Summary of PI and PII Hydrogeologic Characterization Studies – Mamm Creek Area, Garfield County, Colorado

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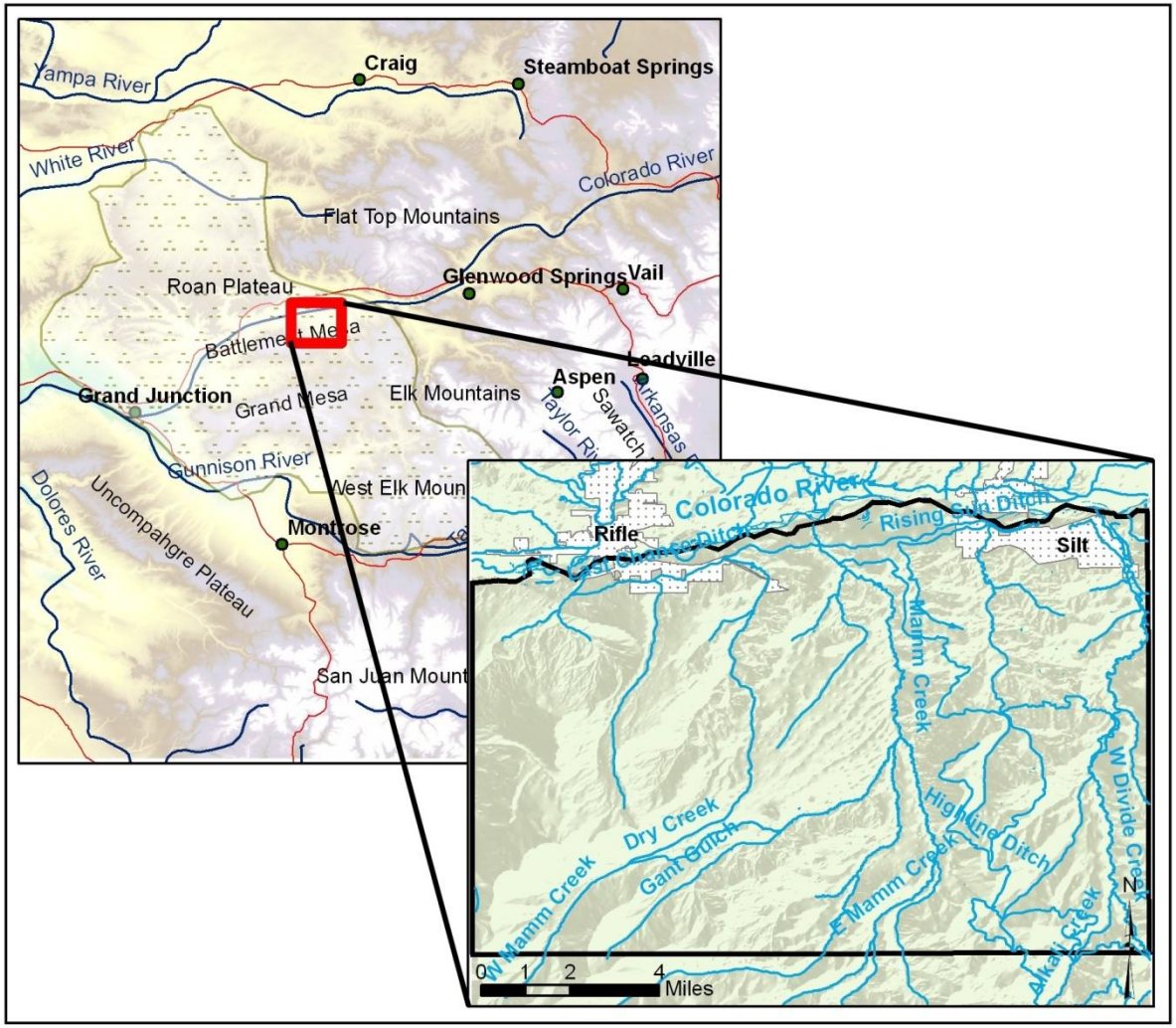
Science Based Solutions

Phase I Study

- Performed by URS using funds from West Divide Creek seep fine (EnCana)
- Provided geological and hydrological background in study area
- Compiled all existing water quality data
- Evaluated the impact of petroleum activities on water quality in the study area

Phase II Study

- Performed by SSP&A
- Re-sampled wells that showed problems with inorganic parameters (F, NO_3 and Se) in study area
- Re-sampled wells with elevated methane that did not have isotopic analyses (use to determine source of gas)
- Sampled producing gas wells for gas and water characterization

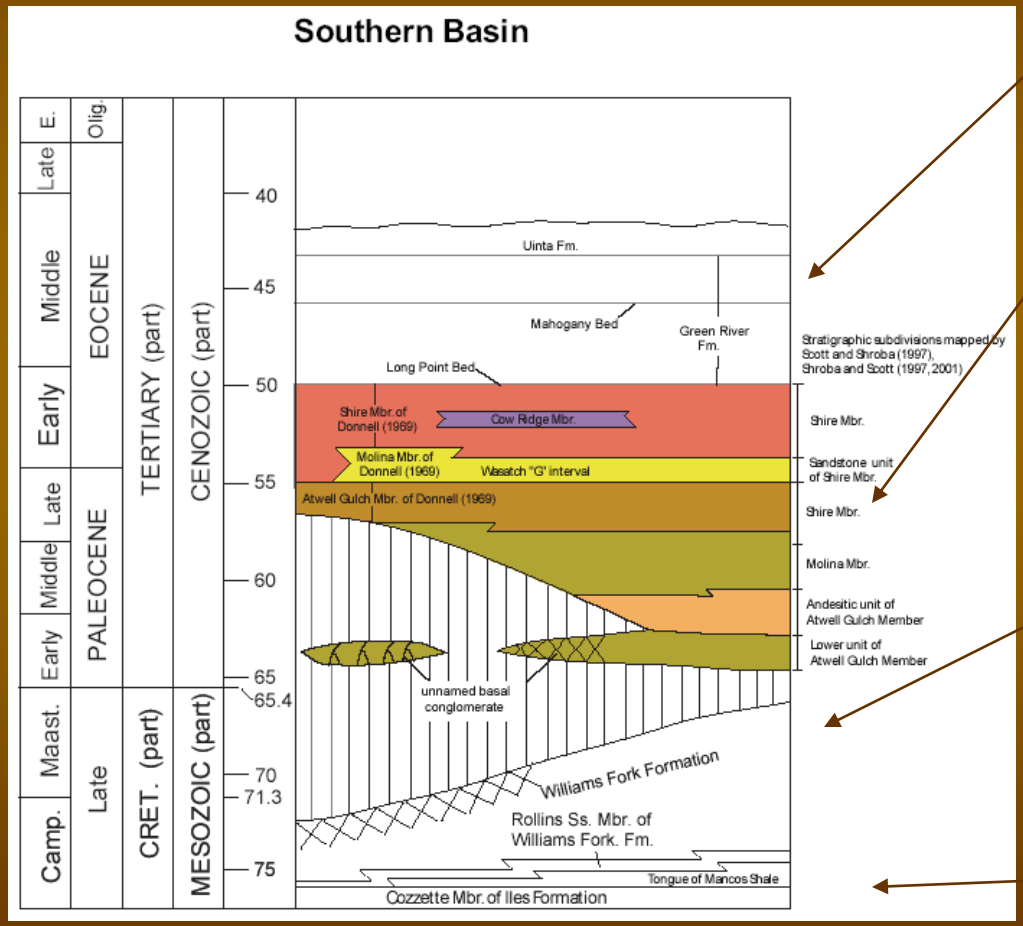


Study Area

South of the Colorado River between Silt and Rifle
Drainage to the north by small streams
Rural with ranches
Wells are in Wasatch Formation have low yields and generally good to poor quality water

Hydrogeologic Model

From Johnson and Flores (2003)



