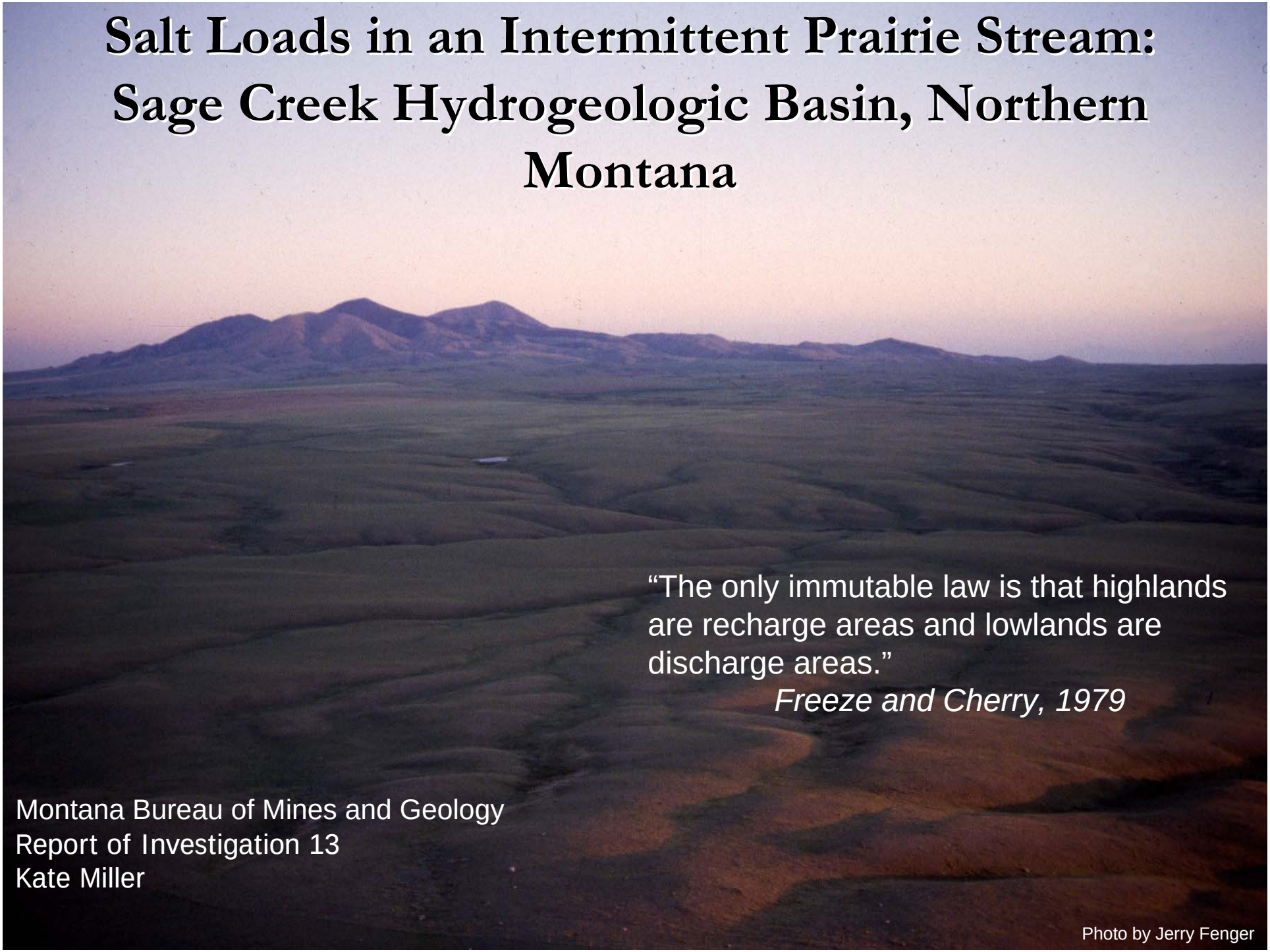
3 Case Studies of Ground Water in Montana

Kate Miller, Supervisor
Compliance Section, PWSB
Formerly Research Hydrogeologist with the MBMG

Salt Loads in an Intermittent Prairie Stream: Sage Creek Hydrogeologic Basin, Northern Montana

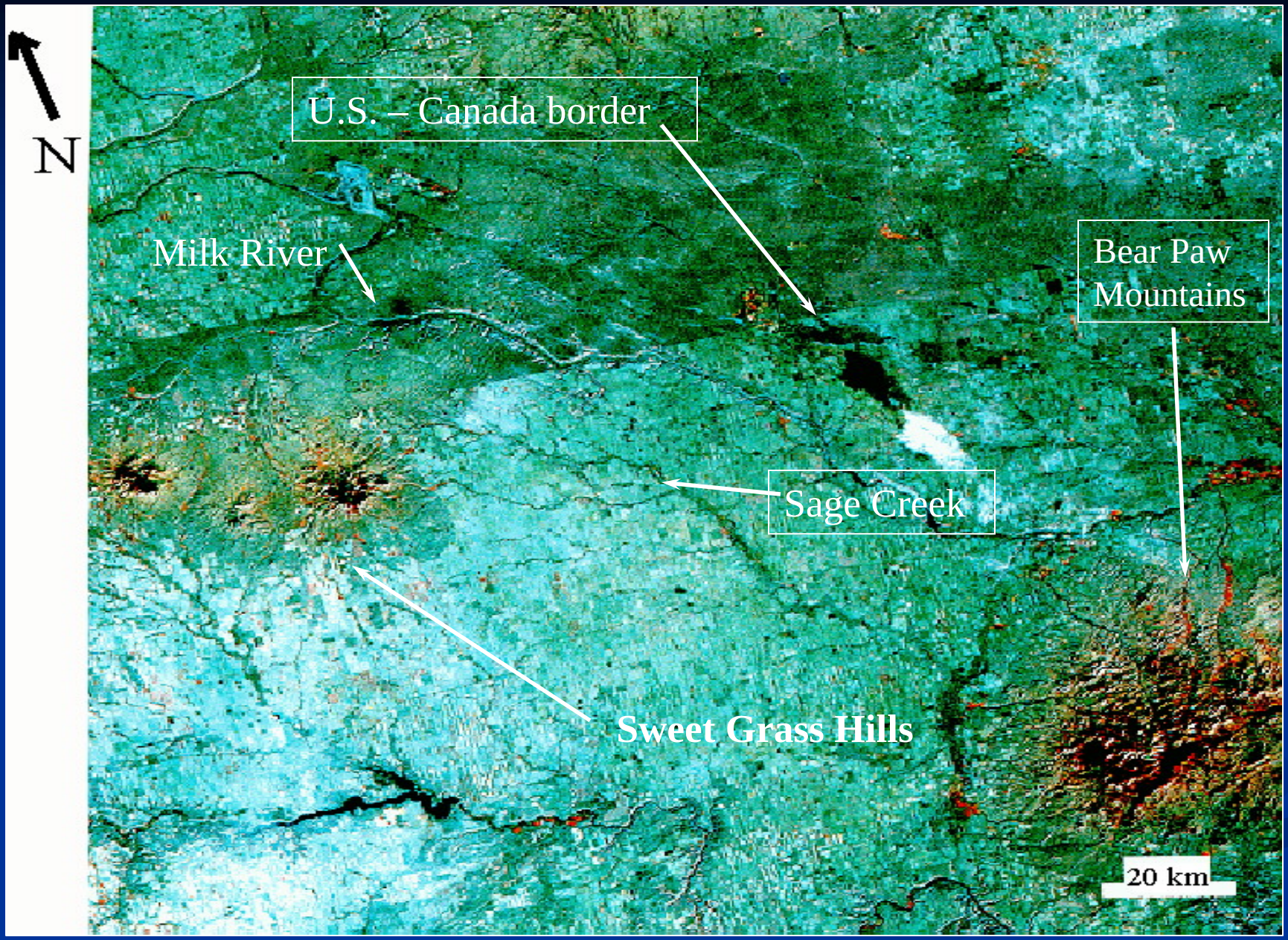


"The only immutable law is that highlands are recharge areas and lowlands are discharge areas."

