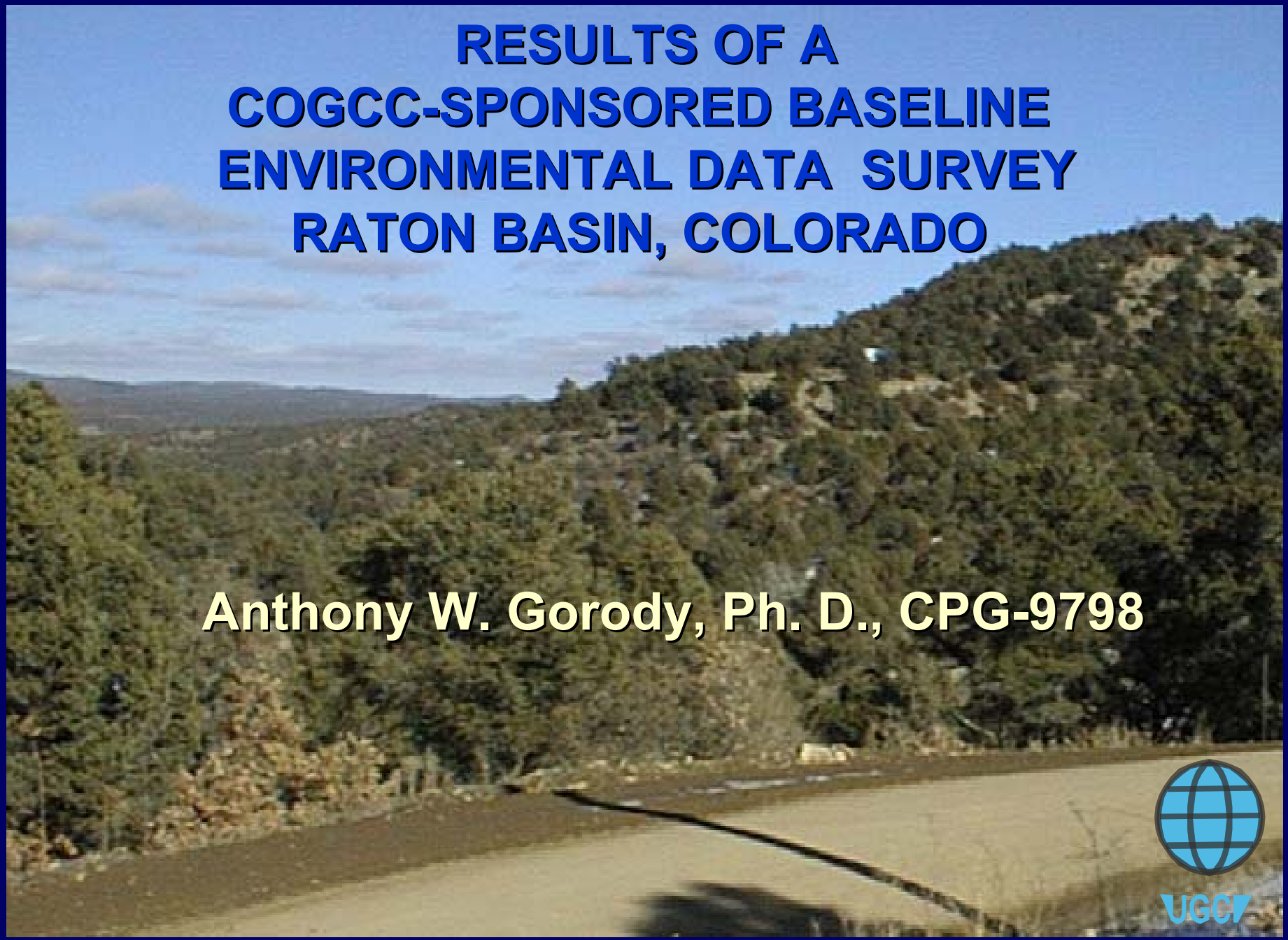
RESULTS OF A COGCC-SPONSORED BASELINE ENVIRONMENTAL DATA SURVEY RATON BASIN, COLORADO



Anthony W. Gorody, Ph. D., CPG-9798

RATON BASIN PROJECT 2000-2003 ACKNOWLEDGEMENTS

- Rich Griebling – COGCC Director
- Debbie Baldwin – Environmental Supervisor
- Jim Milne – GIS Administrator
- Industry Contributors - Cedar Ridge LLC, Evergreen Resources, KLT, Petroglyph Energy Inc., Paul Oldaker (AMOCO)

THIS PRESENTATION ADDRESSES 3 WATER & GAS-RELATED ENVIRONMENTAL ISSUES ASSOCIATED WITH COALBED GAS DEVELOPMENT

- COAL MINE AND CORE HOLE INVENTORY
- METHANE SEEPS
- DISSOLVED METHANE IN GROUNDWATER
- TOOLS FOR ASSESING POTENTIAL IMPACT TO SHALLOW AQUIFERS

MULTIPLE DATA SETS USED IN STUDY

PRODUCED WATER DATA

- COGCC Survey
  - SeaCrest
  - ESN Rocky Mtn.
  - Isotech
- KLT
- PETROGLYPH

COAL MINE INVENTORY

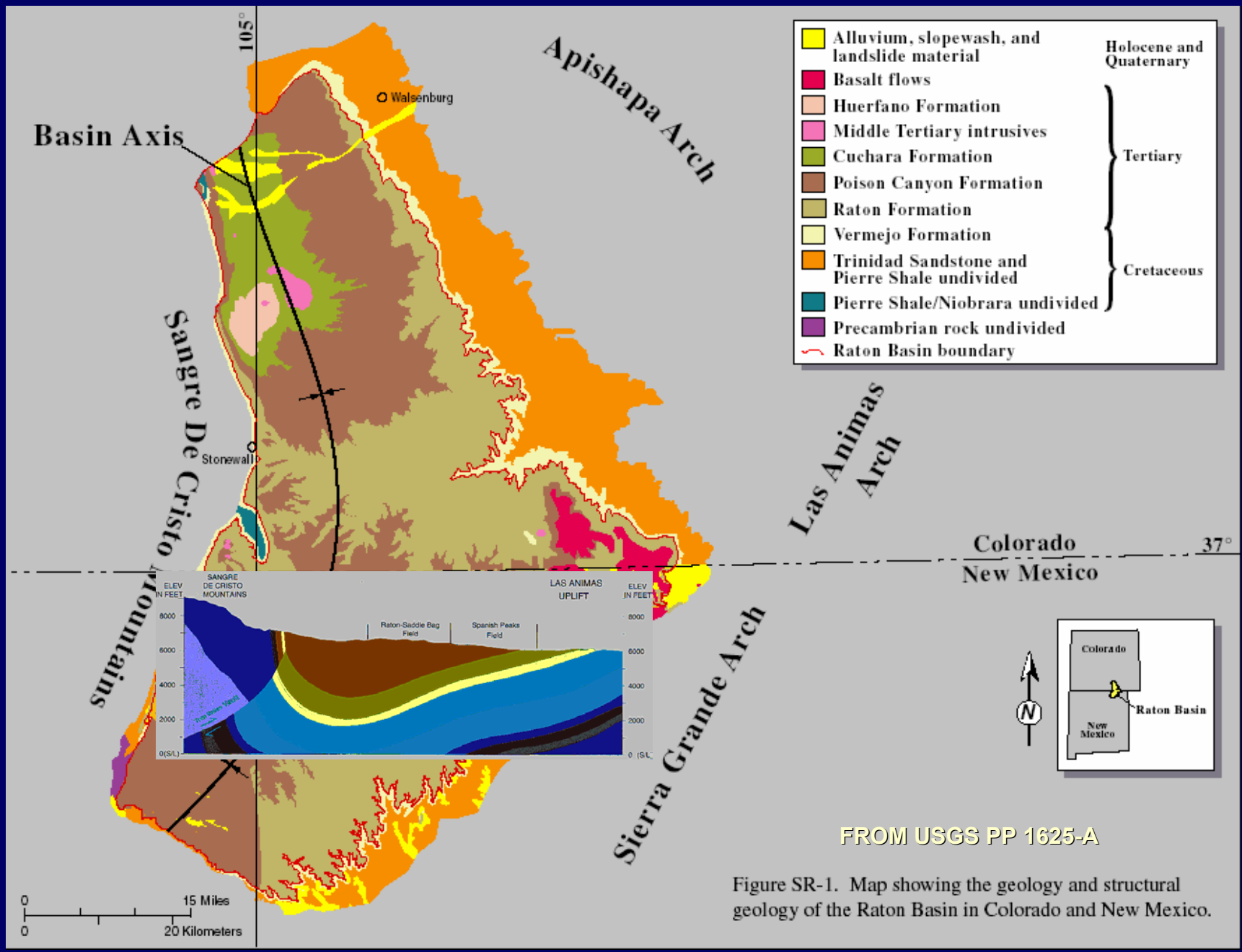
- COGCC Survey

SEEP & GROUNDWATER DATA

- COGCC Survey
  - Seacrest
  - ESN Rocky Mtn.
  - Apogee Scientific
- USGS WSP 2288
- APPLIED ECO.
- CEDAR RIDGE
- AMOCO
- EVERGREEN

OBJECTIVES OF COGCC BASELINE STUDY

- COLLECT, COMPILE, AND ANALYZE A VARIETY OF ENVIRONMENTAL BASELINE INFORMATION
- MAKE DATA AVAILABLE TO STAFF, INDUSTRY & PUBLIC
- DESCRIBE USEFUL METHODS FOR ADDRESSING COMPLAINTS RELATED TO GROUNDWATER ISSUES
- RECOMMEND PROTOCOLS FOR FUTURE MONITORING, SAMPLING, AND ANALYSIS

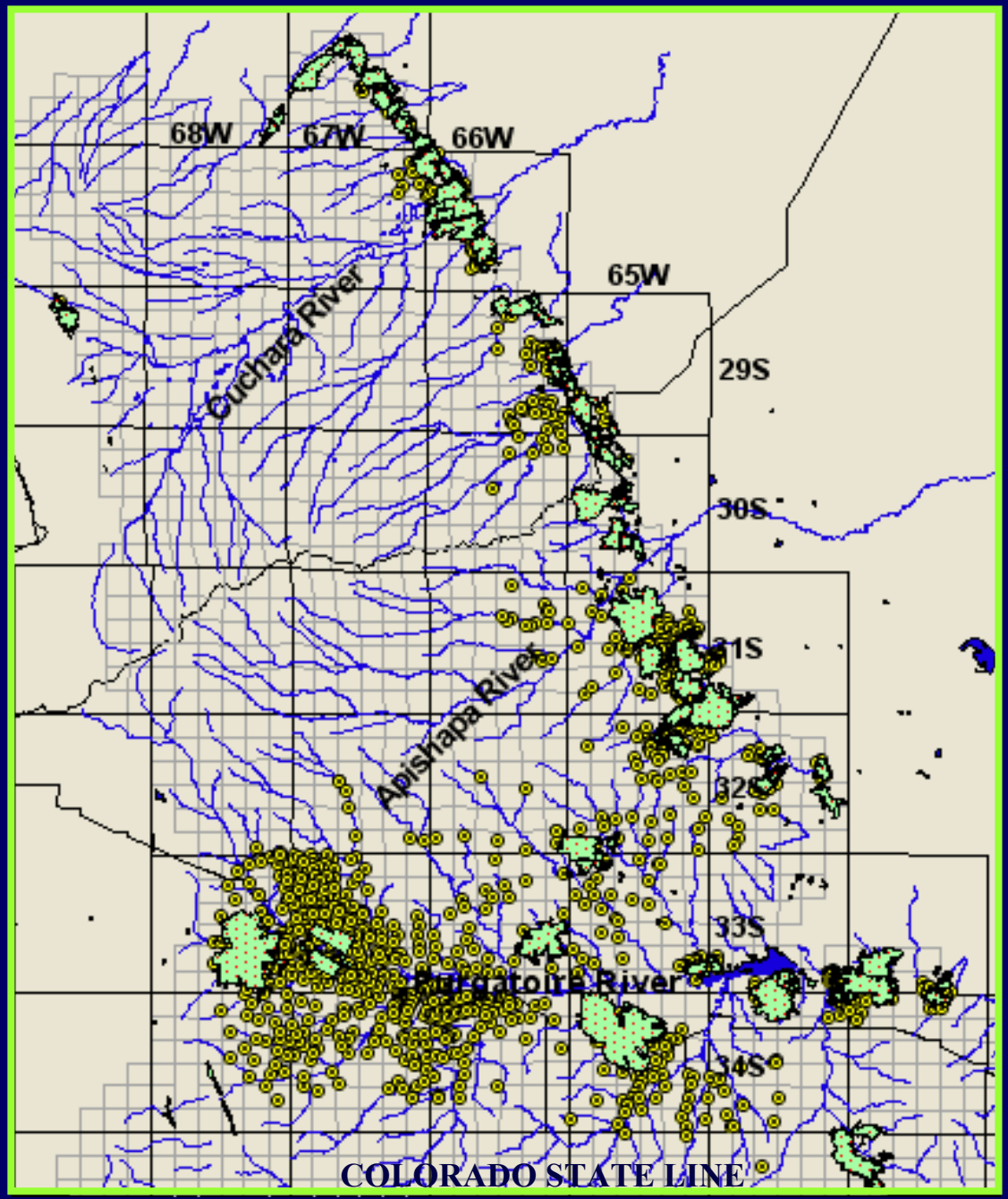


FROM USGS PP 1625-A

Figure SR-1. Map showing the geology and structural geology of the Raton Basin in Colorado and New Mexico.

COAL MINE INVENTORY DIGITIZED: Lewicki & Associates

- 465 MINES IDENTIFIED
- 328 MINE BOUNDARIES DIGITIZED
- MINE PORTALS AND OTHER FEATURES THAT MAY EMIT METHANE DIGITIZED
- LOCATION OF 1411 CORE HOLES DIGITIZED

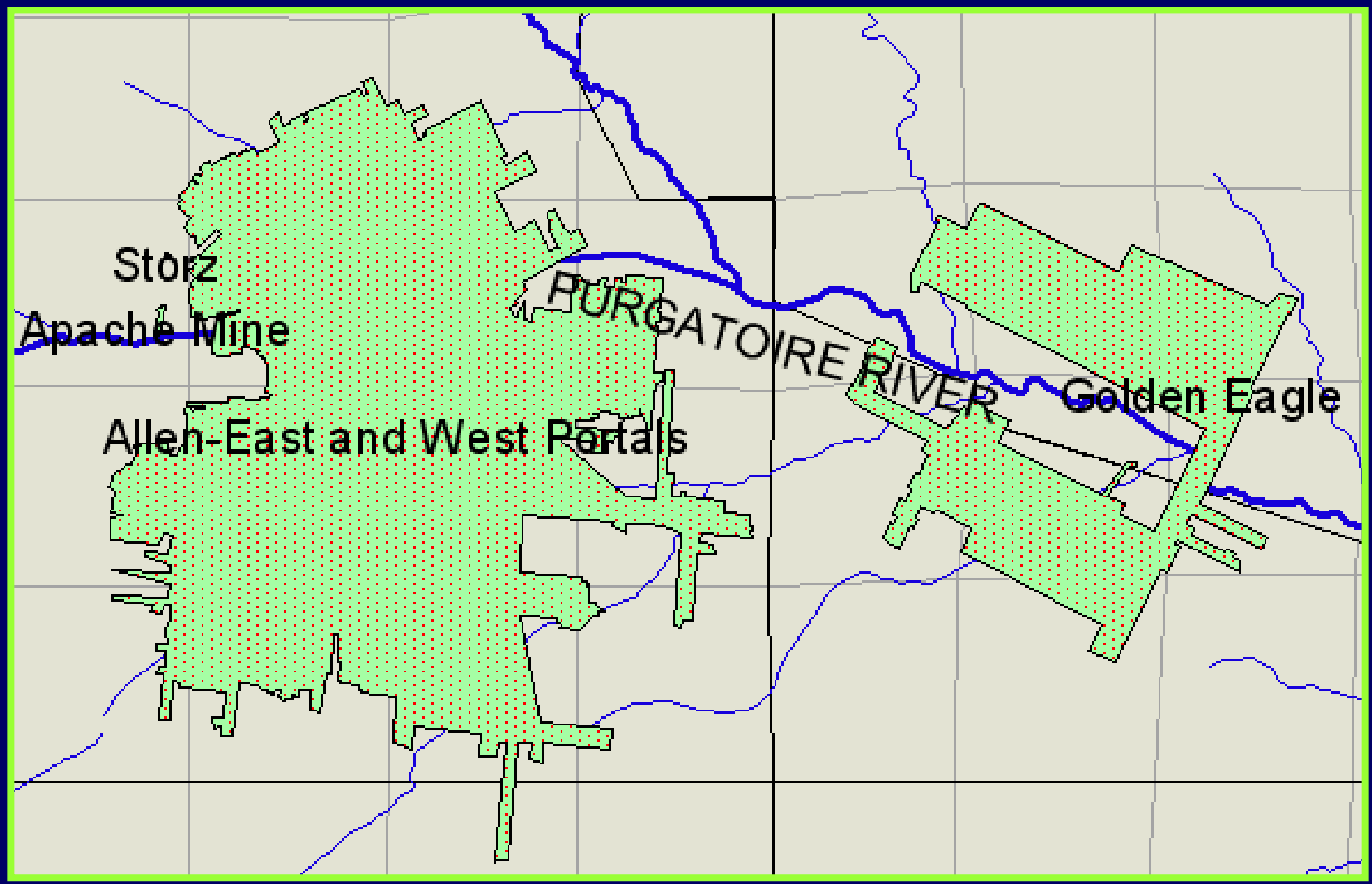


DISTRIBUTION OF DIGITIZED FEATURES

Digitized Mines

Digitized Core Holes

EXAMPLE DEGREE OF DETAIL DIGITIZED



METHANE SEEPS & DISSOLVED METHANE

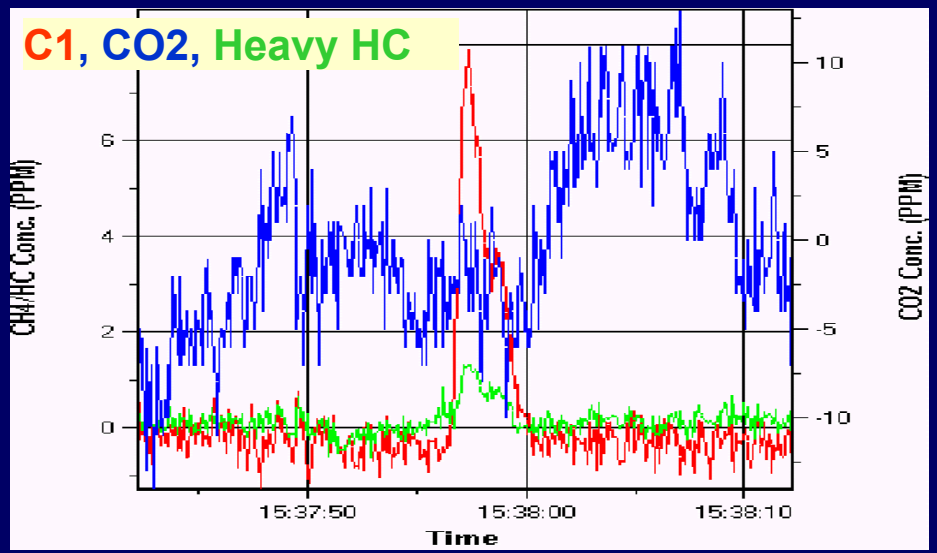
DOCUMENTING BASELINE CONDITIONS

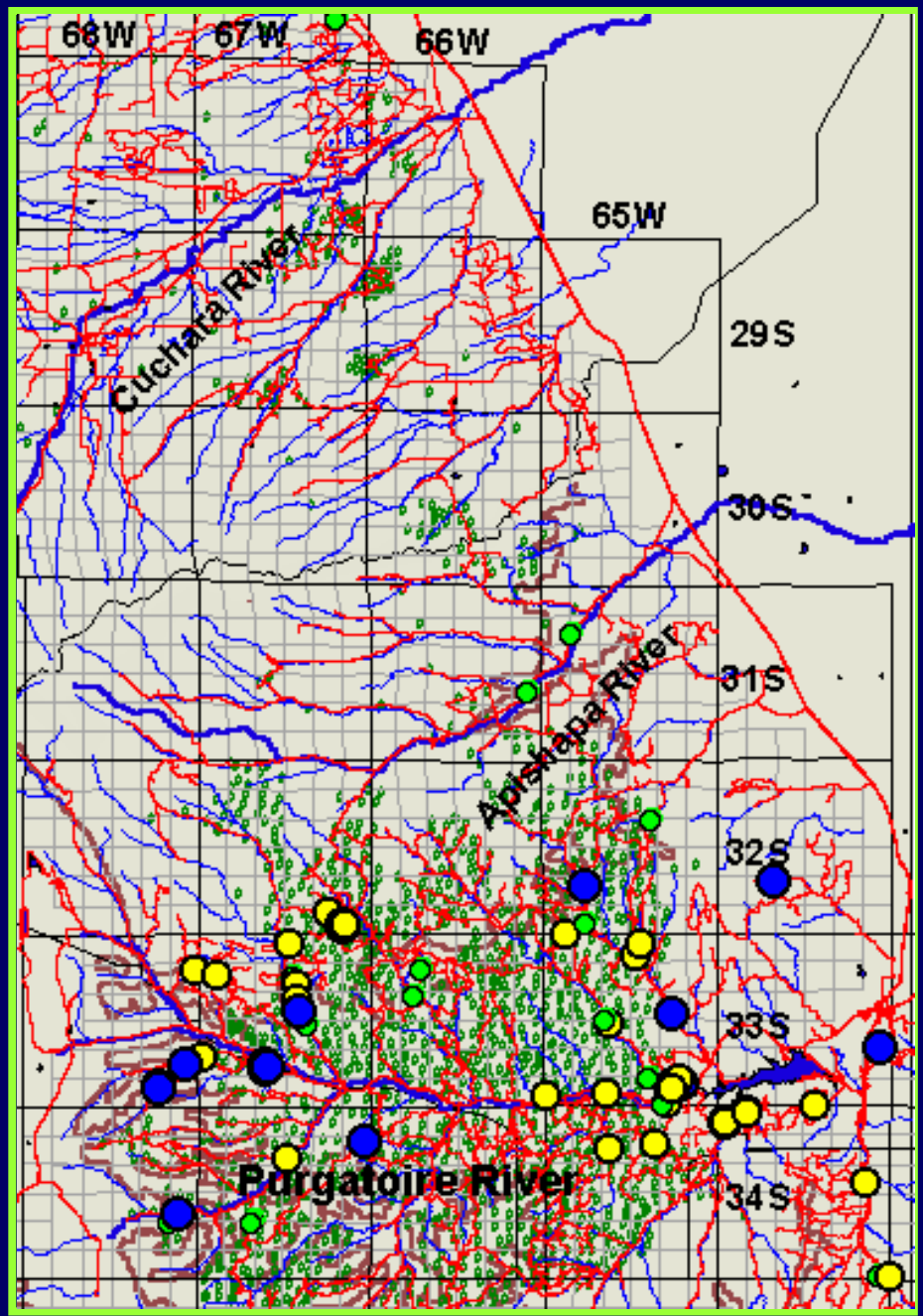
APOGEE SCIENTIFIC

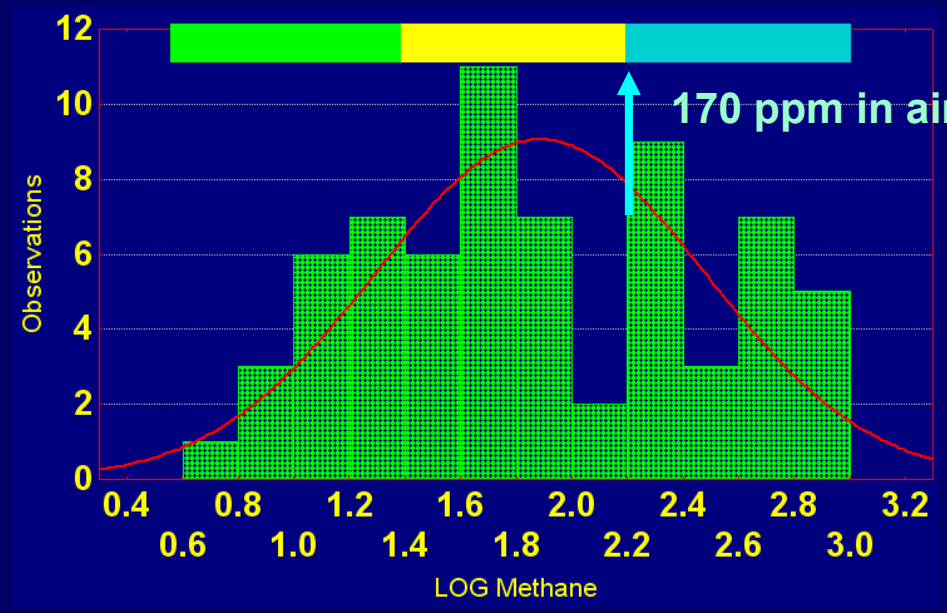
- METHOD USED FOR DETECTING SEEPS
- SEEP DISTRIBUTION AND MAGNITUDE
- RECOMMENDATIONS FOR ADDITIONAL SURVEYS
- DISTRIBUTION OF DISSOLVED METHANE
- USEFUL METHOD FOR IDENTIFYING METHANE SOURCES