Green River and Uinta Formations

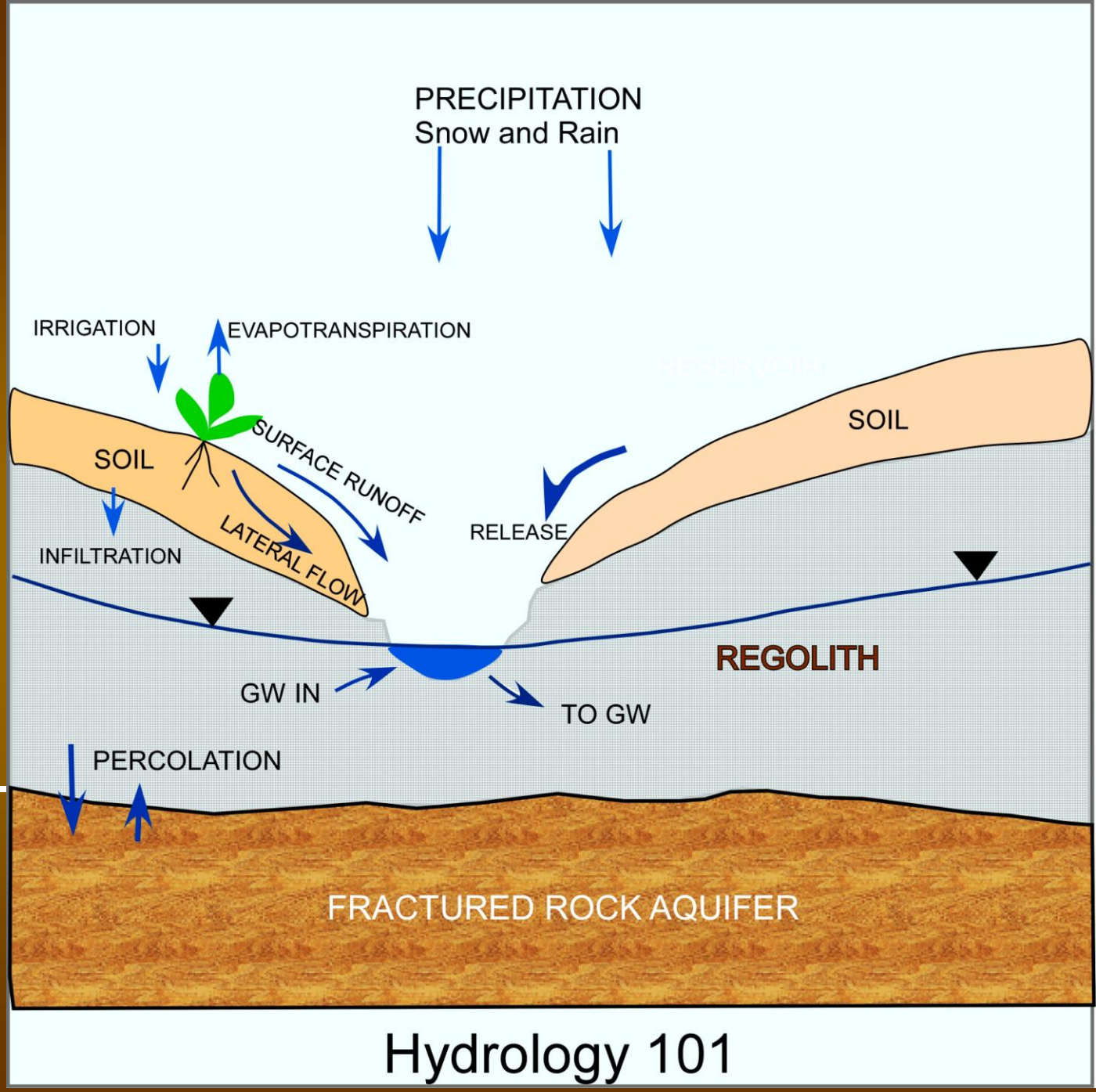
Wasatch Formation: 1,200-5,400ft thick; mudstone with lenticular and amalgamated sandstones; one interval has more tabular sand units

Williams Fork Formation: fluvial sandstone, marginal marine shale and coal beds; contains Mesaverde Group from which natural gas is produced

Mancos Shale

Water moves at
10 - 50 feet/day

Water moves at
0.0007 - 0.23 feet/day



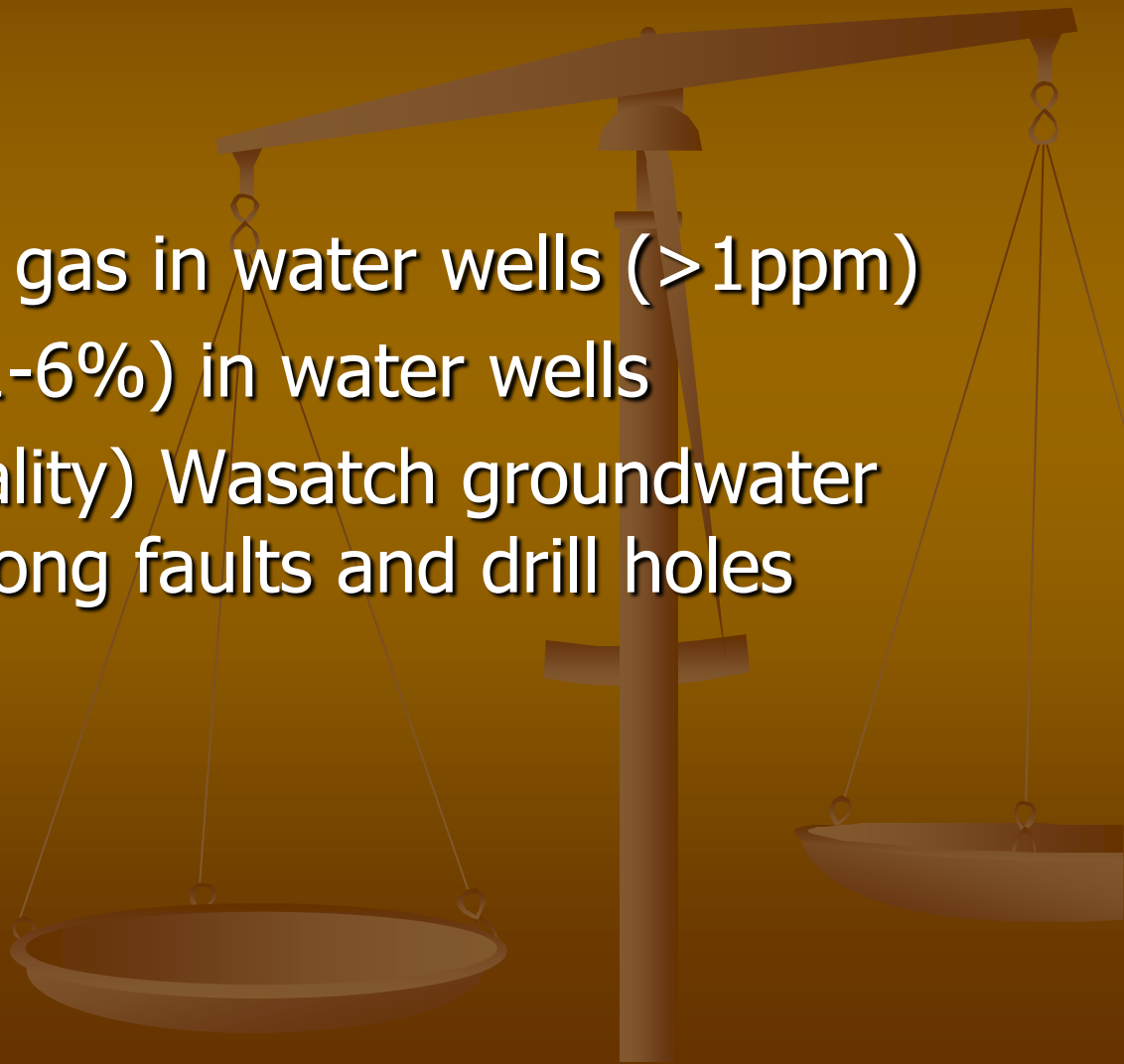
General Comments

- URS study provided valuable background work and "baseline" in Mamm Creek area
- URS study identified problem wells with elevated inorganic parameters (F, NO_3, Se)
- SSP&A followed up on URS study with repeats of problem wells (elevated CH_4, F, NO_3 and Se)
- SSP&A collected 66 well water samples, 16 produced water samples and 15 gas samples (4 gas wells and 11 water wells)
- URS+SSP&A = 705 water samples from 250+ locations

Impacts to Water Quality

- COGCC has defined impact to wells as that which exceeds the Federal or State standards
- Two types of impact
  - Appears unrelated to petroleum activity (F, NO_3, Se)
  - Related to petroleum activity (methane and BTEX)
- Most impact from petroleum wells is not sufficient to trigger regulatory action

What are the Petroleum Impacts?



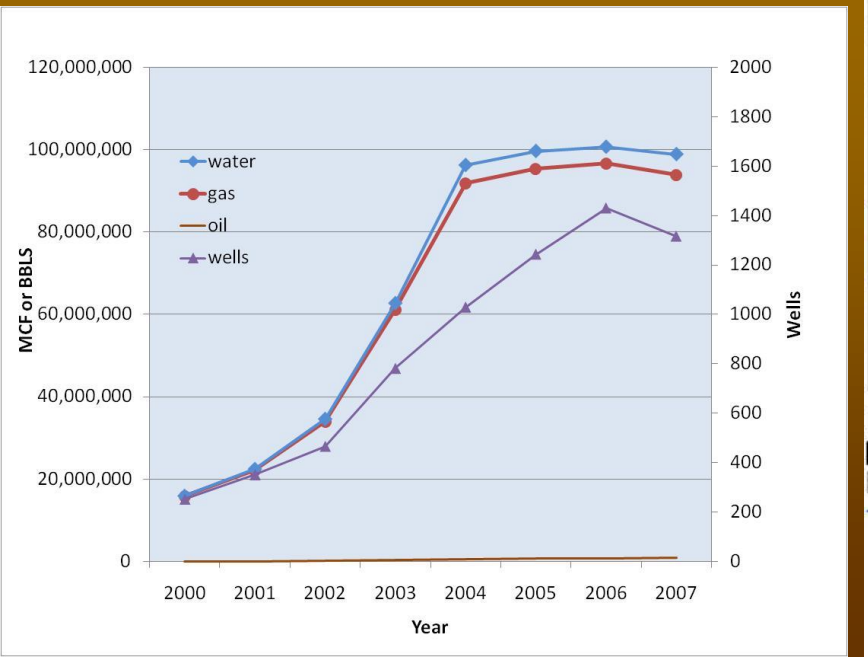
- Elevated methane gas in water wells (>1ppm)
- Produced water (1-6%) in water wells
- Deeper (lower quality) Wasatch groundwater moving upward along faults and drill holes

