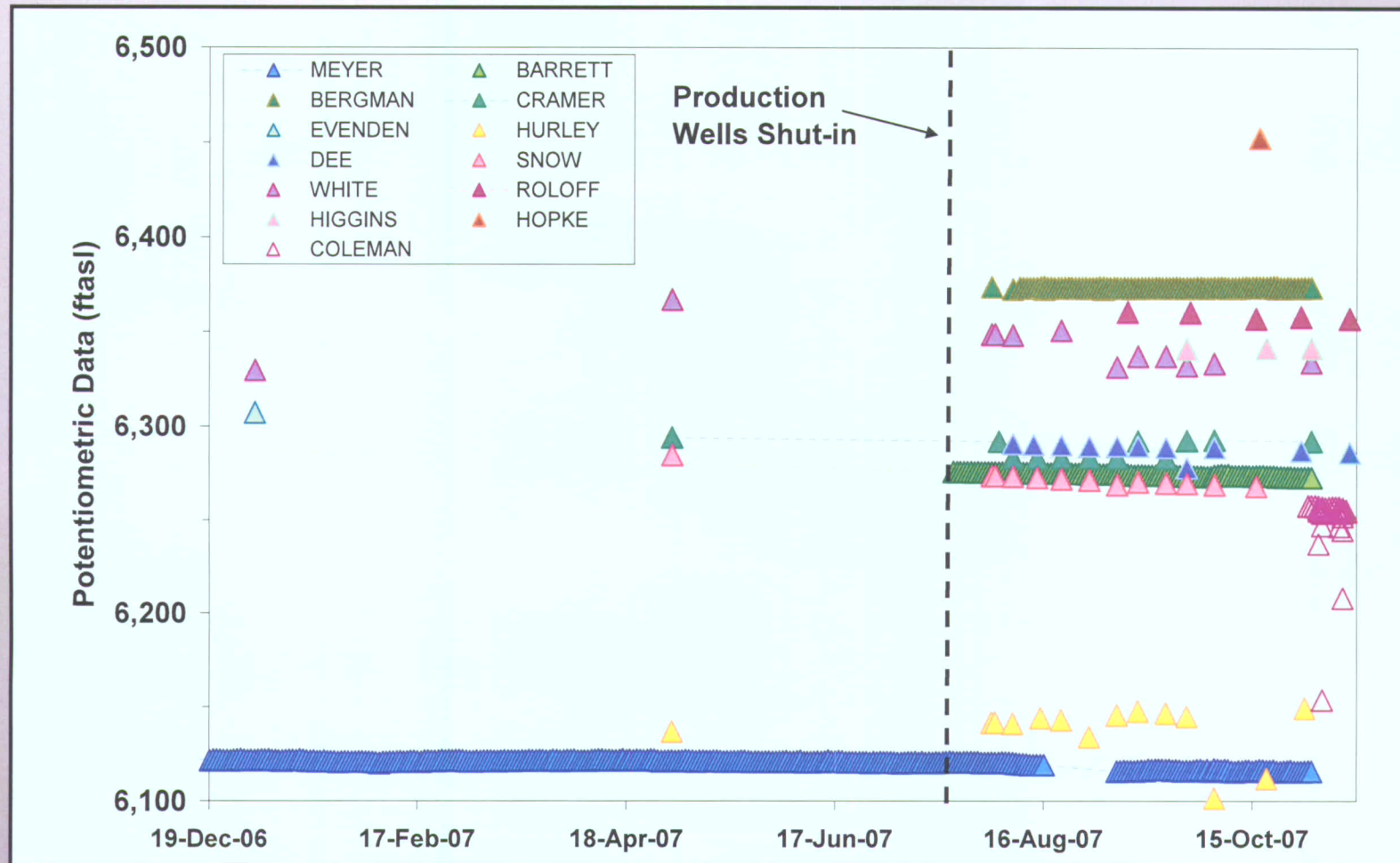




# Production Monitor & Domestic Well Potentiometric Data

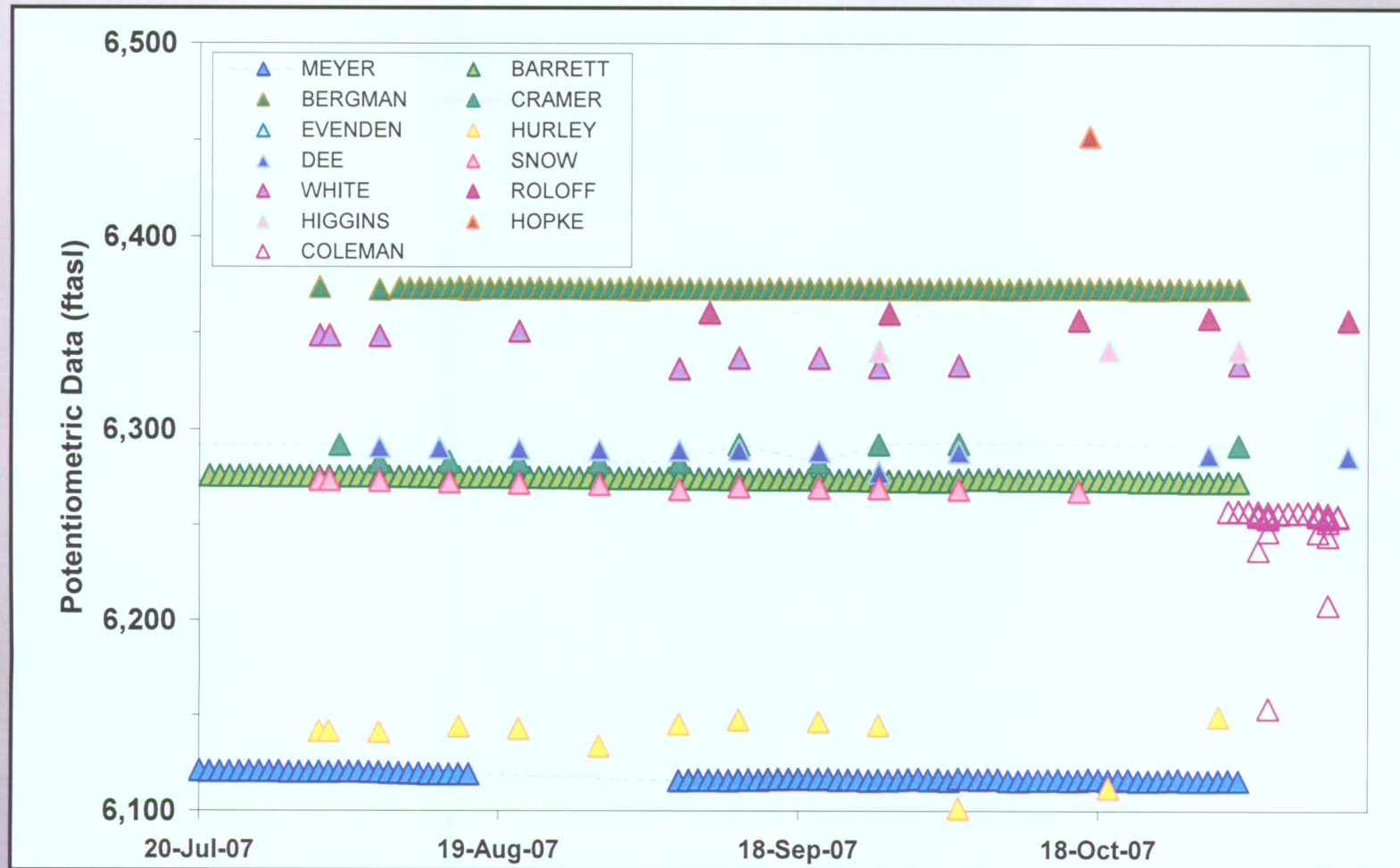


# Domestic Well Potentiometric Data