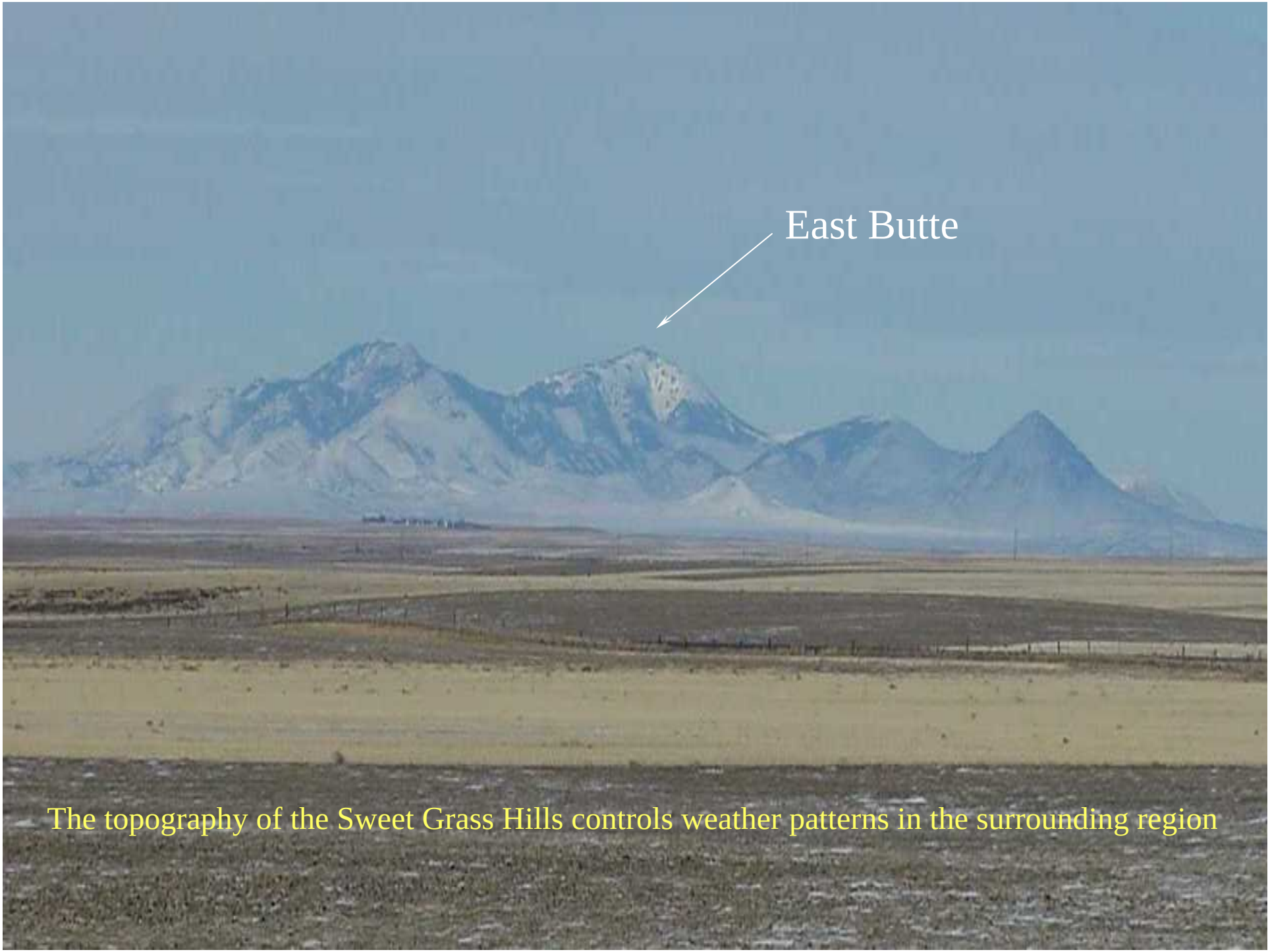
Freeze and Cherry, 1979

Montana Bureau of Mines and Geology
Report of Investigation 13
Kate Miller

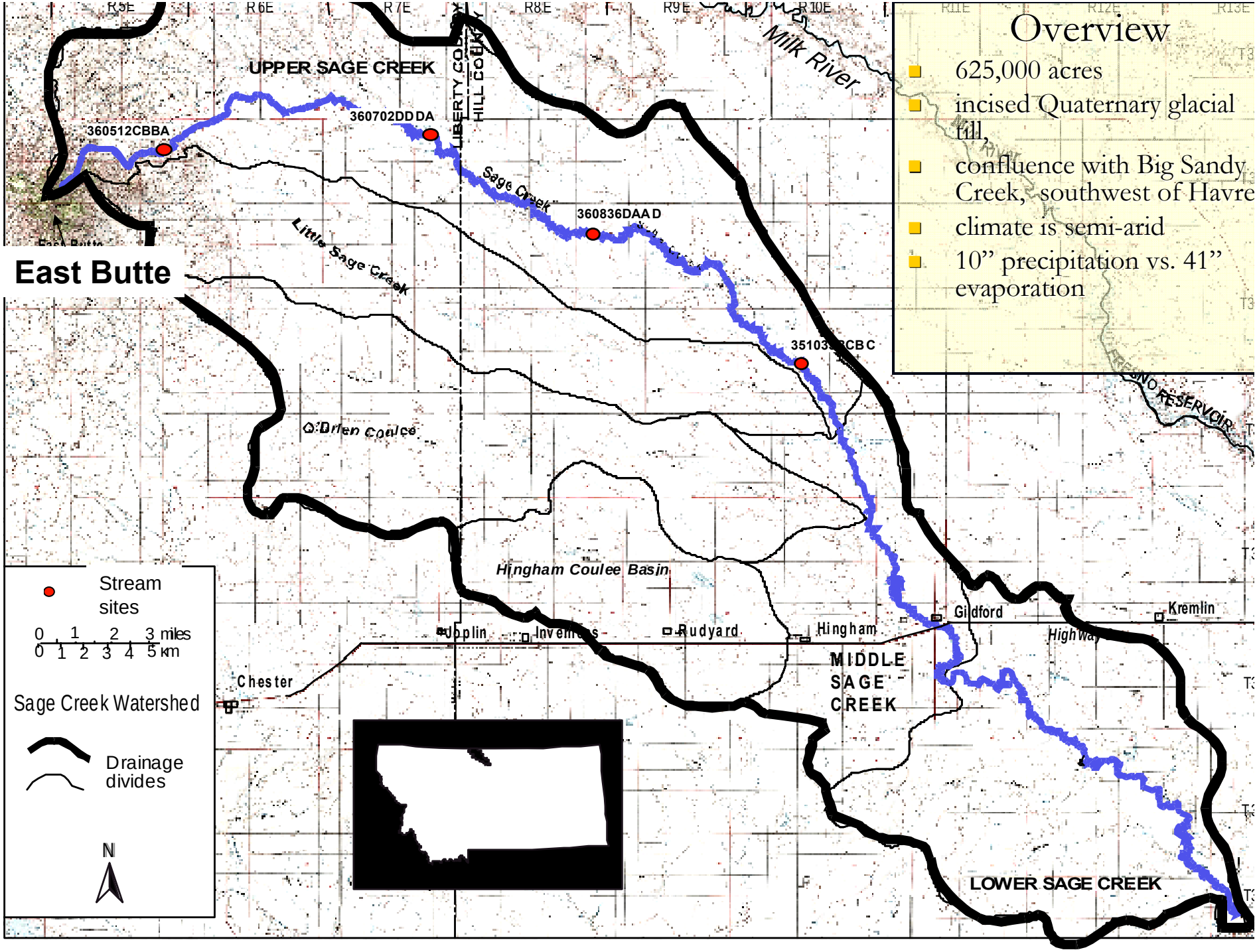
Photo by Jerry Fenger



LandSat Image 10/25/87



The topography of the Sweet Grass Hills controls weather patterns in the surrounding region


Overview
625,000 acres
incised Quaternary glacial till,
confluence with Big Sandy Creek, southwest of Havre
climate is semi-arid
10" precipitation vs. 41" evaporation
UPPER SAGE CREEK
360512CBBA
360702DDDA
360836DAAD
Sage Creek
Little Sage Creek
East Butte
O'Brien Coulee
Hingham Coulee Basin
Milk River
LIBERTY COUNTY
HILL COUNTY
Joplin
Inverness
Rudyard
Hingham
Gildford
Kremlin
Chester
MIDDLE SAGE CREEK
LOWER SAGE CREEK
Stream sites
0 1 2 3 miles
0 1 2 3 4 5 km
Sage Creek Watershed
Drainage divides
N

