# Methane Investigation, Monitoring, and Mitigation Program

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

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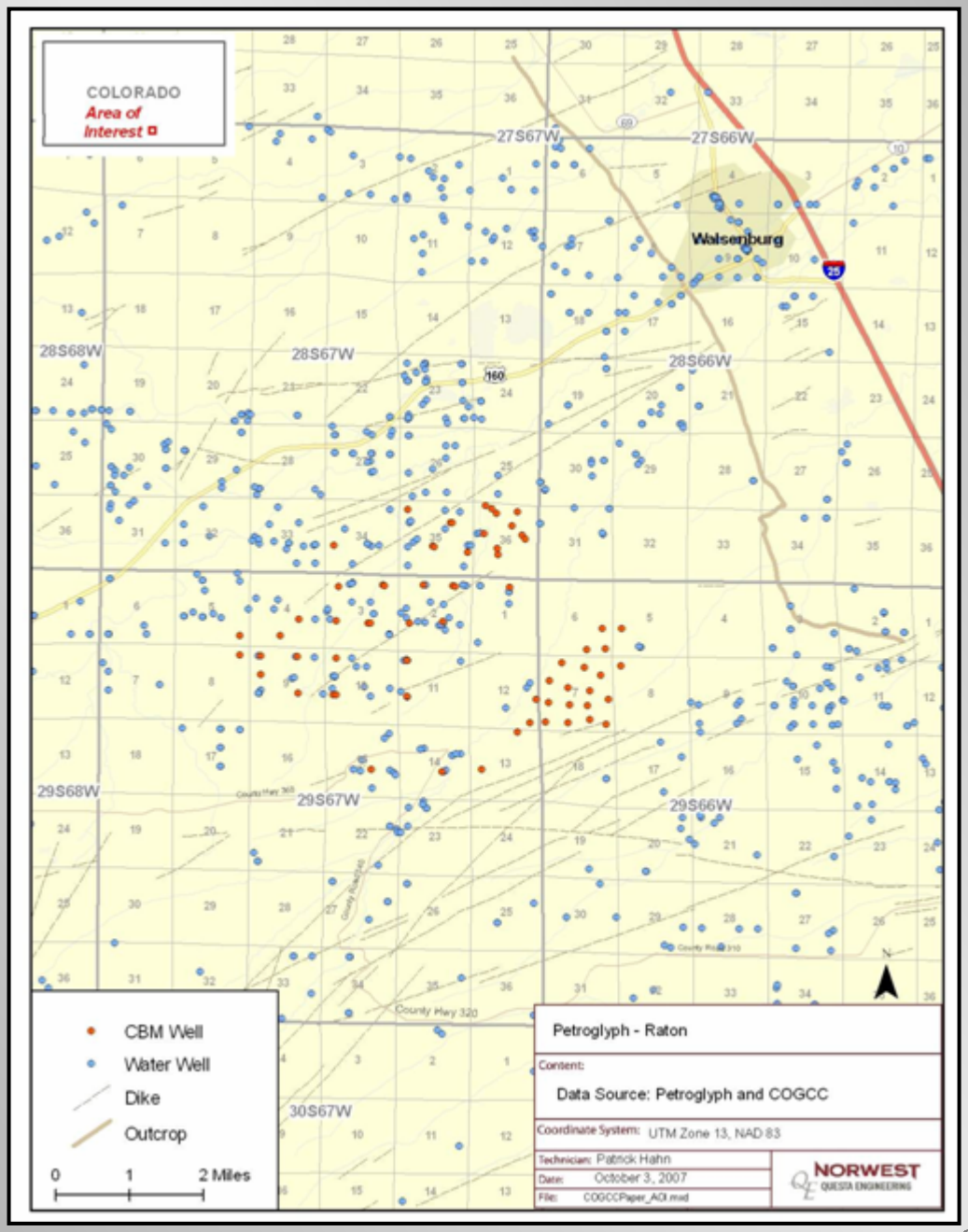
# Methane Investigation, Monitoring, and Mitigation Program (MIMMP)

- 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.

# Area of Interest



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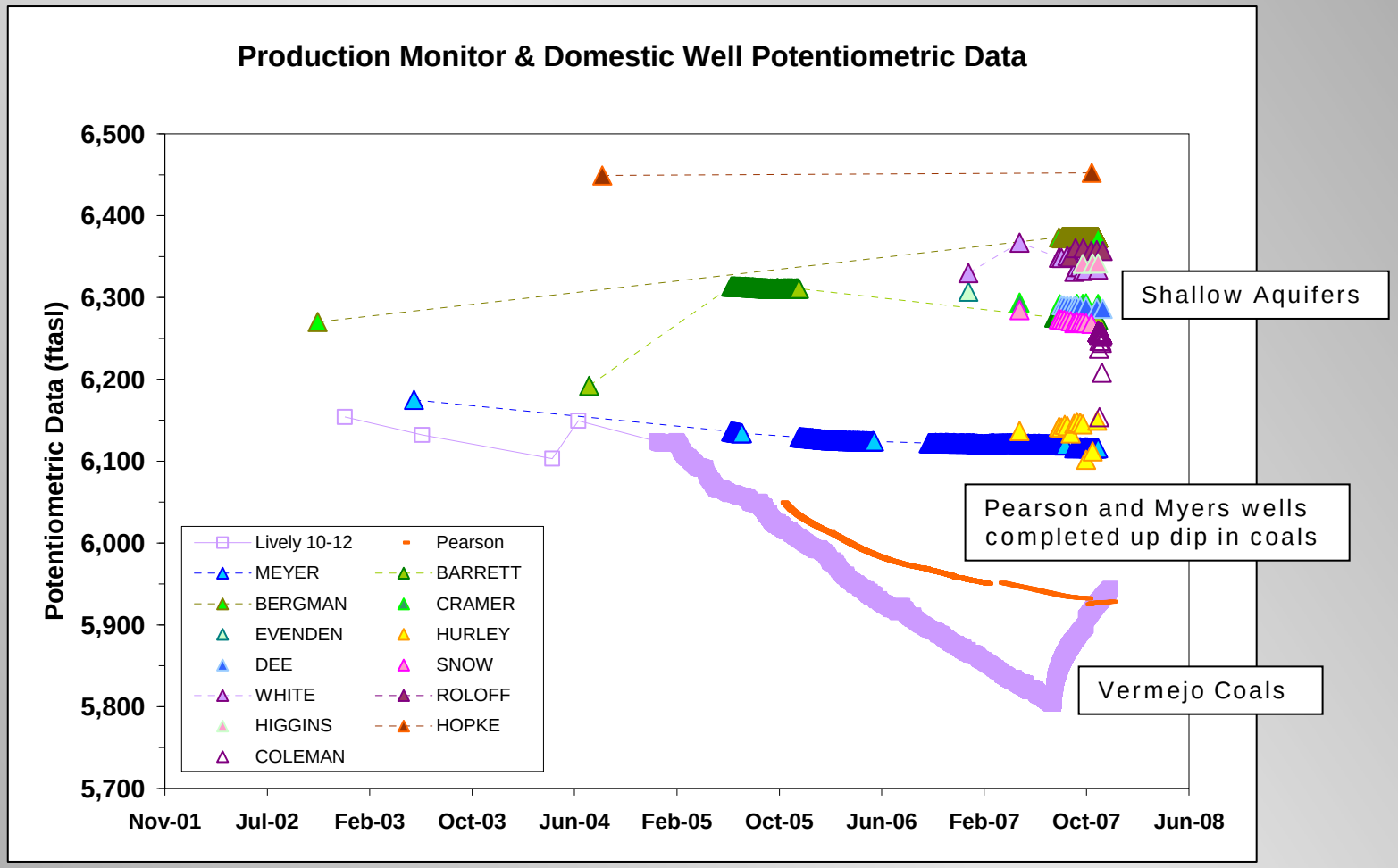
# MIMMP Data Gathering