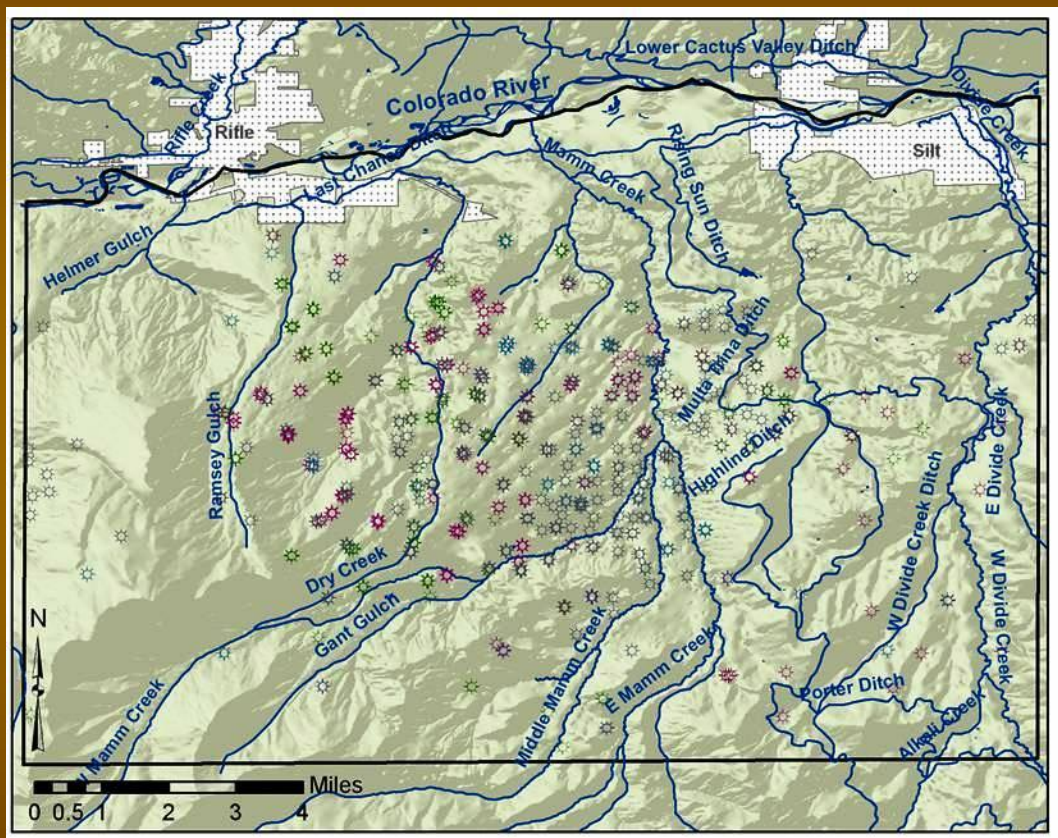
Hydrocarbon Impact 101

- COGCC detected benzene (BTEX component) at West Divide Creek as well as methane, etc.
- Benzene was present because large volumes of hydrocarbons from a well about 0.75 mile away was leaking upward along a fault and through the Creek bottom
- Benzene exceeded maximum allowable concentrations triggering regulatory action
- Benzene (and other hydrocarbons) degrade naturally over time (months to years)
- BTEX contamination will be below detection after moving only 200 feet from the source
- There are over 1000 gas wells (potential point sources) and less than 264 samples points including monitoring wells, ponds, streams and water wells in the study area
- Usually you need at least three sample points for each potential point source to evaluate impact (12-15 at WDC site)

Increasing Methane in Groundwater

- Significant increase in drilling over 8 years
- Amount of produced water has increased in step with gas and number of wells

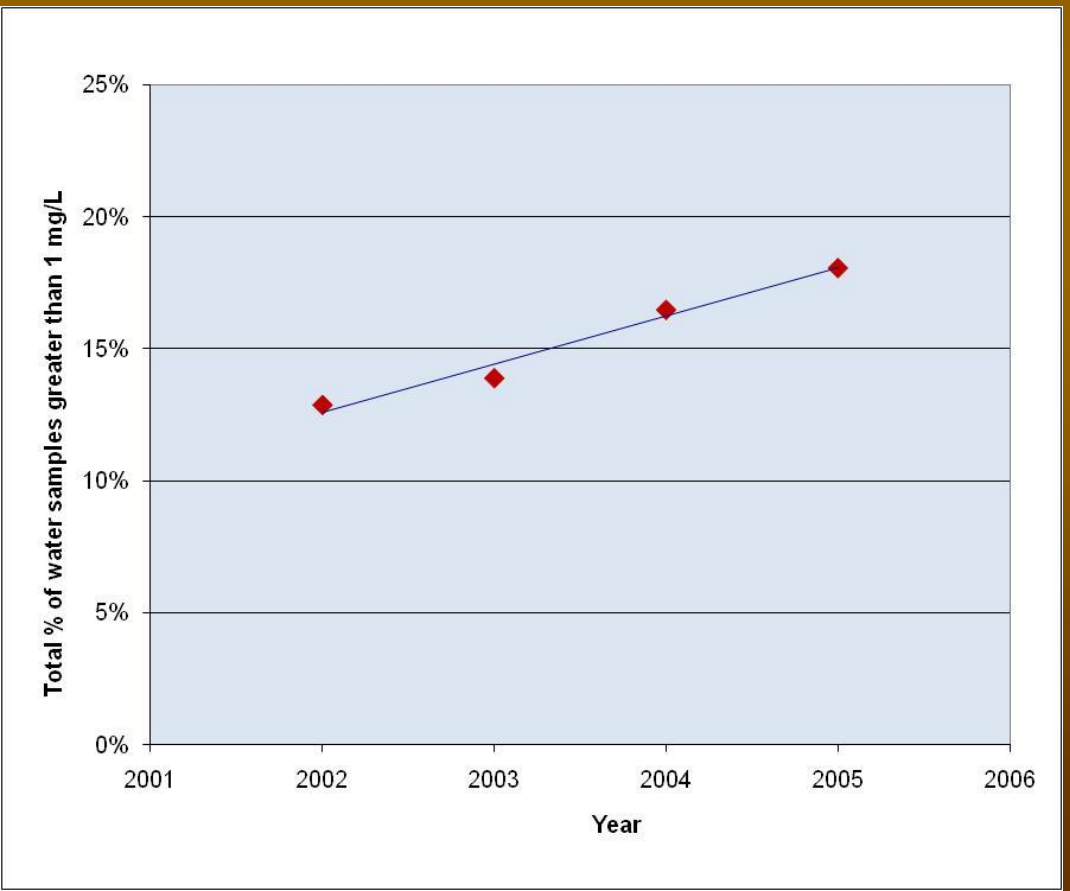




Legend

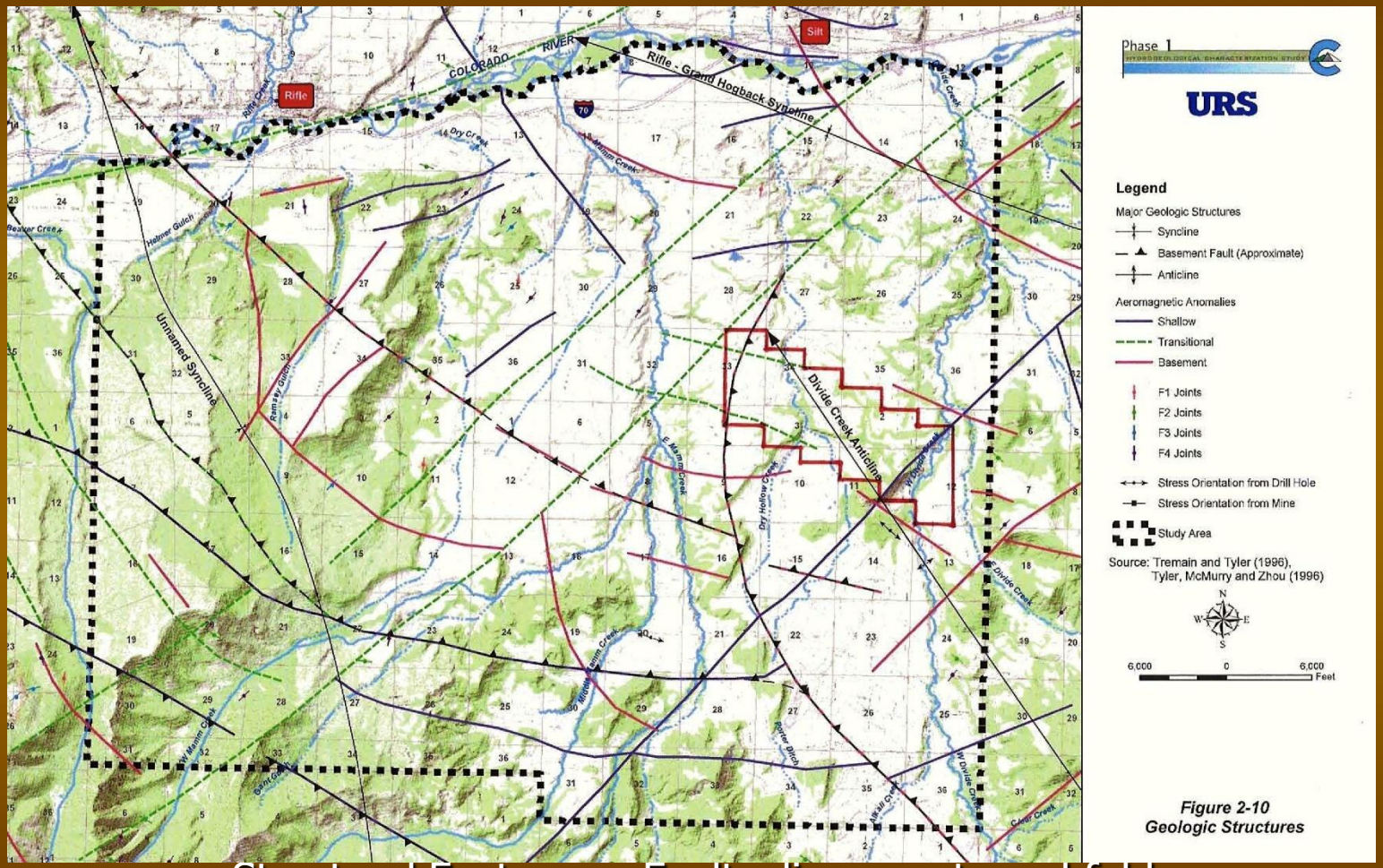
- Study Area
- Municipality
- Streams
- Gas wells drilled prior to 2002
- Gas wells drilled prior to 2003
- Gas wells drilled prior to 2004
- Gas wells drilled prior to 2005

