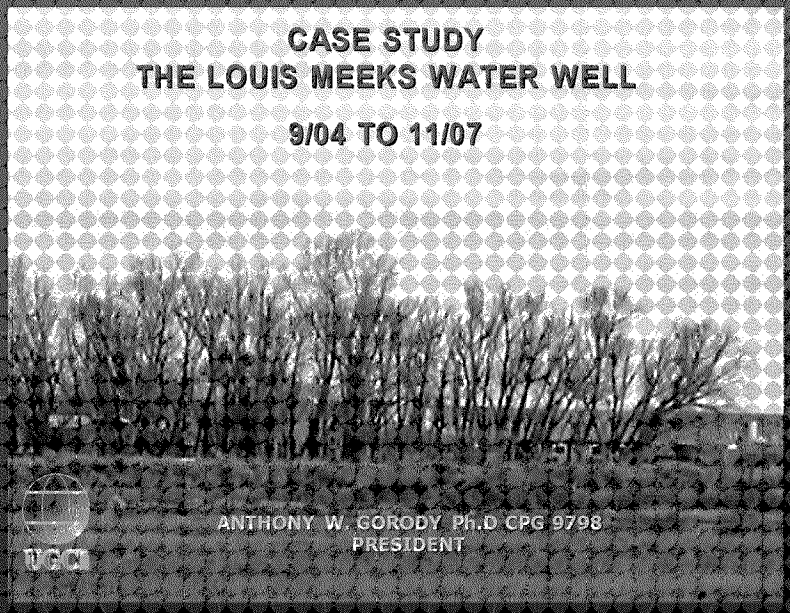
CASE STUDY
THE LOUIS MEEKS WATER WELL

9/04 TO 11/07

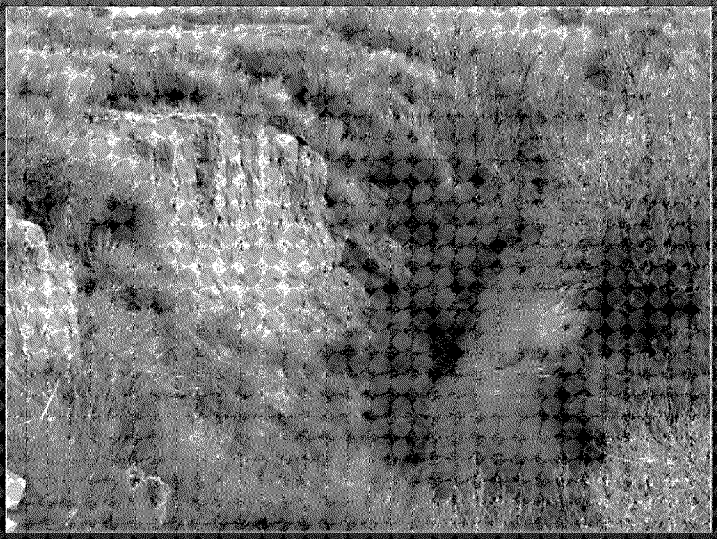


ANTHONY W. GORODY Ph.D CPG 9798
PRESIDENT

TOPICS COVERED TODAY

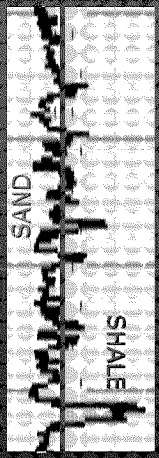
- **HYDROLOGY, GEOLOGY, AND OPERATIONS SETTING**
  - WATER WELLS COMPLETED IN ALLUVIUM AND WIND RIVER FORMATION SEDIMENTS
  - WELLS SENSITIVE TO INFILTRATION OF SURFACE CONTAMINANTS
- **MEEKS WATER WELL**
  - HAS NOT BEEN IMPACTED BY GAS DRILLING AND PRODUCTION OPERATIONS
    - [illegible]
  - WATER QUALITY HAS NOT CHANGED SINCE BEFORE ECANA'S PAVILLION 24-02 WELL COMPLETED
  - WELL IS INFECTED WITH BACTERIA IMPACTING YIELD AND POTABILITY
    - [illegible]
    - CONCLUSION SUPPORTED WITH OTHER DATA
- **PAVILLION 24-02**
  - NO EVIDENCE OF CONNECTION WITH SURFACE WATER
- **SAMPLING QA/QC CONSISTENCY REQUIRED**