- 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

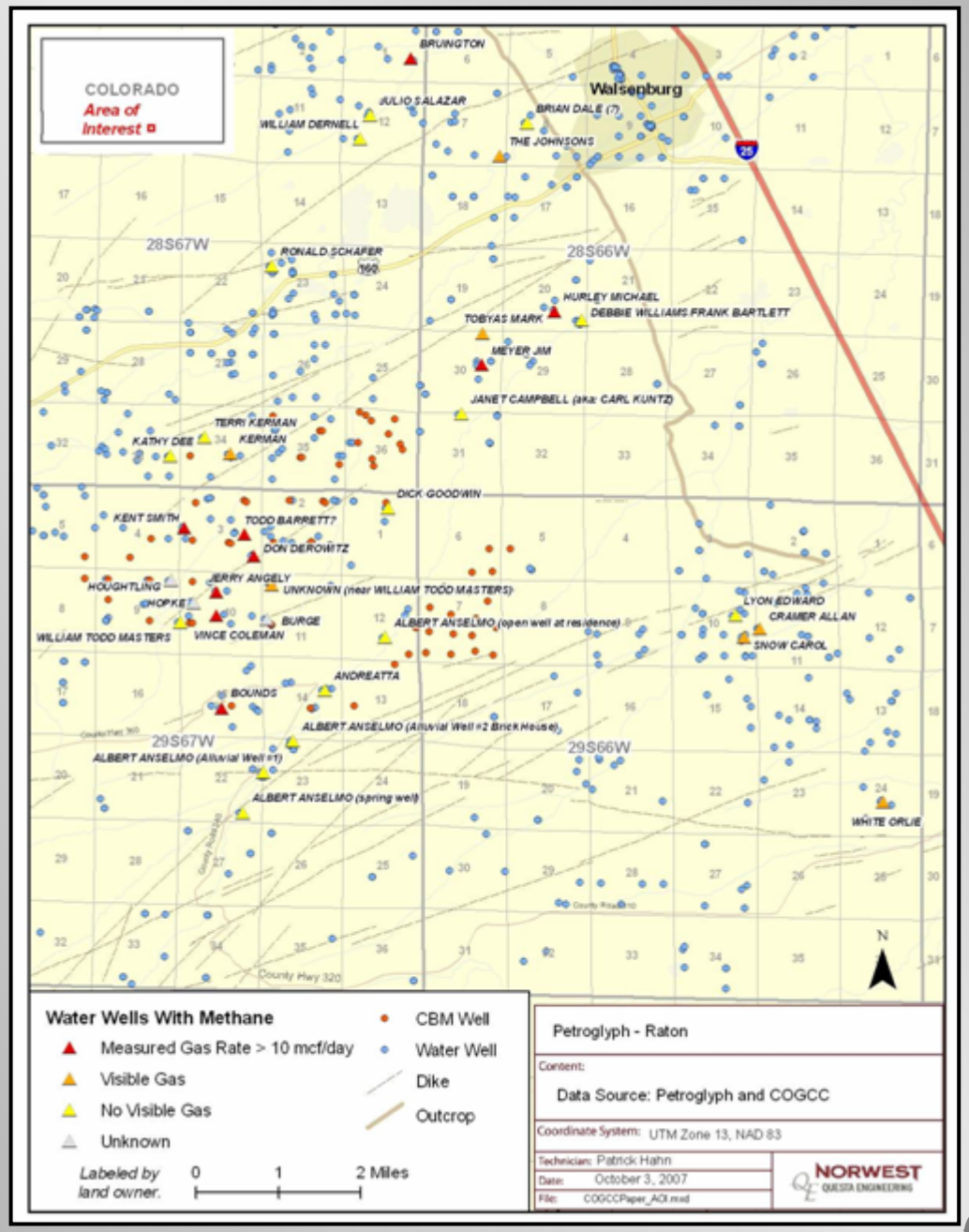


# MIMMP Data Gathering

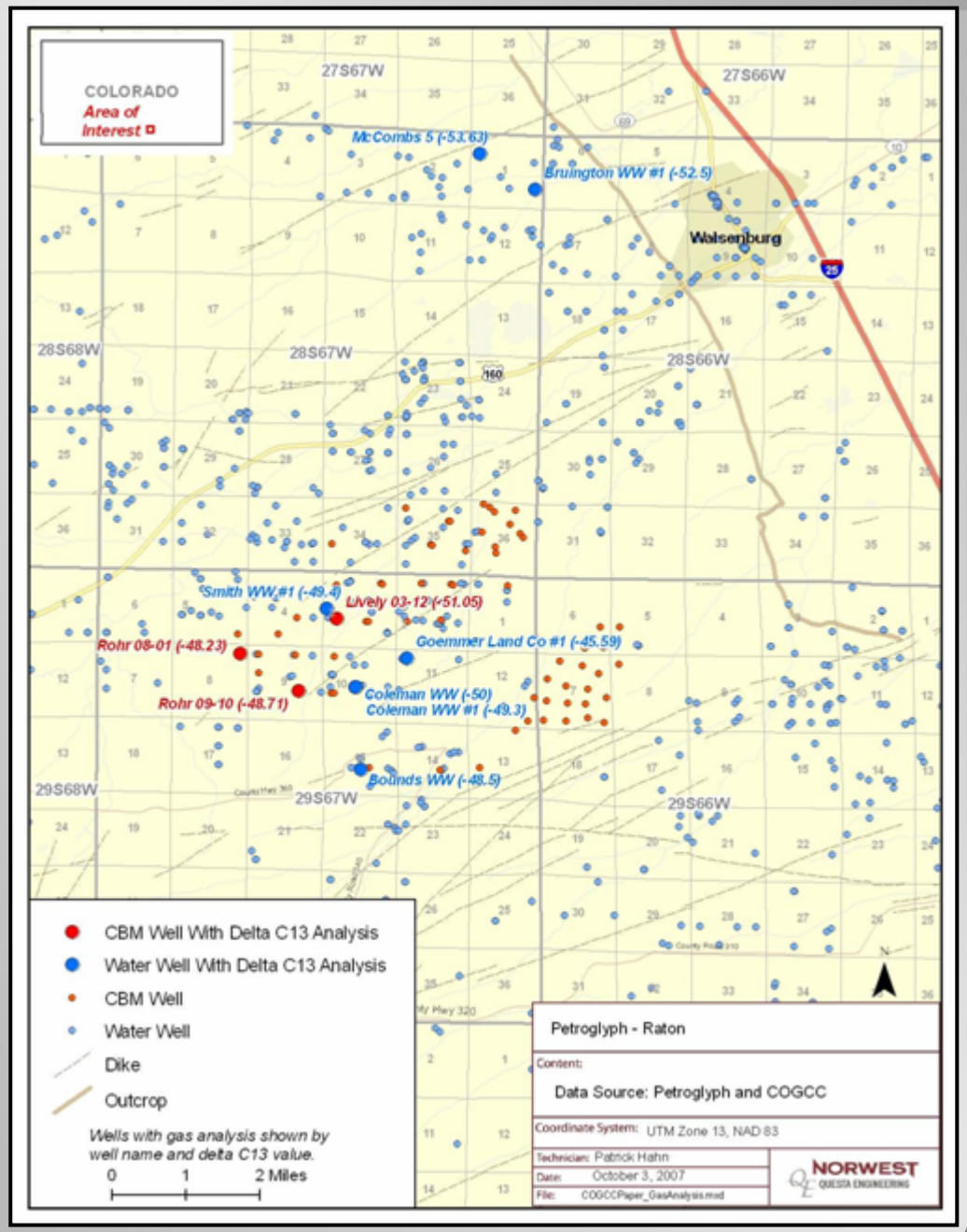
- **Methane Identification and Monitoring of Water Wells**
  - Initial gas sampling for potential methane in 66 water wells
- Currently Monitoring 54 locations
  - 39 in near vicinity on bi-weekly schedule
  - 15 near outcrop/north on monthly schedule
- Gas flow rate measurement and monitoring in 5 shallow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