METHANE SEEPS QUANTIFIED

APOGEE SCIENTIFIC GAS SEEP DATA ACQUISITION EQUIPMENT





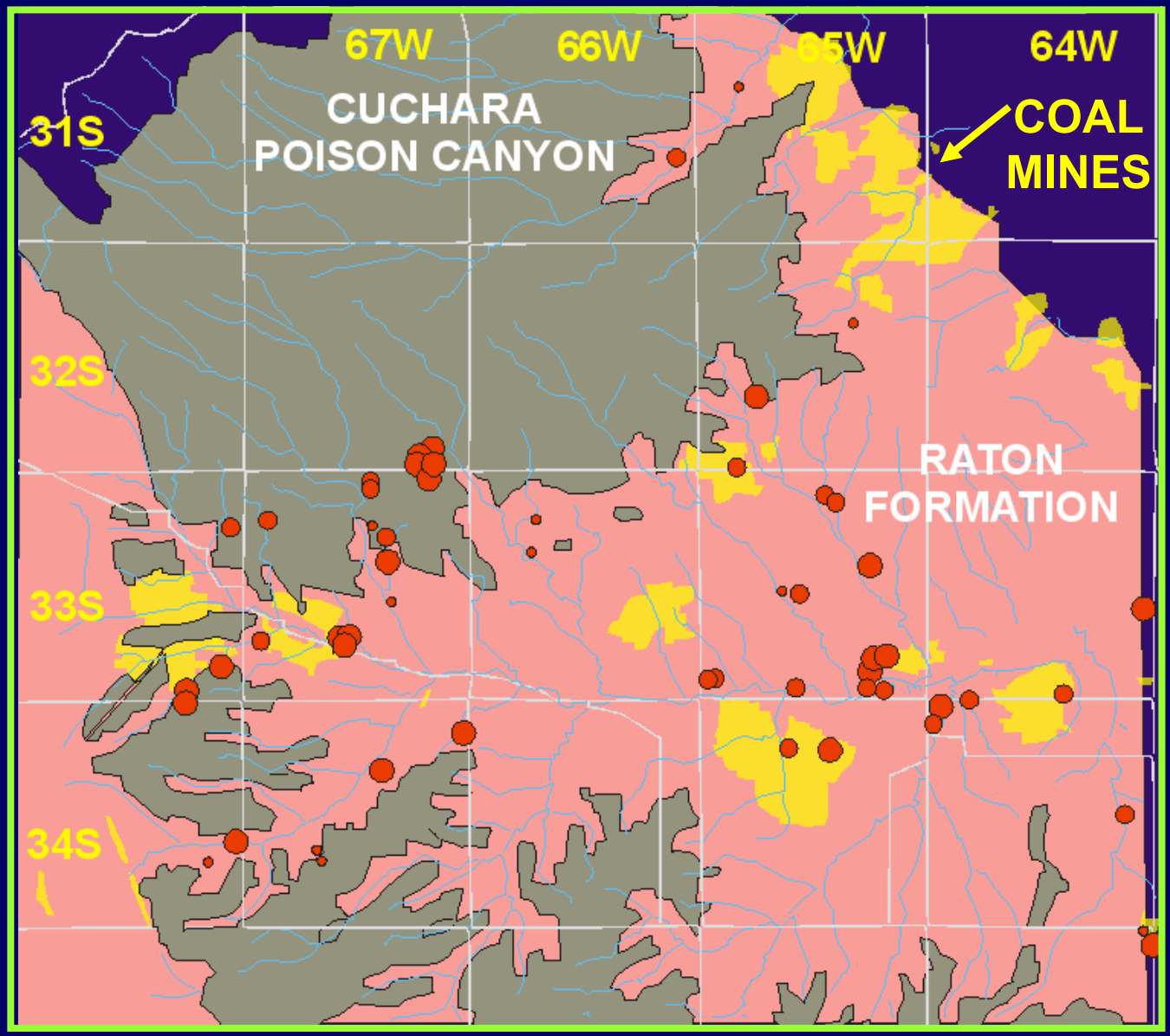


2,749 LINE MILES SURVEYED (Red Lines):

67 SEEPS DETECTED- MOST IN AN AREA AROUND THE PURGATOIRE RIVER

Log Seep Magnitude
- 0.778 - 1.505
- 1.505 - 2.232
- 2.232 - 2.959

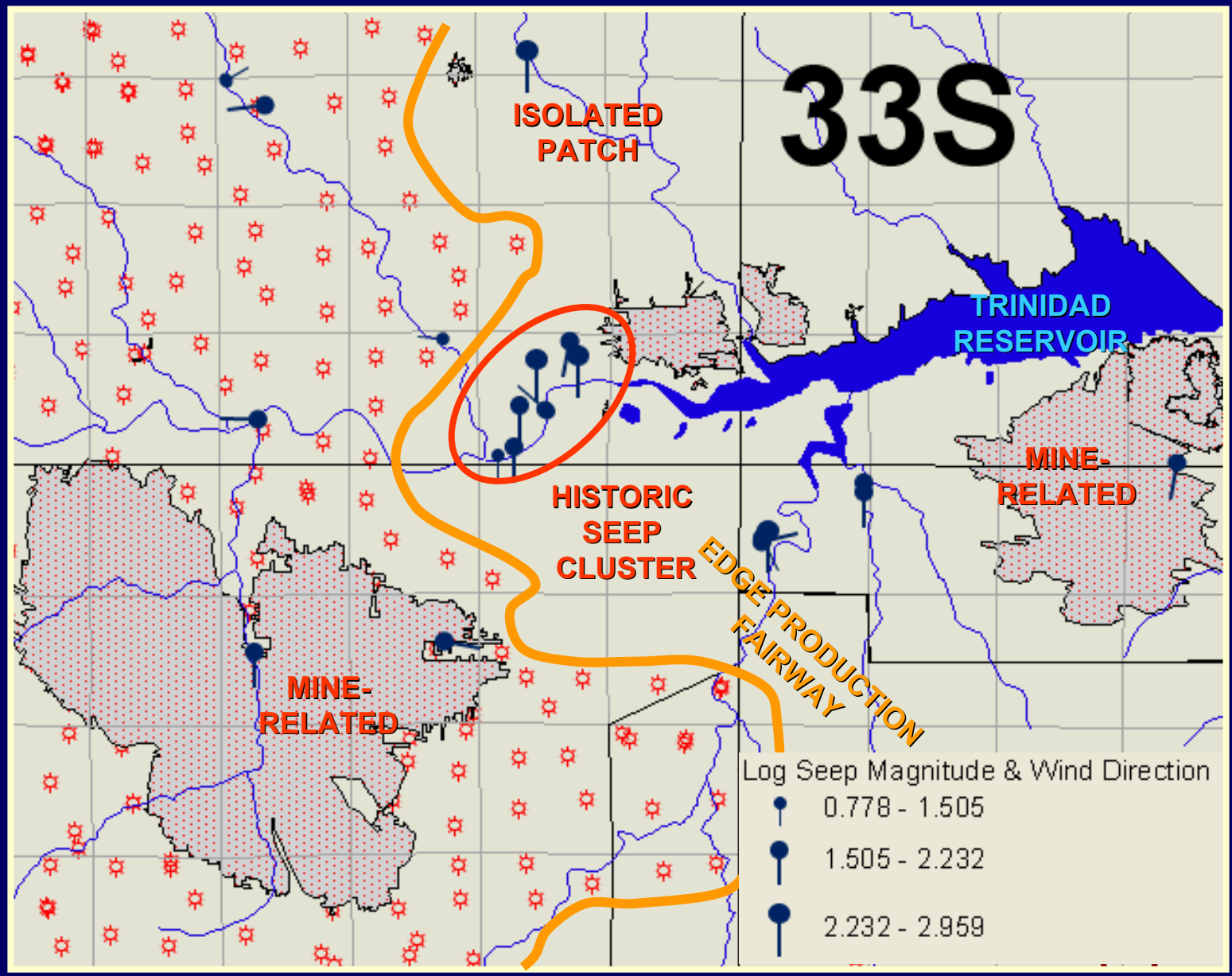
SEEPS OCCUR WITHIN AND AROUND THE OUTCROP LIMITS OF THE COAL-BEARING RATON FORMATION



- FORMATION CONTACT
- UNDER ALLUVIUM
- IN STREAM VALLEYS

SEEPS ASSOCIATED WITH COAL SEAM OUTCROPS

SEEPS OCCUR IN ISOLATED PATCHES, CLUSTERS, & IN ASSOCIATION WITH MINING FEATURES



SEEPS RELATED TO MINES

SUMMARY OF SEEP CHARACTERISTICS

ANTHROPOGENIC ORIGIN

- Mine-related features
- Water wells
- Pipeline right-of-ways
- Other utility Infrastructures
- Gas production?

NATURAL ORIGIN

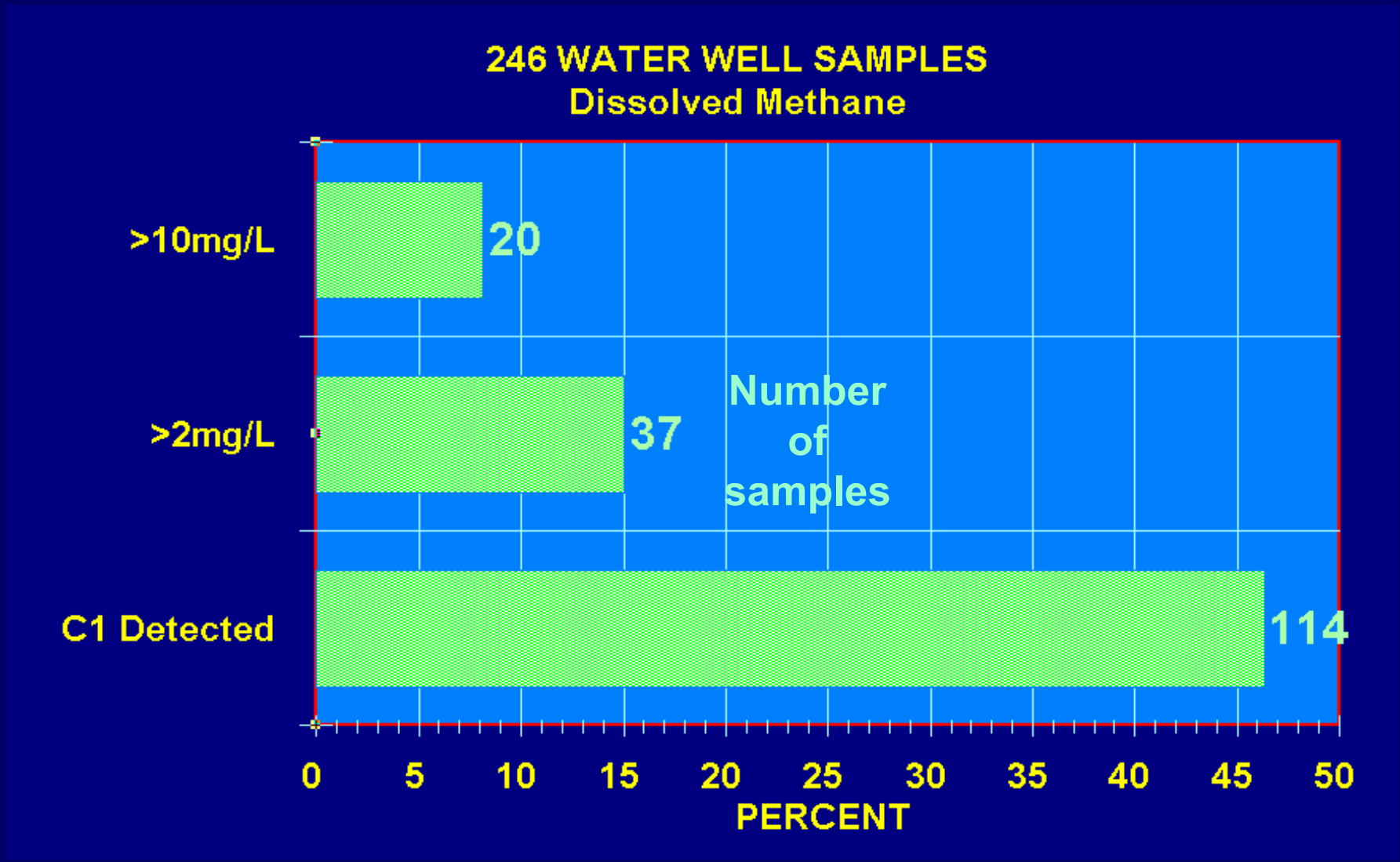
- Within outcrop trace of coal-bearing formation
- Formation contacts
- Dominant in NW & NE-trending linear stream valley traces
- Outcrop buried under shallow alluvial fill
- Historic

IRS IS A GOOD SCREENING TOOL

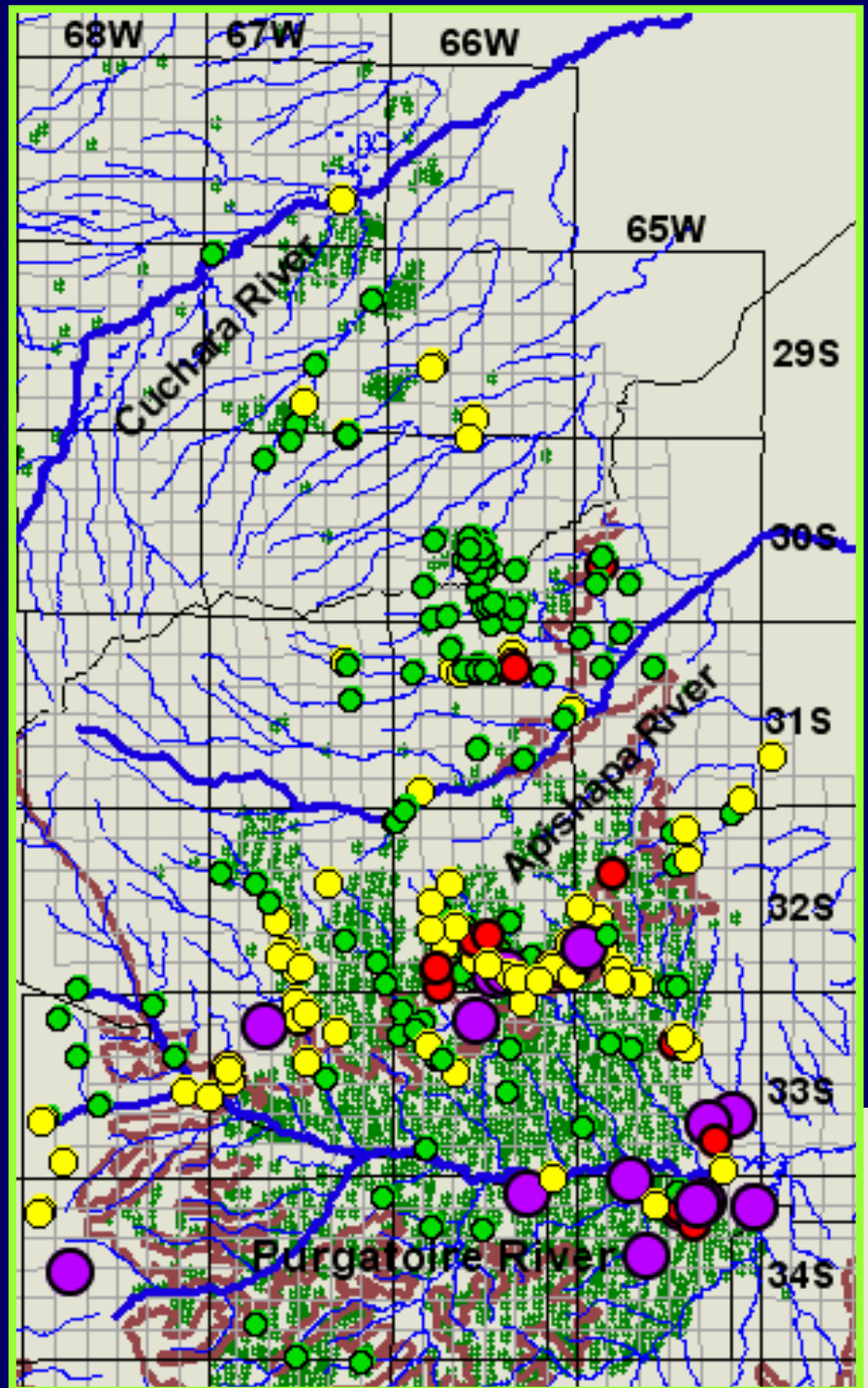
COVER A LOT OF AREA IN SHORT TIME

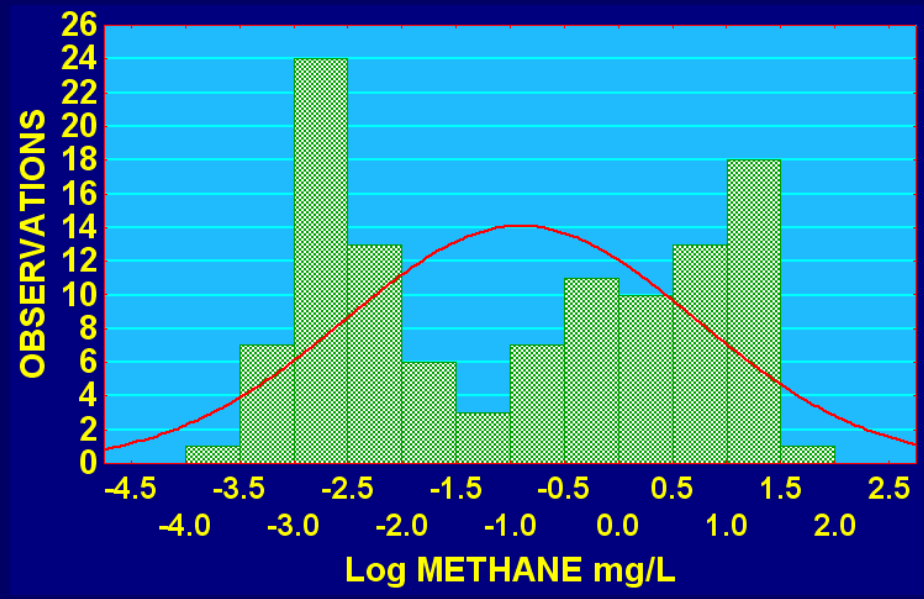
- **RECOMMENDATIONS**
  - FOLLOW UP VAN-BASED SCREENING SURVEY WITH WALKING SURVEY USING PORTABLE FID WHERE NEEDED
  - LOCATE AND ACCURATELY DESCRIBE SOURCE CHARACTERISTICS OF SELECTED SITES
  - SAMPLE GAS FROM LARGER SEEPS FOR LABORATORY ANALYSIS & COMPARE TO PRODUCTION WHERE NEEDED
  - DETERMINE NEED FOR LONG TERM SOIL GAS FLUX MONITORING

DISSOLVED METHANE IN GROUNDWATER QUANTIFIED



LARGE DISSOLVED METHANE OCCURRENCES DISTRIBUTED LIKE SEEPS ALONG CUCHARA-RATON CONTACT & WITHING RATON FM OUCTROP

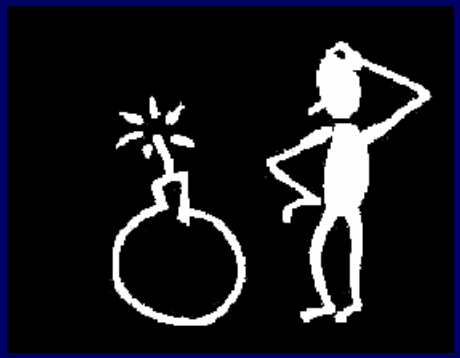




Dissolved Methane
- Not Detected
- Up to 2 mg/L
- 2-10 mg/L
- 10 - 38 mg/L

Producing Wells

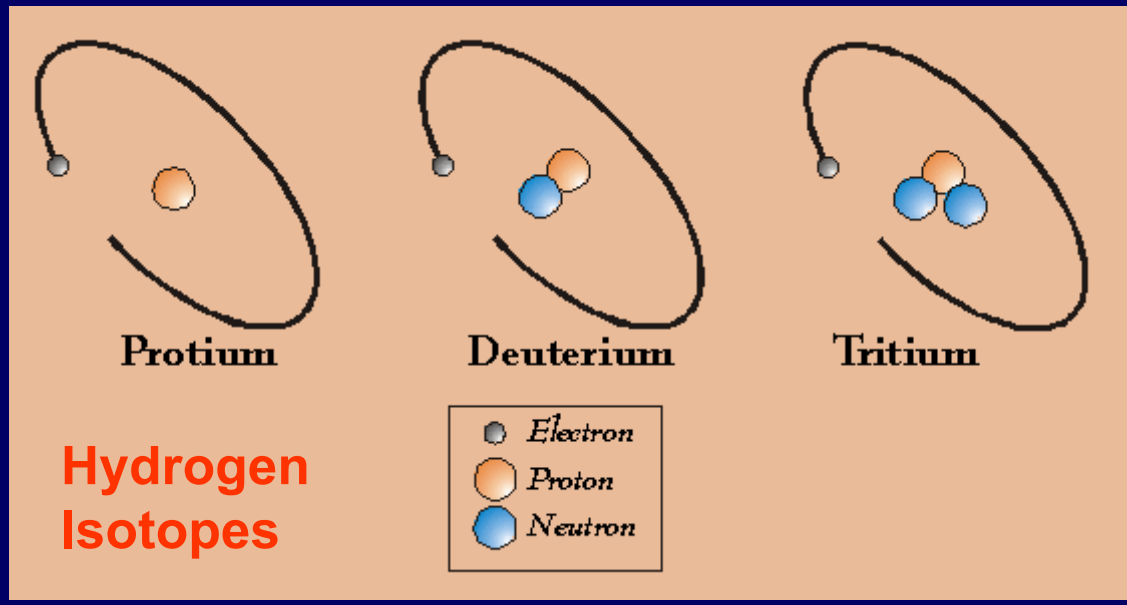
Cuchara -Poison Canyon contact



WHAT IS A STABLE ISOTOPE?