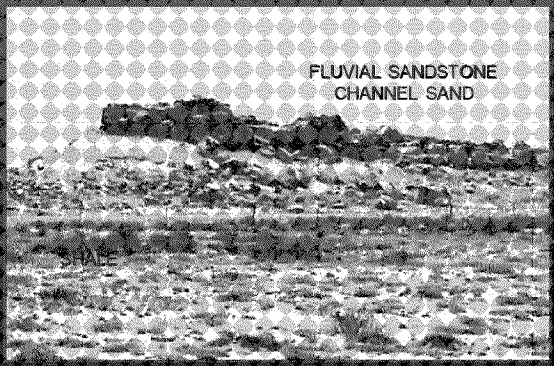
UNCONSOLIDATED ALLUVIAL SEDIMENTS: SHALLOWEST AQUIFER



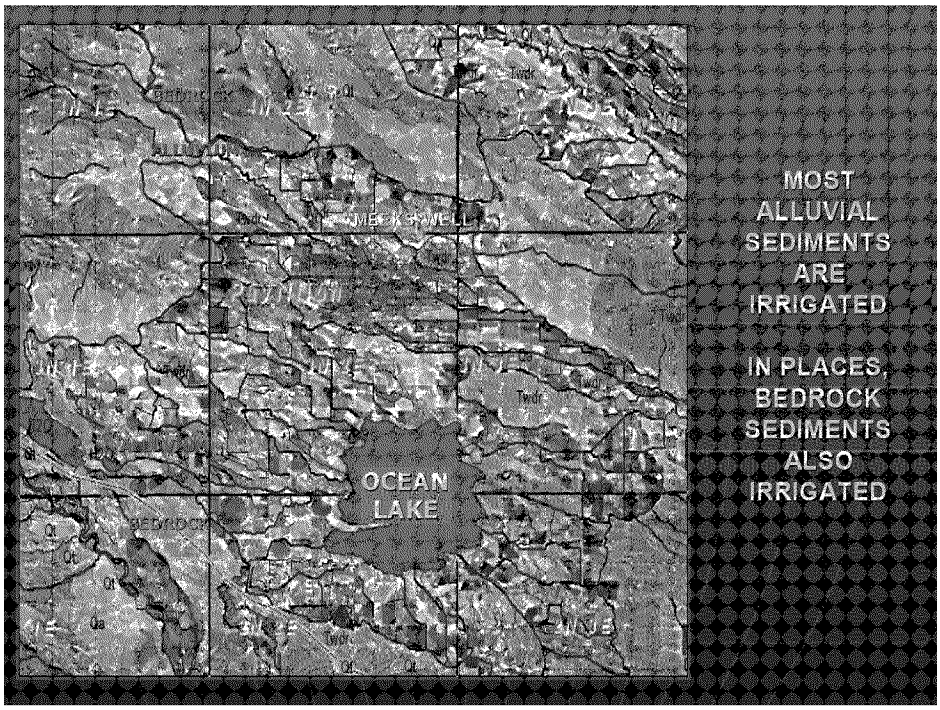
CONSOLIDATED & FRACTURED WIND RIVER FORMATION AQUIFER SANDS ARE THIN AND DISCONTINUOUS

WIND RIVER FM
SHALLOW AQUIFER SANDS





NATURAL GAMMA RAY LOG



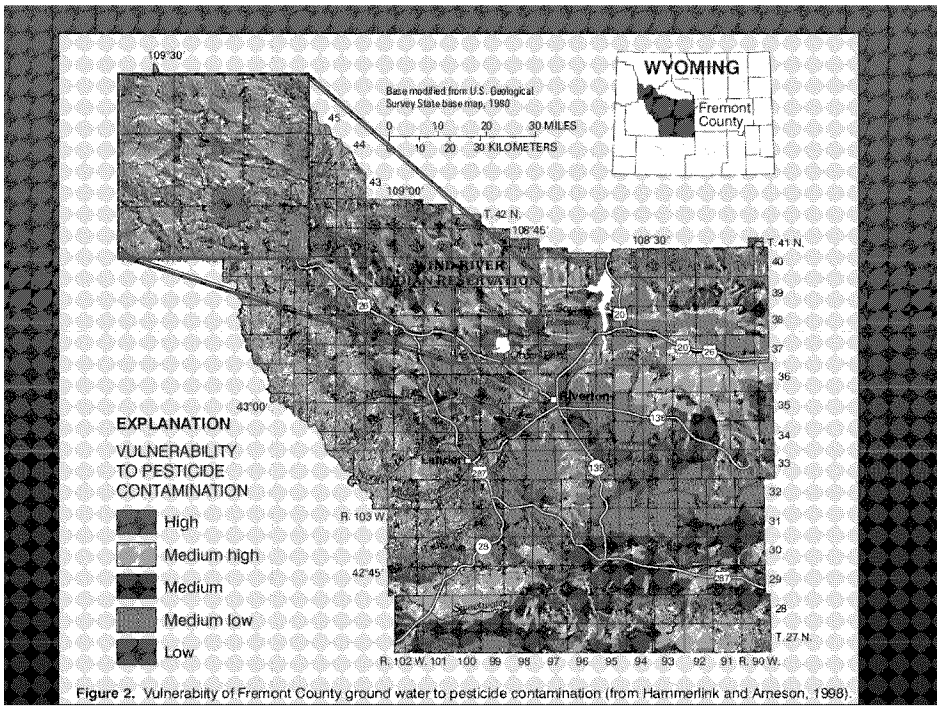
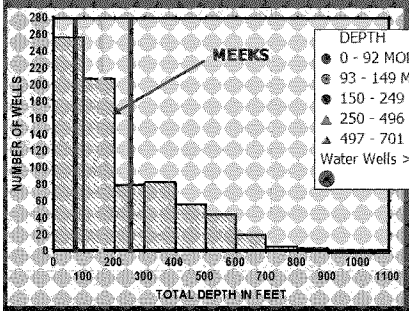
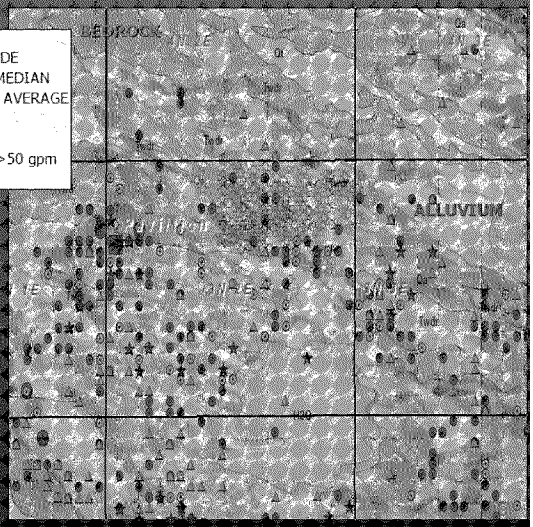


Figure 2. Vulnerability of Fremont County ground water to pesticide contamination (from Hammerlink and Ameson, 1998).