# Water Wells

## Methane and Flow Rates



# Carbon Isotope Analysis



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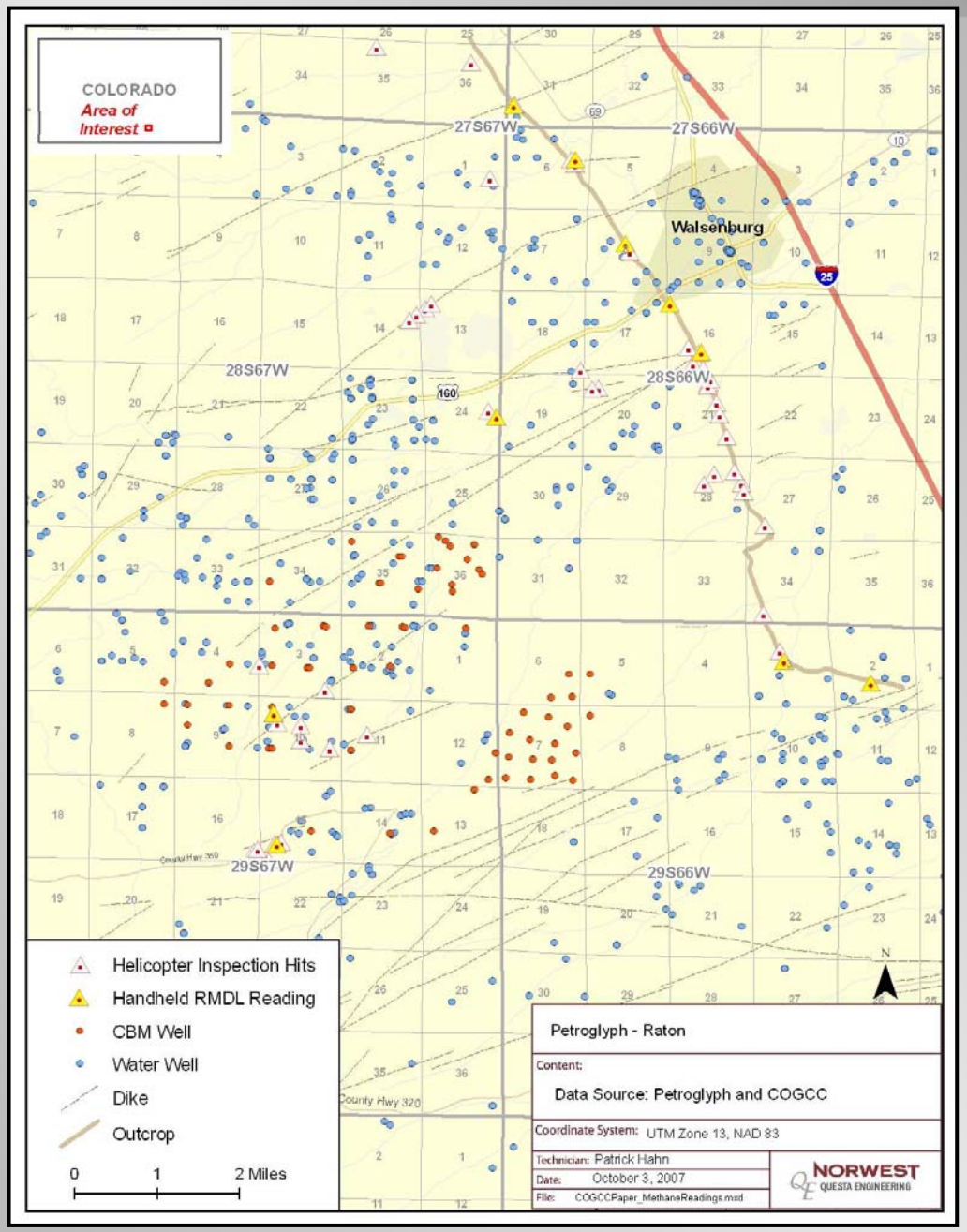
# MIMMP Data Gathering

- **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 Reality #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.

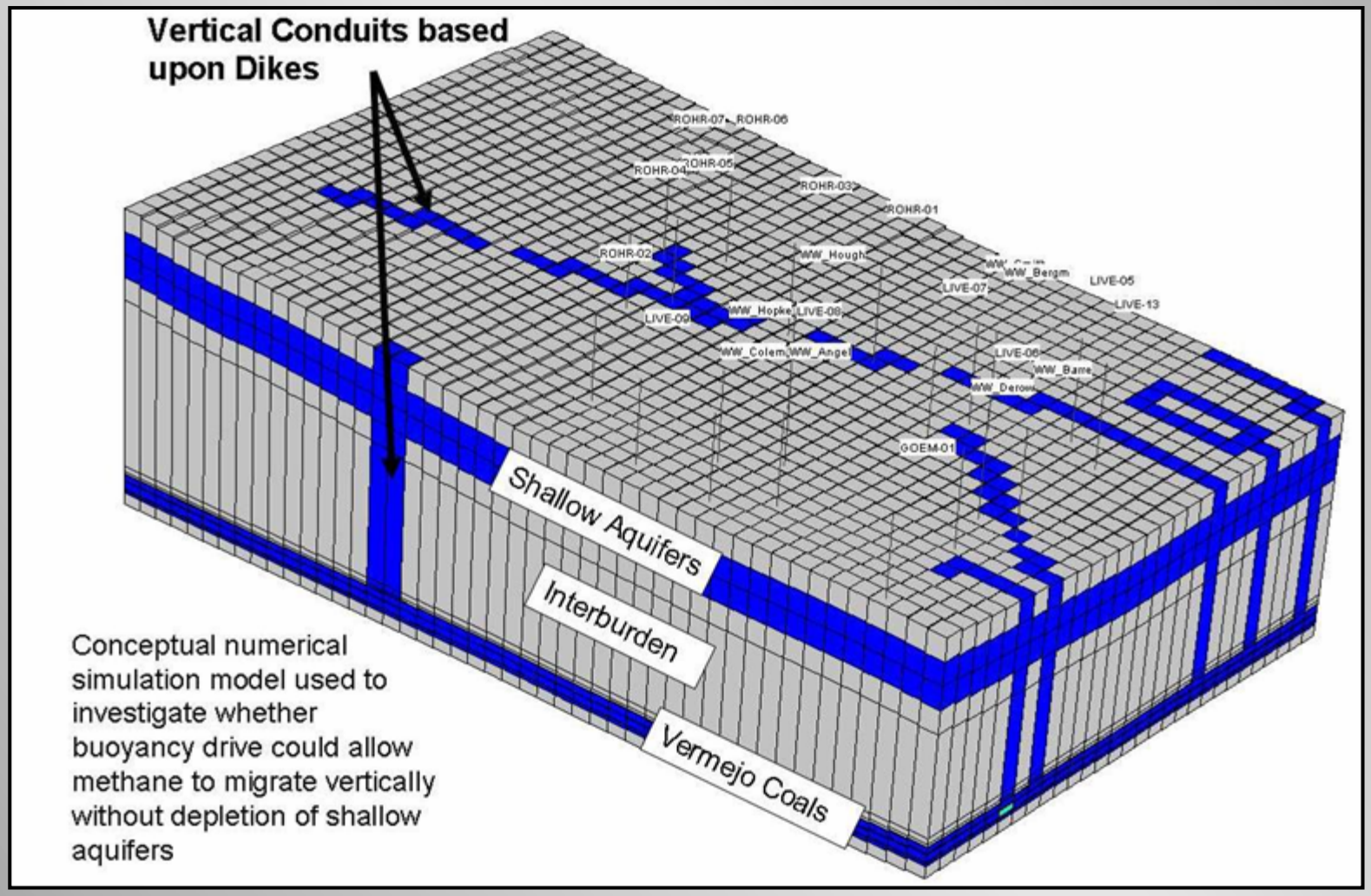
# Vertical Pathways: Identification

- 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.