CADY

Crop/fallow
January, 2002

Native range/pasture

Sage Creek at Joplin Road
(March, 1999)

Sage Creek at Gildford
(January, 2002)

25-Year Flood Occurred in June 2002

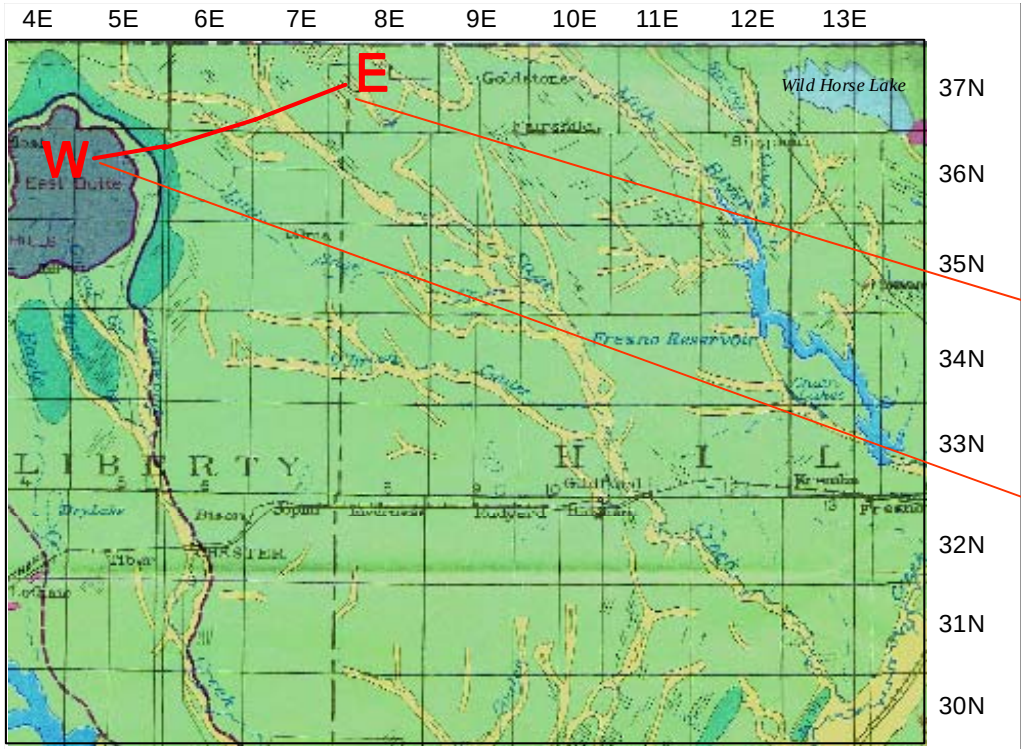
Rationale

Strategy

- Sage Creek is typical of most intermittent streams in the northern Great Plains
- Gain or loss of water via deep seepage is a significant component of streamflow.

- Prove that the stream is controlled by ground-water discharge.
- Quantify salt loading to the watercourse from ground water.

Hydrogeologic Setting



EXPLANATION

Glacial lake deposits
Fine sand, silt, and clay of glacial lakes... and other smaller glacial lakes (Wild Horse Lake). Includes some areas of till and bedrock where the mantling lake deposits have been removed or are patchy in distribution. Boundaries and existence of some lakes inferred solely from distribution of erratics, altitudes of spillways, and from topography.

End or marginal moraine deposits
End moraines of high local relief or marginal areas of stagnation moraines, consisting mostly of till. Includes some kame moraines and other minor ice-contact stratified deposits.

Ground moraine deposits
Also includes recessional moraines and oblation moraines of low local relief; consists mostly of till. Includes some kames, eskers, and other minor ice-contact stratified deposits.

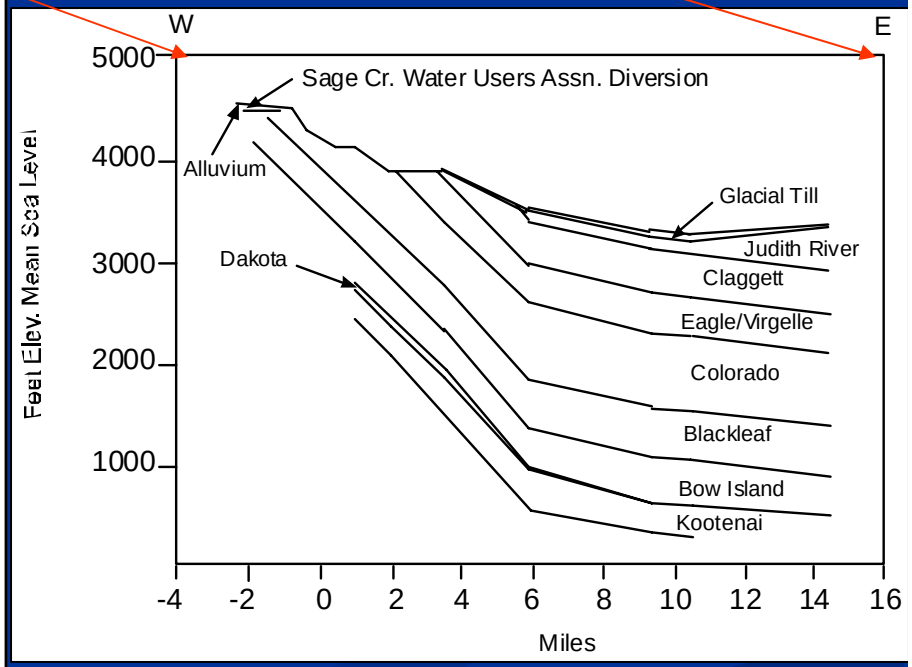
Outwash, inwash, and terrace deposits
Mainly stratified silt, sand, and gravel. Deposits in some channels are thin to nearly absent. Meltwater channels too small to be shown separately are represented by black arrows.

Ice-contact stratified drift deposits
Mostly silt, sand, and gravel. Only larger deposits shown.

Unglaciated areas
Paleozoic and Mesozoic sedimentary rocks uptilted and intruded by igneous rocks.

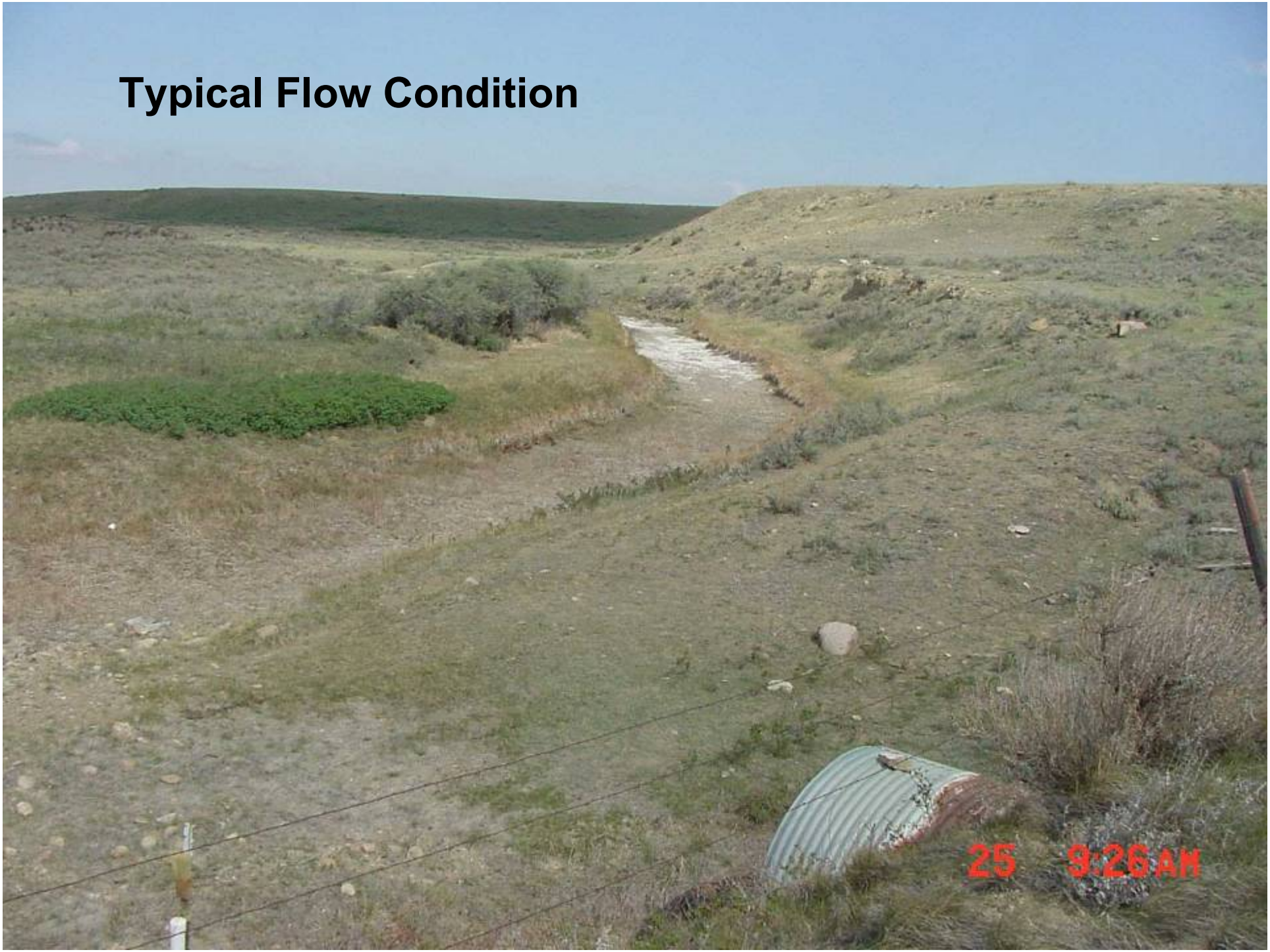
Trace of cross section (fig.4)