STABLE ISOTOPES ARE USEFUL TOOLS USED TO DETERMINE THE ORIGIN OF FLUIDS AND GASES.

Many elements can exist in different forms known as isotopes. They differ in the number of neutrons in the nucleus but do not differ in the number of protons. Stable isotopes are not radioactive.

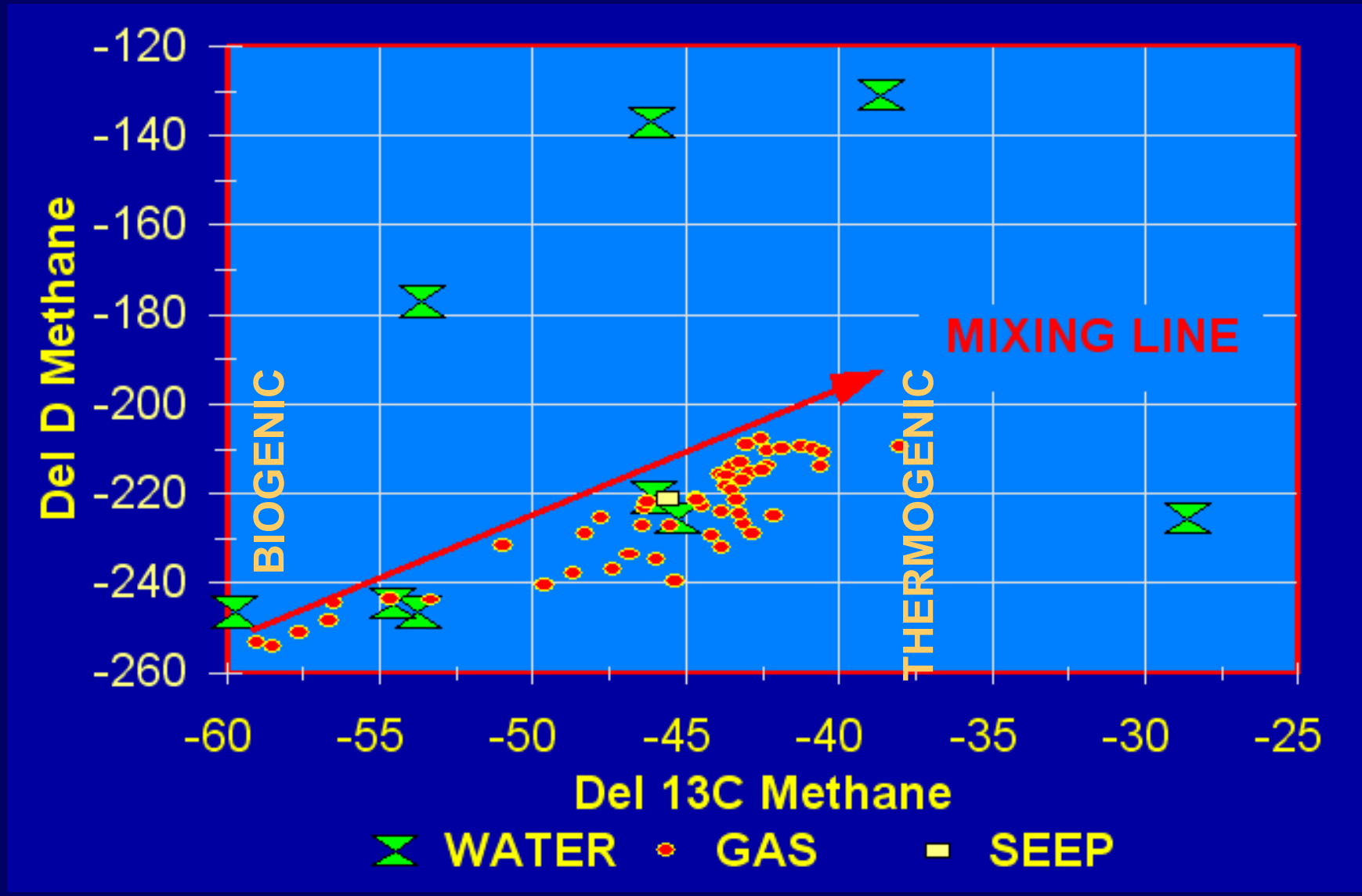


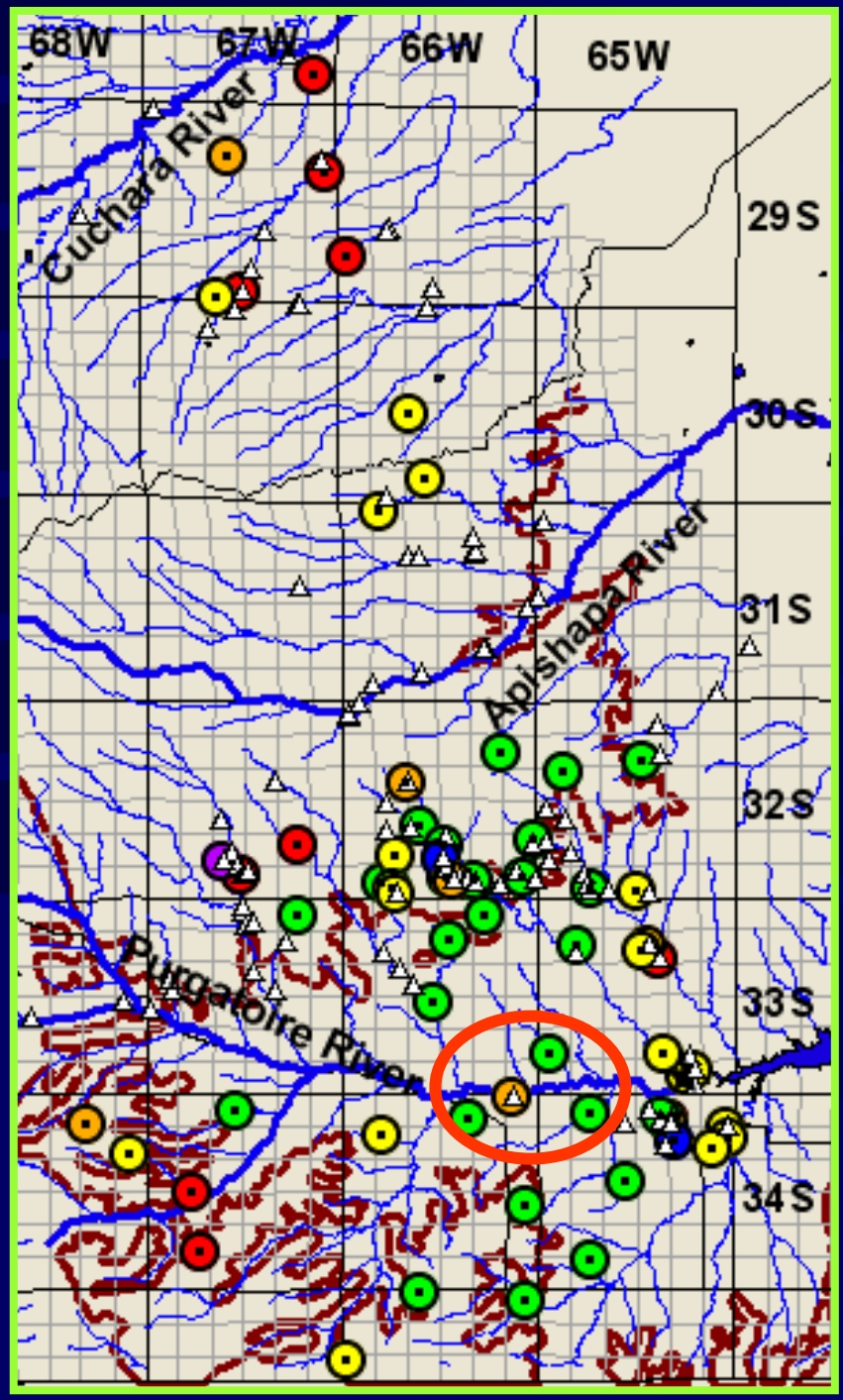
Hydrogen Isotopes

Carbon Isotopes:

Isotope	Protons	Neutrons	Abundance	Type
^{12}C	6	6	98.98%	Stable
^{13}C	6	7	1.11%	Stable
^{14}C	6	8	trace	Unstable

LARGE RANGE IN STABLE C AND H ISOTOPES IN PRODUCED METHANE IS DIAGNOSTIC OF MIXED BIOGENIC AND THERMOGENIC SOURCES





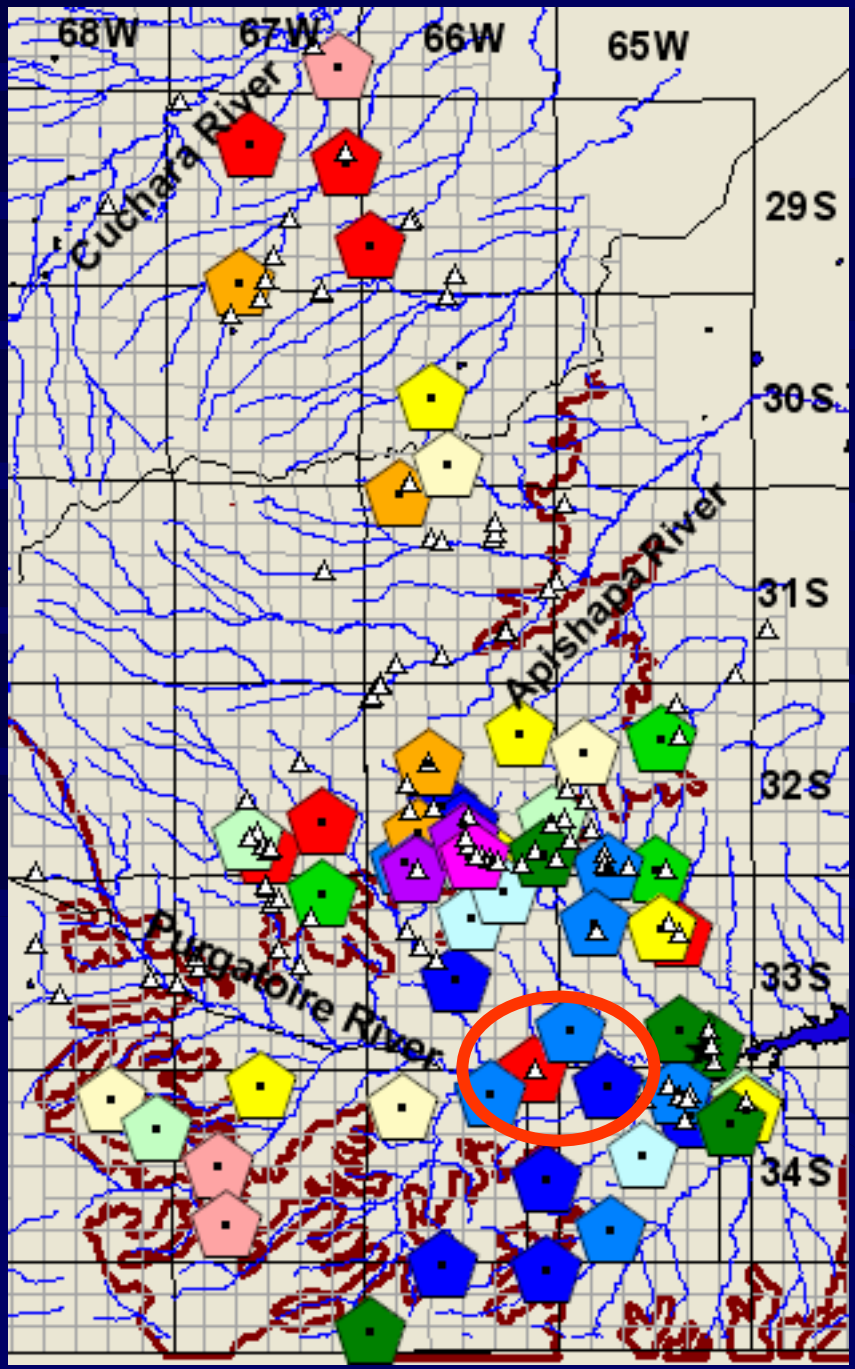
DISTRIBUTION OF STABLE CARBON ISOTOPES IN METHANE AMONG ALL SAMPLES (Del ^{13}C CH_4)

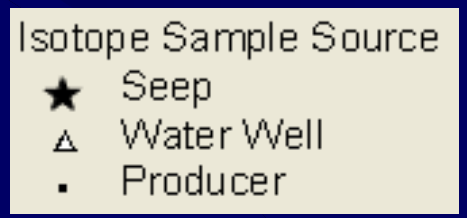
SPATIAL VARIABILITY SUFFICIENT FOR DIAGNOSTIC ANALYSIS

Del 13 Methane
- -62 - -55
- -55 - -50
- -50 - -45
- -45 - -40
- -40 - -35
- -35 - -29

Isotope Sample Source
- Seep
- Water Well
- Producing Well

Cuchara -Poison Canyon contact

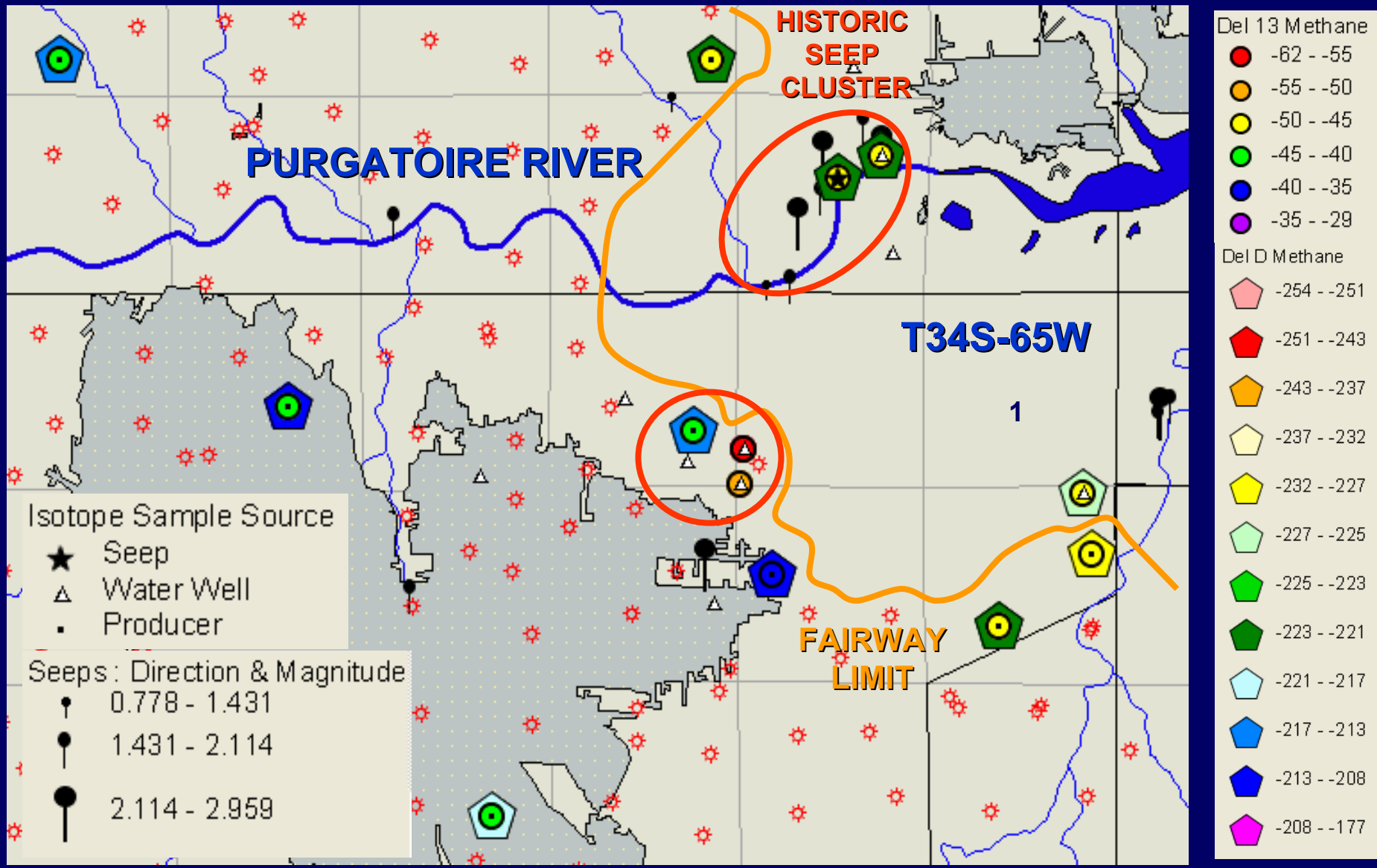




DISTRIBUTION OF DEUTERIUM IN METHANE AMONG ALL SAMPLES (Delta D CH_4)

SPATIAL VARIABILITY SUFFICIENT FOR DIAGNOSTIC ANALYSIS

COMBINED, STABLE ISOTOPES OF METHANE PROVIDE EXCELLENT FORENSIC TOOL

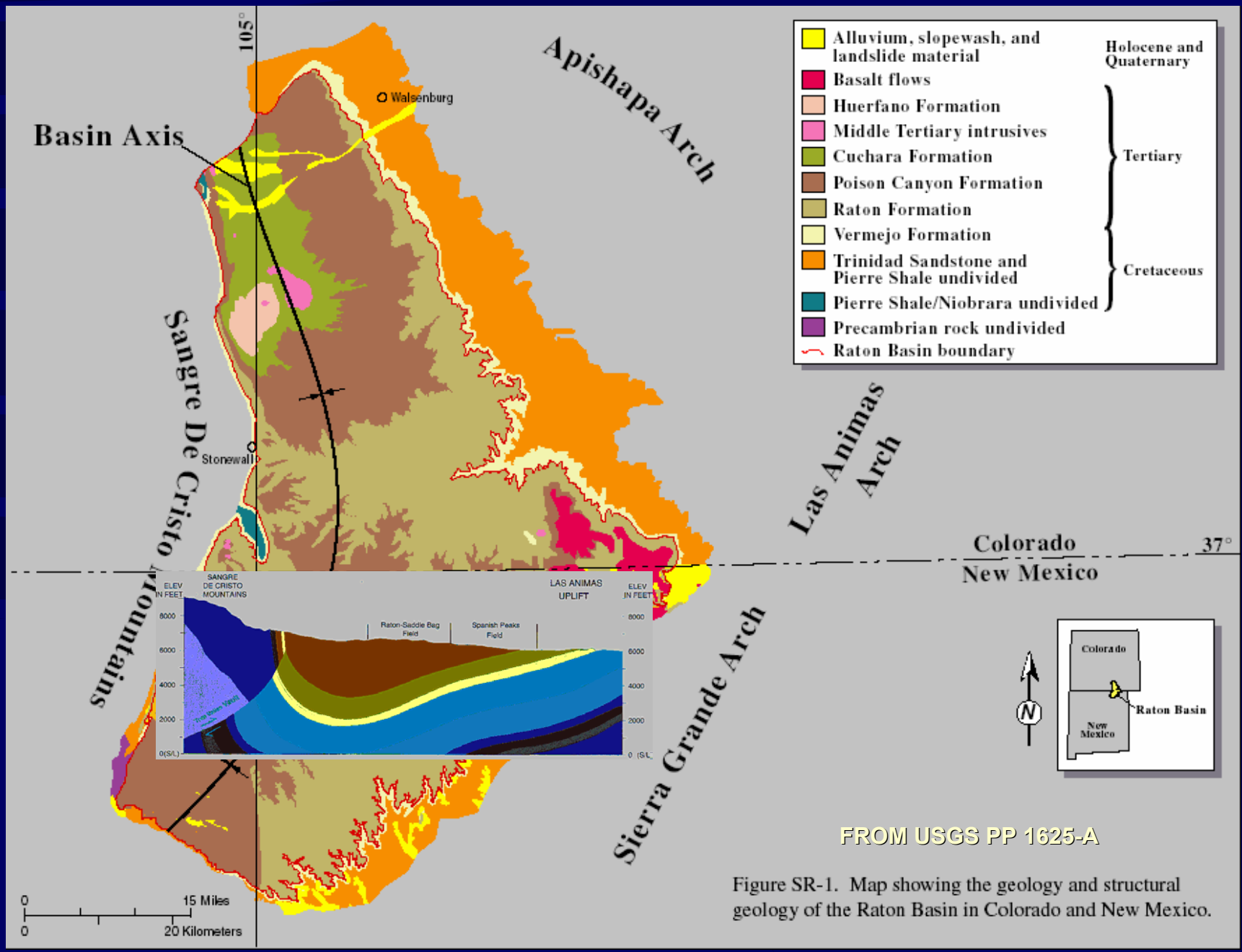


SUMMARY DISSOLVED METHANE

- DISSOLVED METHANE OCCURS WITHIN OUTCROP BOUNDARY OF RATON FORMATION
- REGULAR MEASURMENT OF DISSOLVED METHANE IN WATER WELLS IS RECOMMENDED AS A SAFETY PRECAUTION
- STABLE ISOTOPES USEFUL FOR DETERMINING METHANE SOURCE AND FOR COMPARISON WITH GAS FROM PRODUCING WELLS