Increasing Methane in Groundwater

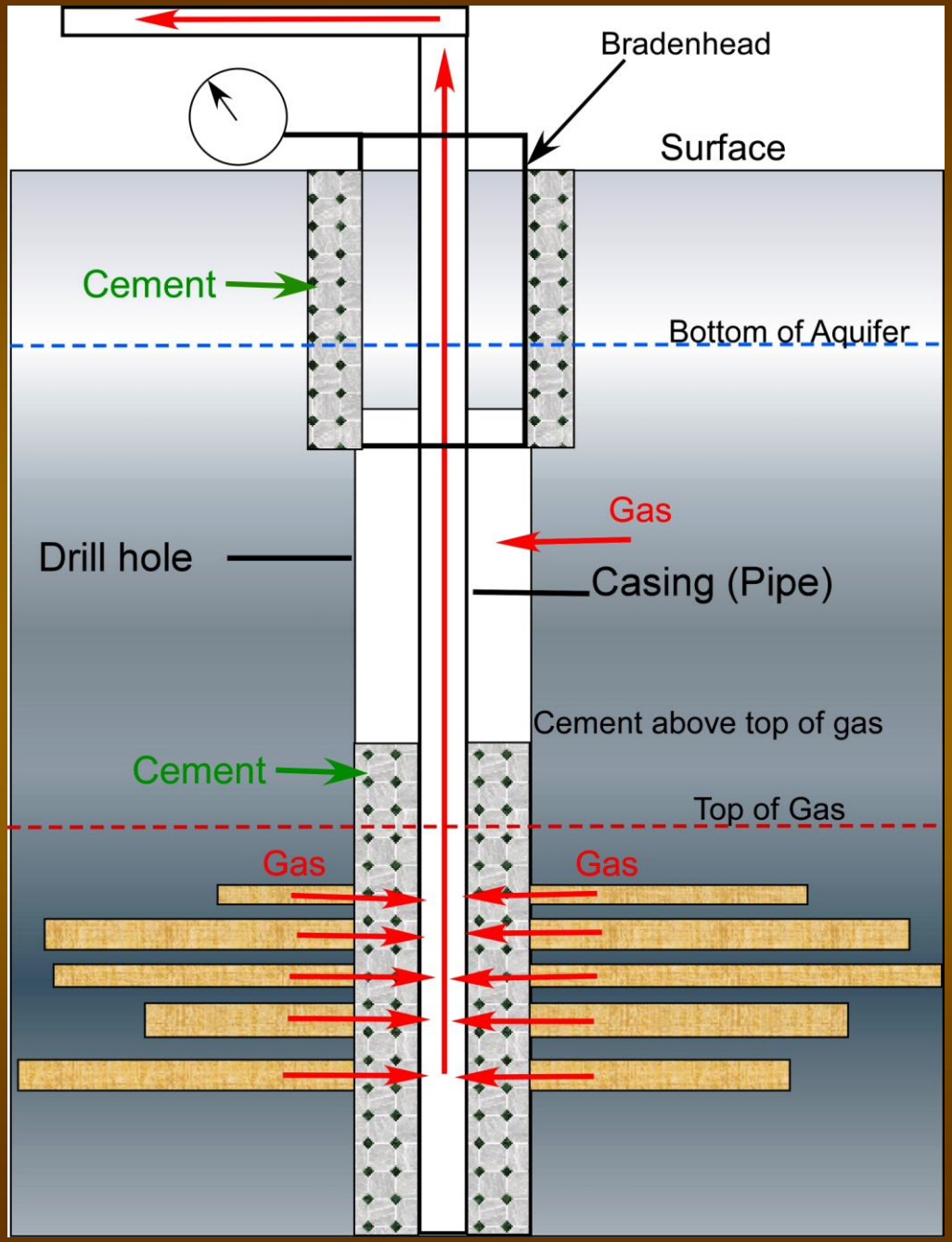


- Pre-drilling methane was < 1ppm
- Average methane in water wells and surface ponds has increased each year as the number of gas wells drilled has increased

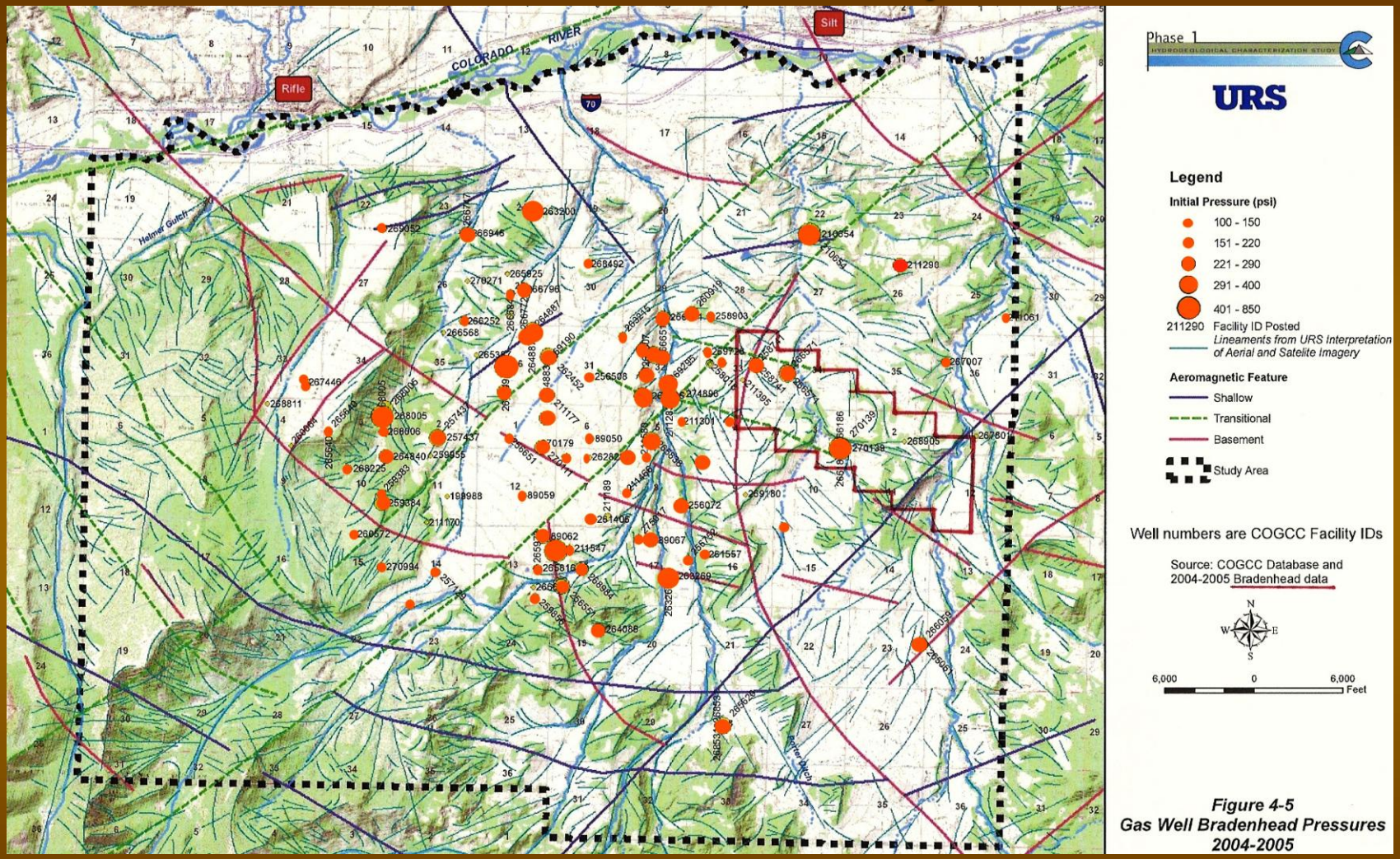
Geology of Area



- Structural Features – Faults, lineaments and folds
- Provides paths of weakness for fluid and gas movement
- Major feature is the Divide Creek Anticline