Figure 3. Glacial features of the Sage Creek watershed (excerpted from Colton and others, 1961).



Sediment Transport Near Headwaters

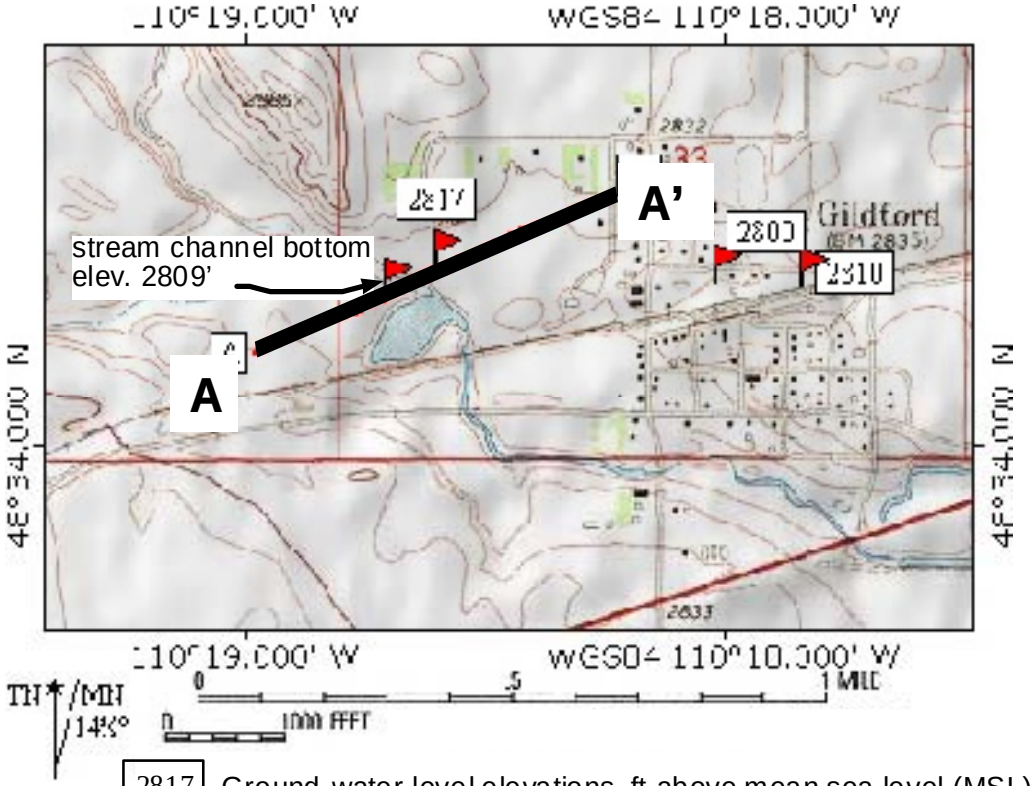
Typical Flow Condition



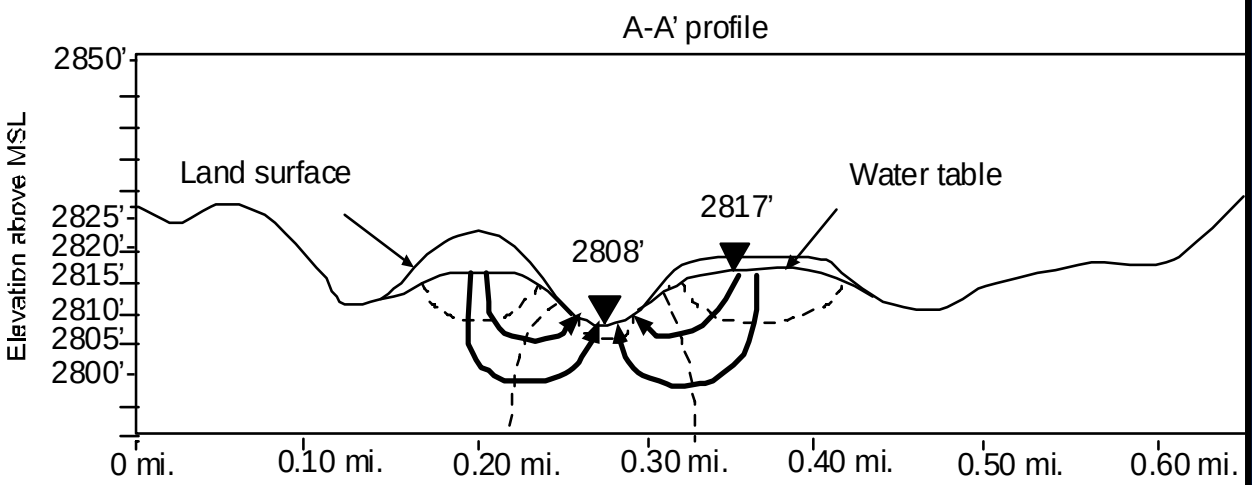
Step 1.
Proving that Sage Creek is Controlled by Ground-Water Discharge

Factors controlling streamflow in intermittent streams :

- Total discharge = ground-water discharge (or baseflow if flowing) + surface runoff + interflow
- **Surface runoff:** flow dependent on precipitation events, spring runoff, irrigation return flows. Sage Creek is an intermittent stream in an arid climate; surface runoff is very transient and "flashy."
- **Interflow:** lateral movement of water in the unsaturated zone during and immediately following a precipitation event – also transient and "flashy."