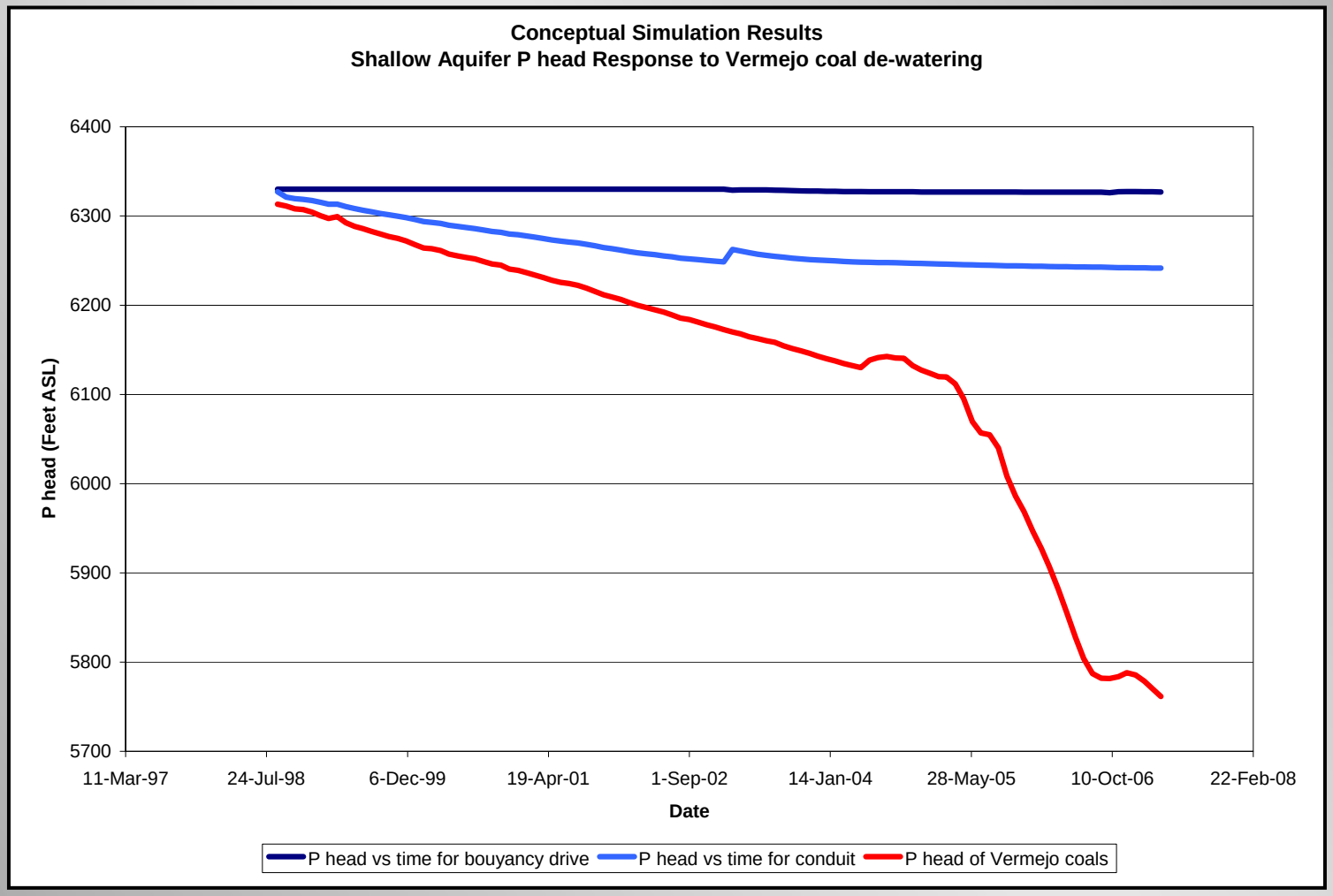
# Vertical Pathways: Identification

- 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.