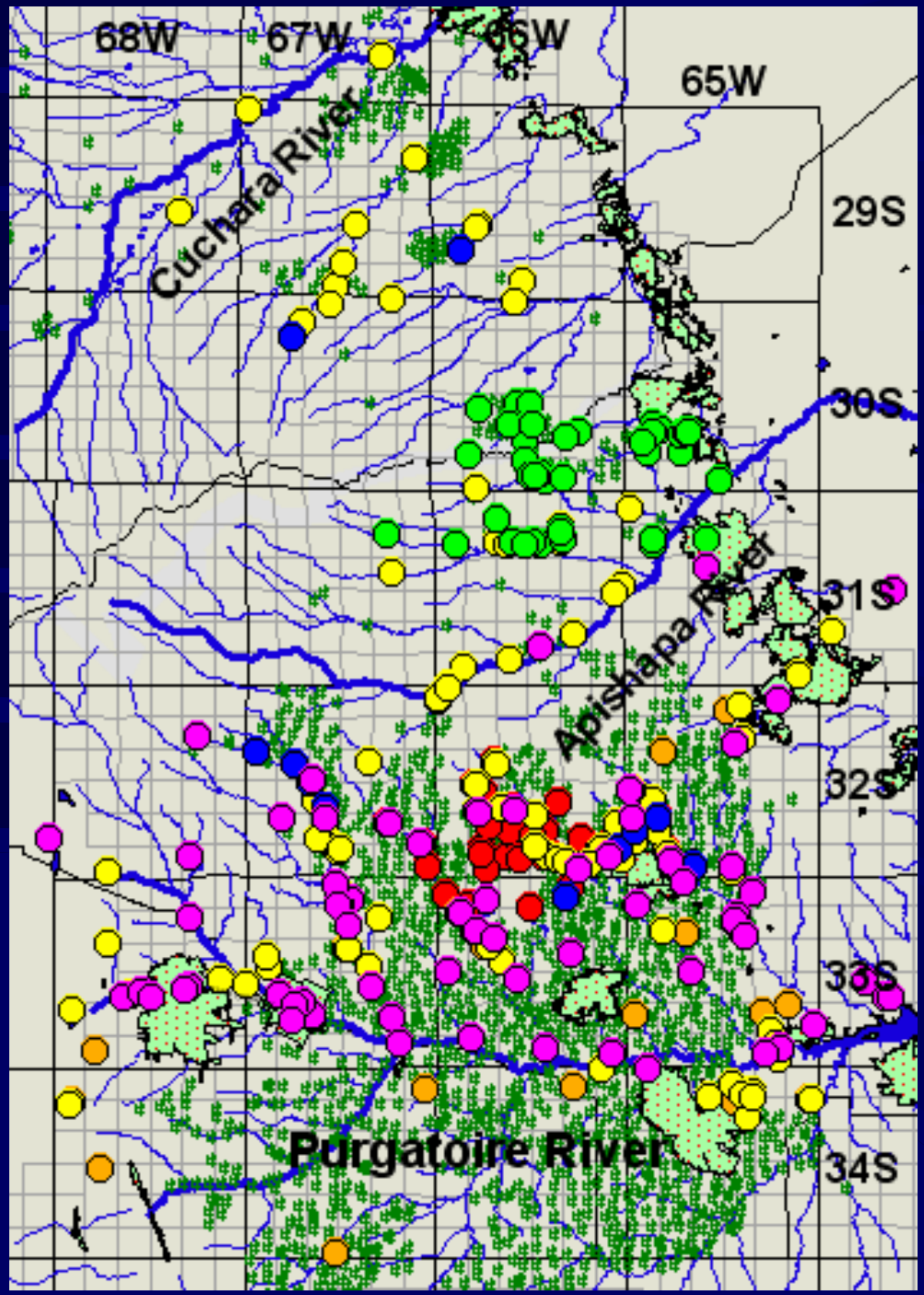
EVALUATING THE POTENTIAL FOR AQUIFER DRAWDOWN IN RESPONSE TO COALBED GAS OPERATIONS

- APPROACH
  - CHARACTERIZE WATER QUALITY



FROM USGS PP 1625-A

Figure SR-1. Map showing the geology and structural geology of the Raton Basin in Colorado and New Mexico.

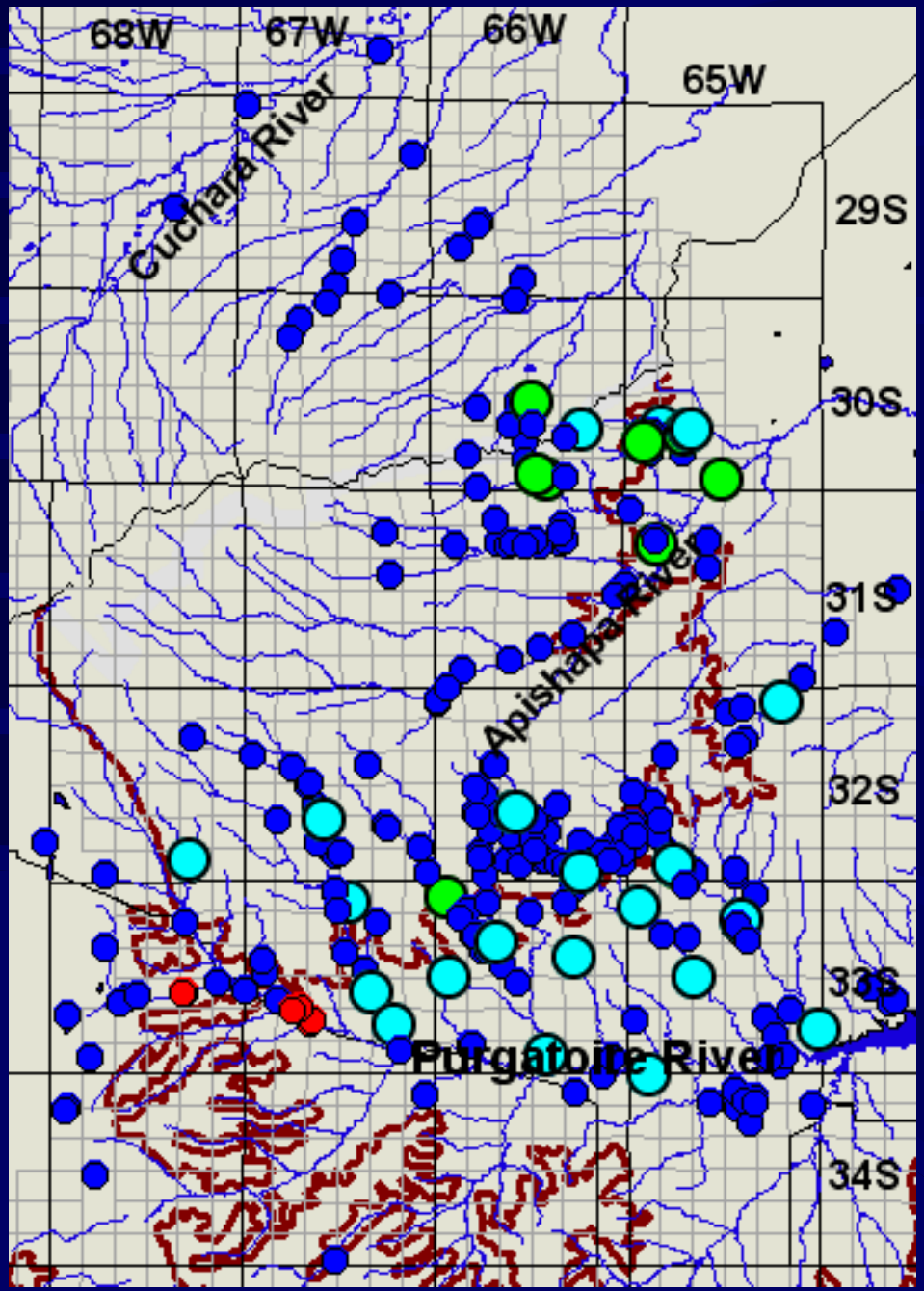


GOOD COVERAGE OF SHALLOW GROUNDWATER IN PRODUCING AREA

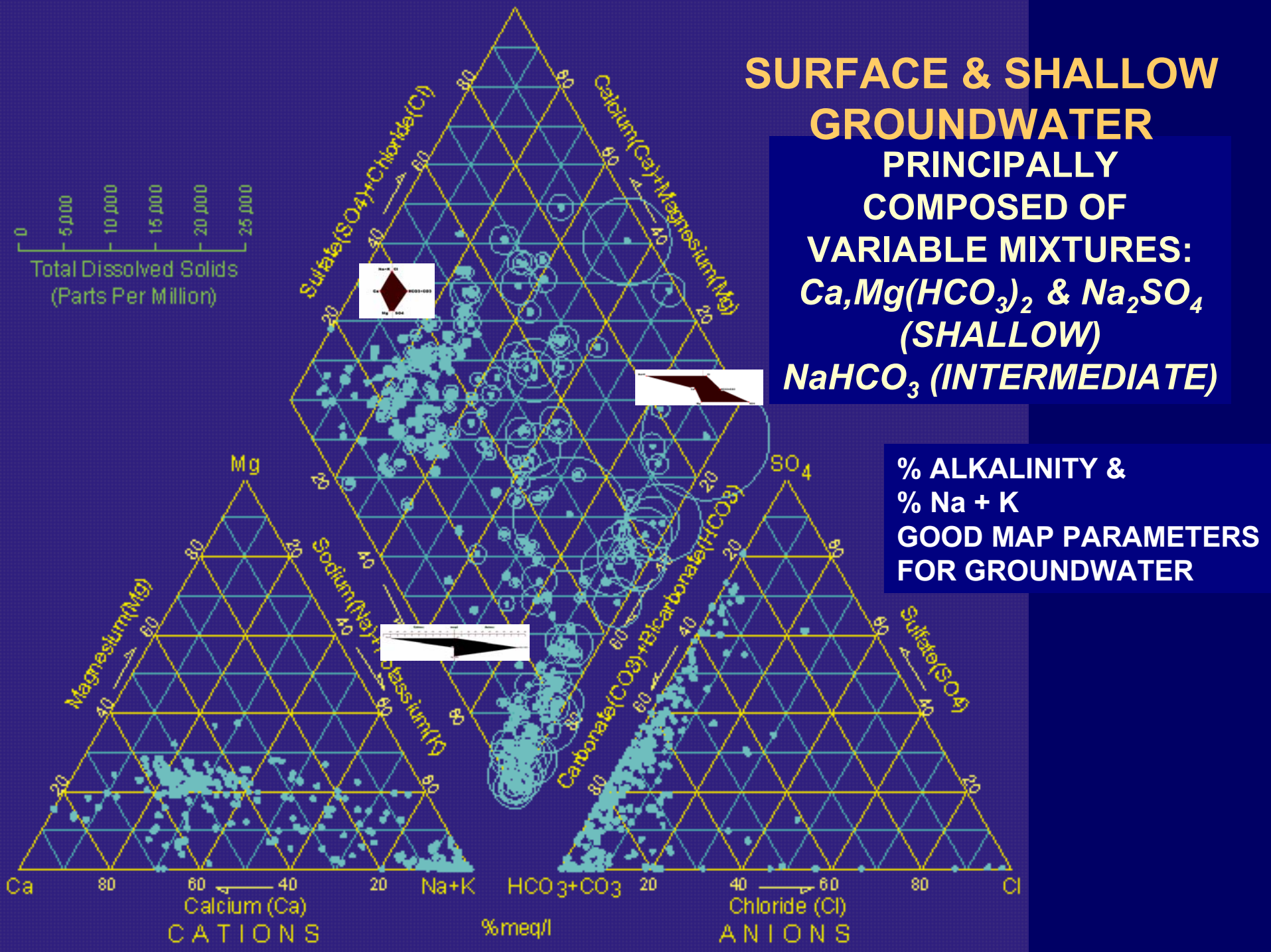
300 SAMPLES FROM 266 SITES MEET CHARGE BALANCE REQUIREMENTS OF +/-10%

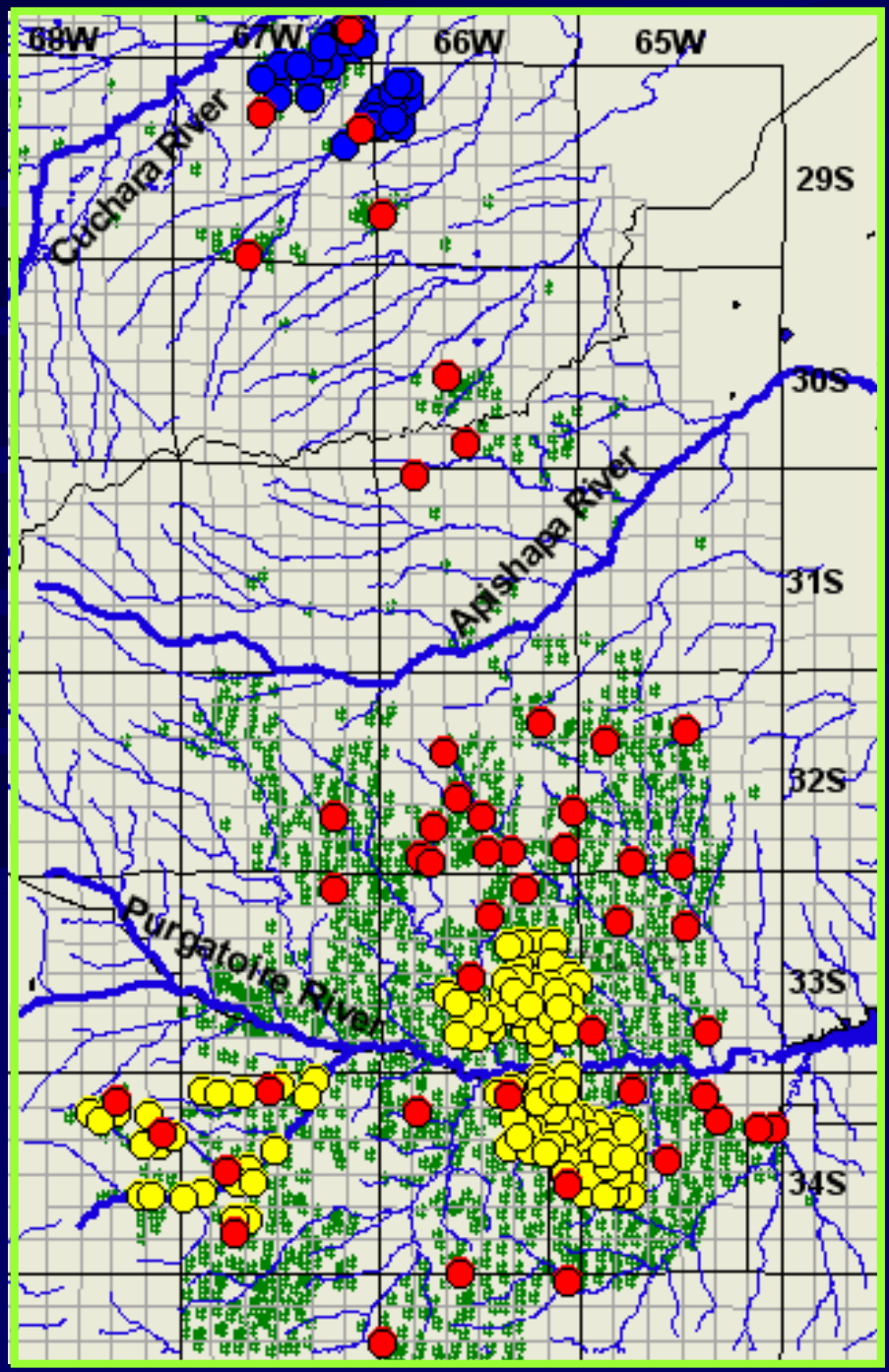
Producing Wells

Groundwater Data Sources
- Amoco
- Applied Eco
- COGCC
- Cedar Ridge
- Evergreen
- USGS



SAMPLES COLLECTED FROM A VARIETY OF SOURCES


SURFACE & SHALLOW GROUNDWATER
PRINCIPALLY COMPOSED OF VARIABLE MIXTURES:
Ca,Mg(HCO3)2 & Na2SO4 (SHALLOW)
NaHCO3 (INTERMEDIATE)
% ALKALINITY &
% Na + K
GOOD MAP PARAMETERS FOR GROUNDWATER
0
5,000
10,000
15,000
20,000
25,000
Total Dissolved Solids
(Parts Per Million)
Sulfate(SO4)+Chloride(Cl)
Calcium(Ca)+Magnesium(Mg)
Sodium(Na)+Potassium(K)
Carbonate(CO3)+Bicarbonate(HCO3)
Mg
SO4
Magnesium(Mg)
Sulfate(SO4)
Ca
Na+K
HCO3+CO3
Cl
Calcium (Ca)
CATIONS
%meq/l
Chloride (Cl)
ANIONS