DOMESTIC WATER WELLS IN T 2,3,4 N AND R 1,2,3 E



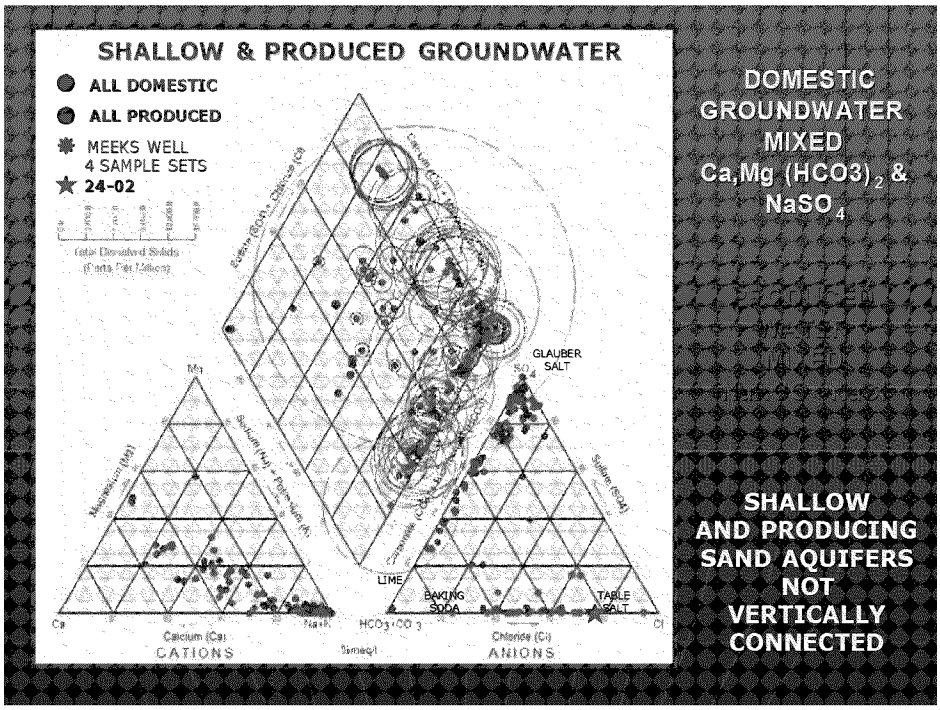


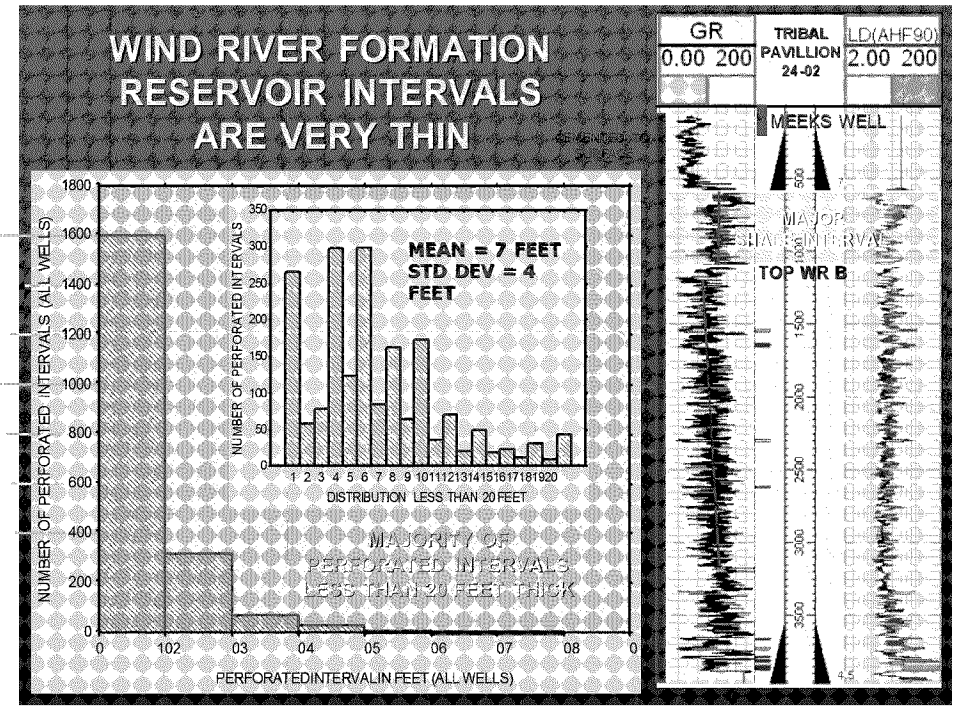
WELLS DEEPER THAN 50' ARE MOST LIKELY TO BE TAPPING BEDROCK AQUIFERS

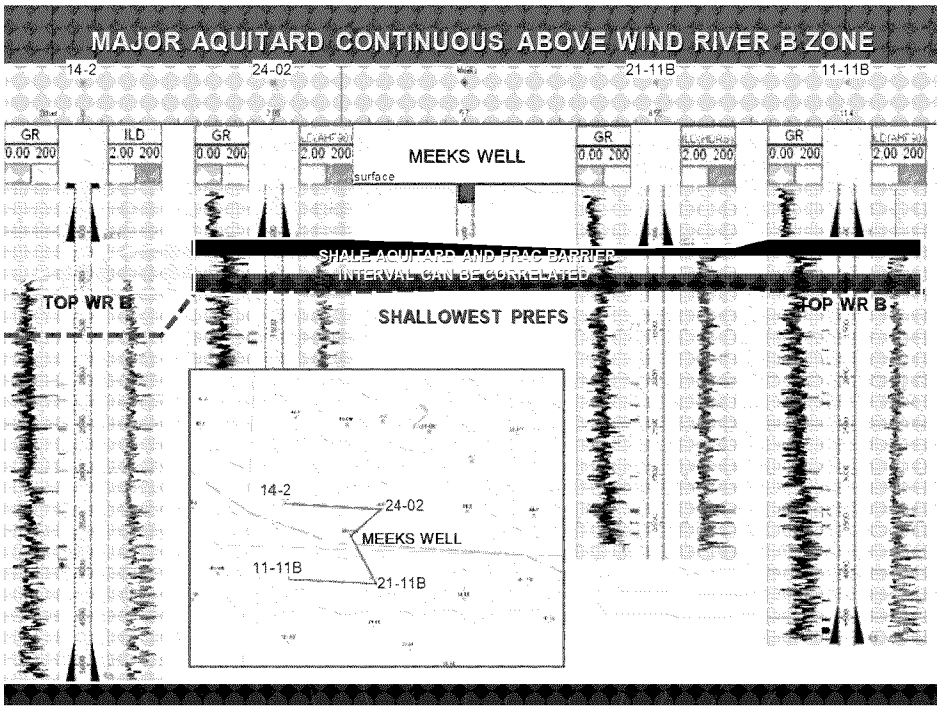
GEOLOGIC MAP

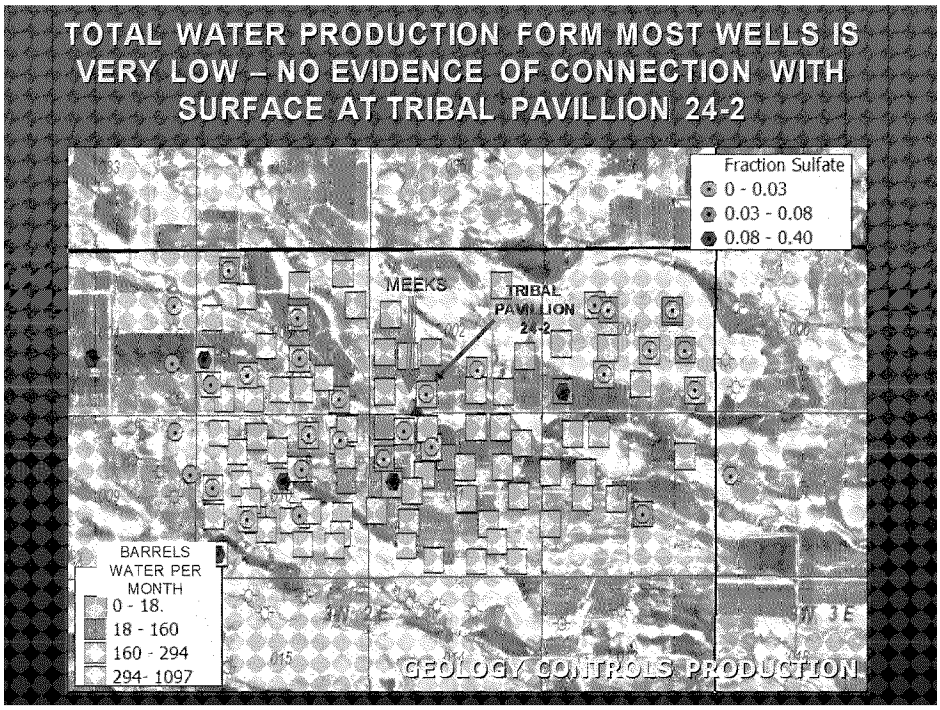
SURFACE AND GROUNDWATER WATER QUALITY

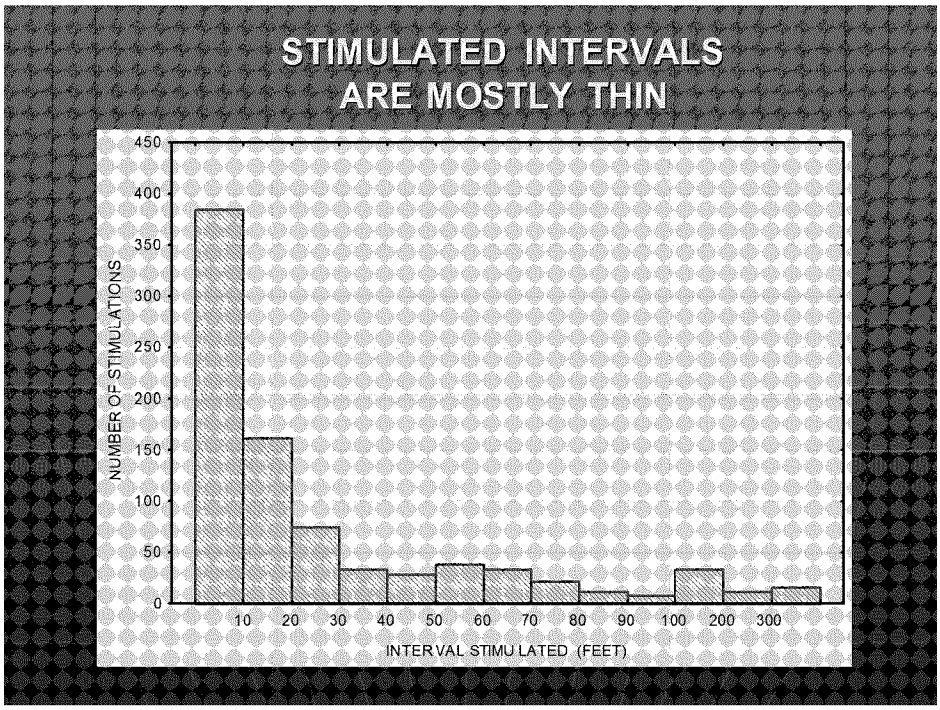
- AVAILABLE WATER ANALYSIS DATA SOURCES
  - USGS
  - WATER RESOURCES RESEARCH INSTITUTE