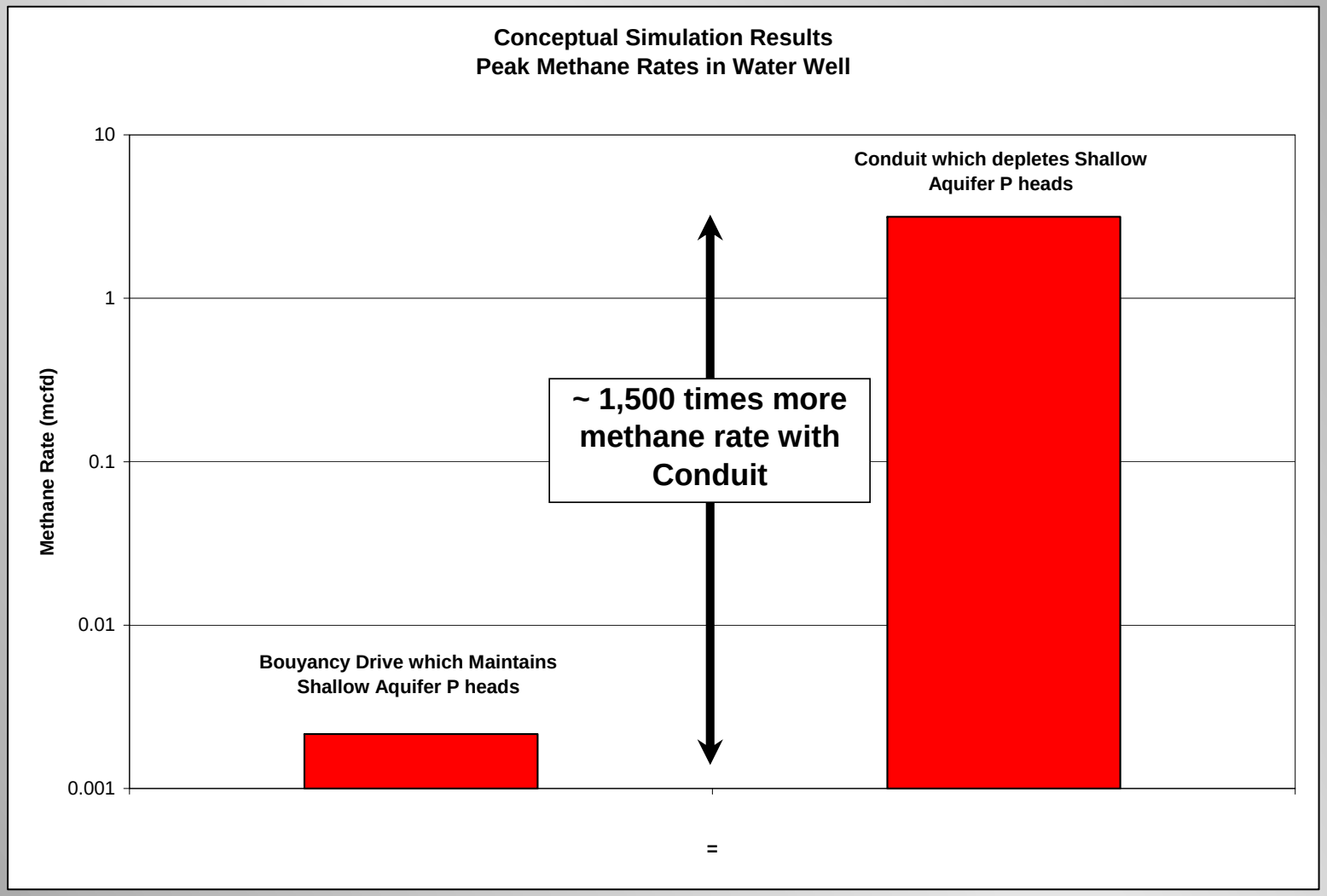
# Methane Buoyancy through Dikes



# Methane Buoyancy through Dikes



# Methane Buoyancy through Dikes



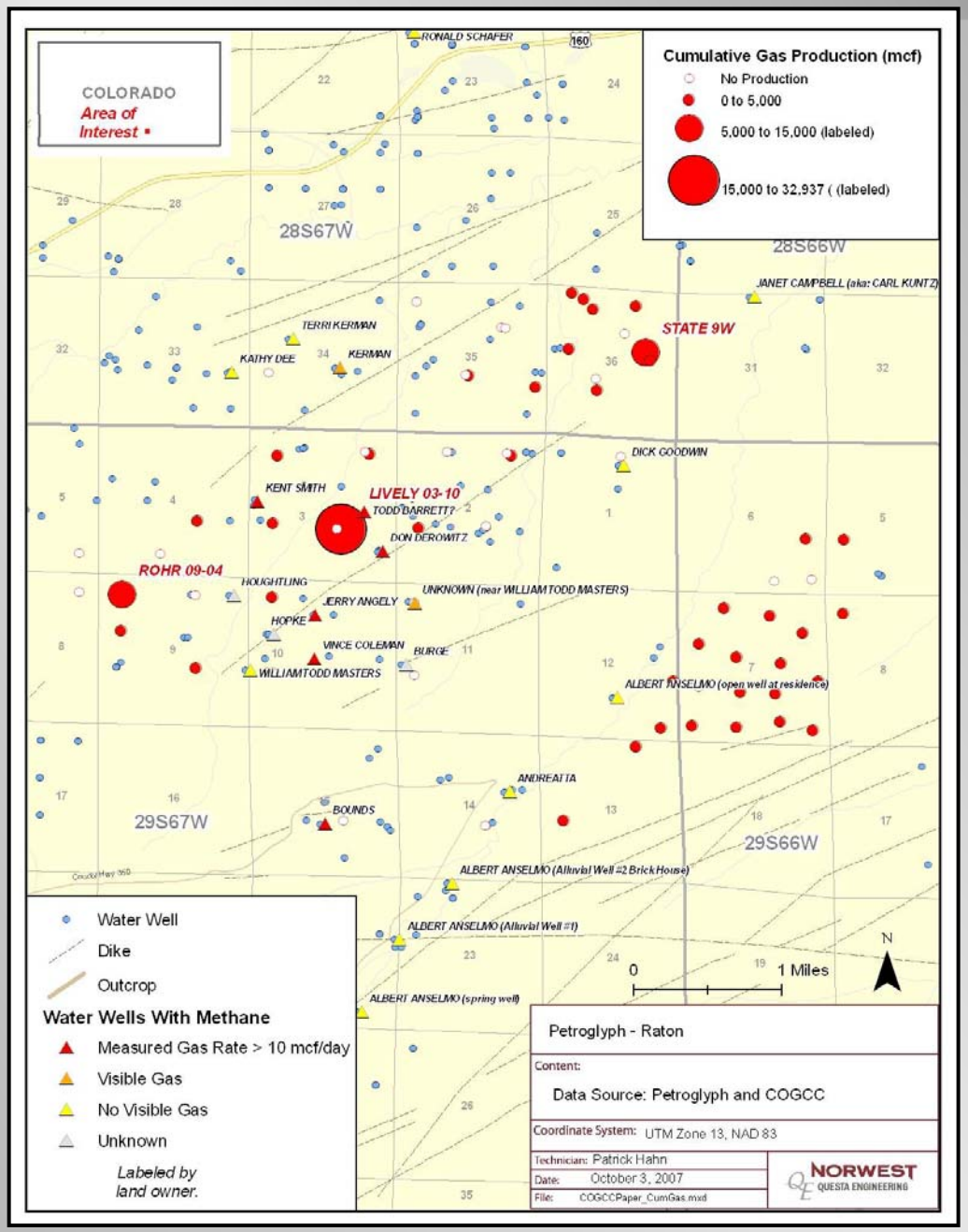
# Vertical Pathways: Identification

- 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.**