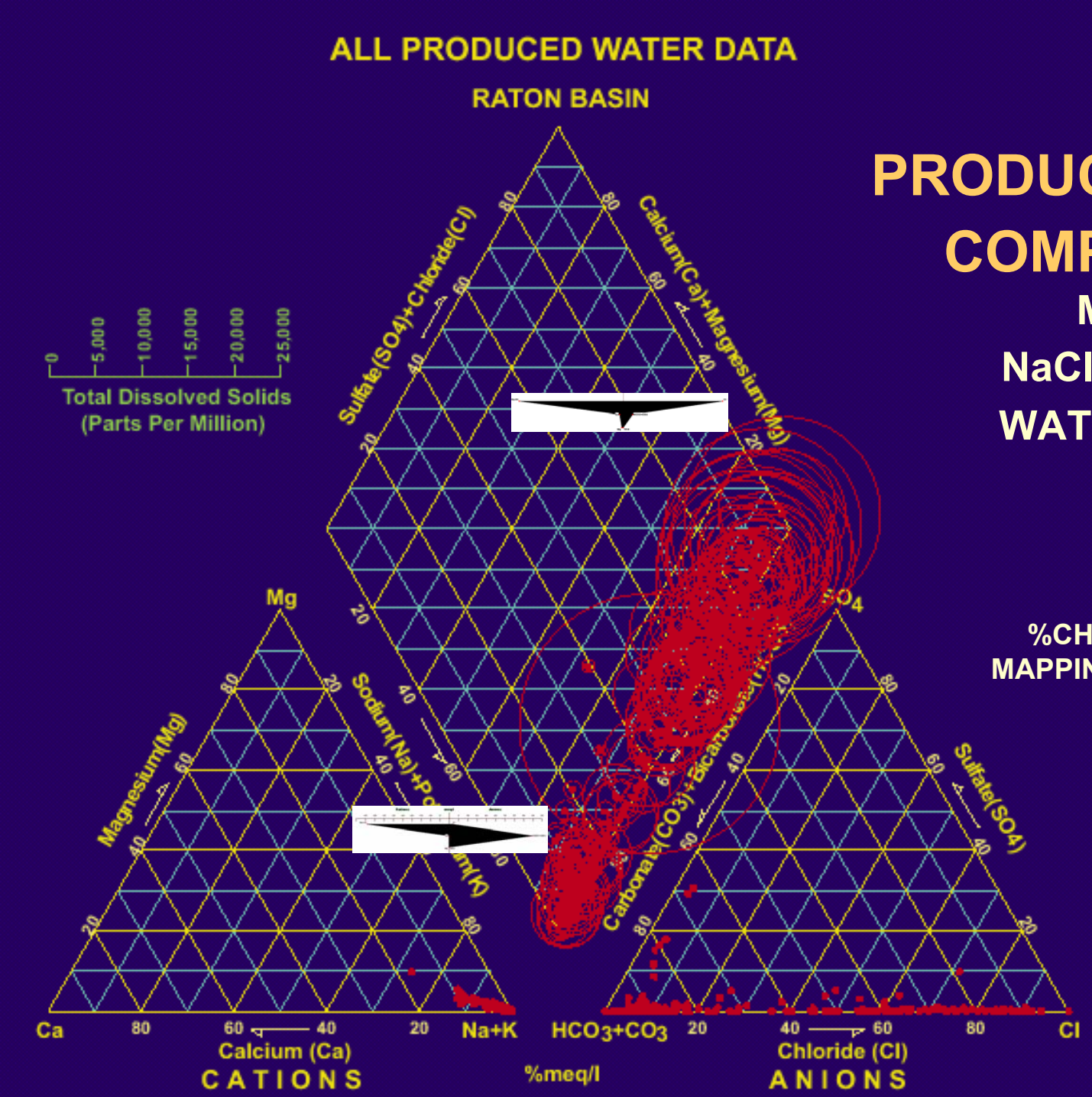


SOURCE AND DISTRIBUTION OF PRODUCING WELLS SAMPLED

- COGCC
- KLT PRODUCTION
- PETROGLYPH

REASONABLY REPRESENTATIVE SAMPLE SET

Producing Wells



PRODUCED WATER COMPOSITION

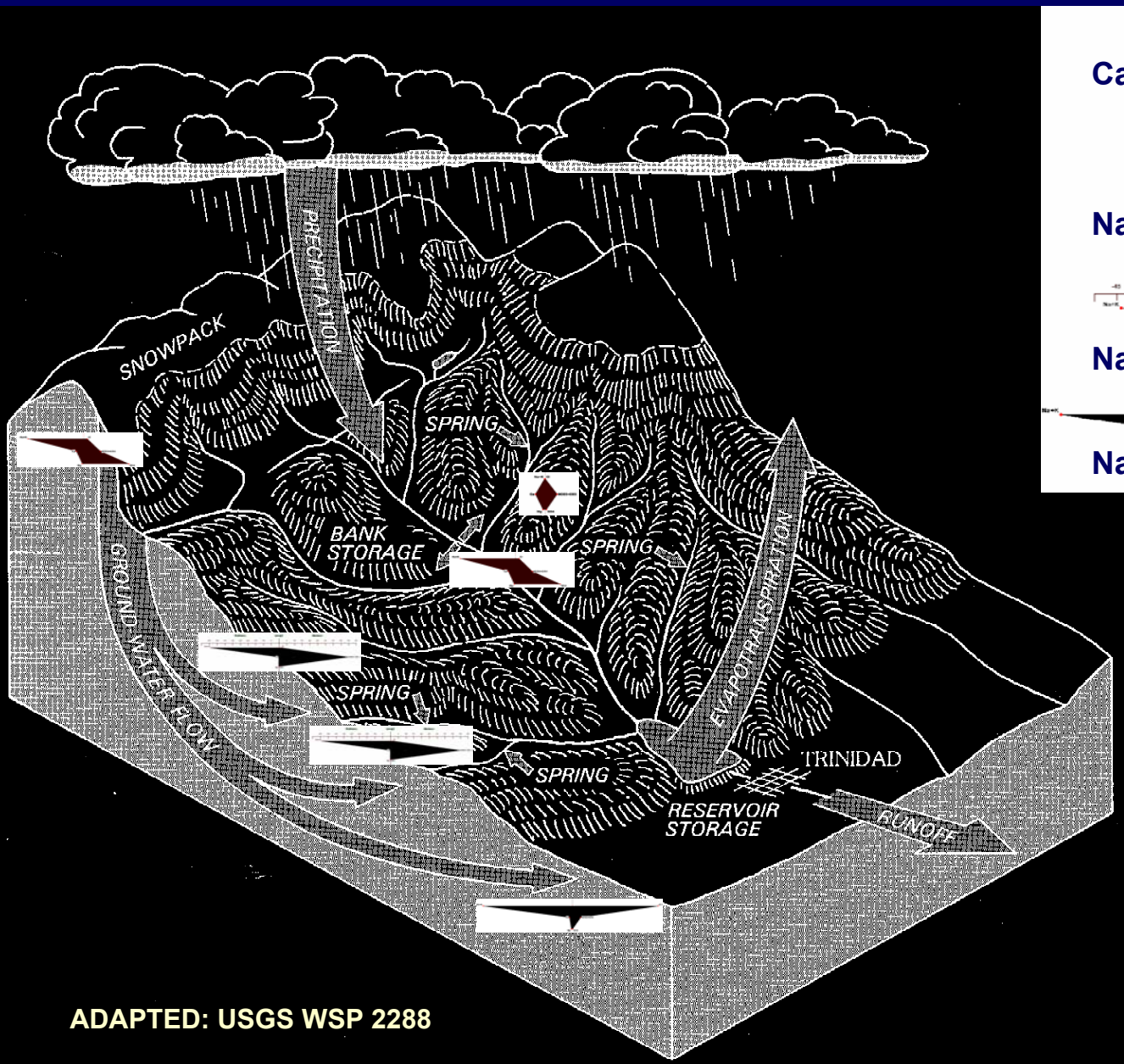
MIXED

$NaCl$ & $NaHCO_3$

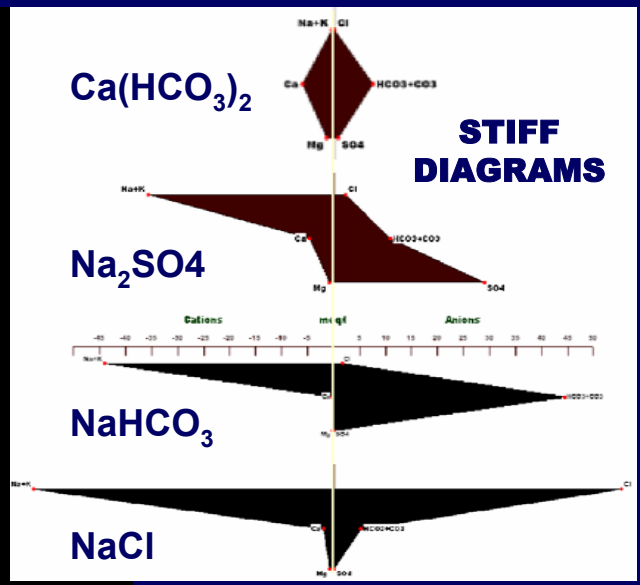
WATER TYPES

%CHLORIDE & TDS
MAPPING PARAMETERS

GENERALIZED HYDROLOGIC CYCLE FOR PURGATOIRE



ADAPTED: USGS WSP 2288



4 MAIN WATER TYPES IN THE BASIN

OCCUR AS MIXTURES

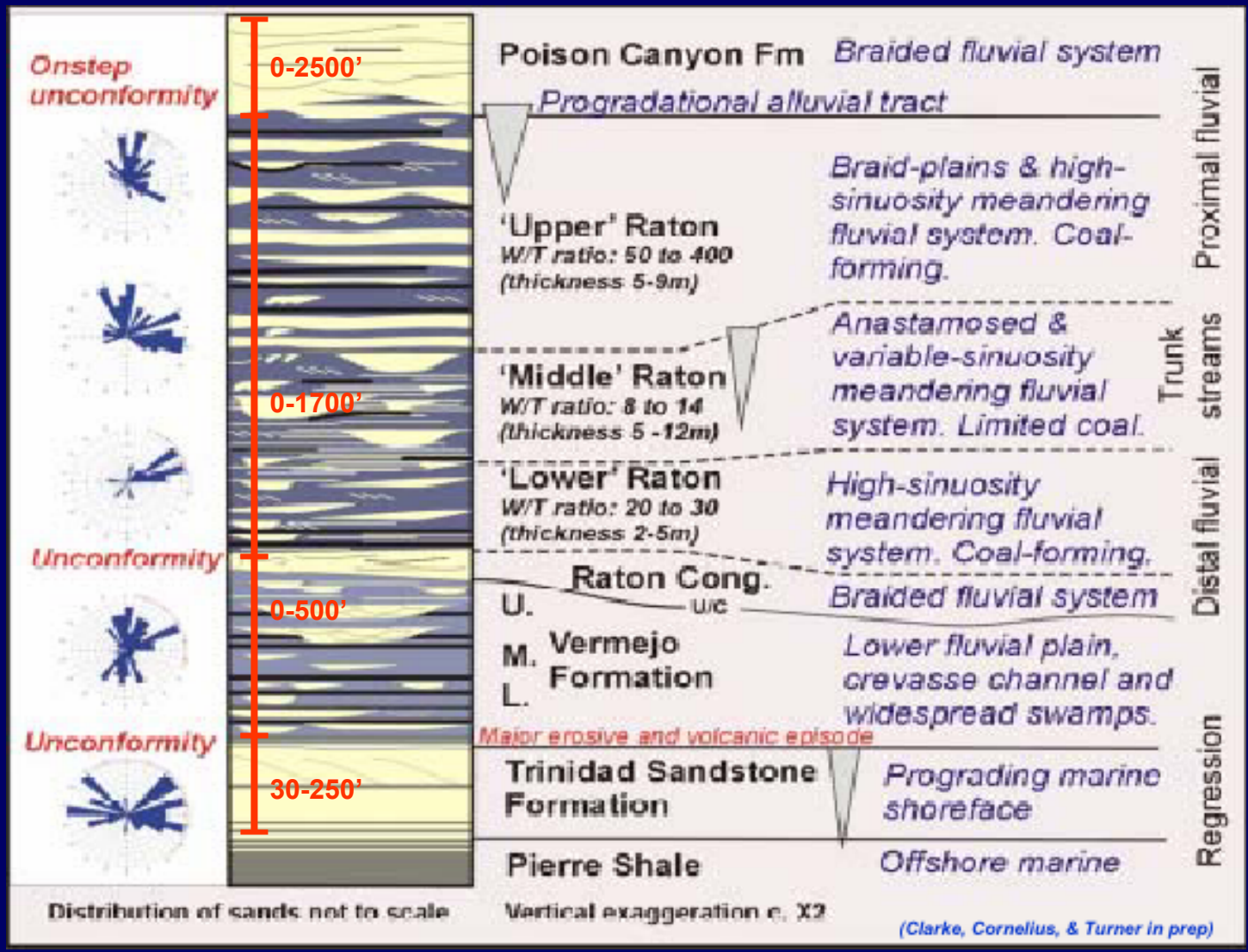
ADDRESSING COMMUNICATION BETWEEN SHALLOW AQUIFERS AND GAS PRODUCING ZONES

- PUBLIC CONCERN THAT PRODUCING WATER FROM COAL IS IMPACTING AVAILABILITY OF WATER FROM SHALLOW AQUIFERS
- NO REGIONAL, SYSTEMATIC MONITORING OF SHALLOW GROUNDWATER LEVELS ESTABLISHED IN THE BASIN
- NEED TO DEVELOP SCREENING METHODS USING AVAILABLE DATA THAT IDENTIFY AREAS WHICH MAY BE AT RISK OF CROSS-AQUIFER COMMUNICATION

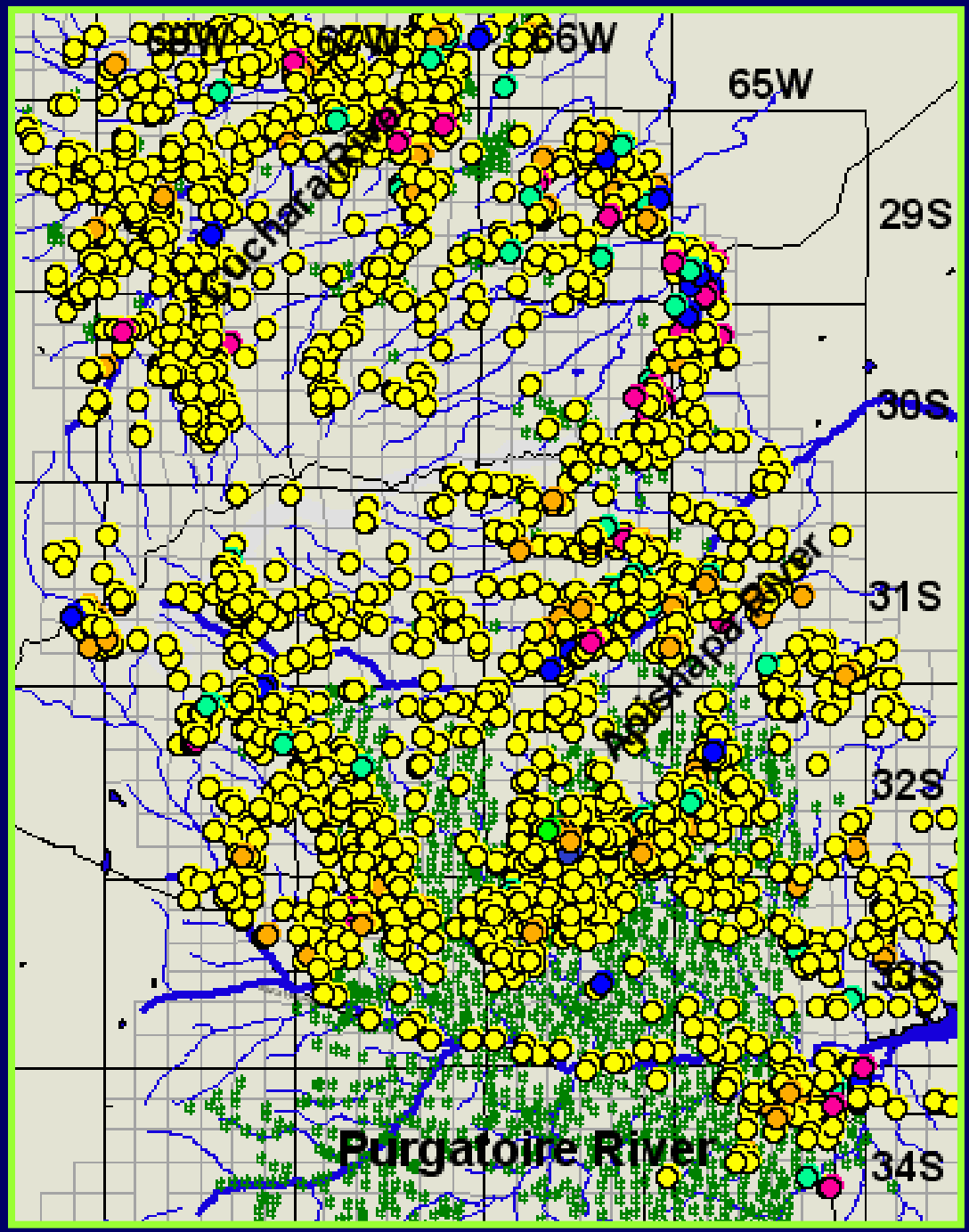
APPROACH FOR IDENTIFYING SCREENING TOOLS

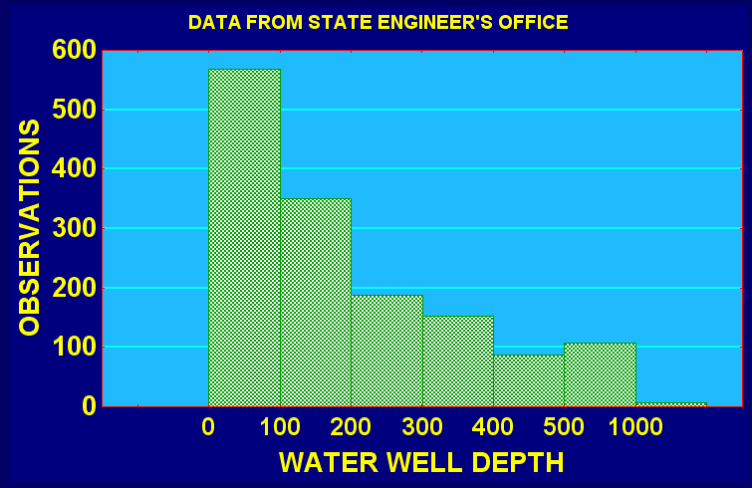
- MAP AREAS WHERE WATER WELLS AND PRODUCING WELL COMPLETIONS ARE IN CLOSE VERTICAL AND LATERAL PROXIMITY
- IDENTIFY DIAGNOSTIC PARAMETERS THAT DIFFERENTIATE SHALLOW GROUNDWATER AND PRODUCED WATER
- MAP DIAGNOSTIC PARAMETERS
  - IDENTIFY HOW THEY VARY ACROSS THE BASIN
  - IDENTY HOW THEY CHANGE WITH TIME
- DETERMINE WHICH PARAMETERS IN PRODUCED WATER MAY INDICATE POSSIBLE CONNECTION WITH SHALLOW AQUIFERS

EXTREME HETEROGENEITY IN SEDIMENTS OF GEOLOGIC COLUMN



From: Cornelius,C., 2002, 4th Unconventional Gas Symposium, Calgary





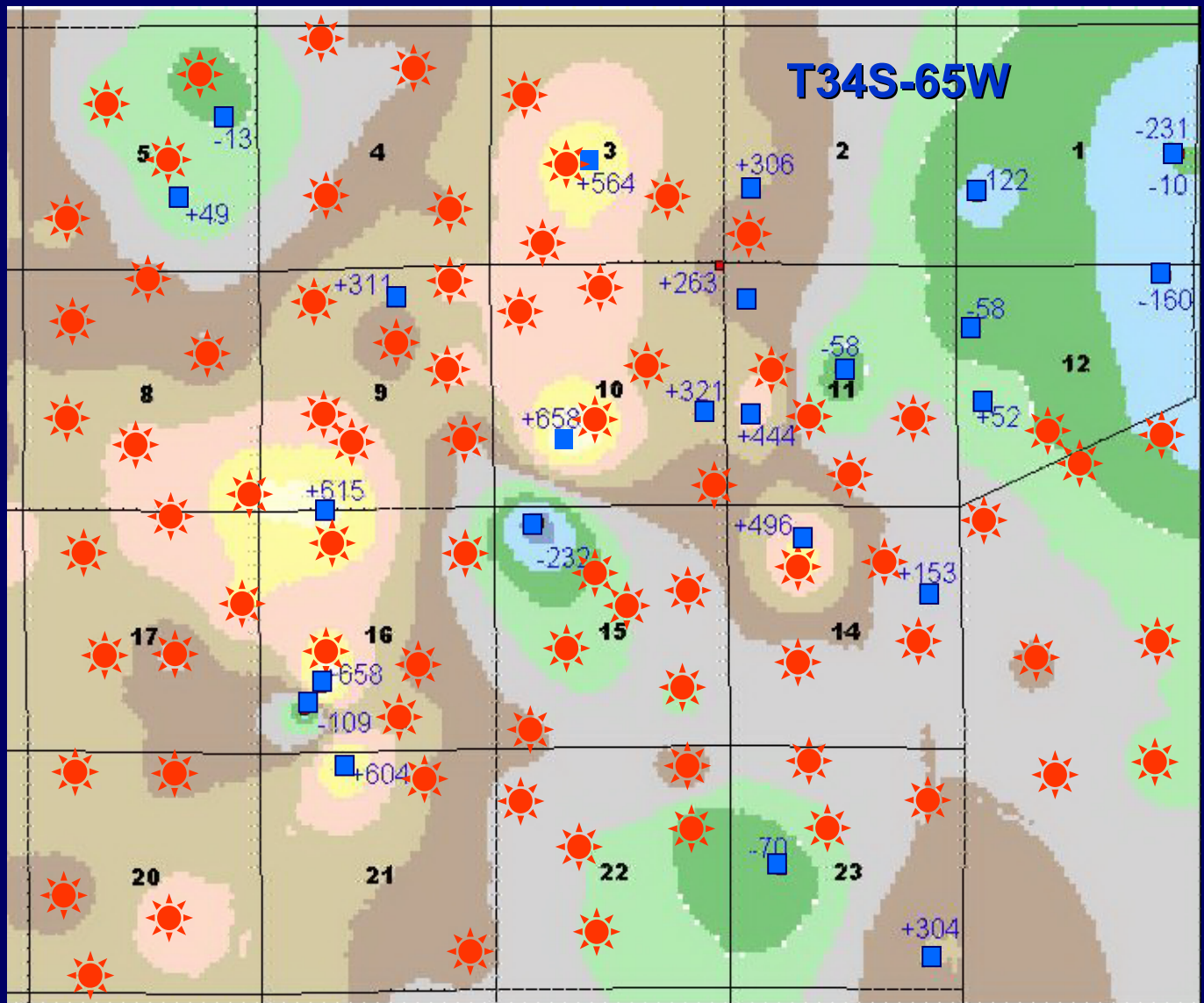
MOST DOMESTIC WATER WELLS ARE SHALLOW AND FAR ABOVE THE TOP PERFORATIONS OF PRODUCING COAL SEAMS

(DATA FROM SEO, AMOCO)

Water Well Depths (ft)

- 0 - 100
- 100 - 200
- 200 - 300
- 300 - 400
- 400 - 2000

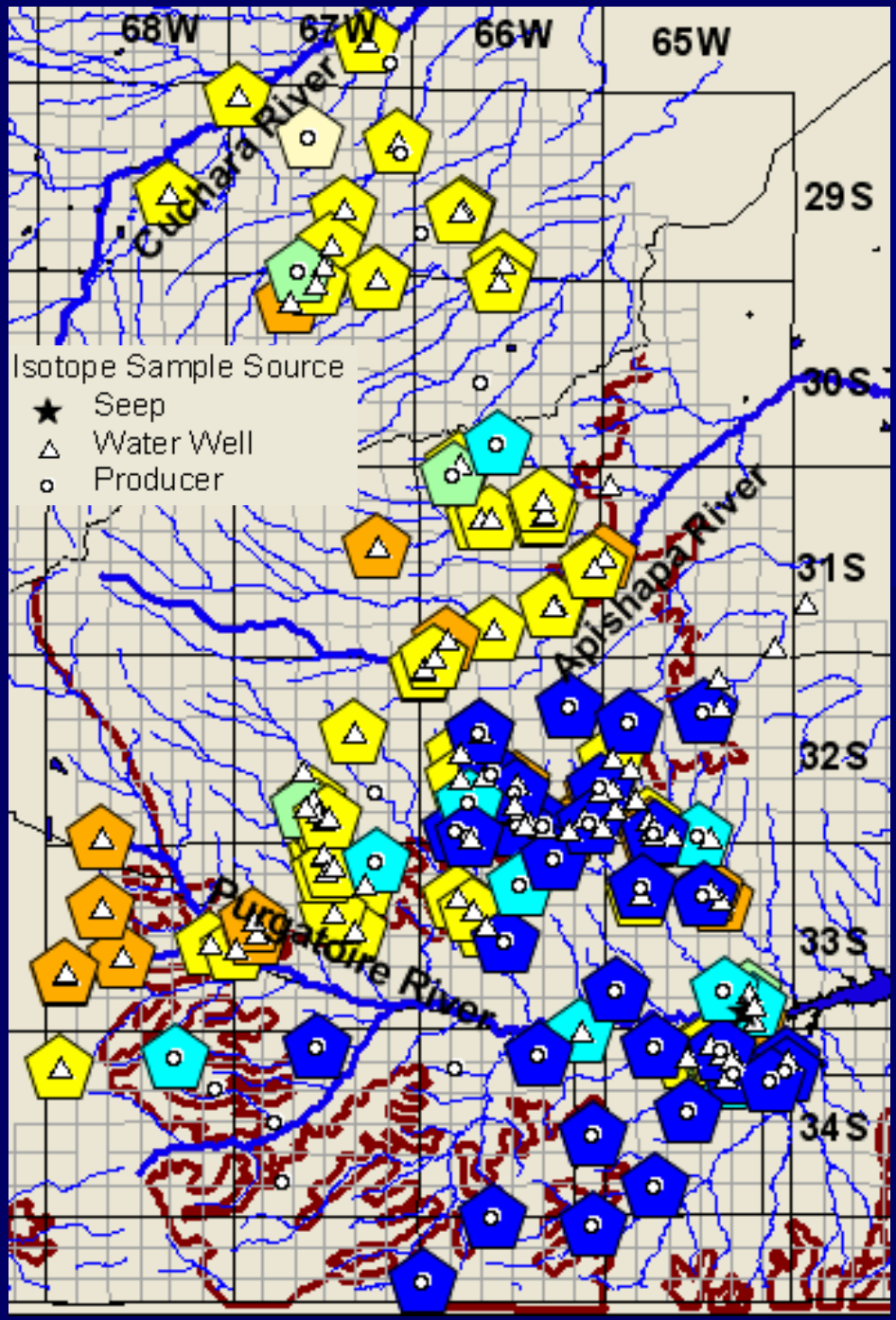
IN SOME AREAS THERE IS CLOSE LATERAL AND VERTICAL PROXIMITY BETWEEN DOMESTIC WATER WELL & PRODUCING WELL COMPLETIONS