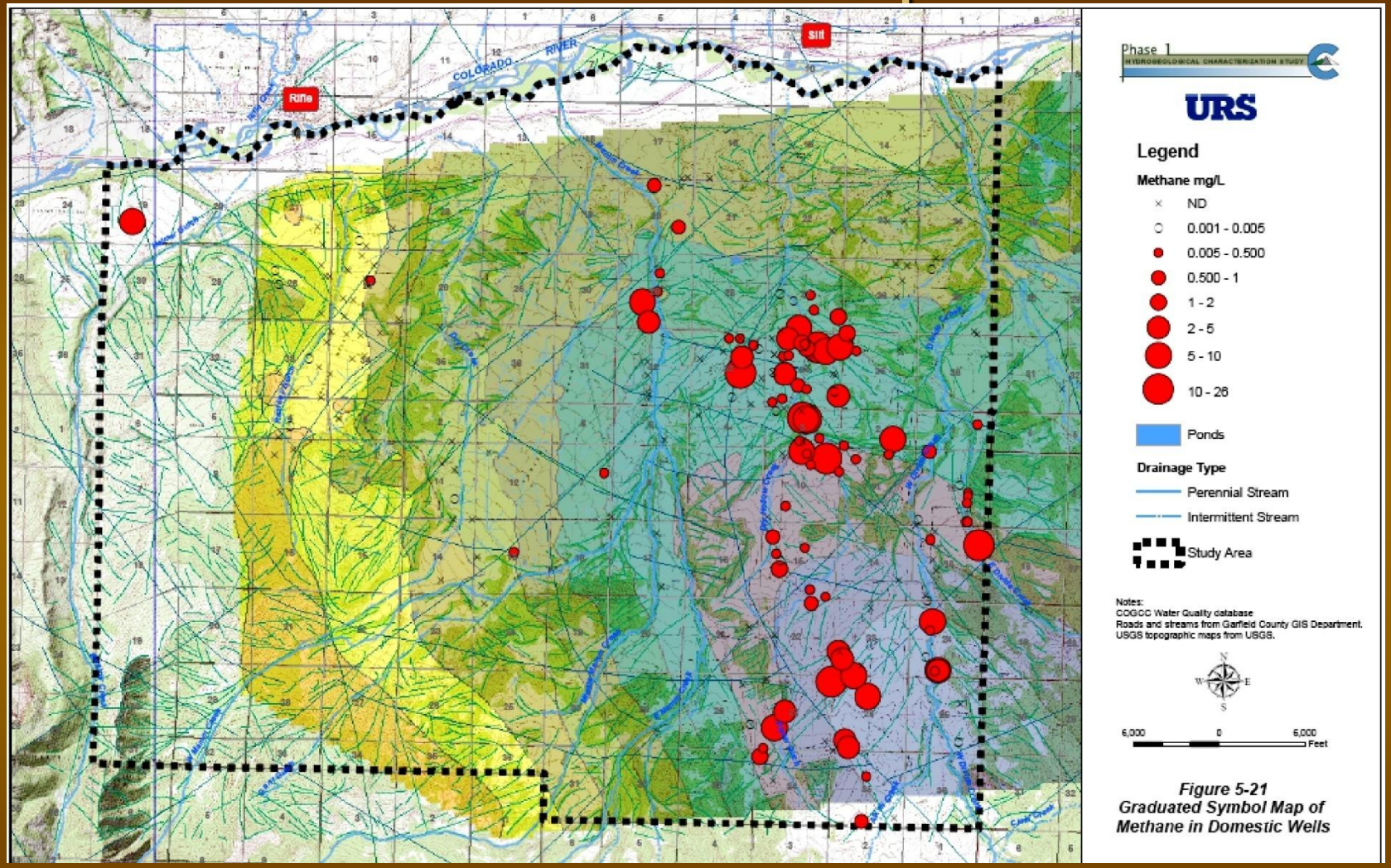

Bradenhead
Surface
Cement
Bottom of Aquifer
Gas
Drill hole
Casing (Pipe)
Cement above top of gas
Cement
Top of Gas
Gas
Gas

Where are the impacts?



- Bradenhead Pressure
- Indicates upward gas movement from Wasatch
- Higher along structural features

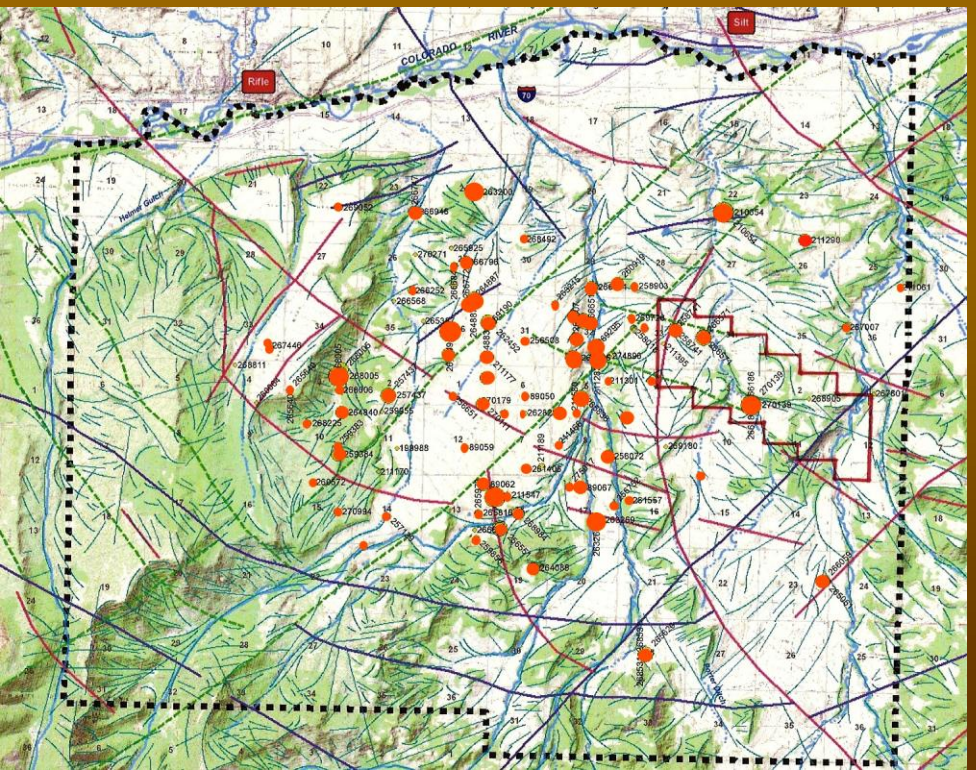
Where are the impacts?

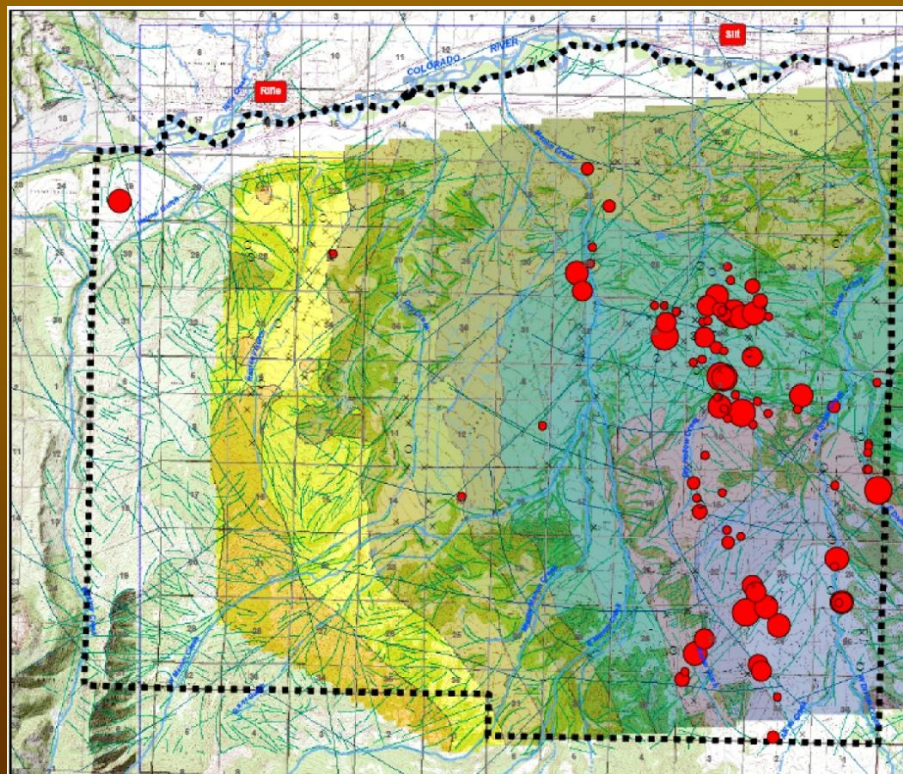


- Elevated Methane in Groundwater
- Indicates upward gas movement from Wasatch/Produced Gas
- Produced gas source is probably near-surface leaks

Where are the impacts?