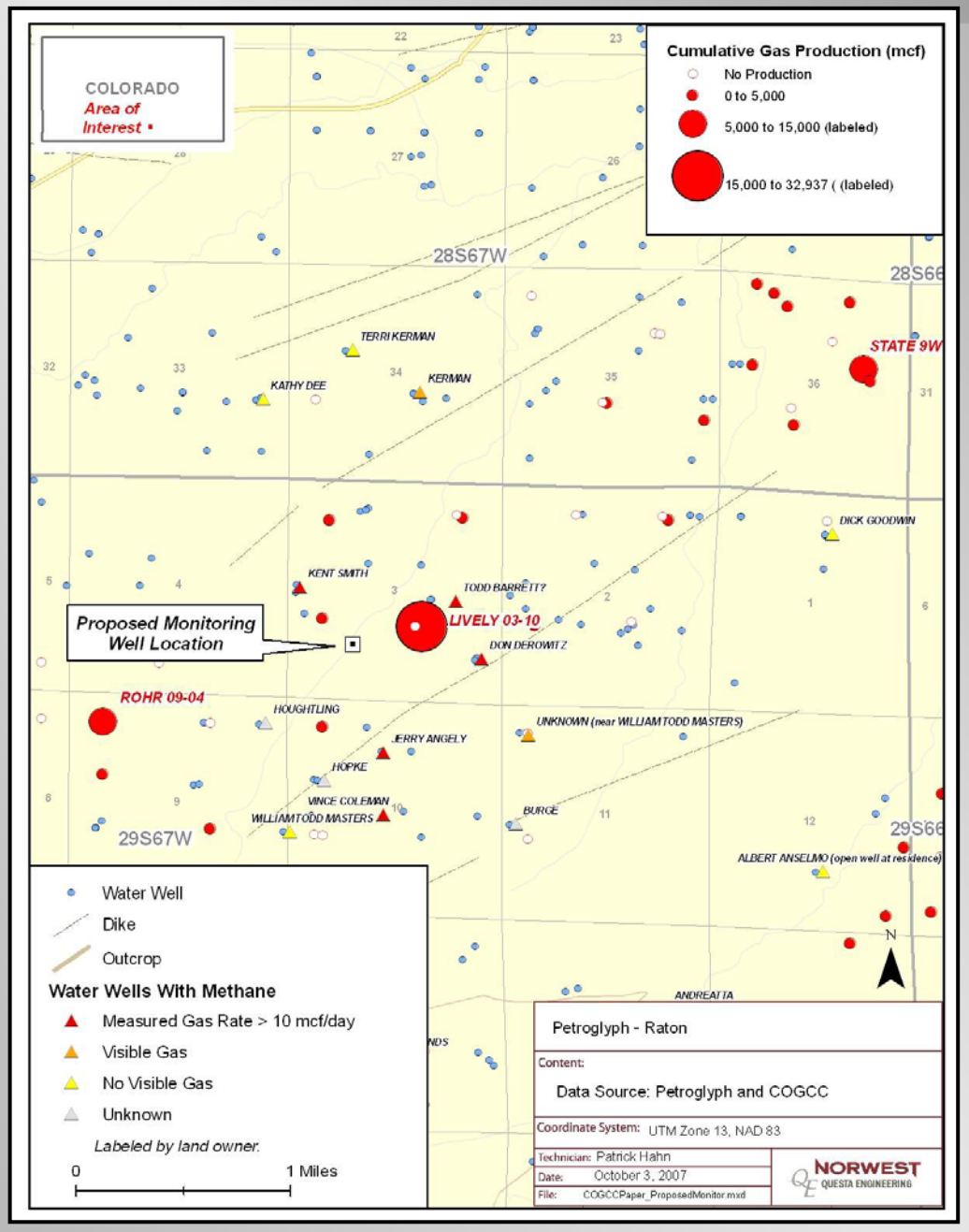
# Shallow Aquifer Mitigation Program

- 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

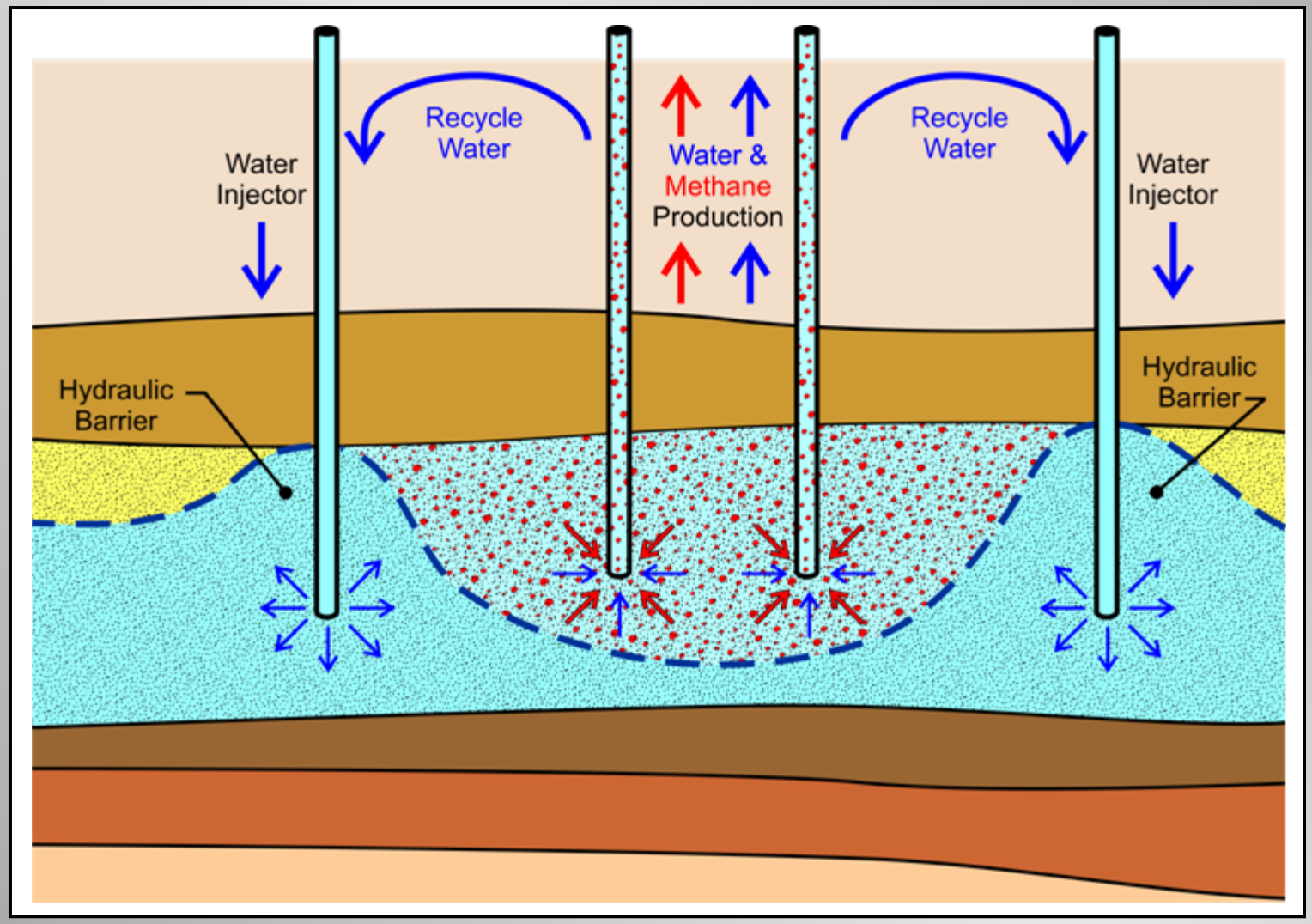
# Proposed Shallow Aquifer Monitoring Well Location



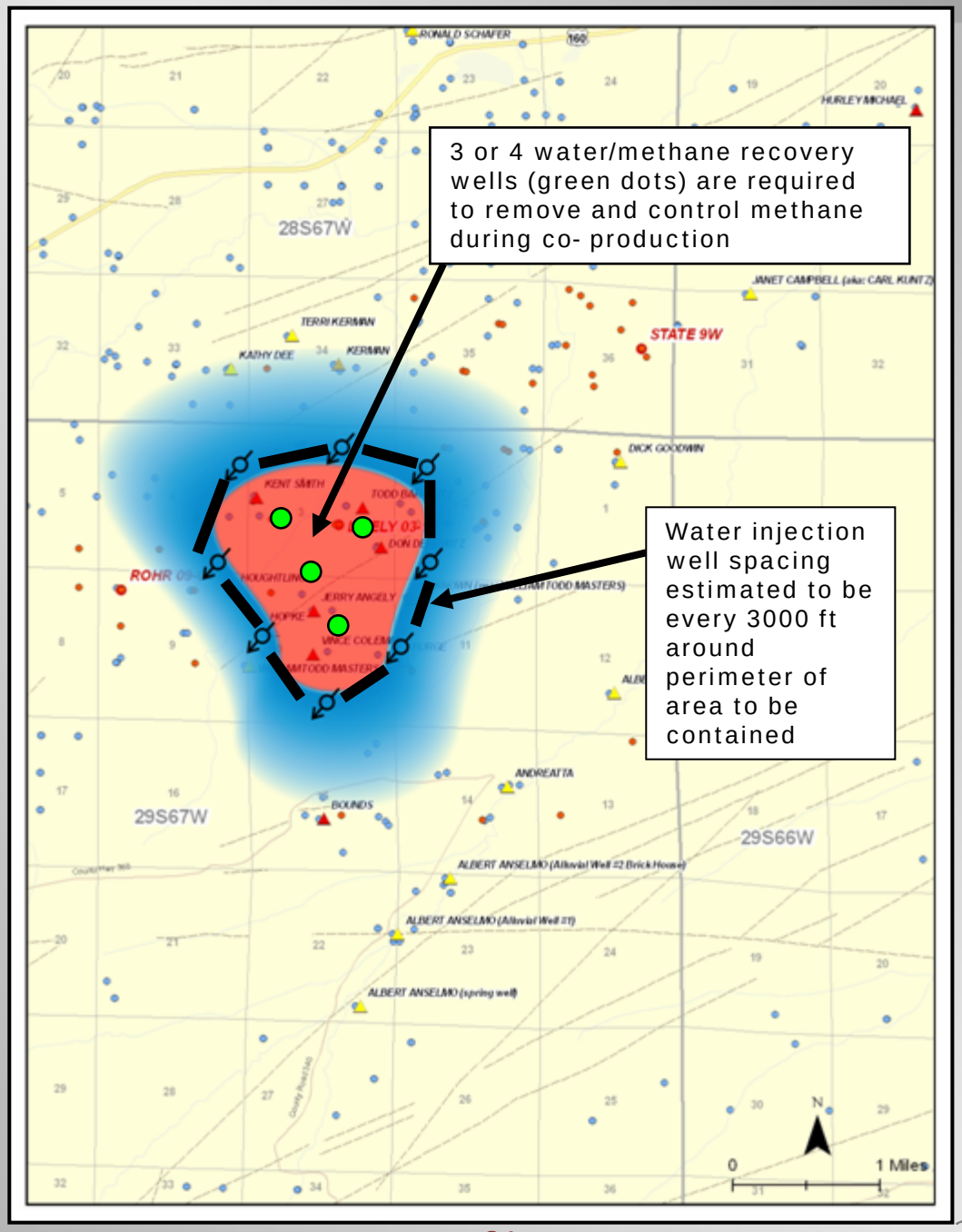
# Phase II Shallow Aquifer Mitigation Program