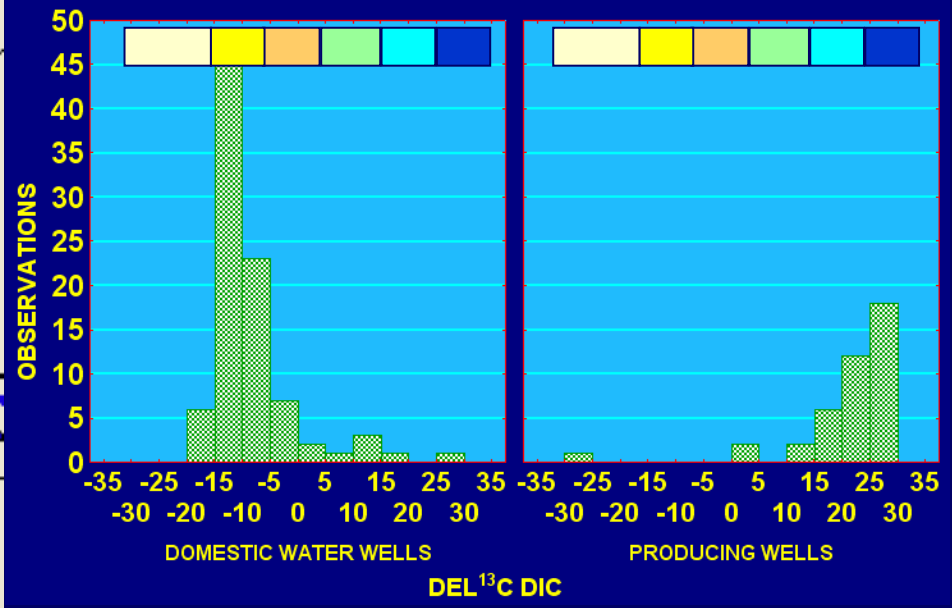


AREAS IN GREEN: PRODUCING WELLS & GROUNDWATER WELLS COMPLETED WITHIN 100 VERTICAL FEET OF ONE ANOTHER

DISTANCE (FT) BETWEEN COMPLETIONS

- -300 - -200
- -200 - -100
- -100 - -1
- 1 - 100
- 100 - 200
- 200 - 300
- 300 - 400
- 400 - 500
- 500 - 600
- 600 - 700
- No Data

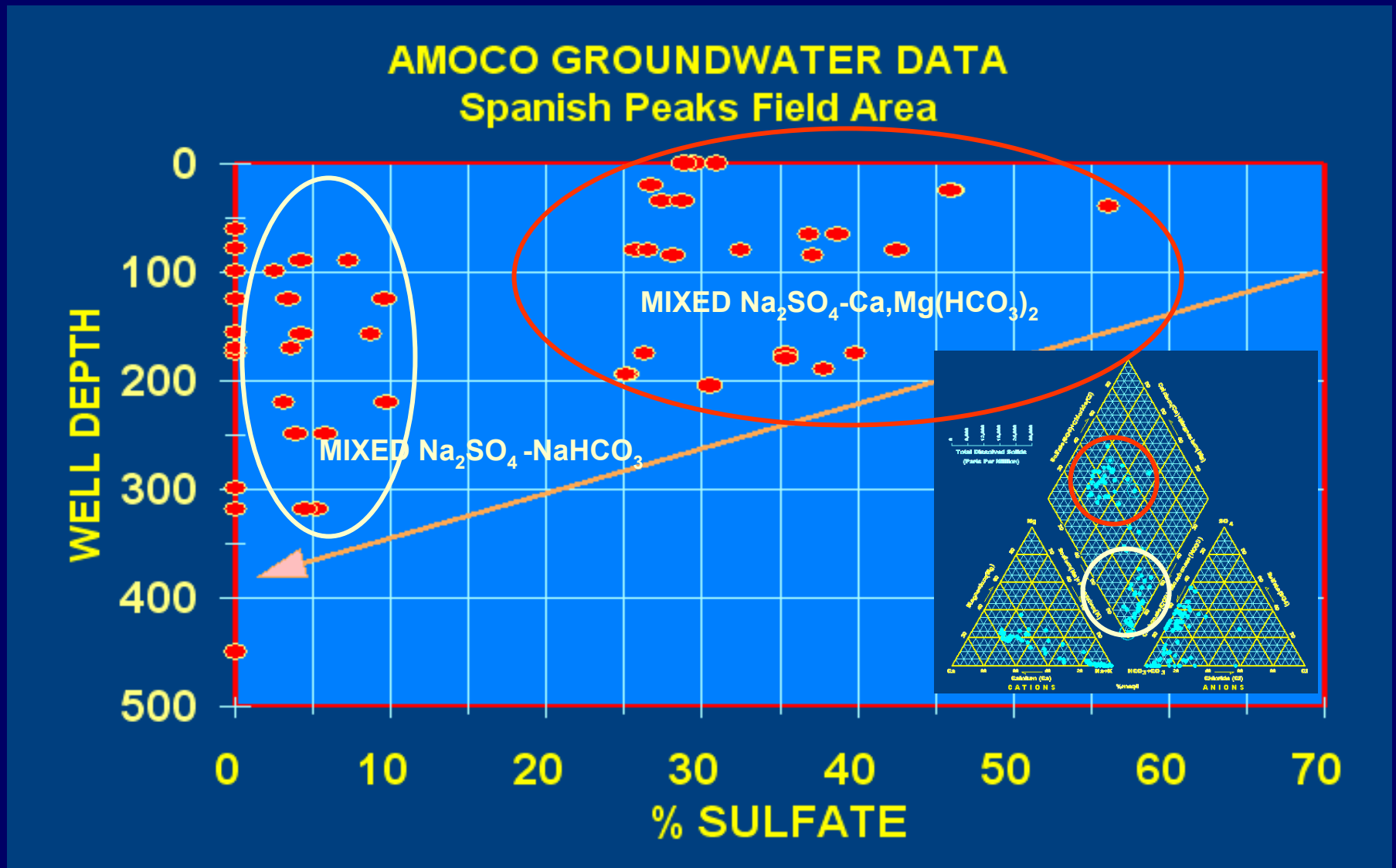




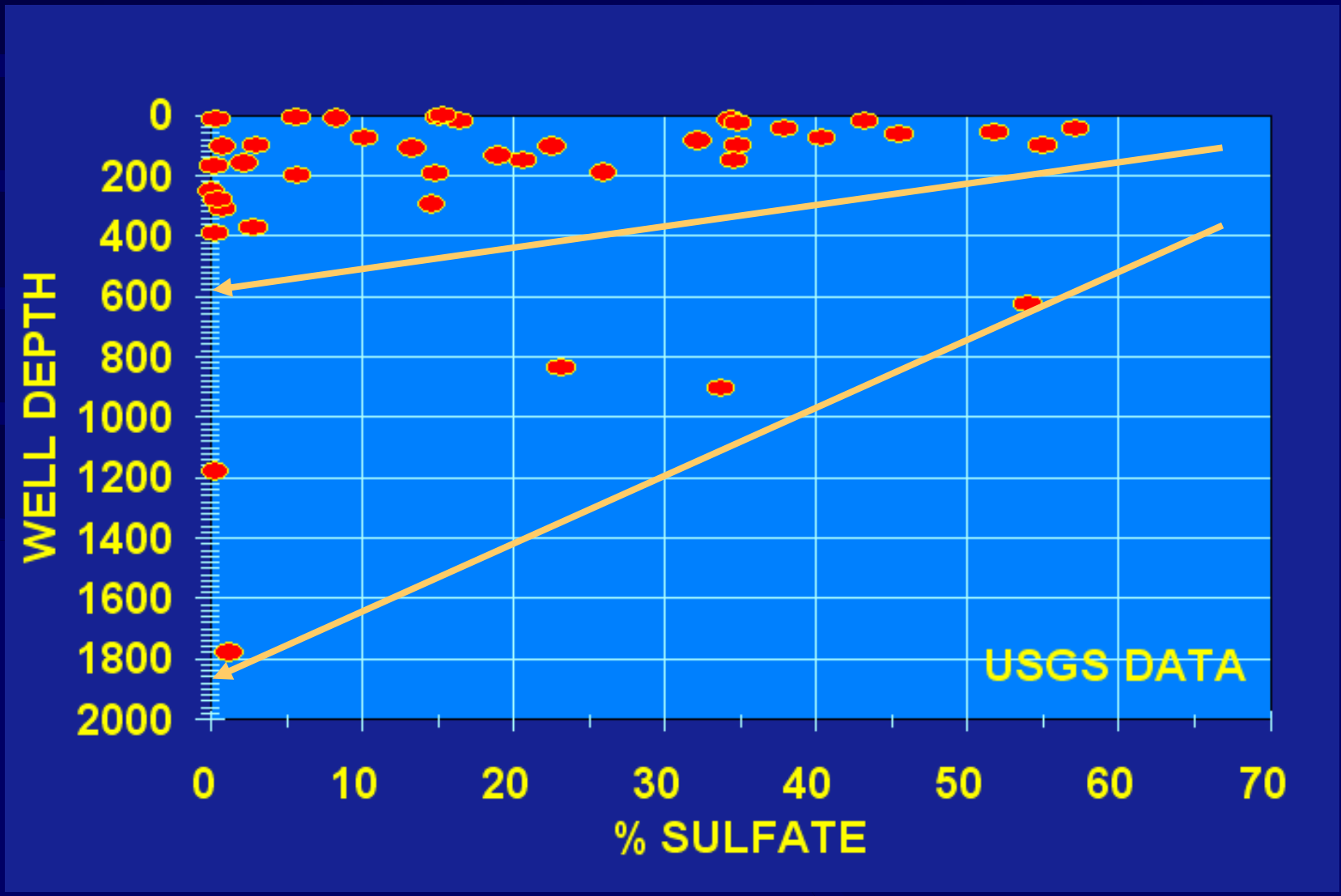
ORIGIN OF BICARBONATE COMMON TO PRODUCED AND SHALLOW WATER CAN BE DETERMINED (DEL ^{13}C DIC)

GROUNDWATER SAMPLES DISTINCTLY DIFFERENT FROM PRODUCED WATER SAMPLES

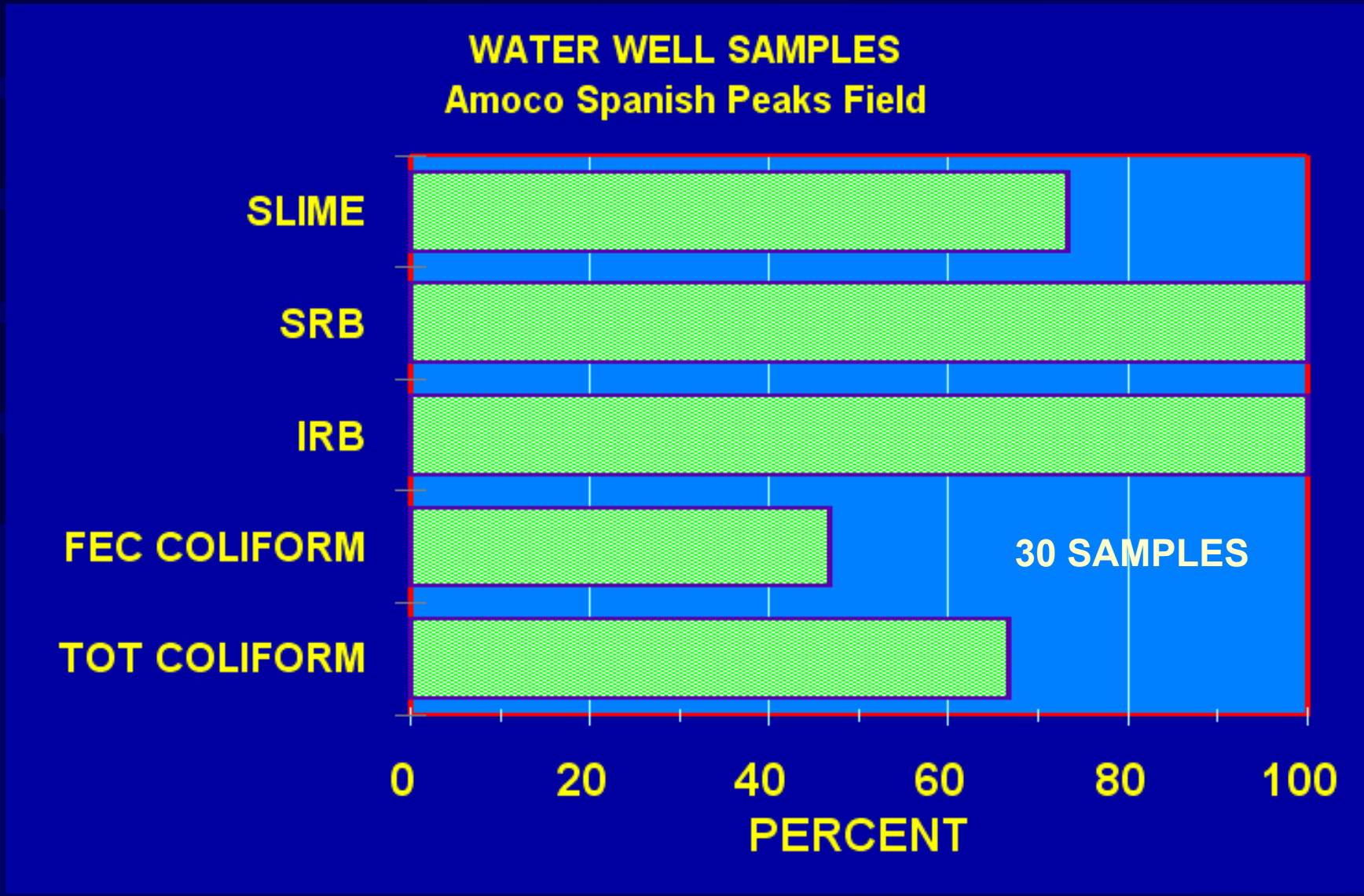
SULFATE DECREASES WITH DEPTH



USGS DATA ALSO INDICATE A SULFATE DECREASES WITH DEPTH DUE TO BACTERIAL REDUCTION AND DILUTION



UBIQUITOUS BACTERIA PLAY PRINCIPAL ROLE IN SHALLOW GROUNDWATER REACTIONS

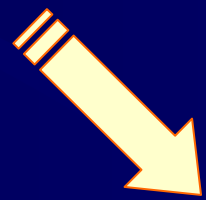


STAGNANT WATER PROMOTES THE FOLLOWING NATURAL REACTIONS THAT DETERIORATE WATER QUALITY

BACTERIAL CONSORTIA FOUL WELLS

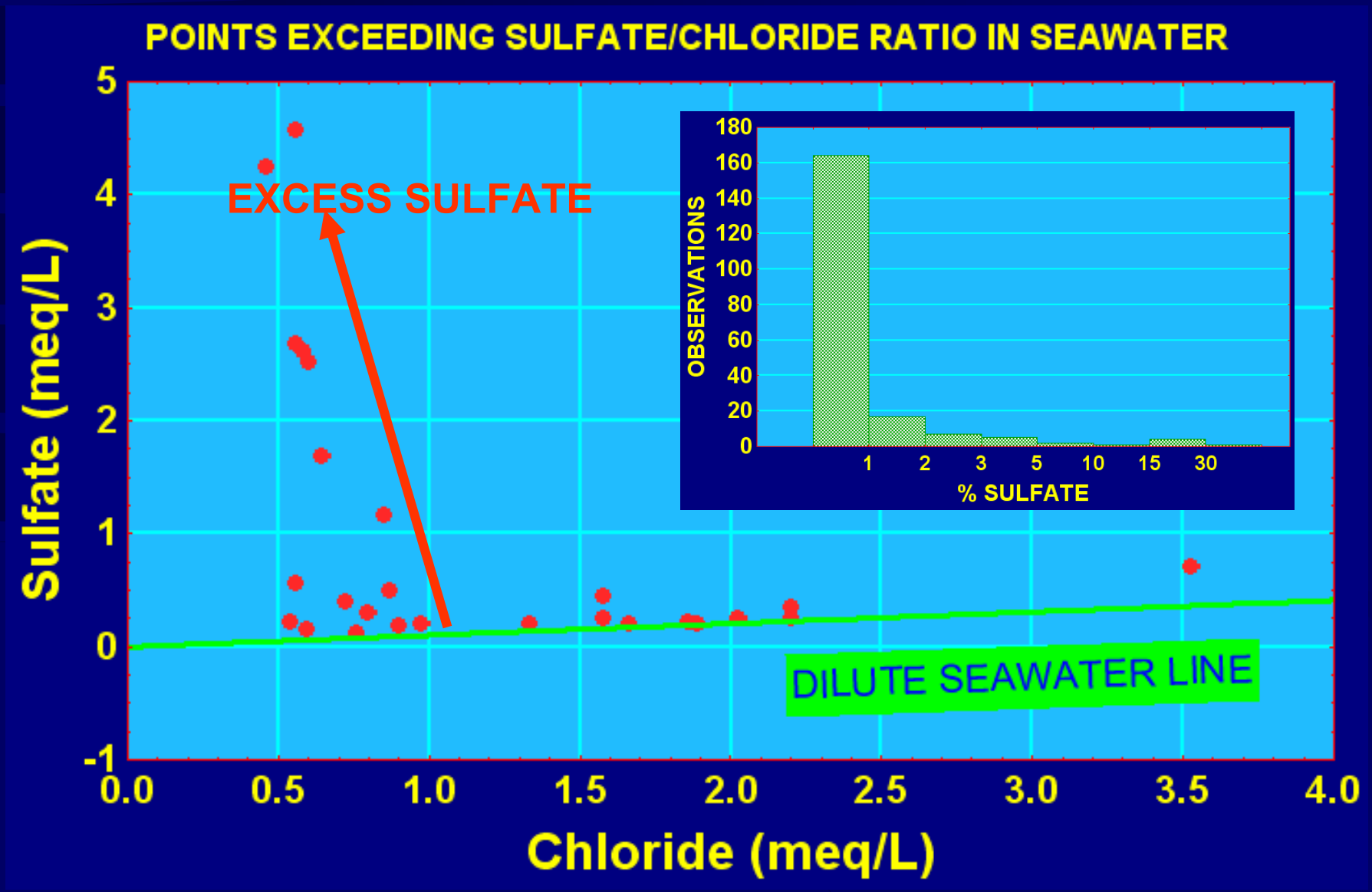
- CONSUME OXYGEN AND TURN WATER STAGNANT
- BIOSLIME CLOGS PERFORATIONS
- MINERAL SCALING CLOGS PERFORATIONS