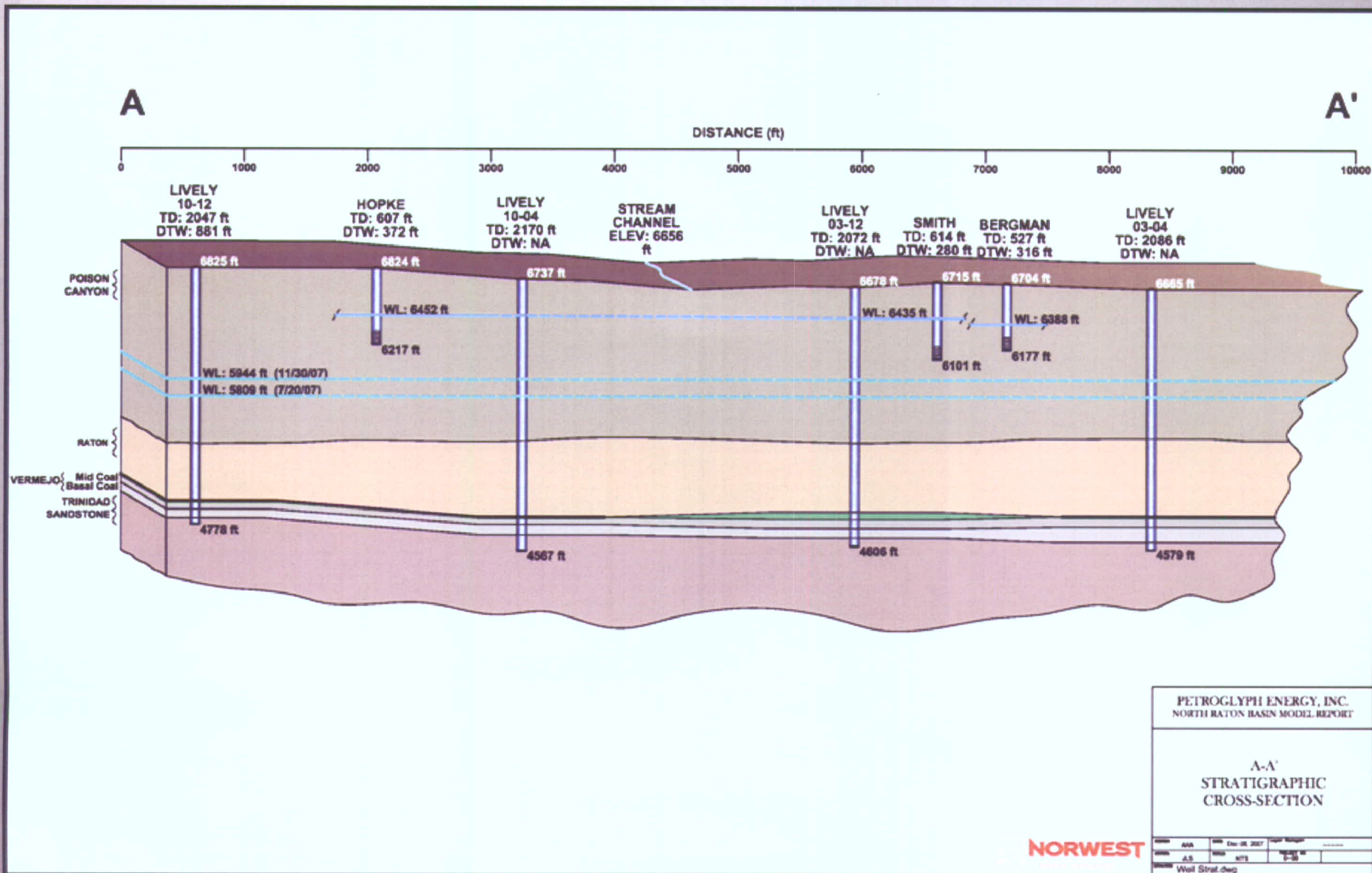
# Domestic Well Potentiometric Data











# Poison Canyon Aquifer

- USGS Water-Supply Paper 1805 (McLaughlin 1966)
  - Confined aquifer
  - Periodic extended draughts with decrease in water well yields & not meeting needs
  - “Yields small quantities of water to wells and springs in western part of county.”
  - Associated with “perennial water shortages”