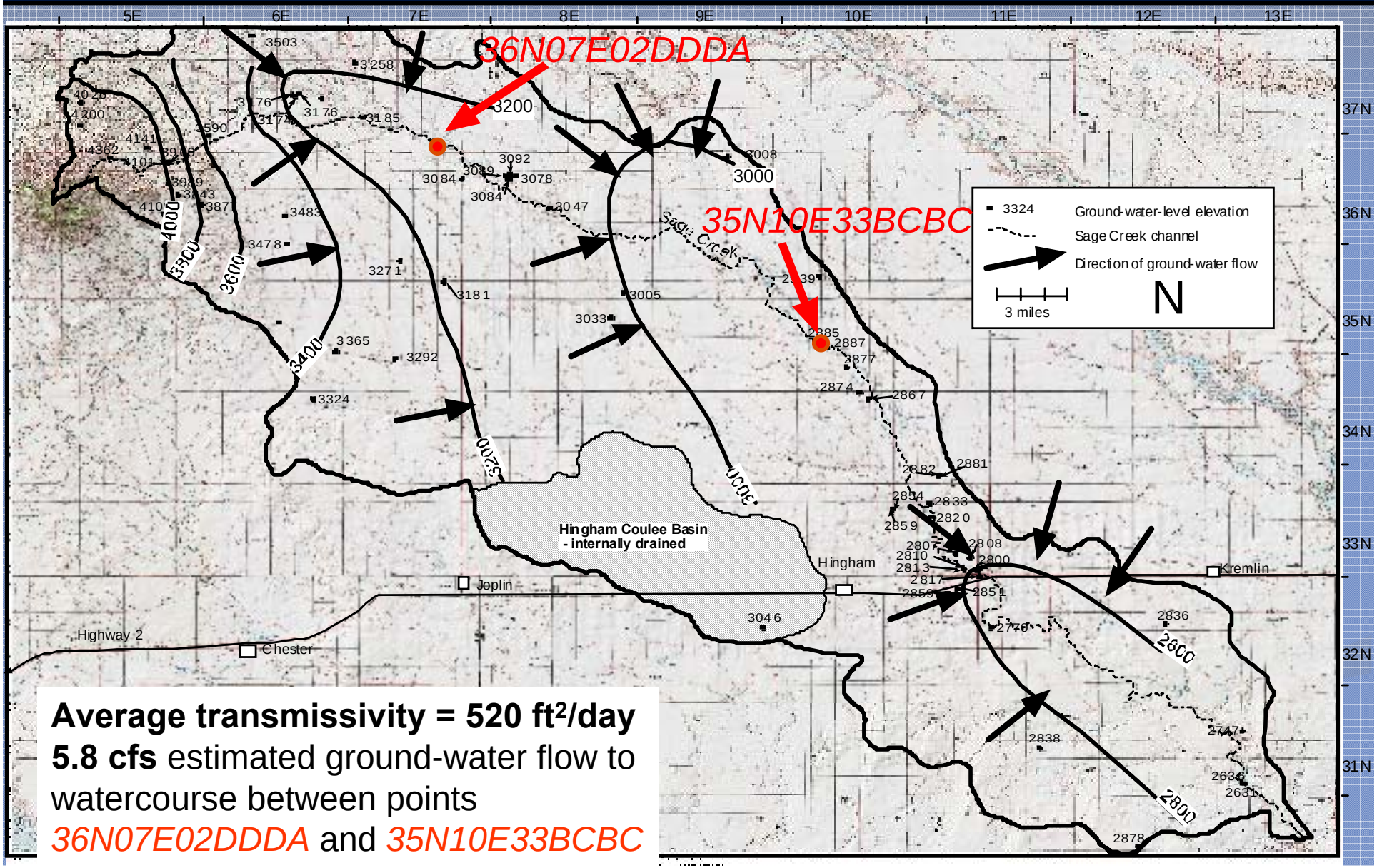
2817 Ground-water-level elevations, ft above mean sea level (MSL)



Vertical ground-water flow net

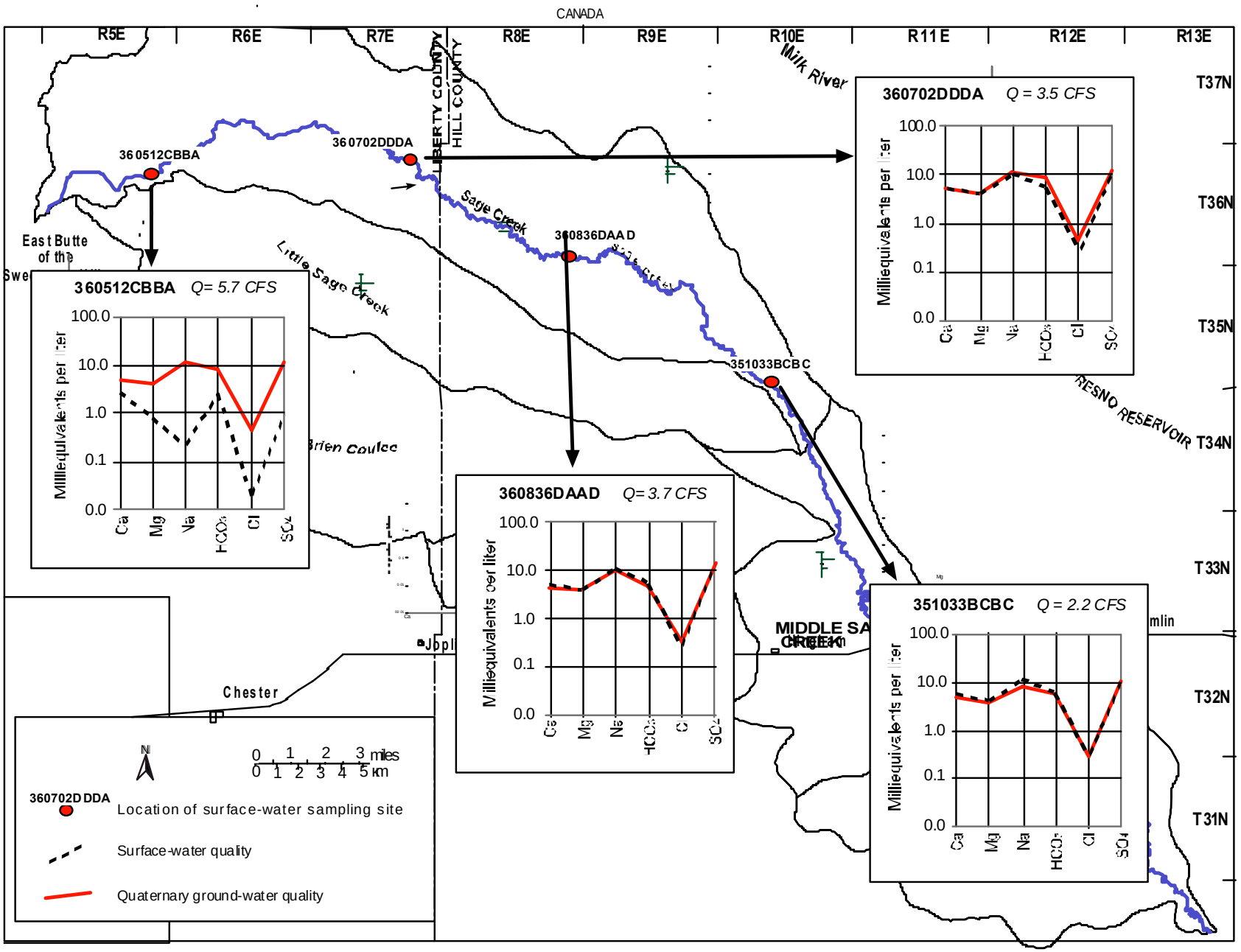
near Gildford illustrating ground-water delivery from recharge areas to the creek bottom discharge area (after Hubbert, 1940).

Water-Table Contours for Quaternary Deposits



Average transmissivity = 520 ft²/day
5.8 cfs estimated ground-water flow to watercourse between points *36N07E02DDDA* and *35N10E33BCBC*