  - WYOMING WATER DEVELOPMENT COMMISSION
  - DEQ
  - BASELINE (ENCANA)
  - PRODUCED WATER (ENCANA)

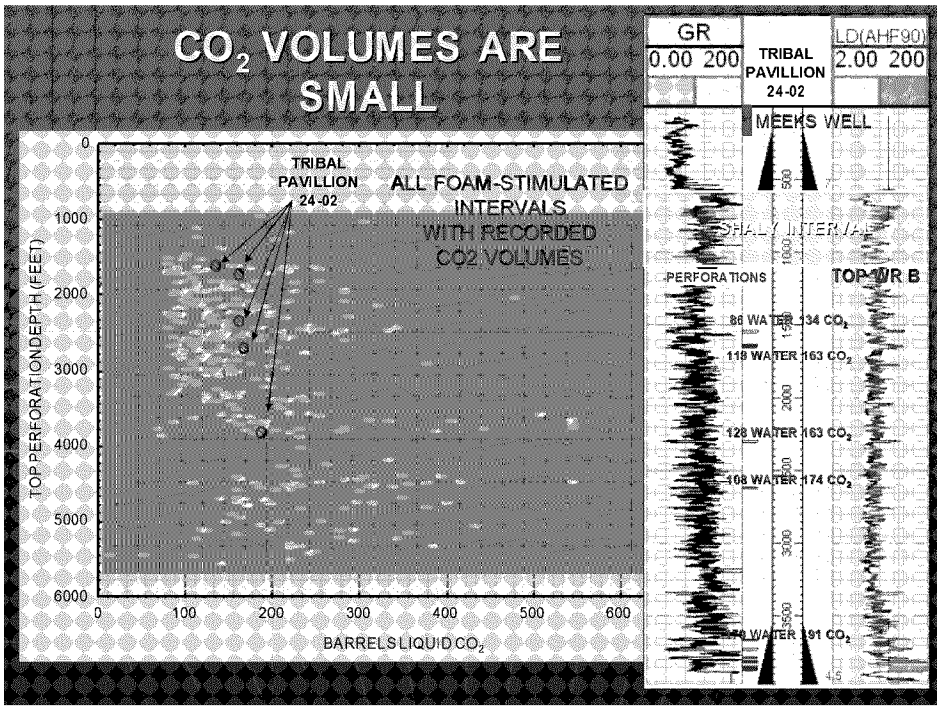

SHALLOW & PRODUCED GROUNDWATER
ALL DOMESTIC
ALL PRODUCED
MEEKS WELL
4 SAMPLE SETS
24-02
GLAUBER SALT
LIME
BAKING SODA
TABLE SALT
Calcium (Ca)
CATIONS
Chloride (Cl)
ANIONS
DOMESTIC GROUNDWATER MIXED Ca,Mg $(HCO3)_2$ & $NaSO_4$
SHALLOW AND PRODUCING SAND AQUIFERS NOT VERTICALLY CONNECTED