# Poison Canyon Transmissivity Calculations

Pump Test Data From SEO Drillers Records and Theis Solution Transmissivity Results

Well ID	Pumping Rate (gpm)	Depth Water Encountered (ftbls)	SWL (ftbls)	Pumping WL (ftbls)	Elapsed Time (min)	T (ft <sup>2</sup> /min)	Estimated Saturated Thickness (ft)	K (ft/d)	Permeability (md)
Angely	6	563	330	700	150	0.0032	142	0.45	168
Bergman	10	420	289	527	180	0.0085	107	0.91	337
Derowitsch	9	585	535	681	180	0.0085	89	0.76	280
Hopke	13	528	381	607	90	0.0112	79	0.89	329
Kerman	7	235	200	460	90	0.0052	232	1.21	450
Conley	12	313	146	348	180	0.0121	35	0.42	156

Permeability calculated from 2.7 ft/day per darcy @ fluid density equal to 62.4 lb/ft<sup>3</sup>

# Poison Canyon - Confined Aquifer

Well Owner	Depth First Water Encountered (ftbbs)	Static Water Level (ftbbs)	Rise In Head (ft)
Angely	563	330	233
Barr	340	249	91
Barrett	838	515	323
Bergman	420	289	131
Campbell (Kuntz)	384	214	170
Conley	313	146	167
Derowitsch	585	535	50
English	232	200	32
Goodwin	436	235	201
Higgins	287	195	92
Hopke	528	381	147
Kerman	235	200	35
Martin	497	280	217
Meyer	550	400	150
Roloff	138	135	3
Ryerson	93	45	48
Smith	516	280	236
Wolahan	294	183	111



# Elevation of Confined Layer?

Landowner	Elevation (z)	TD	TD Elevation	Gas	>100% LEL	>10 mcf/day
BARRETT	6734	865	5869	Yes	Yes	Yes
MASTERS	6845	847	5998	Yes	No	No
COLEMAN	6845	823	6022	Yes	Yes	Yes
ANGELY	6775	706	6069	Yes	Yes	Yes
DEROWITSCH	6750	681	6069	Yes	Yes	Yes
SMITH	6715	614	6101	Yes	Yes	Yes
HOUGHTLING	6732	607	6125	Yes	Yes	No
KERMAN	6597	467	6130	Yes	No	No
ENGLISH	6638	507	6131	No	No	No
BERGMAN	6704	527	6177	Yes	Yes	No
HOPKE	6824	607	6217	Yes	Yes	No
GOODWIN	6702	467	6235	No	No	No
CONLEY	6590	348	6242	No	No	No
MAY	6694	443	6251	No	No	No
SEARLE	6610	305	6305	No	No	No
GOEMMER CATTLE	6624	145	6479	No	No	No
RANKINS	6642	110	6532	No	No	No
LOWRY	6605	40	6565	No	No	No
COLORADO SWITZER	6710	140	6570	No	No	No
CARSELLA	6798	160	6638	No	No	No
WILLIS	6858	216	6642	No	No	No
McPHERSON	6860	210	6650	No	No	No
BURGE	6916	210	6706	Yes	Yes	No
BOUNDS	7184	323	6861	Yes	Yes	Yes

# Aquifer Testing

- Monitor Well & Select Injection Wells
  - Rate step test
    - Test range of rates ~15 min per rate
    - Optimum pumping rate/time for long term test
  - 24 to 72 hr constant rate drawdown test
    - Monitor water and gas flows
    - Hydraulic conductivity
    - Specific storage (cross-borehole interference)
      - Monitor pressure at nearby domestic wells
      - Monitor pressure at mitigation injection/production wells