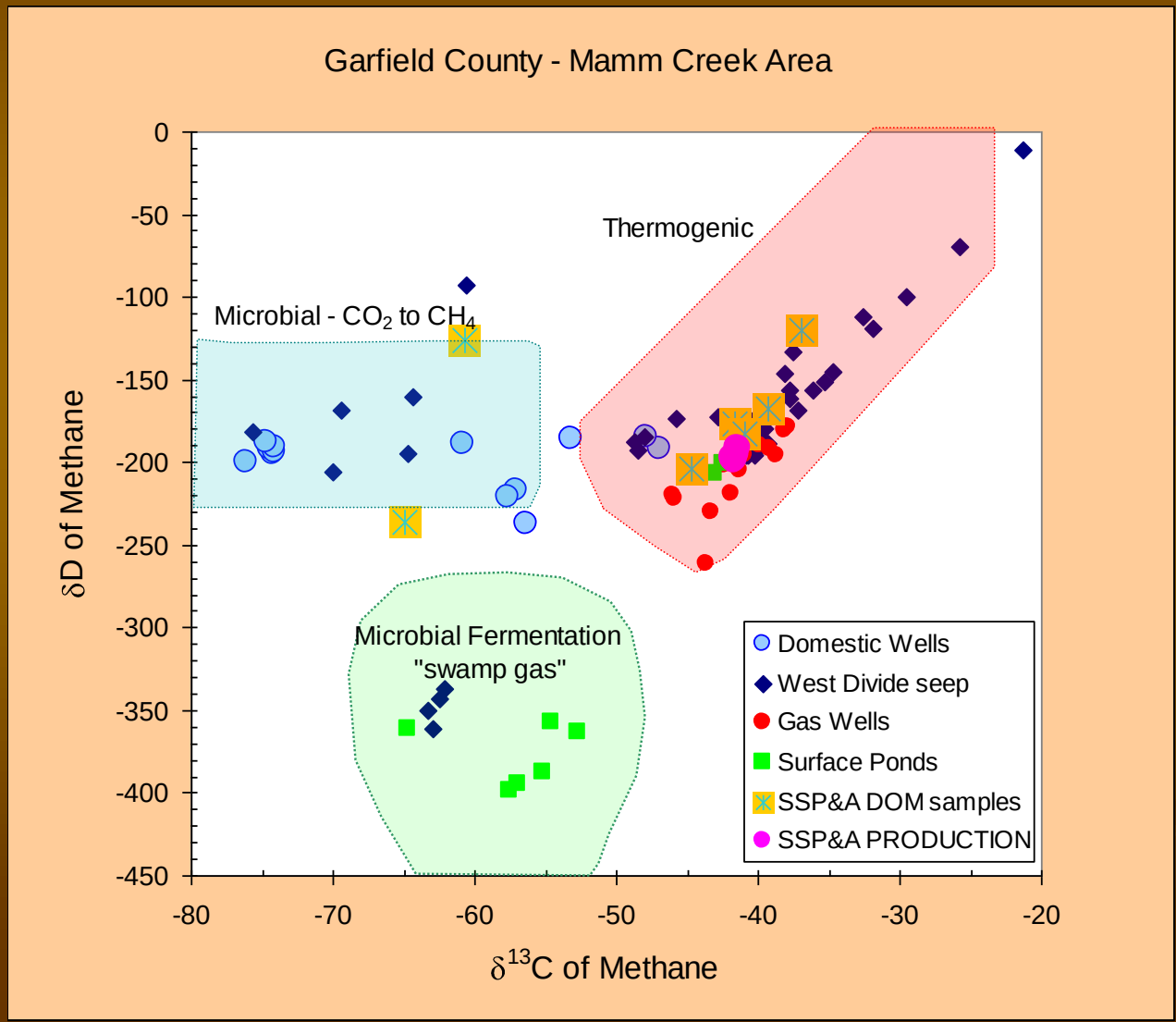
While many of the groundwater wells with elevated methane are near or in the Special Drilling Zone, some are found farther south





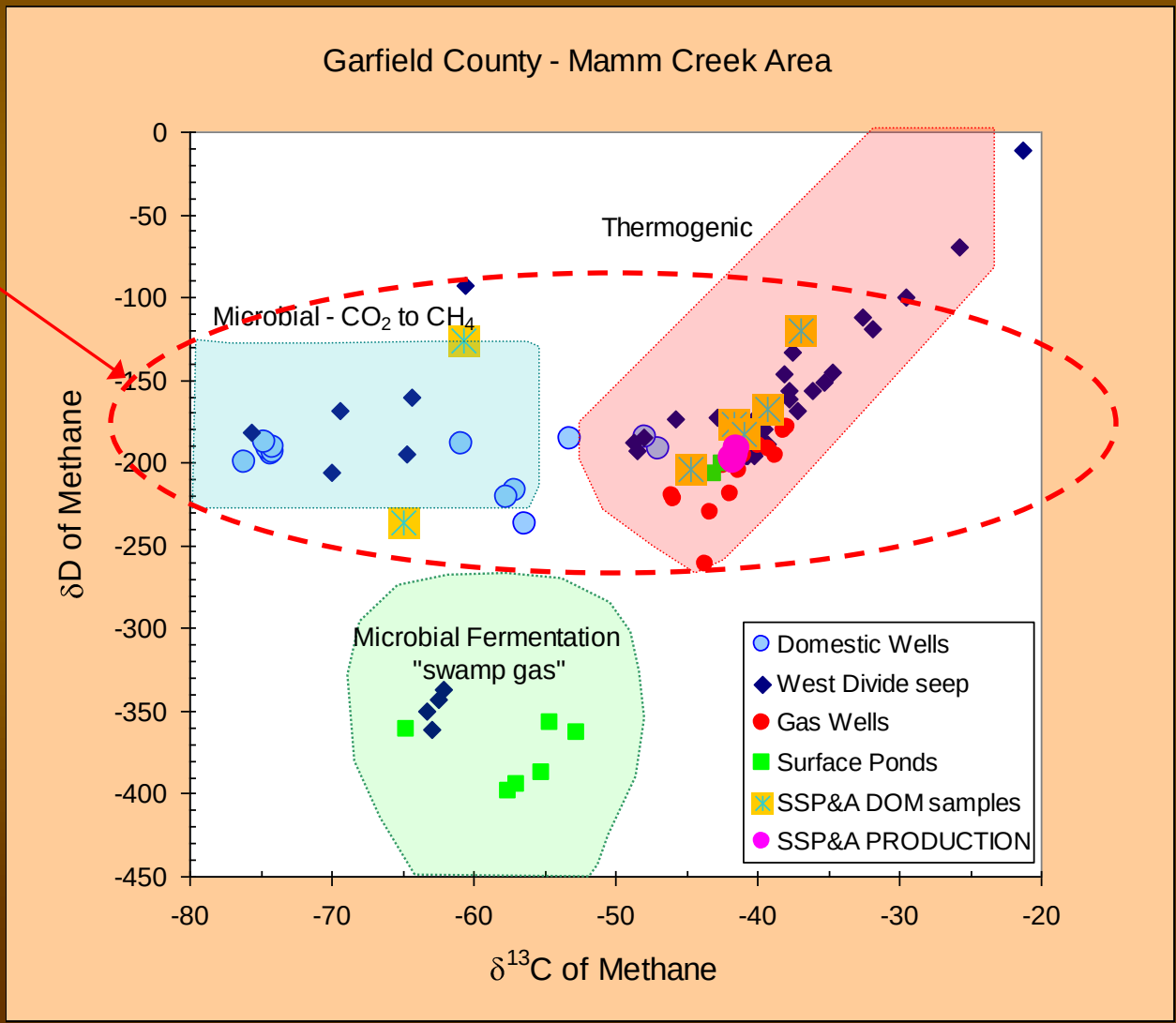
Isotopic Data

- Used to tell source of methane
- COGCC has proposed there are "false positives" that appear thermogenic, but are leftover after microbial oxidation of CH_4
- Unlikely explanation given many seep samples are produced gas (thermogenic) and there is no accompanying CO_2



Isotopic Data

- Two types of thermogenic methane
- Both types appear at WDC seep
- Second type from microbial conversion of Williams Fork Fmn. CO_2 to CH_4



Water Quality

- Basically three types of water
  - Natural background surface and near-surface Ca-Na-HCO_3 water with <500ppm TDS and low chloride and sulfate (potable is < 500ppm)
  - Natural groundwater from the wells, Na-Ca-HCO_3-SO_4 with higher TDS (not always potable)
  - Impacted groundwater with either or both elevated methane (>1ppm) and a NaCl component, very variable TDS, usually not potable

Where are the impacts?