- 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



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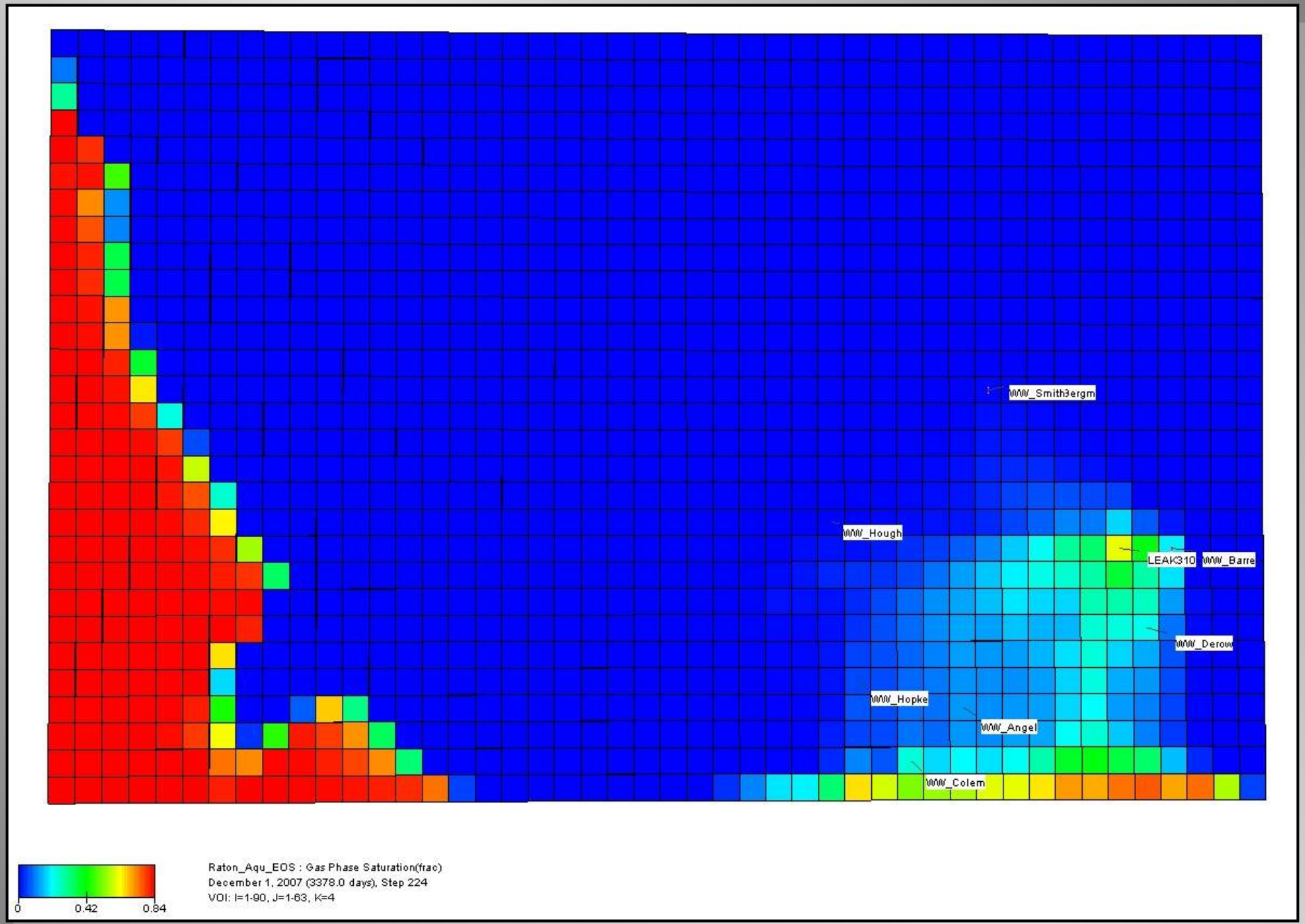
# Aquifer Model Description for Hydraulic Barrier Proof of Concept