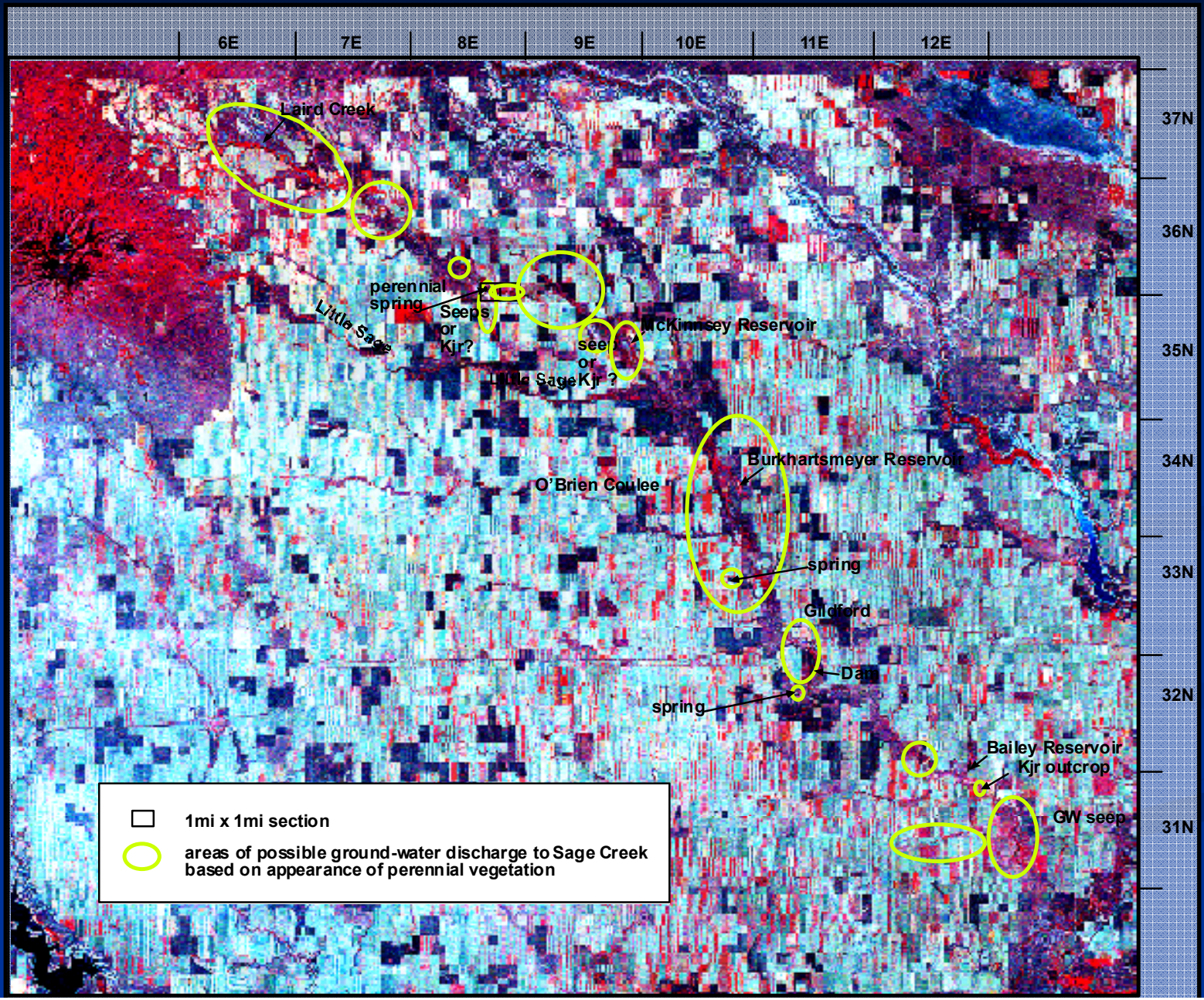
Compare Ionic Signatures of Ground Water and Surface Water



Saline Seep into Stream Channel

- Saline seep occurs in ground-water discharge areas
- Ground water in the Quaternary deposits is characterized as a sodium-sulfate type water typical of saline seeps
- Bank slumpage causes increase of in-stream **TSS, TDS, and nutrients**

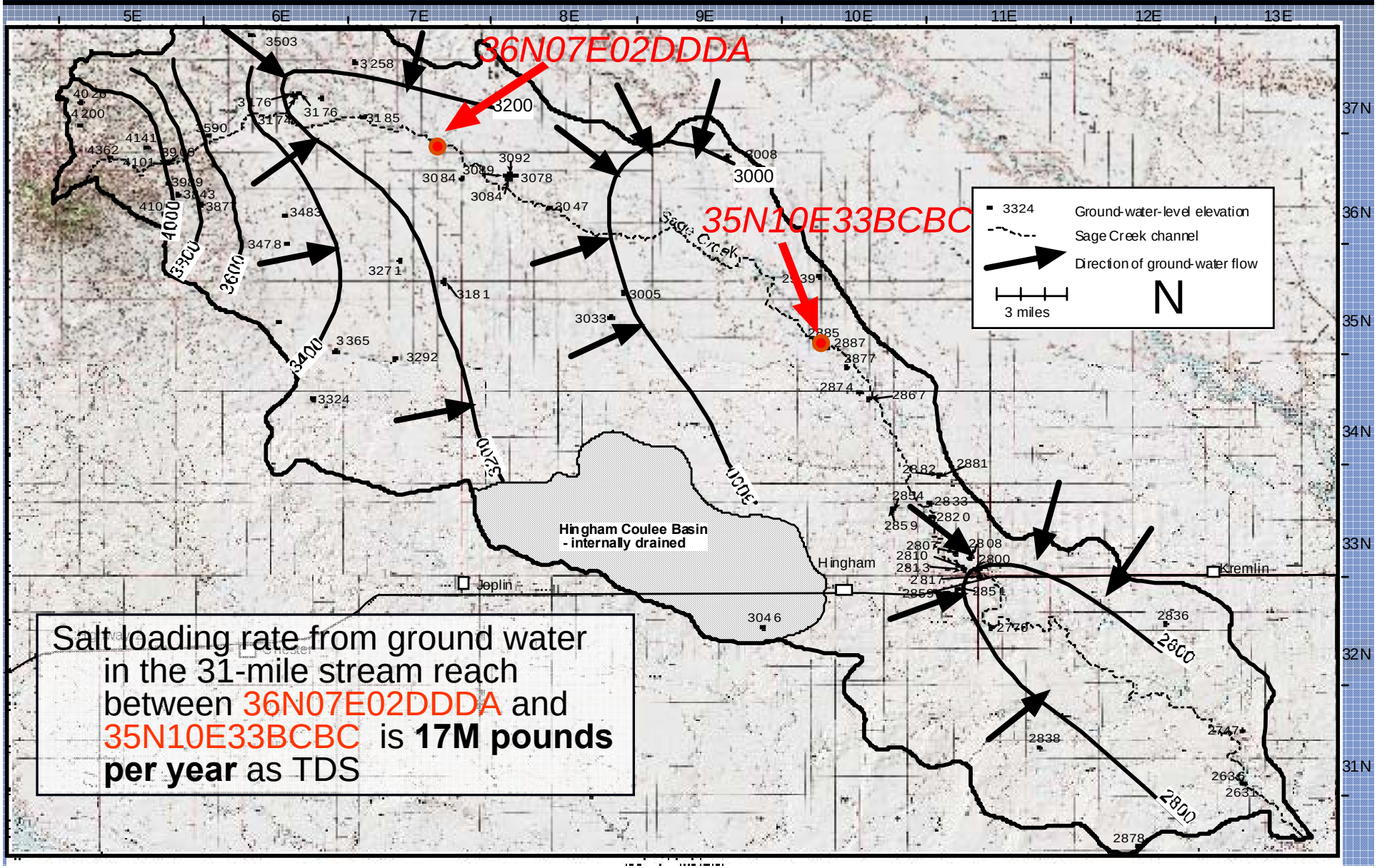
LandSat Infrared View, September 1992



Summary of Evidence that Sage Creek is Controlled by Ground-Water Discharge

- Gaining stream in the middle and lower reaches
- Perennial pools in the absence of precipitation or runoff
- Hydraulic data allow an estimate of the ground-water flow rate to the channel of about 5.8 cfs in the 31-mile stream reach between the sites 360602DDDA and 351033BCBC.
- Stream water-quality signatures in the middle portion of the watershed are identical to those of ground water found in Quaternary deposits.
- Visual evidence of saline seep occurring in the stream channel
- IR evidence of perennial vegetation along the watercourse