WIND RIVER FORMATION RESERVOIR INTERVALS ARE VERY THIN
NUMBER OF PERFORATED INTERVALS (ALL WELLS)
PERFORATEDINTERVALIN FEET (ALL WELLS)
MEAN = 7 FEET
STD DEV = 4 FEET
NUMBER OF PERFORATED INTERVALS
DISTRIBUTION LESS THAN 20 FEET
MAJORITY OF PERFORATED INTERVALS LESS THAN 20 FEET THICK
GR
TRIBAL PAVILLION 24-02
LD(AHF90)
MEEKS WELL
MAJOR SHALE INTERVAL
TOP WR B

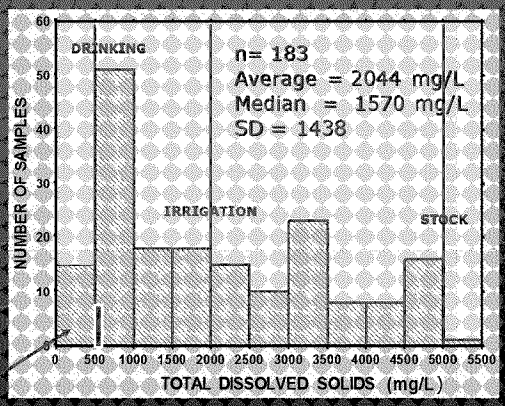

MAJOR AQUITARD CONTINUOUS ABOVE WIND RIVER B ZONE
14-2
24-02
21-11B
11-11B
GR
ILD
MEEKS WELL
surface
SHALE AQUITARD AND FRAC BARRIER
INTERVAL CAN BE CORRELATED
TOP WR B
SHALLOWEST PREFS
14-2
24-02
MEEKS WELL
11-11B
21-11B


TOTAL WATER PRODUCTION FORM MOST WELLS IS VERY LOW – NO EVIDENCE OF CONNECTION WITH SURFACE AT TRIBAL PAVILLION 24-2
Fraction Sulfate
0 - 0.03
0.03 - 0.08
0.08 - 0.40
MEEKS
TRIBAL PAVILLION 24-2
BARRELS WATER PER MONTH
0 - 18.
18 - 160
160 - 294
294- 1097
GEOLOGY CONTROLS PRODUCTION


STIMULATED INTERVALS
ARE MOSTLY THIN
NUMBER OF STIMULATIONS
0
50
100
150
200
250
300
350
400
450
10
20
30
40
50
60
70
80
90
100
200
300
INTERVAL STIMULATED (FEET)


CO2 VOLUMES ARE
SMALL
TRIBAL
PAVILLION
24-02
ALL FOAM-STIMULATED
INTERVALS
WITH RECORDED
CO2 VOLUMES
TOP PERFORATIONDEPTH (FEET)
0
1000
2000
3000
4000
5000
6000
0
100
200
300
400
500
600
BARRELS LIQUID CO2
GR
0.00 200
TRIBAL
PAVILLION
24-02
LD(AHF90)
2.00 200
MEEKS WELL
SHALY INTERVAL
PERFORATIONS
TOP WR B
86 WATER 134 CO2
118 WATER 163 CO2
128 WATER 163 CO2
108 WATER 174 CO2
WATER 191 CO2