- 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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WW_Hough
LEAK310
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WW_Hopke
WW_Angel
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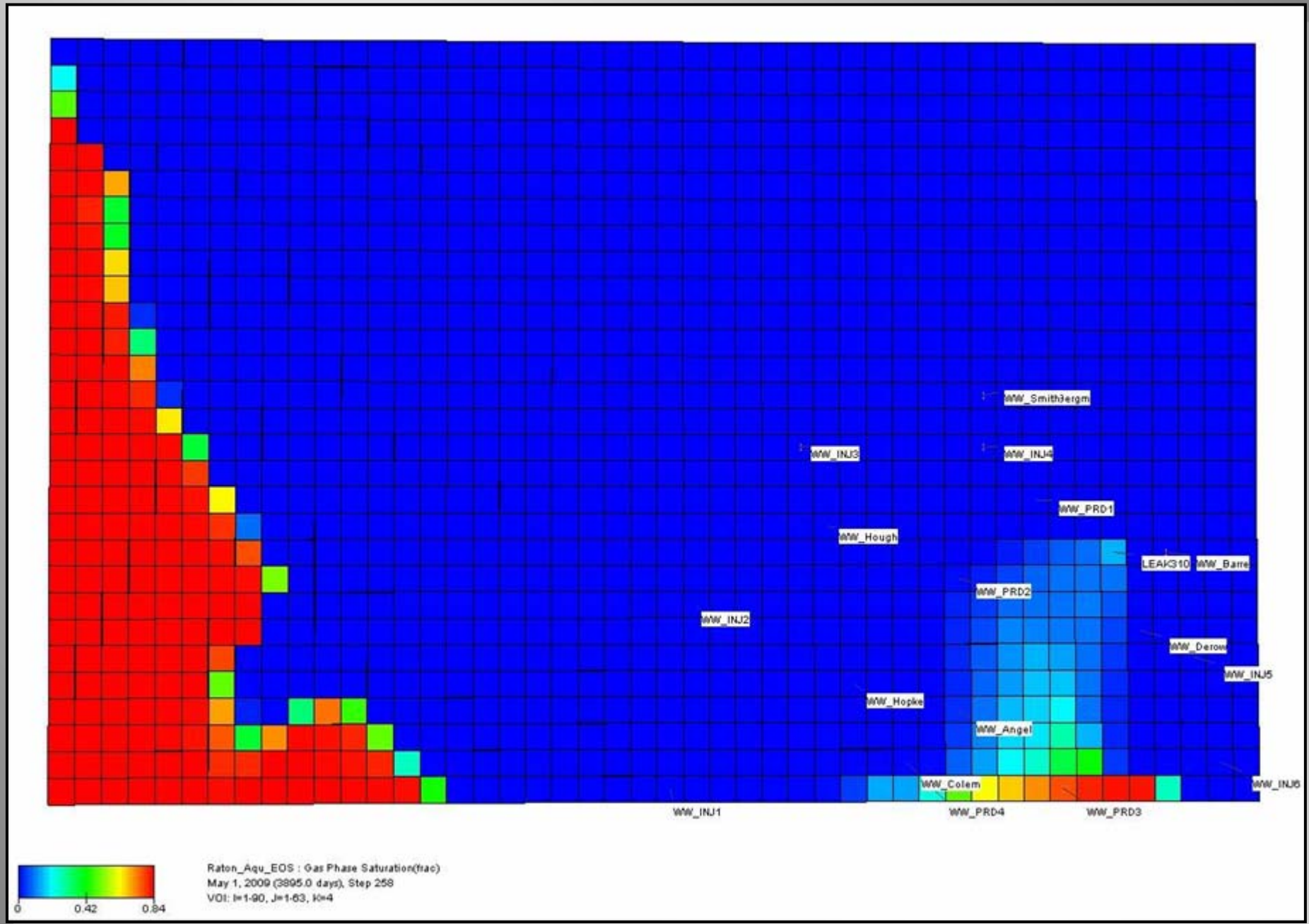
Raton_Aqu_EOS : Gas Phase Saturation(frac)
December 1, 2007 (3378.0 days), Step 224
VOI: I=1-90, J=1-63, K=4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WW_Hopke
WW_Angel
WW_Colem
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Raton_Aqu_EOS : Gas Phase Saturation(frac)
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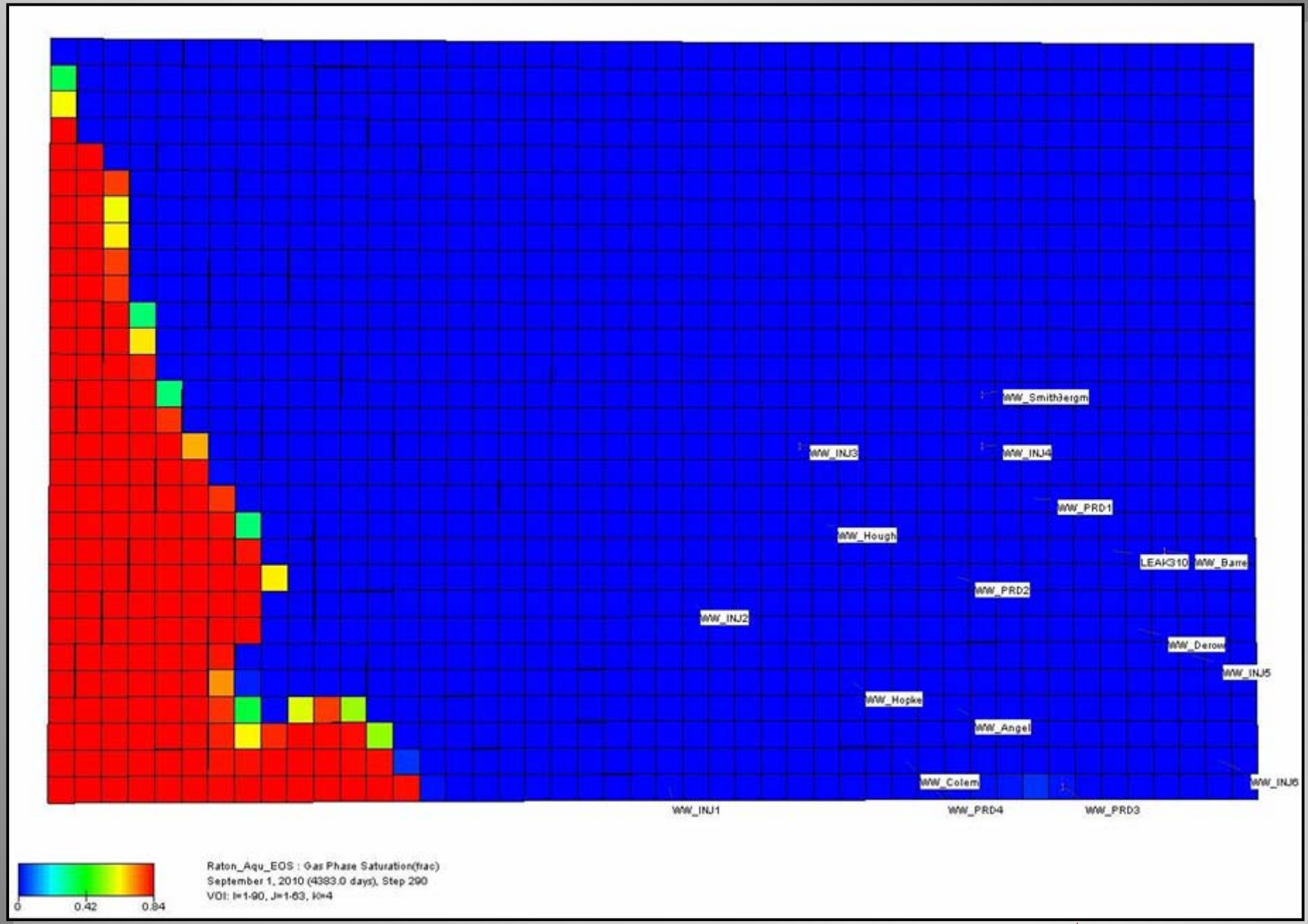
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WW_INJ5
WW_Hopke
WW_Angel
WW_Colem
WW_INJ6
WW_INJ1
WW_PRD4
WW_PRD3
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Raton_Aqu_EOS : Gas Phase Saturation(frac)
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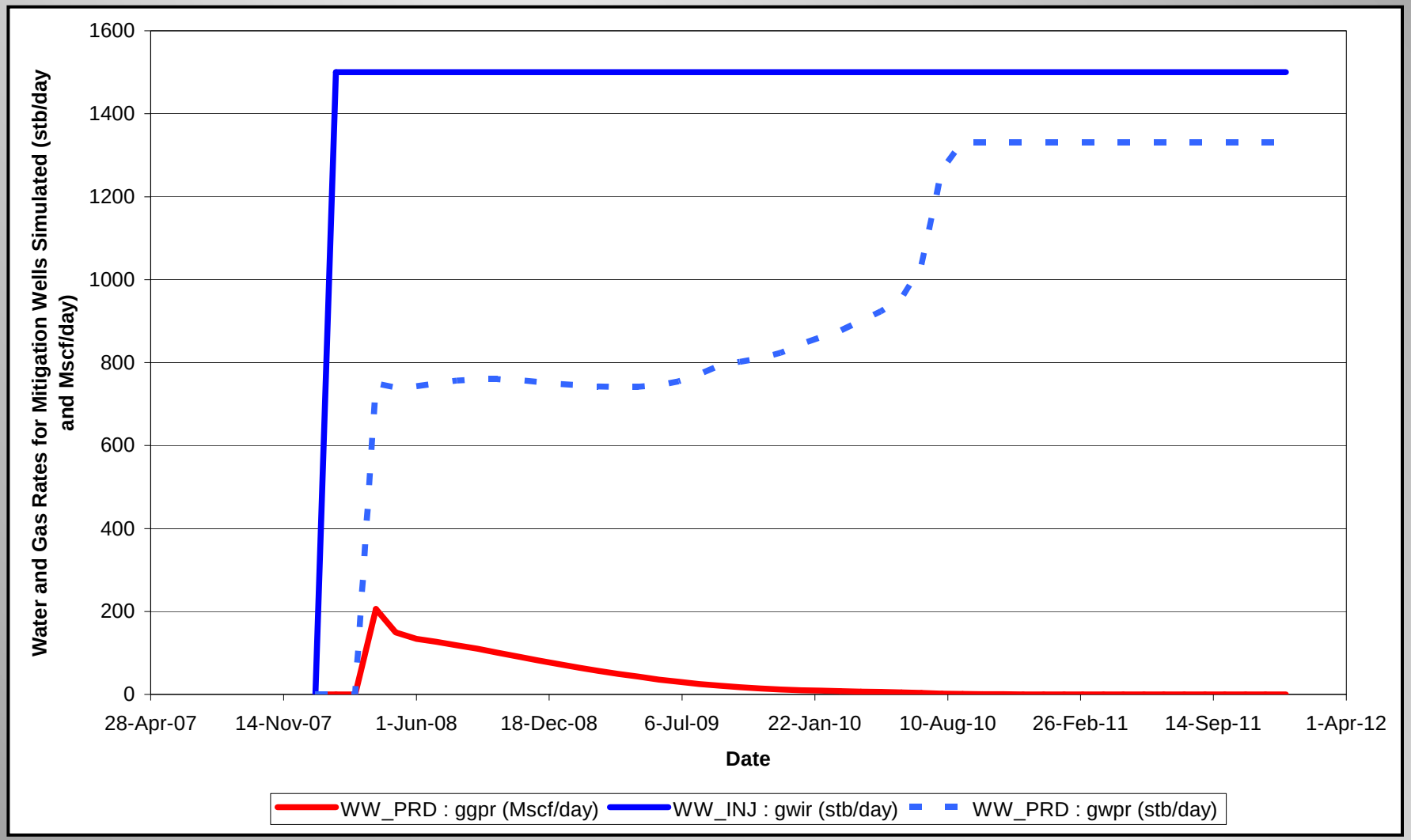
VOI: I=1-90, J=1-63, k=4

# 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 creating 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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