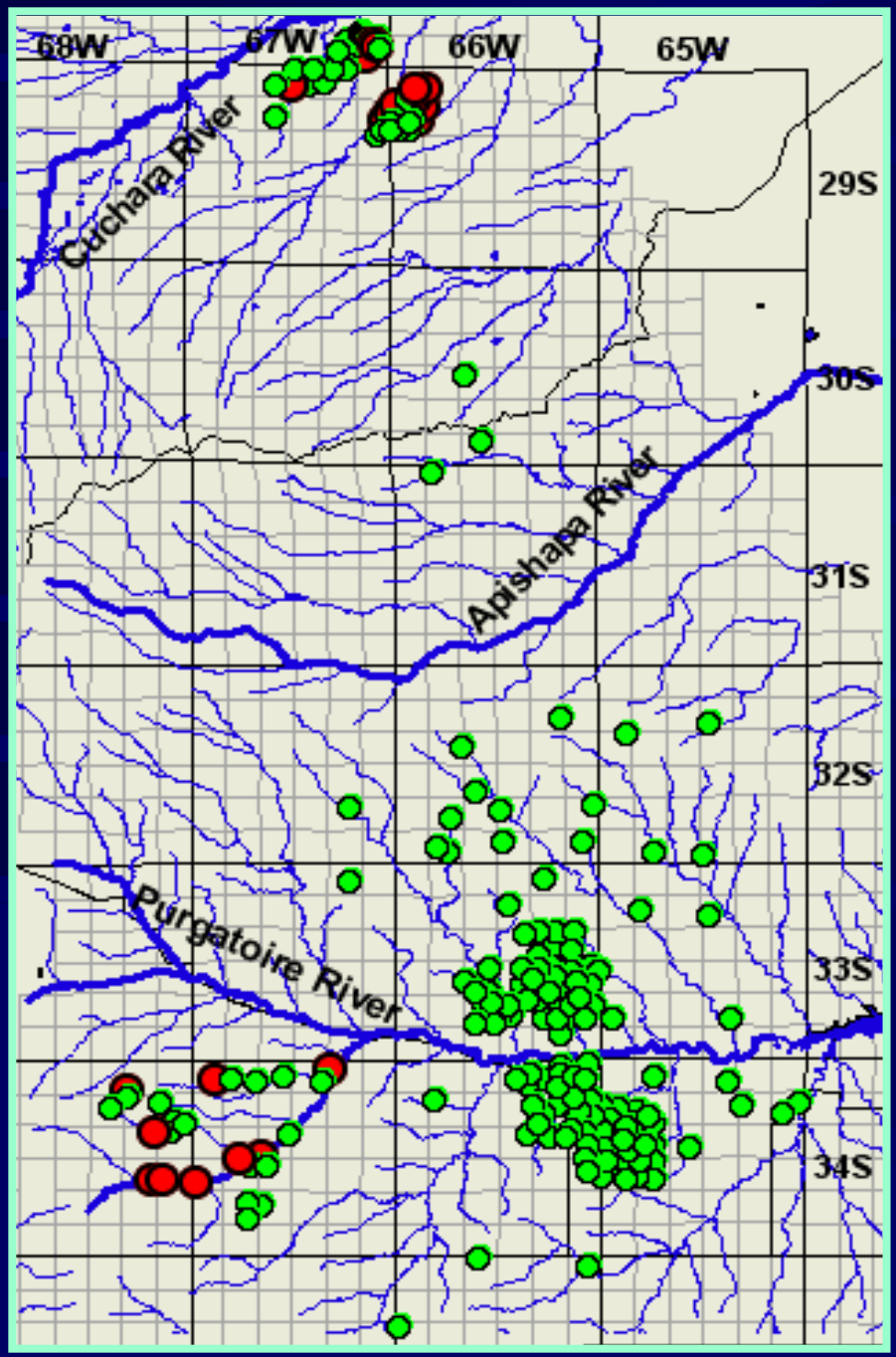
RESULT:



WELL YIELD IMPAIRED

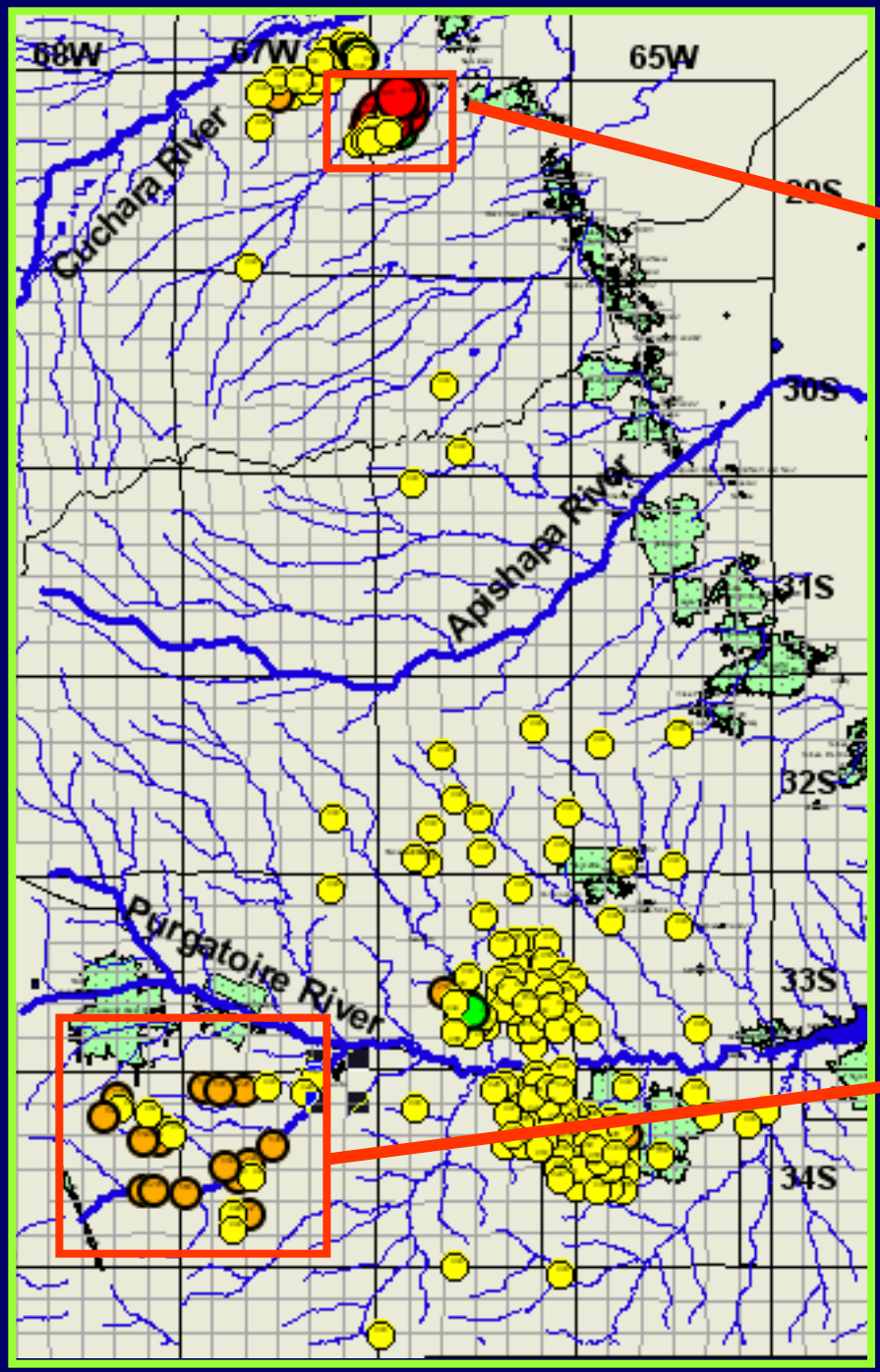
SOME SULFATE IN PRODUCED WATERS ORIGINATES FROM DILUTE CONNATE SEAWATER

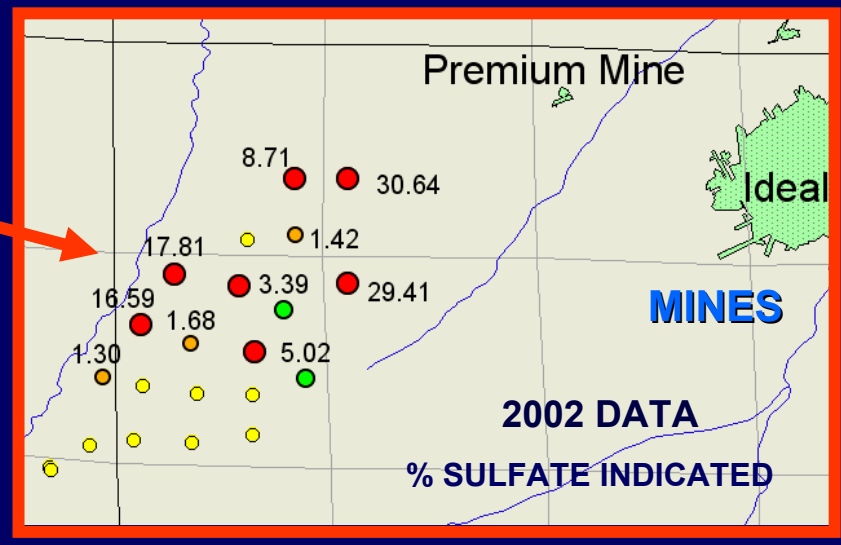




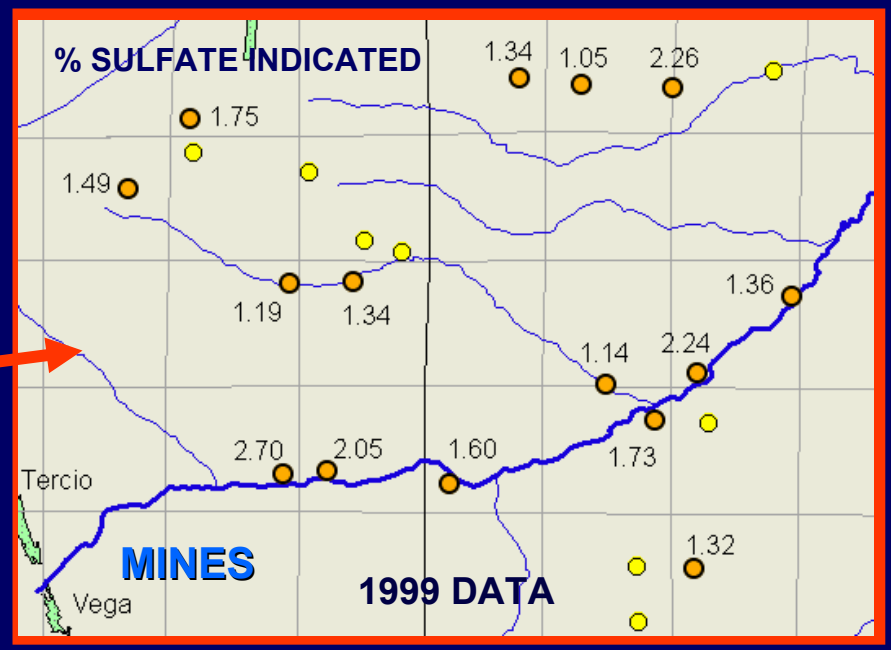
PRODUCING WELLS CONTAININGSULFATE IN EXCESS OF THAT PREDICTED BY DILUTING SEAWATER

Sulfate To Chloride Ratio (meq/L)
- <= Seawater
- > Seawater 0.103



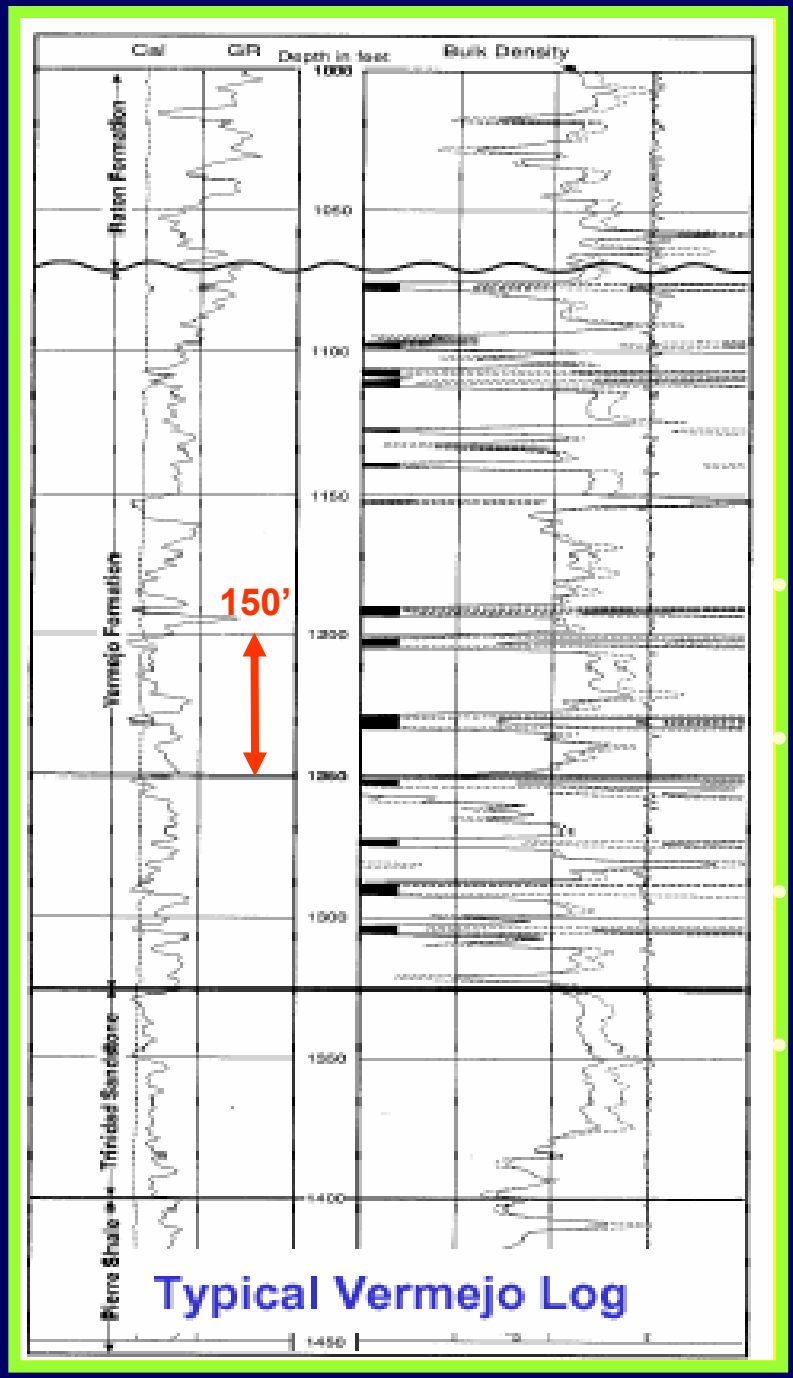


SOME WELLS NEAR OUTCROPS MAY REQUIRE FURTHER INVERSTIGATION



SPATIAL AND TEMPORAL STUDY OF KLT PRODUCING WELLS:
VISUALIZING AQUIFER RESPONSE

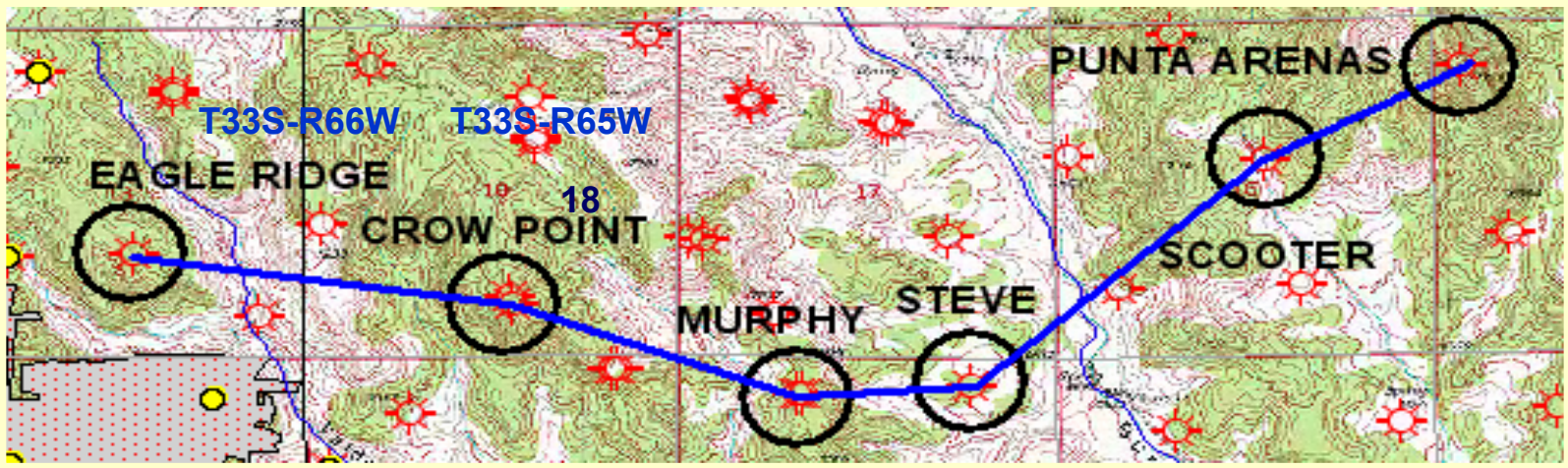
- 95 PAIRS OF SAMPLES EVALUATED
- AVERAGE LAG TIME BETWEEN SAMPLES 3 YRS. FROM 1999 - 2002
- EARLY DATA SET CONTAINS ALL MAJOR IONS
- LATE DATA SET CONTAINS LIMITED DATA INCLUDING DISSOLVED CHLORIDE & BICARBONATE CONTENT
- DATA USEFUL TO EXAMINE
  - POTENTIAL FOR COMMUNICATION WITH SURFACE
  - PRODUCTION COMPARTMENTATION
  - REGIONAL FLOW RATE BOUNDARIES
  - LOCAL FLOW RATE BOUNDARIES

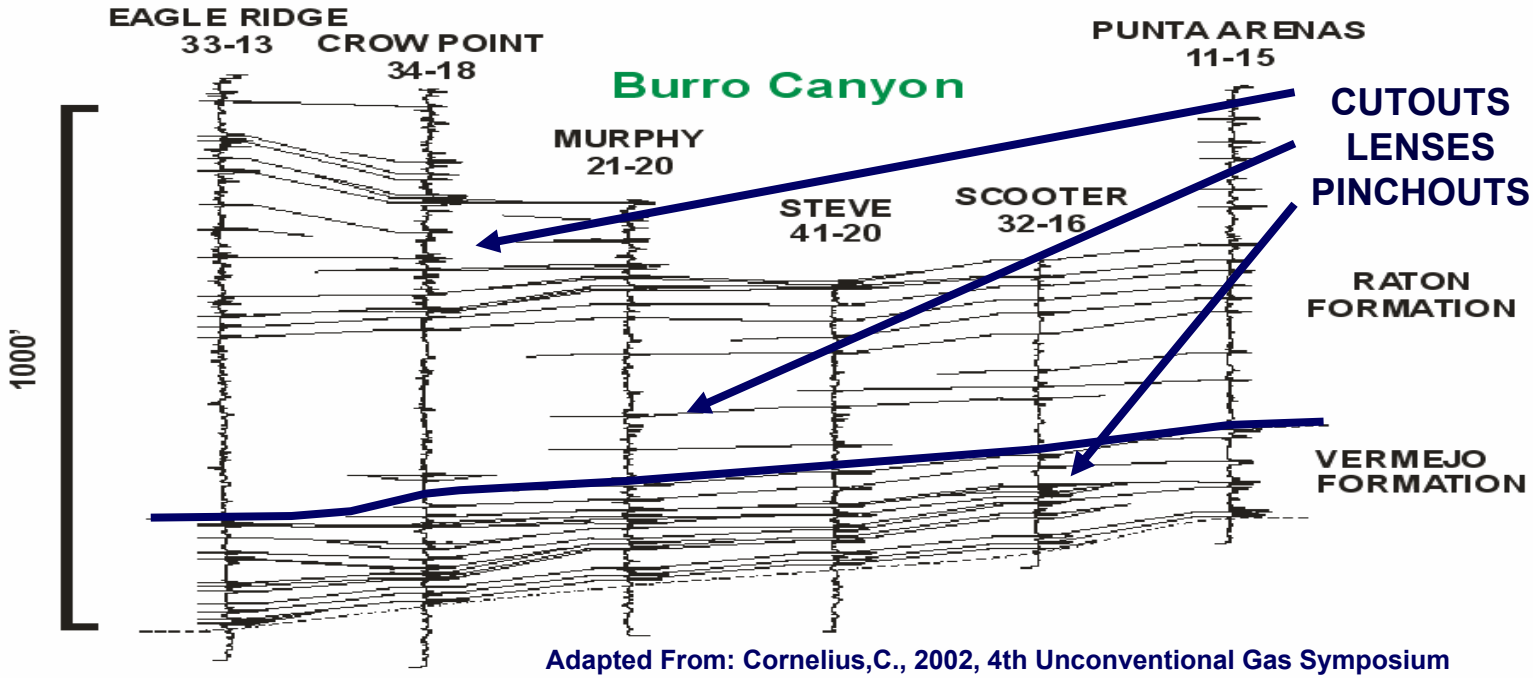


KLT WELLS COMPLETED IN VERMEJO FORMATION

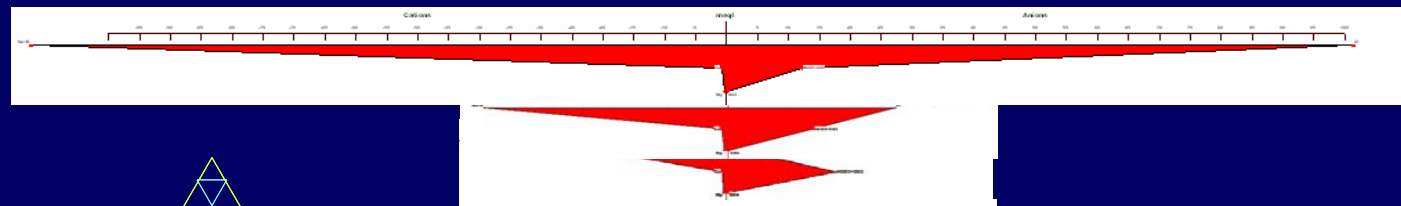
- MULTIPLE THIN COAL SEAM COMPLETIONS
- SEAMS HAVE VARIABLE COMPOSITION
- REQUIRE ENHANCEMENT TO PRODUCE
- WATER AND GAS PRODUCTION RATES NOT CONSIDERED FOR THIS ANALYSIS