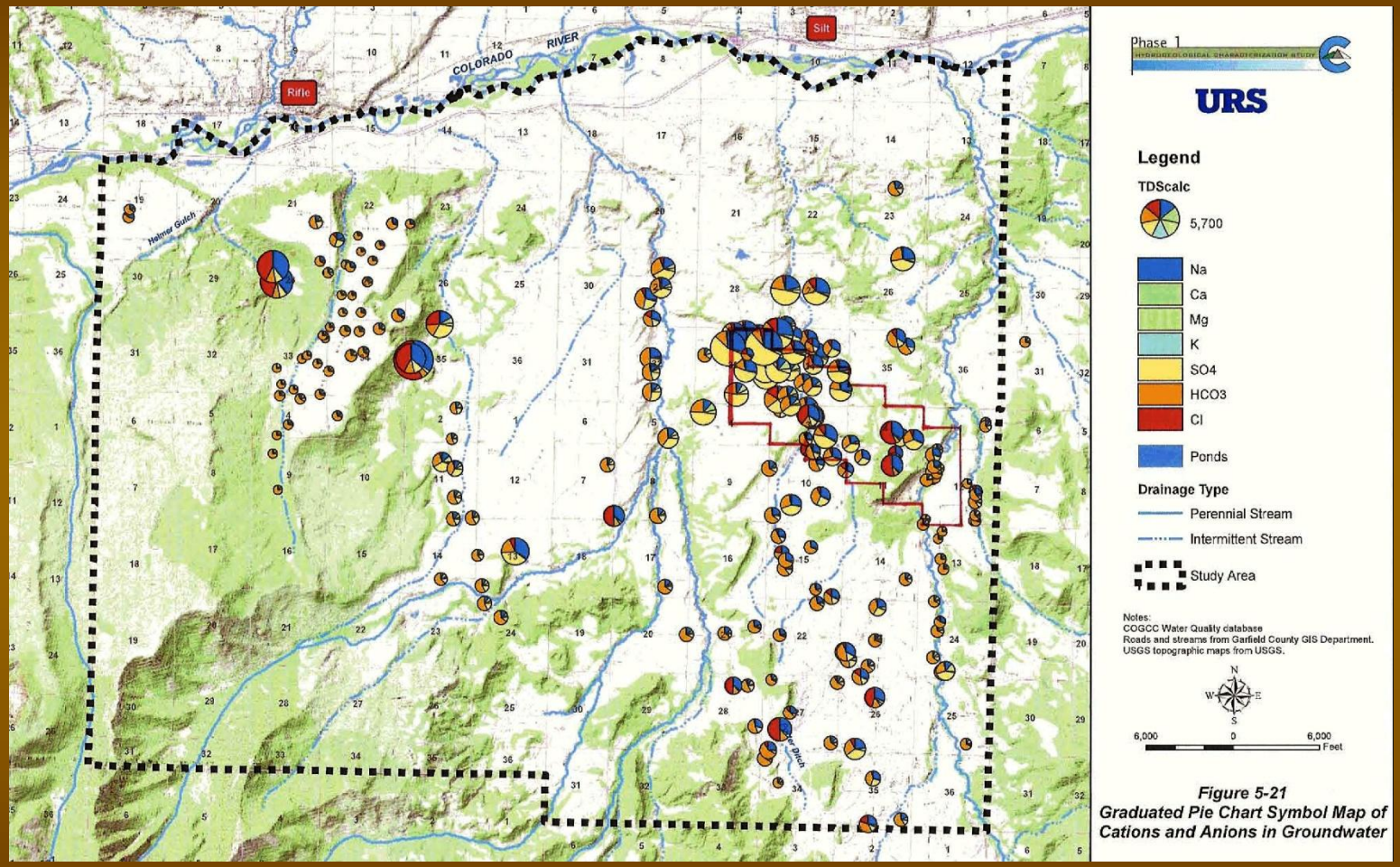
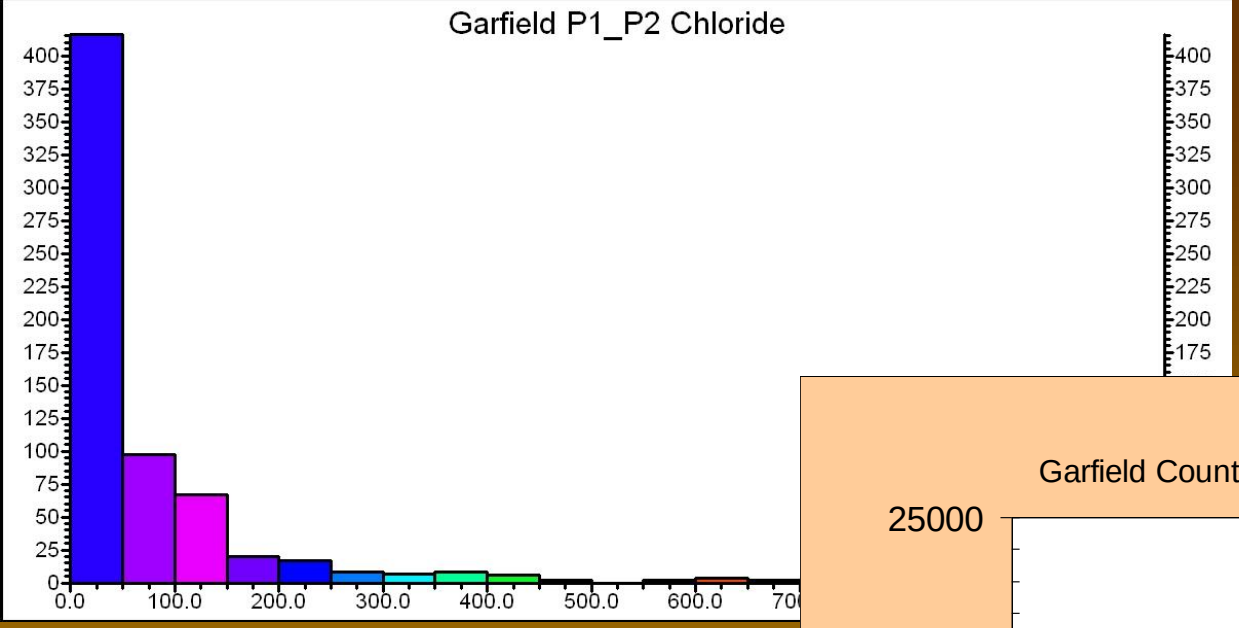
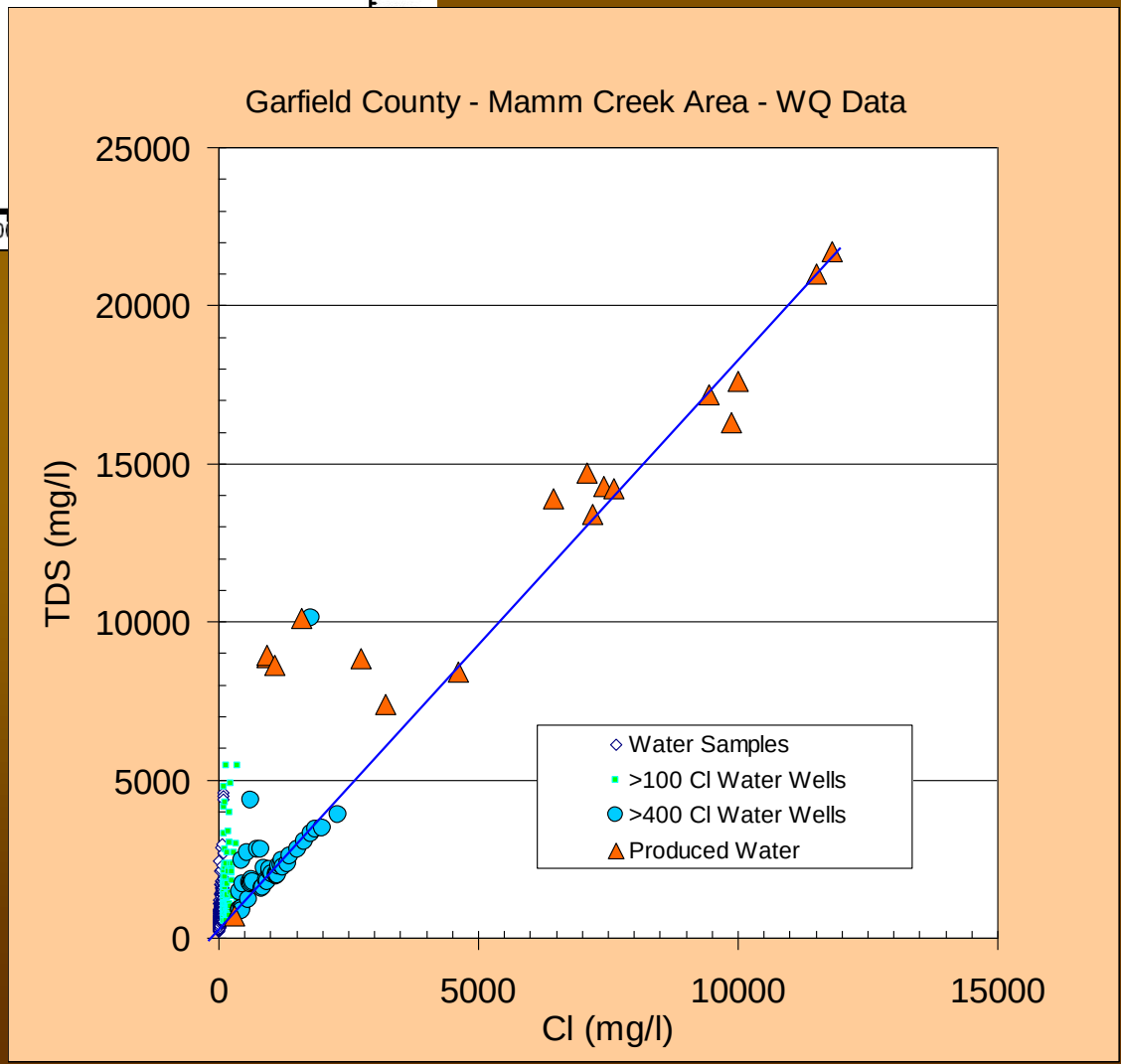