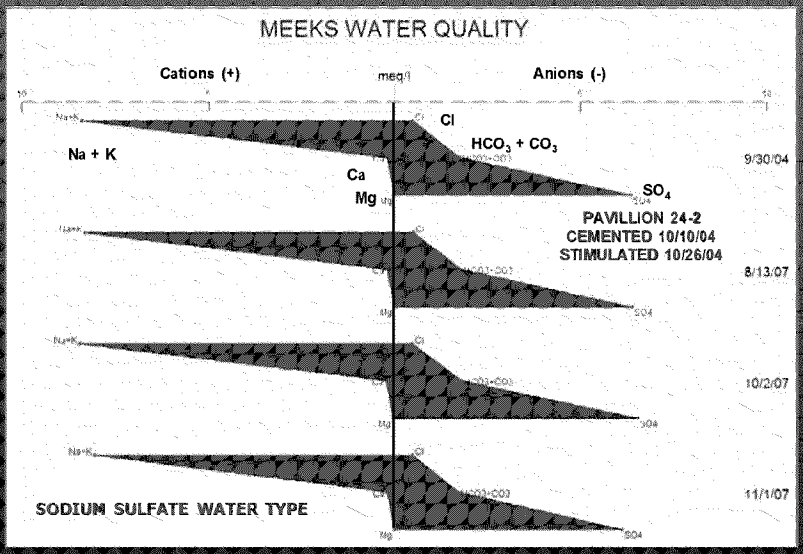
WATER QUALITY IN WIND RIVER AND PAVILLION AREA WELLS HIGHLY VARIABLE



1 teaspoon table salt = 5500 mg

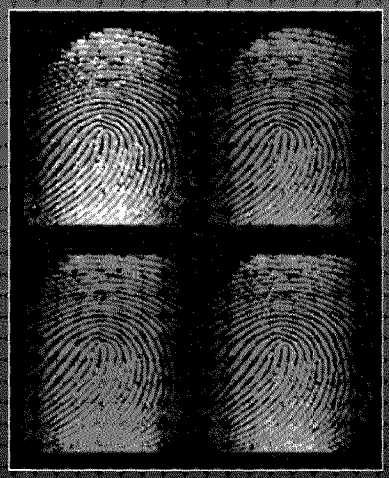
Meeks
508-536 mg/L

MEEKS WATER QUALITY HAS NOT CHANGED SINCE FIRST SAMPLED IN BASELINE PROGRAM OF 2004



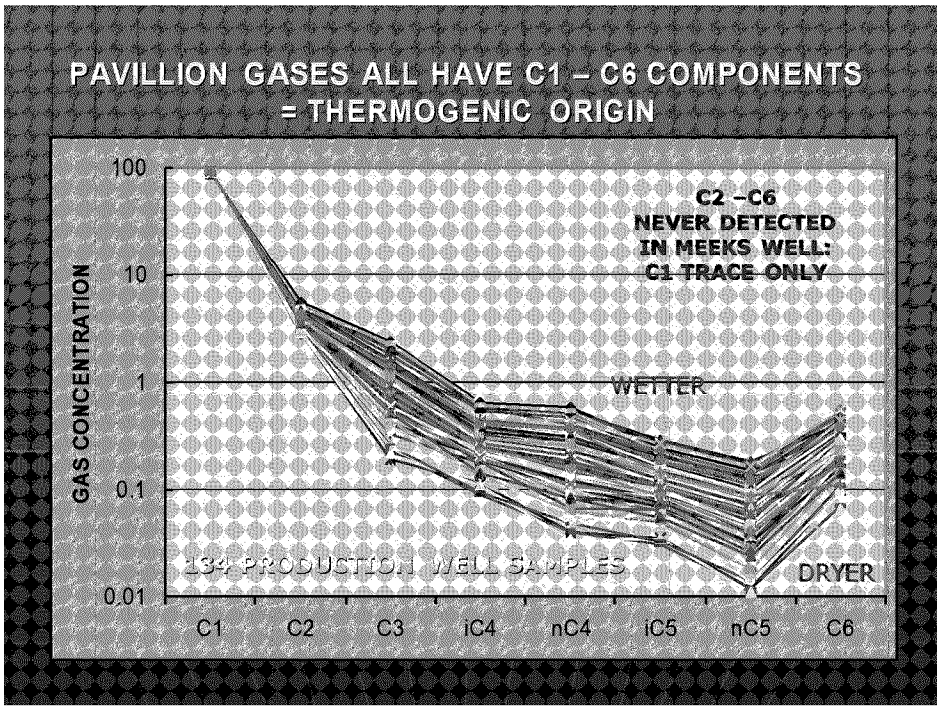
NATURAL GAS AND CONDENSATE SOURCES CAN BE READILY IDENTIFIED

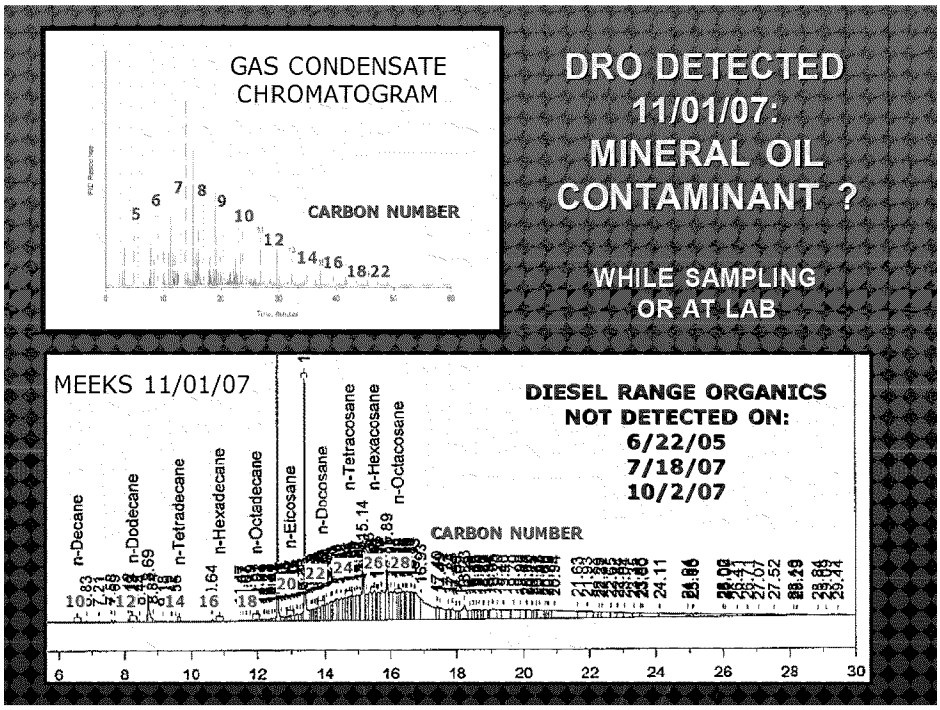
- GASES WITH METHANE THROUGH PENTANE HYDROCARBONS ARE THERMOGENIC
- GASES WITH JUST METHANE AND/OR WITH LITTLE ETHANE ARE SWAMP GAS (MICROBIAL)
- LIQUID PRODUCTS CAN BE IDENTIFIED ON THE BASIS OF CHROMATOGRAPHY



MEEKS WATER WELL SAMPLING SUMMARY

- **5/18/04**
  - TDS 536 SO_4 NO_3 Hardness
- **9/30/04**
  - Inorganics : Major Ions
- **4/5/05 Faucet sample**
  - Inorganics : Major Ions
  - Organics: VOC (8260)
  - C_1-C_6: Dissolved methane only
- **6/22/05 Well sample**
  - Organics: GRO-DRO (8015), VOC (8260), SVOC (8270)
- **12/05 Well Sample**
  - Inorganics :
  - Organics: TPH
- **7/06**
  - Organics: GRO
  - Dissolved methane: 0.16 mg/L
- **7/18/07 Well sample**
  - Organics: GRO-DRO (8015), VOC (8260), SVOC (8270)
- **8/13/07 Well sample**
  - Inorganics : Major Ions
  - C_1-C_6: Dissolved methane only 0.04 mg/L
- **10/2/07 Well Sample (Unsupervised Meeks)**
  - Inorganics : Major Ions
  - Organics: GRO-DRO (8015), VOC (8260), SVOC (8270) & Pesticides (8081)
  - Dissolved methane: 0.024 mg/L
- **11/1/07 Well Sample**
  - Organics: GRO-DRO (8015), VOC (8260), SVOC (8270)
  - Dissolved methane: 0.028 mg/L