NEARBY CROSS SECTION SHOWS VARIABILITY IN VERMEJO COAL CONTINUITY

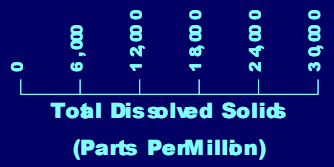




Adapted From: Cornelius,C., 2002, 4th Unconventional Gas Symposium

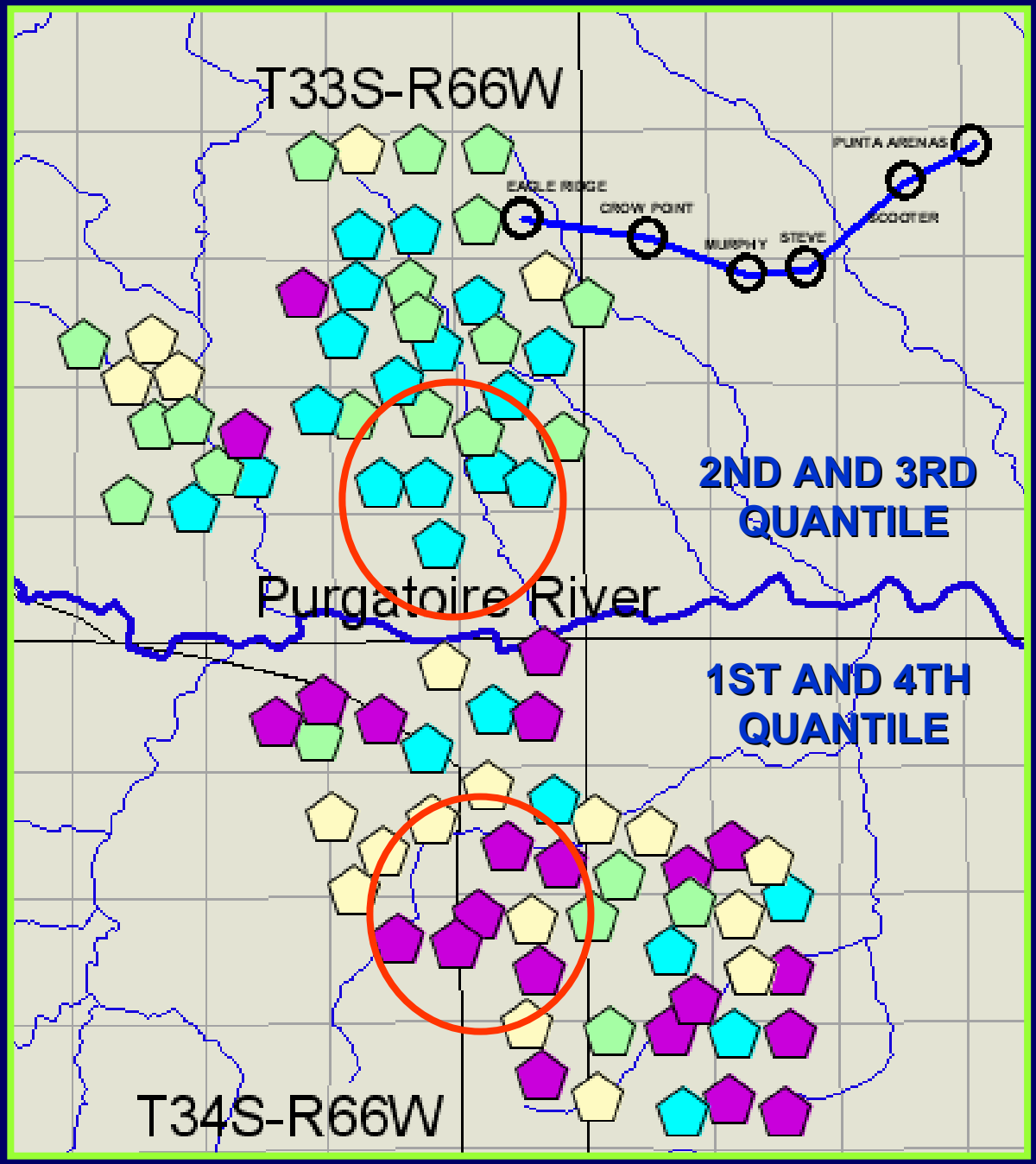


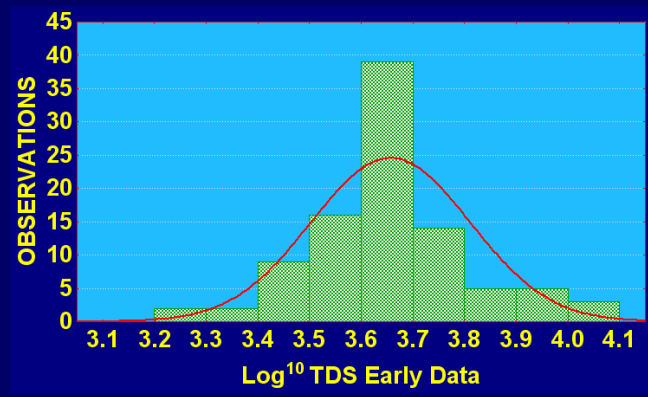
MIXED NaCl-NaHCO$_3$ WATER TYPES



PRODUCED KLT WATER COMPOSITION

%CHLORIDE OR % BICARBONATE & TDS GOOD MAPPING PARAMETERS

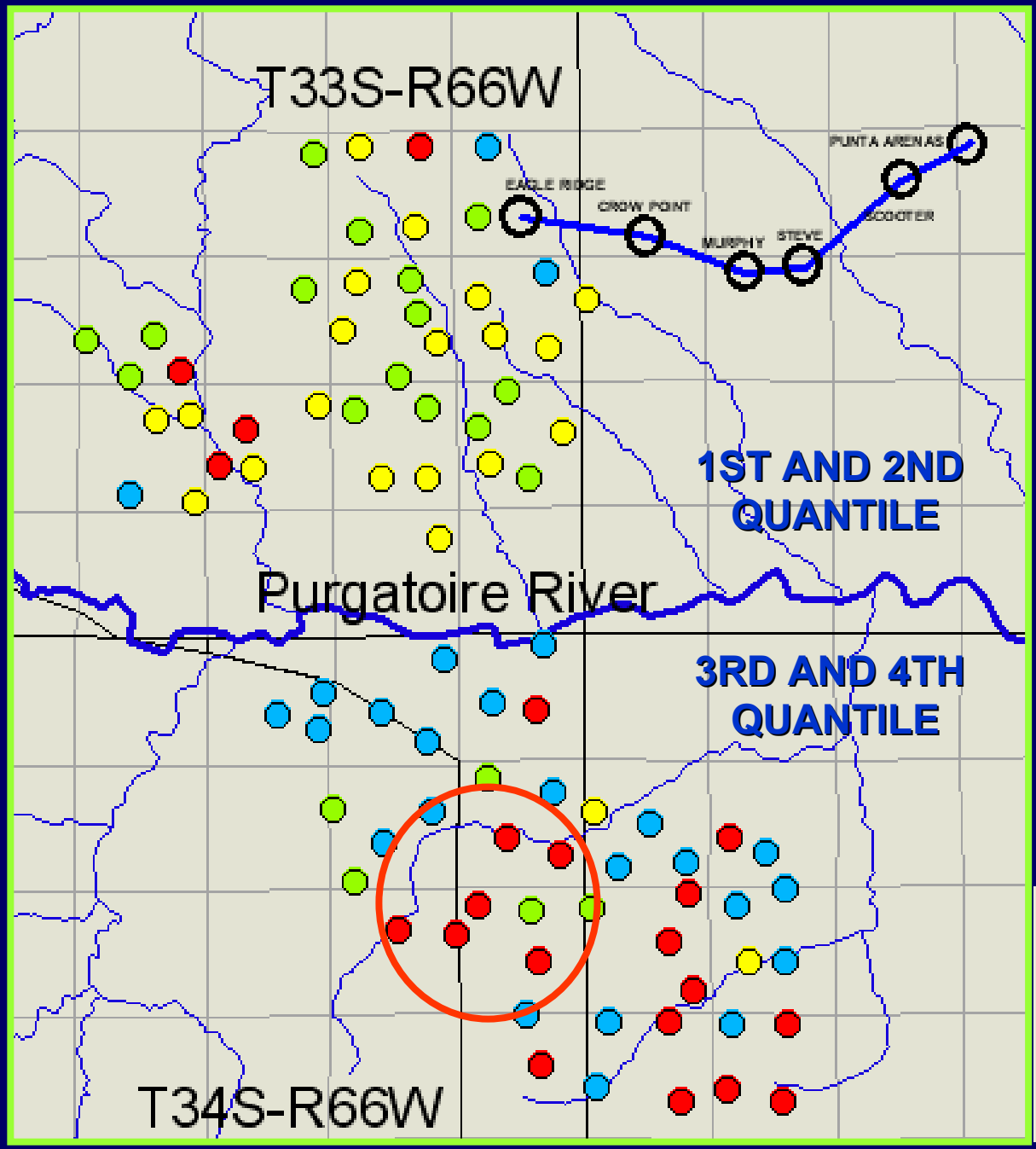




TDS DIFFERS ACROSS PURGATOIRE DIVIDE

TDS (mg/L) EARLY

- 1st Quantile
- 2nd Quantile
- 3rd Quantile
- 4th Quantile

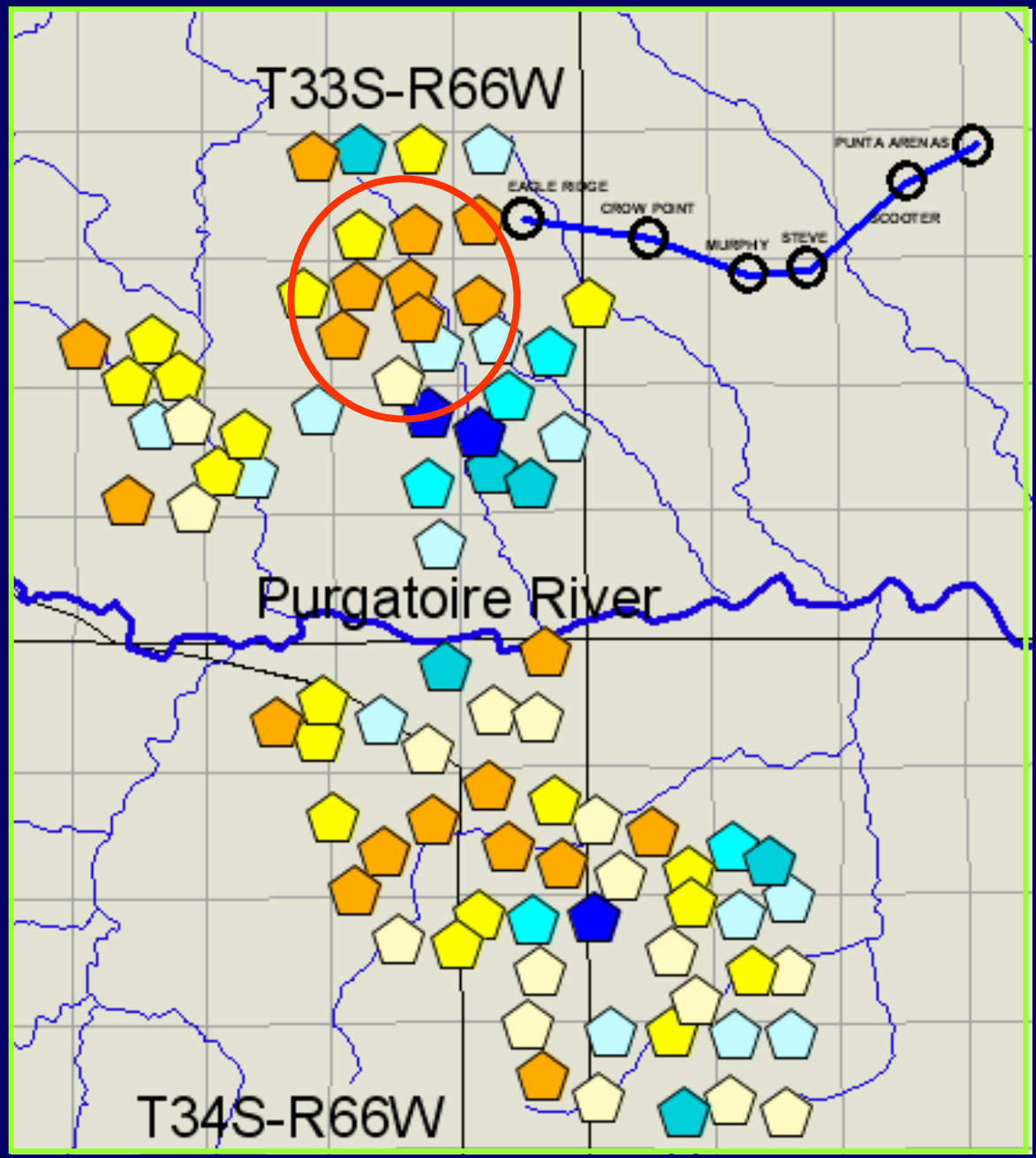


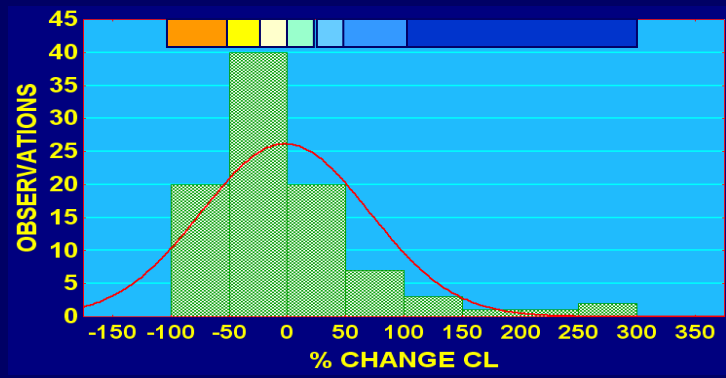
% CHLORIDE DIFFERS ACROSS PURGATOIRE RIVER

EVIDENCE OF REGIONAL GROUNDWATER DIVIDE

% Cl (Early)

- 1st Quantile 3 - 58
- 2nd Quantile 58 - 69
- 3rd Quantile 69 - 84
- 4th Quantile 84 - 95





CHANGES IN CL CONCENTRATION

Percent Change Cl mg/L

- -100 - -50
- -50 - -25
- -25 - 0
- 0 - 25
- 25 - 50
- 50 - 100
- 150 - 300

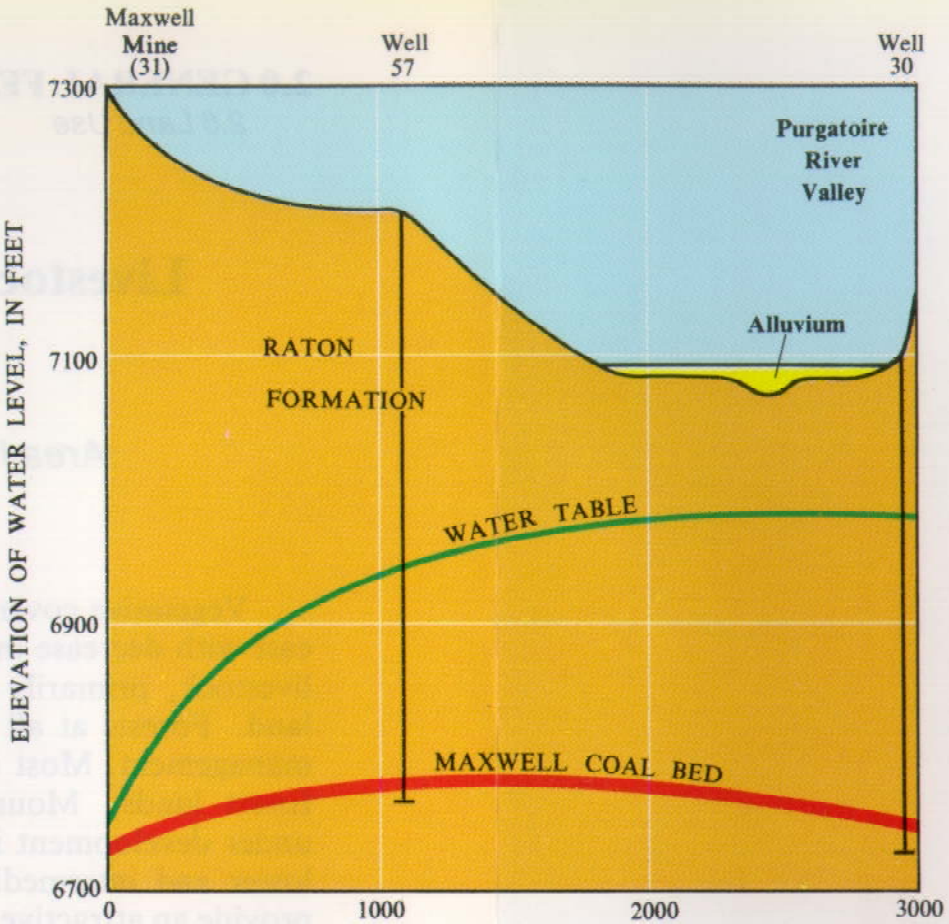
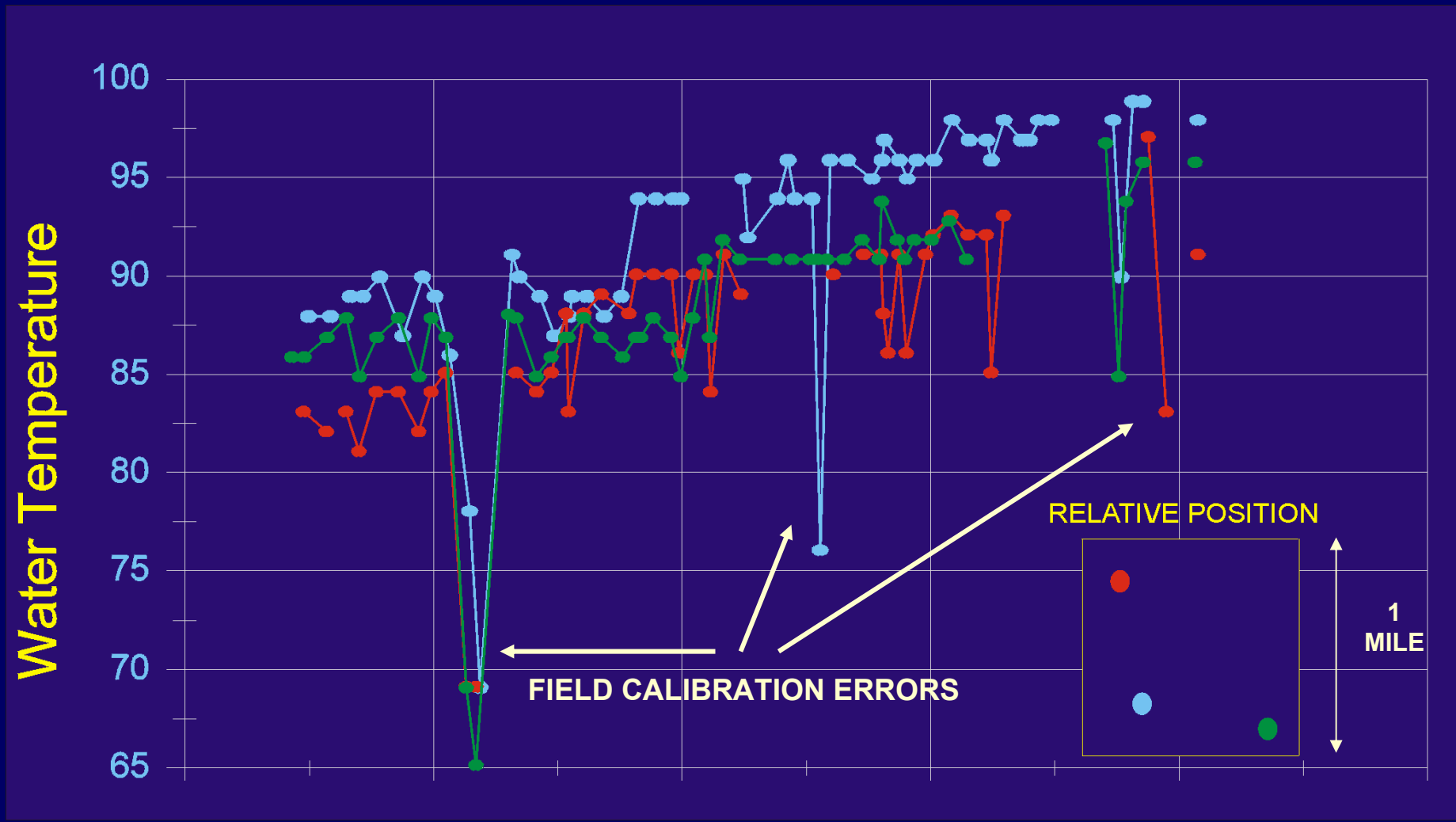


Figure 2.5.3-2 Drawdown of water table by mine pumps near the Maxwell Mine, Colorado, 1980.

RESULTS CONSISTENT WITH USGS OFR-83-132

CHANGES IN PRODUCED WATER TEMPERATURE USEFUL FORENSIC TOOL TO EVALUATE CONNECTION WITH SHALLOW AQUIFERS



SUMMARY:

USEFUL SCREENING TOOLS TO ADDRESS POTENTIAL IMPACT ON SHALLOW AQUIFERS

- TRILINEAR DIAGRAMS - VIEW MIXING TRENDS AND SELECT MAP PARAMETERS
- SPATIAL MAPS - LARGE SCALE HETEROGENEITY
- TEMPORAL MAPS - SMALL SCALE HETEROGENEITY & CONNECTIVITY OF AQUIFERS
- SULFATE CONTENT: SURFACE WATER MARKER
- ^{13}C DIC- HCO_3 : SURFACE MARKER, SOURCE MARKER
  - (SPATIAL & TEMPORAL)
- PRODUCED WATER TEMPERATURE
- COMPLETION INFORMATION
  - BASE WATER WELL PERFORATION
  - TOP PRODUCING WELL PERFORATION

CONCLUSIONS

- POTENTIAL IMPACT TO SHALLOW AQUIFERS CAN BE SCREENED AS FOLLOWS:
  - MAP LATERAL AND VERTICAL PROXIMITY OF GROUNDWATER AND PRODUCED WATER COMPLETIONS
    - MONITOR SHALLOW AQUIFER WATER LEVELS WHERE NEEDED
  - ANALYZE PRODUCED WATER PROPERTIES
    - INITIAL MAJOR ION ANALYSES
    - STABLE ISOTOPIC ANALYSIS OF DISSOLVED BICARBONATE
    - PERIODIC MONITORING DURING DRY AND WET SEASONS
      - MONITOR CHANGES IN TDS AND SULFATE CONTENT
    - REGULAR, CALIBRATED TEMPERATURE SURVEYS
- SCREEN FOR METHANE WITH IRS AND DISSOLVED METHANE MEASUREMENTS
  - THE ORIGIN OF METHANE CAN BE DETERMINED USING STABLE ISOTOPE MEASUREMENTS

Raton Basin Project 2000-2003
Further Investigations

- Monitor Water Wells that are in Close Vertical Proximity to CBM Gas Wells
- Utilize Chemical Data to Identify Areas for Further Investigation
- Update Data in the Project Area