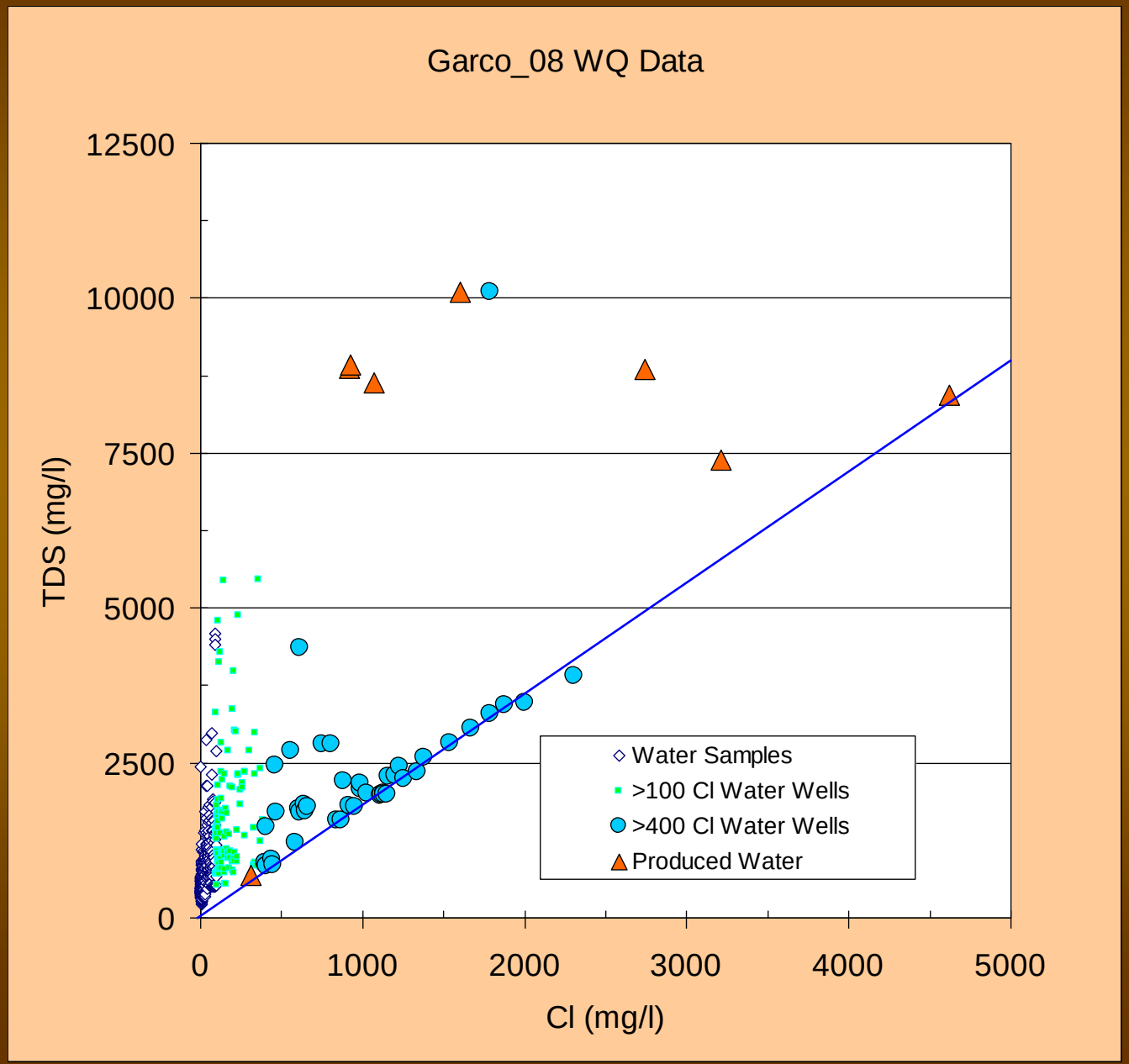
Figure 5-21
Graduated Pie Chart Symbol Map of Cations and Anions in Groundwater

- Higher Salinity (TDS) in "Special Drilling Zone"
- Indicates upward movement of water from Wasatch and produced water
- More impact along structural features



Key indication of produced water impact is chloride
Groundwater has low chloride, produced water has high chloride




Garco_08 WQ Data
12500
10000
7500
5000
2500
0
TDS (mg/l)
0
1000
2000
3000
4000
5000
Cl (mg/l)
Water Samples
>100 Cl Water Wells
>400 Cl Water Wells
Produced Water

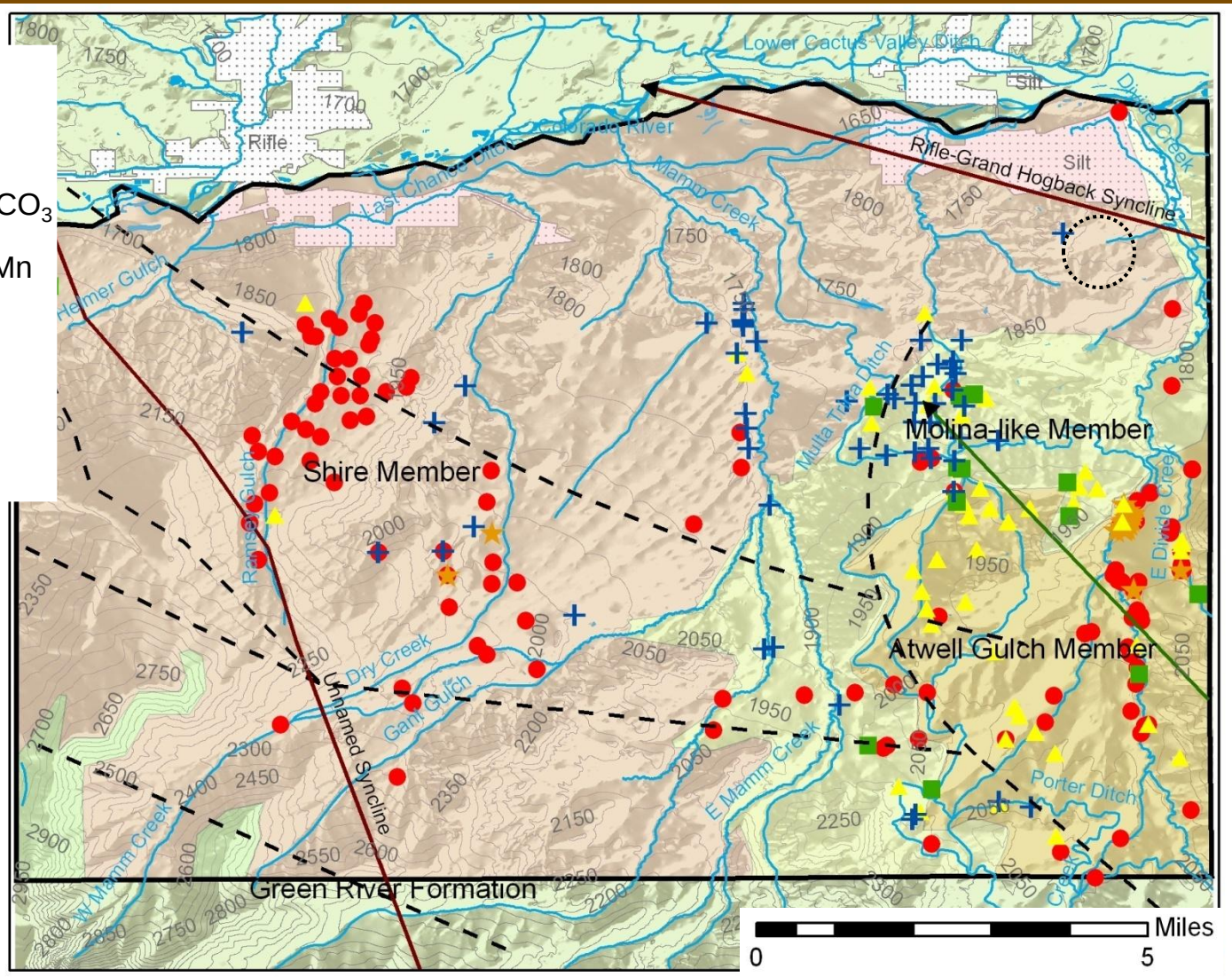
Where are the impacts?

Water samples

Cluster

- 1 Background, Ca-Mg-HCO_3
- 2 Ca-Mg-HCO_3 with Fe-Mn
- 3 Na-SO_4-Cl
- 4 High TDS, Na-Cl
- 5 High TDS, Na-SO_4-Cl

Alternative water evaluation using statistical methods
Groups samples by similarity into clusters
Five basic types
Types 4 and 5 have impact



Conclusions

- Natural background water quality is moderate to poor in water wells
- There are a few groundwater wells that show persistent elevated nitrate, selenium and fluoride not related to petroleum activities
- COGCC has defined impact from petroleum activity as concentrations of BTEX and methane that exceed regulatory limits
- Levels of produced gas and water below regulatory action are present in many groundwater wells and this type of impact is increasing with more drilling

Questions?

Drilling Pads, north of study area