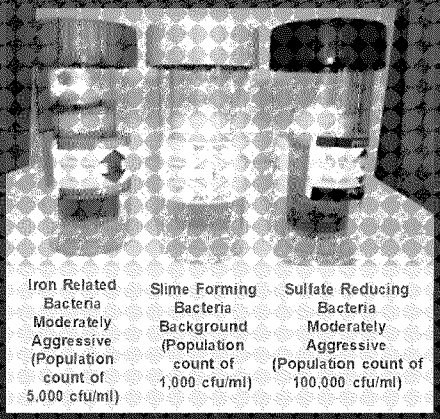

PAVILLION GASES ALL HAVE C1 – C6 COMPONENTS
= THERMOGENIC ORIGIN
GAS CONCENTRATION
100
10
1
0.1
0.01
C2 –C6
NEVER DETECTED
IN MEEKS WELL:
C1 TRACE ONLY
WETTER
134 PRODUCTION WELL SAMPLES
DRYER
C1
C2
C3
iC4
nC4
iC5
nC5
C6

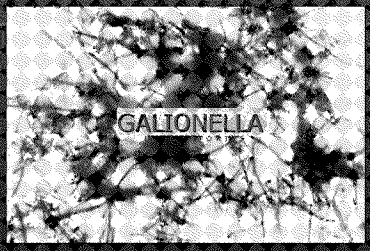

GAS CONDENSATE
CHROMATOGRAM
CARBON NUMBER
DRO DETECTED
11/01/07:
MINERAL OIL
CONTAMINANT ?
WHILE SAMPLING
OR AT LAB
MEEKS 11/01/07
n-Decane
n-Dodecane
n-Tetradecane
n-Hexadecane
n-Octadecane
n-Eicosane
n-Docosane
n-Tetracosane
n-Hexacosane
n-Octacosane
CARBON NUMBER
DIESEL RANGE ORGANICS
NOT DETECTED ON:
6/22/05
7/18/07
10/2/07

¾ DOMINANT SOURCE OF WATER WELL COMPLAINTS

- ODORS
- WATER QUALITY
- WATER QUANTITY

BACTERIA IN WATER

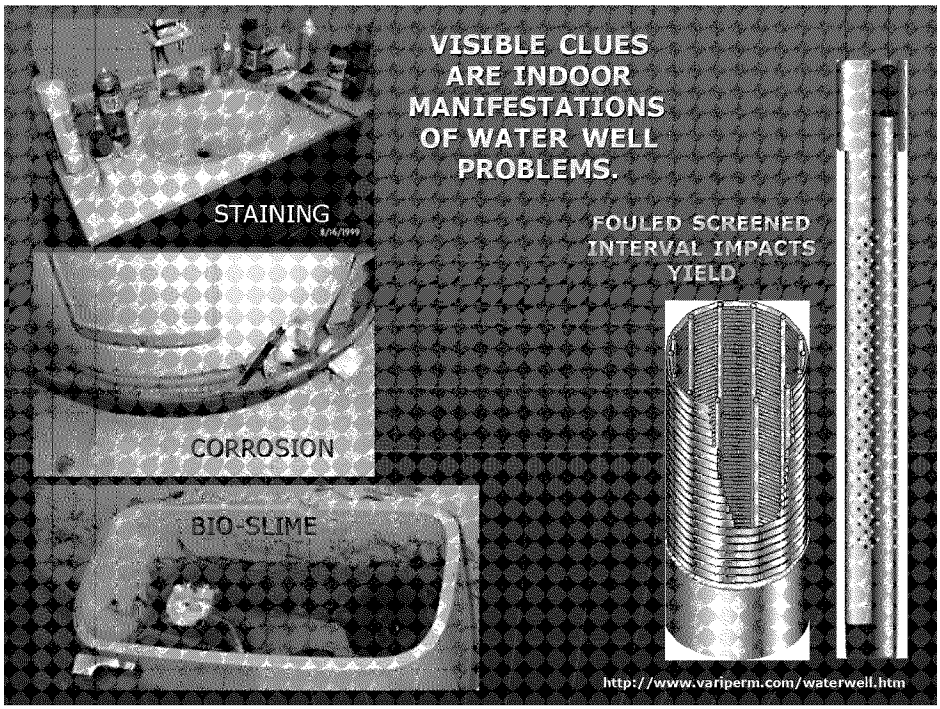


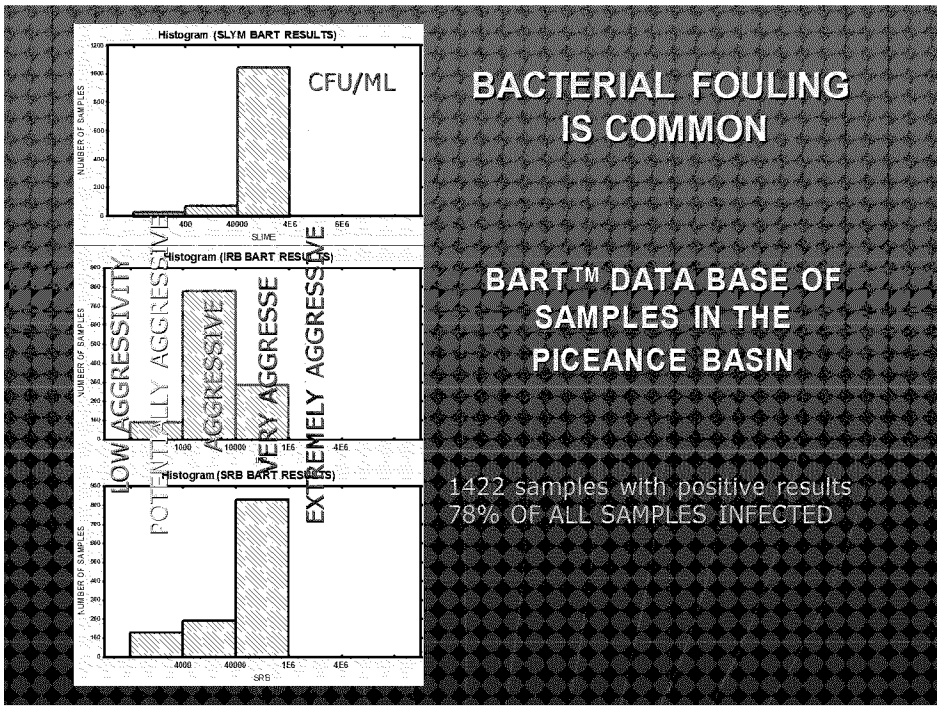


BIOLOGIC ACTIVITY REACTION TESTS (BART™)

POOR WATER WELL MAINTENANCE PRACTICES ARE LEADING CAUSE OF WATER WELL PROBLEMS

WELL CLOGGING, ODORS, AND POOR TASTE ARE MEDIATED BY BACTERIA


VISIBLE CLUES ARE INDOOR MANIFESTATIONS OF WATER WELL PROBLEMS.
STAINING
CORROSION
BIO-SLIME
FOULED SCREENED INTERVAL IMPACTS YIELD
http://www.variperm.com/waterwell.htm


Histogram (SLYM BART RESULTS)
CFU/ML
NUMBER OF SAMPLES
SLIME
Histogram (IRB BART RESULTS)
LOW AGGRESSIVITY
POTENTIALLY AGGRESSIVE
AGGRESSIVE
VERY AGGRESSIVE
EXTREMELY AGGRESSIVE
Histogram (SRB BART RESULTS)
SRB
BACTERIAL FOULING IS COMMON
BART™ DATA BASE OF SAMPLES IN THE PICEANCE BASIN
1422 samples with positive results
78% OF ALL SAMPLES INFECTED

OBSERVATIONS AT MEEKS WELL ARE CONSISTENT WITH SEVERE BIOFOULING

CLASSIC SYMPTOMS OF HIGH LOADING WITH NUISANCE BACTERIA:

- **Declining yield**
  - Difficulty purging well
- **Declining water quality**
  - Poor odor and bad taste
- **Low dissolved oxygen**
  - 7/05 0.62; 12/05 0.82 mg/L
- **Iron-related bacteria (IRB exist in filamentous consortia with slime formers):**
  - Repeated BART™ Cultures positive for IRB
  - Hydrocarbon-like odor
  - Yellow staining of porcelain fixtures
  - High dissolved iron content
  - Carbon filtering removes complexed iron (8/13/07 carbon vs. polypropylene filter: 8.4 mg/L vs. 1.1 mg/L)
- **Slime formers**
  - Visible after time in standing water as floating filamentous colonies
- **Sulfate-Reducing Bacteria (SRB)**
  - Repeated BART™ cultures positive for SRB
  - Carbon filtering removes complexed iron
  - 1.3 mg/L dissolved sulfide measured 12/05
  - Hydrocarbon-like odor

QUALITY ASSURANCE IS A PROCESS OF CONTINUAL IMPROVEMENT

Checklists
Protocols
Reliability-Reproducibility
Documentation
Training - Communication

CONSISTENT SAMPLING AND ANALYSIS PROTOCOLS ARE NECESSARY

- FIELD PARAMETERS
  - T°, dO, Eh, pH, Ec, Visual
- MAJOR IONS
  - INCLUDE MINOR ELEMENTS
- ORGANICS
  - BTEX (8260)
  - GRO-DRO (8260)
  - TEPH
  - DISSOLVED METHANE (SK175)
  - C_1-C_6 CHROMATOGRAPHY
- BART™
  - IRB, SRB, SLIME
- BLANKS
  - LAB METHOD, FIELD
- DUPLICATES

STL

CHECK LABORATORY DATA FOR QUALIFIERS

DATA QUALIFIER PAGE

GLYCOL SOLUBILITY
>10,000,000 UG/L (10%)

These definitions are provided in the event the data in this report requires the use of one or more of the qualifiers. Not all qualifiers defined below are necessarily used in the accompanying data package.

ORGANIC DATA QUALIFIERS

ND or U Indicates compound was analyzed for, but not detected.

J Indicates an estimated value. This flag is used either when estimating a concentration for tentatively identified compounds where a 1:1 response is assumed, or when the data indicates the presence of a compound that meets the identification criteria but the result is less than the sample quantitation limit but greater than zero.

C This flag applies to pesticide results where the identification has been confirmed by GC/MS.

B This flag is used when the analyte is found in the associated blank, as well as in the sample.

E This flag identifies compounds whose concentrations exceed the calibration range of the instrument for that specific analysis.

D This flag identifies all compounds identified in an analysis at the secondary dilution factor.

N Indicates presumptive evidence of a compound. This flag is used only for tentatively identified compounds, where the identification is based on the Mass Spectral library search. It is applied to all TIC results.

EXAMPLE OF LAB CONTAMINATION

AQUEOUS-SW8463 8015- ALL GLYCOLS	ESTIMATE		DETECTION LIMIT				
Diethylene glycol	2600	J	5000	UG/L	8015	10/06/2007 12:35	LMW
Ethylene glycol	ND		5000	UG/L	8015	10/06/2007 12:35	LMW
Propylene Glycol	ND		5000	UG/L	8015	10/06/2007 12:35	LMW
Triethylene glycol	4300	BJ	5000	UG/L	8015	10/06/2007 12:35	LMW

SUMMARY

- HYDROLOGY, GEOLOGY, AND COMPLETION TECHNOLOGY NOT CONDUCIVE FOR VERTICAL COMMUNICATION WITH MEEKS WELL
  - AQUIFER SANDS THIN AND LATERALLY DISCONTINUOUS
  - MAJOR AQUITARD/FRACTURE BARRIER BETWEEN WIND RIVER A AND B ZONES
  - PERFORATED AND COMPLETED INTERVALS WELL BELOW MEEKS WELL DEPTH
  - COMPLETION VOLUMES FOR STIMULATION SMALL
- THERE IS NO EVIDENCE OF VERTICAL COMMUNICATION AT EITHER THE PAVILLION 24-2 OR THE MEEKS WELL
  - NO EVIDENCE OF HYDROCARBONS IN MEEKS WELL
  - NO CHANGE IN WATER QUALITY SINCE BEFORE PAVILLION 24-2 COMPLETED
  - NO WATER PRODUCTION AT PAVILLION 24-2
  - NO SULFATE IN WATER
- MEEKS WELL EXHIBITS CLASSIC SYMPTOMS OF BIOFOULING
  - DECLINING YIELD AND WATER QUALITY
  - NUISANCE BACTERIA CULTURED WITH BART
  - [illegible]
  - SLIME FORMERS GROW WITHOUT CULTURE
- FUTURE SAMPLING AND ANALYSIS SHOULD BE CONSISTENT

QUESTIONS AND ANSWERS

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