Step 2. Quantify Salt Loading

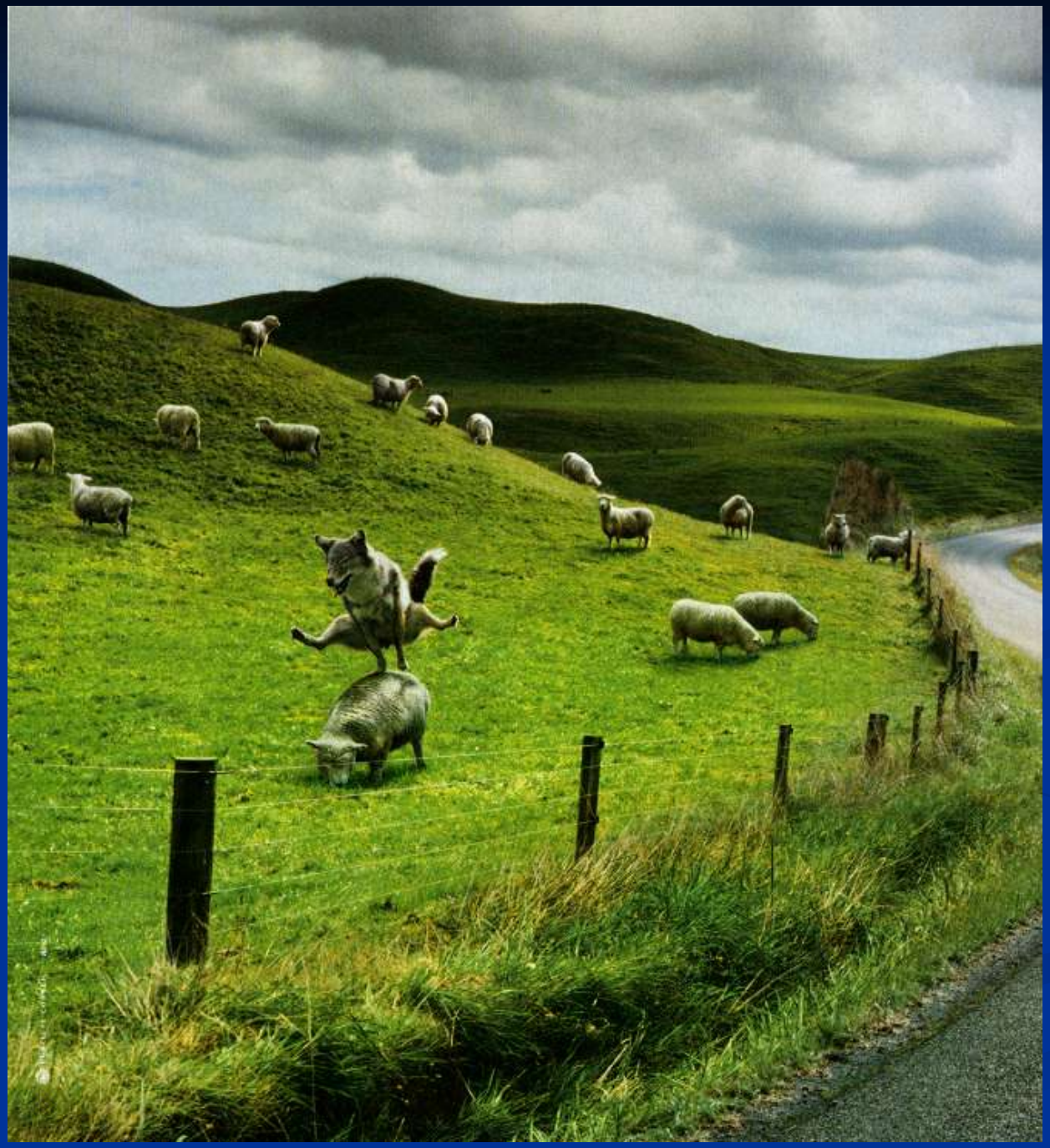


Salt loading rate from ground water in the 31-mile stream reach between 36N07E02DDDA and 35N10E33BCBC is **17M pounds per year** as TDS

Water-Quality Degradation

- Dryland salinity
- Implement land uses that reduce the quantity of ground-water discharge to the watercourse through the process of dryland salinity.

Photo by Jerry Fenger



Use agriculture as a tool in resource protection

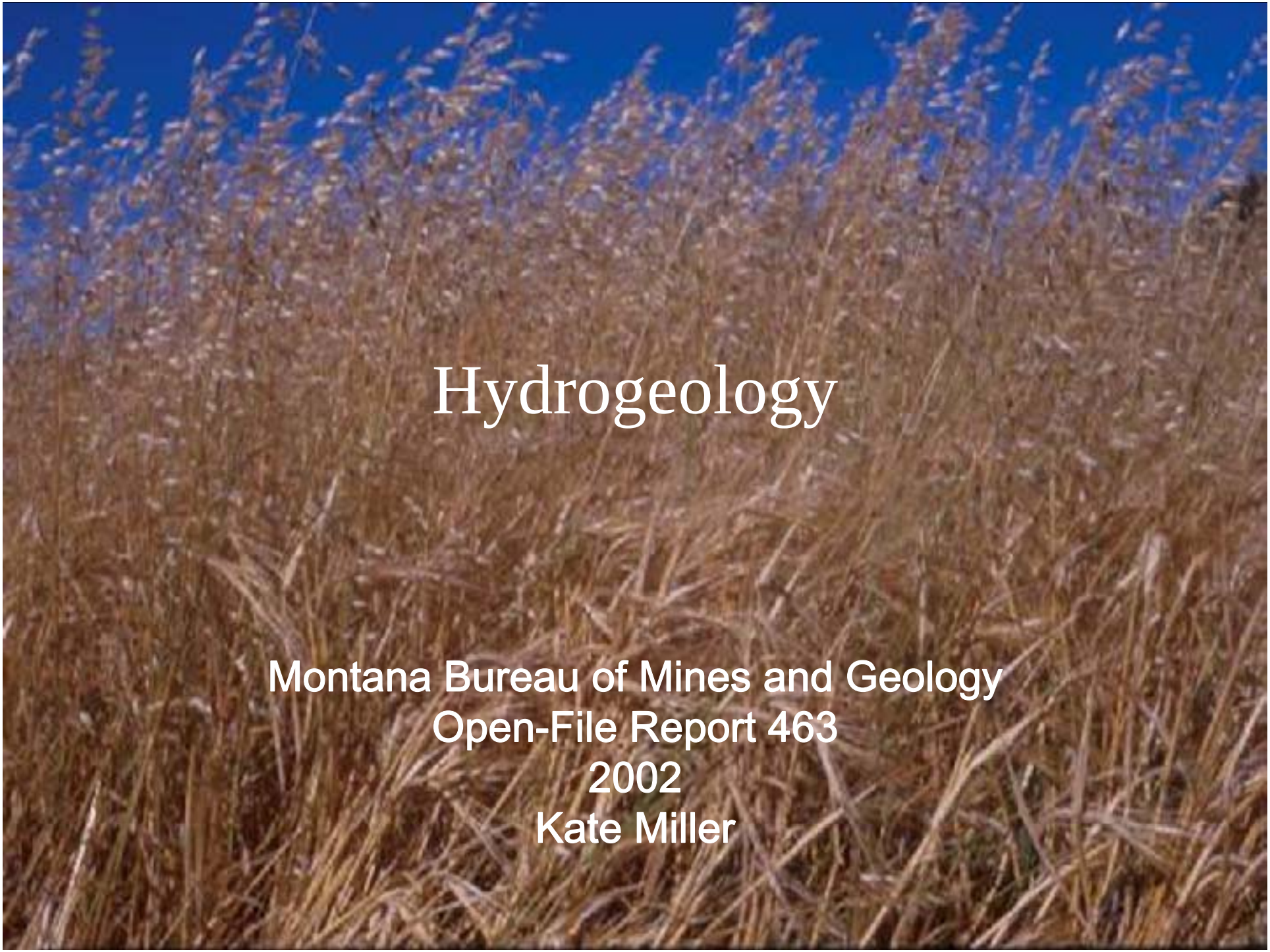
The Greenfields Bench Aquifer

Part 1:

Summarize the Hydrogeology

Part 2:

Irrigation Methods and Assert Herbicide in Ground Water



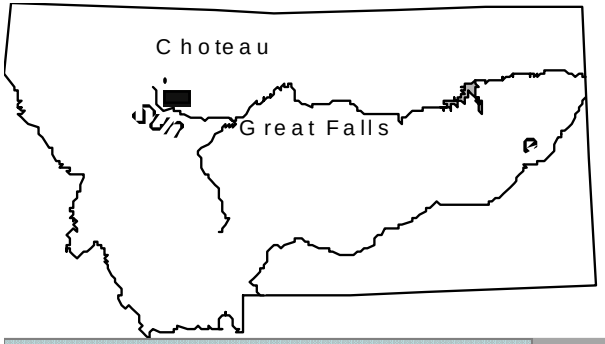
Hydrogeology

Montana Bureau of Mines and Geology
Open-File Report 463
2002
Kate Miller

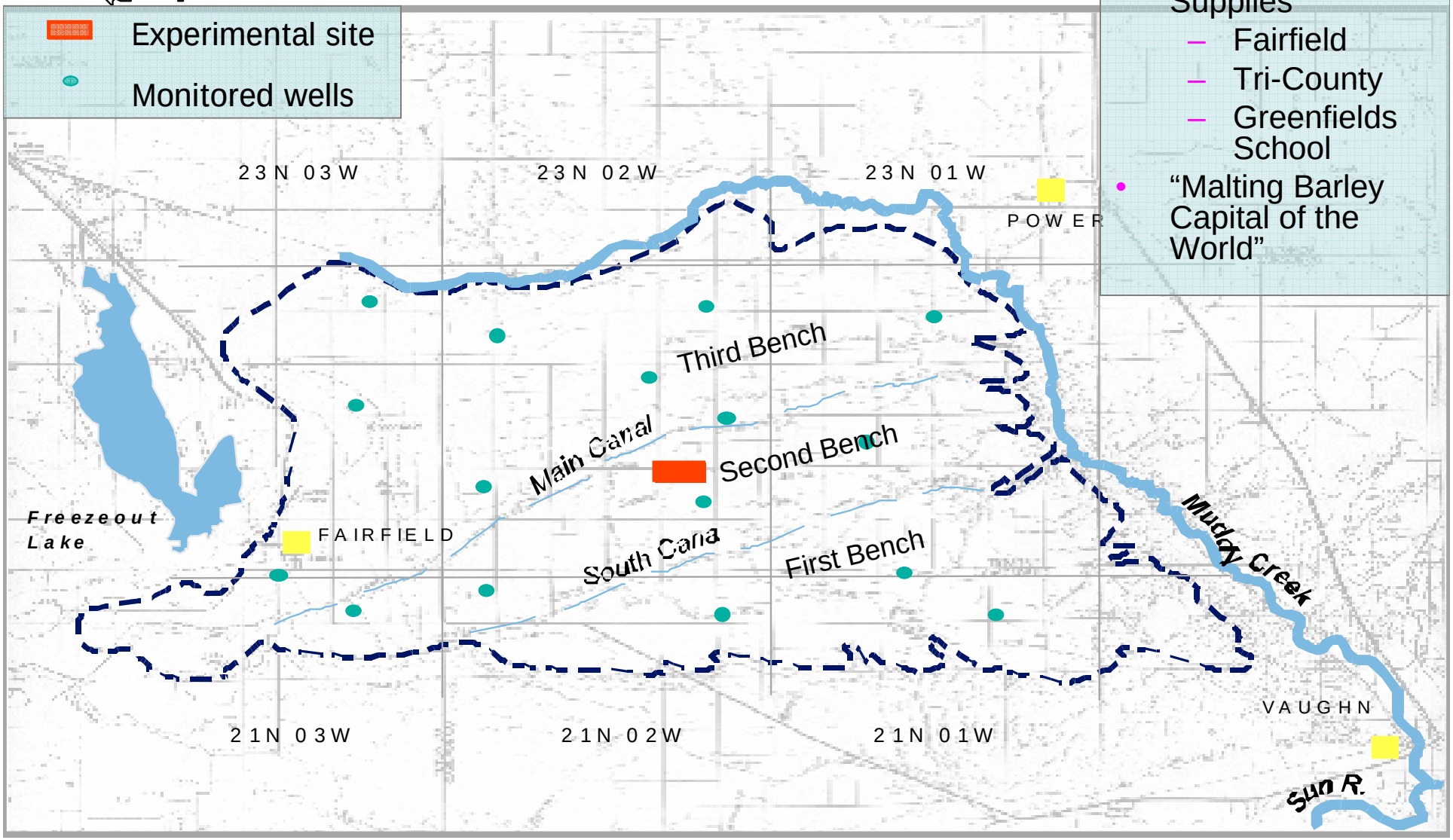
Objectives

- Determine if Health Advisory levels for pesticides were being exceeded on the Bench
- Hydrogeologic controls on ground-water flow and pesticide transport
- Compare irrigation practices on Assert herbicide transport to ground water

Greenfields Bench Geography



- 84,000 acres
- 300 ft. local relief
- Gravel covered bedrock
- 3 Public Water Supplies
  - Fairfield
  - Tri-County
  - Greenfields School
- "Malting Barley Capital of the World"



Fun Facts

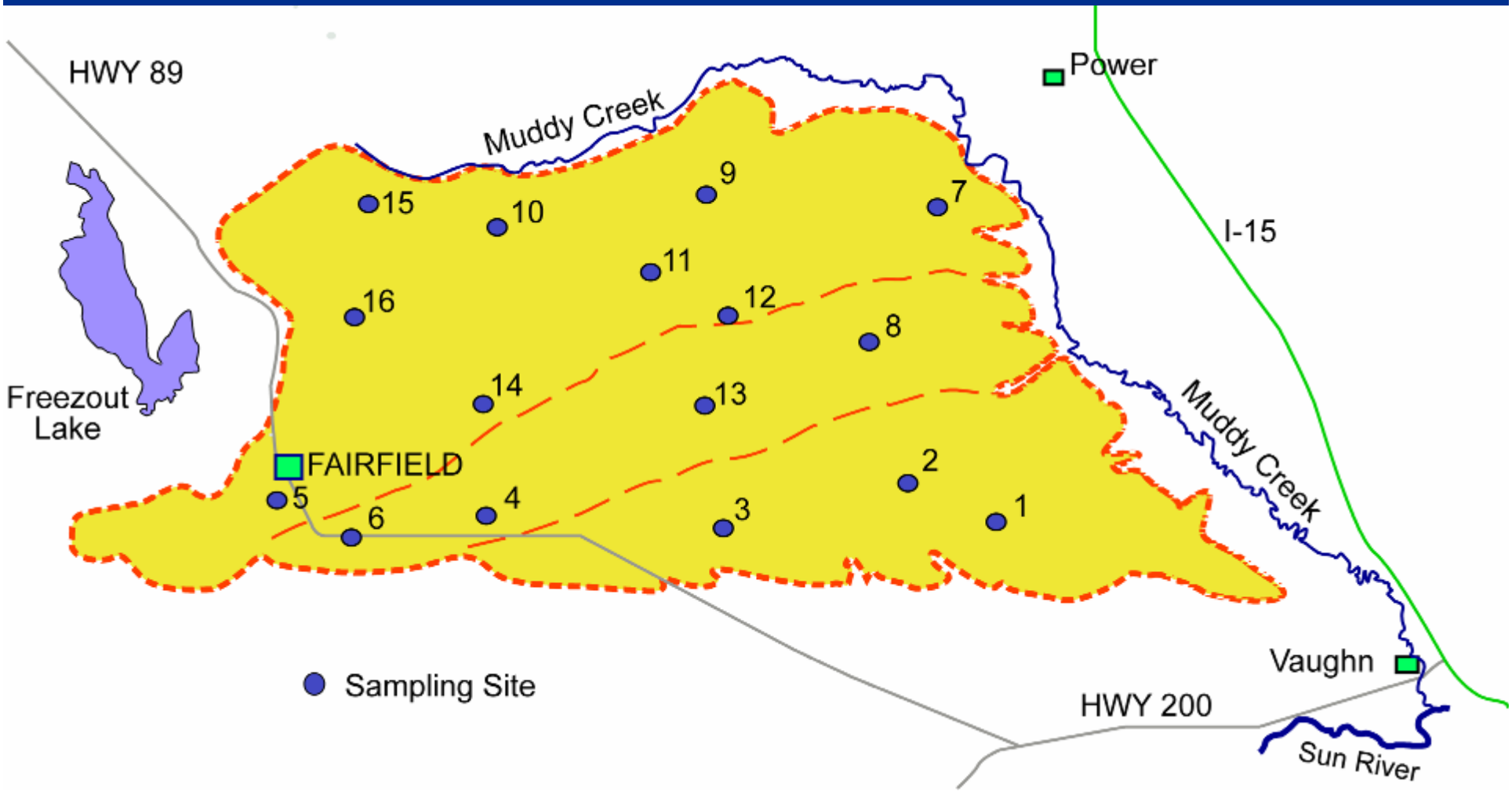
- Mean annual precipitation 12.35”
- Evaporation rate 38-40 in. per year
- Irrigation water supplied from Gibson Reservoir; discharged mostly to Muddy Creek
- Greenfields Bench aquifer is an unconfined, sole-source alluvial aquifer that supplies water for 3 public water systems and approximately 400 private wells.

- Some of the agricultural chemicals used:
  - Assert (Imazamethabenz-methyl)
  - Achieve (tralkoxydim)
  - Picloram
  - 2,4-D
  - Prometon
  - clopyralid

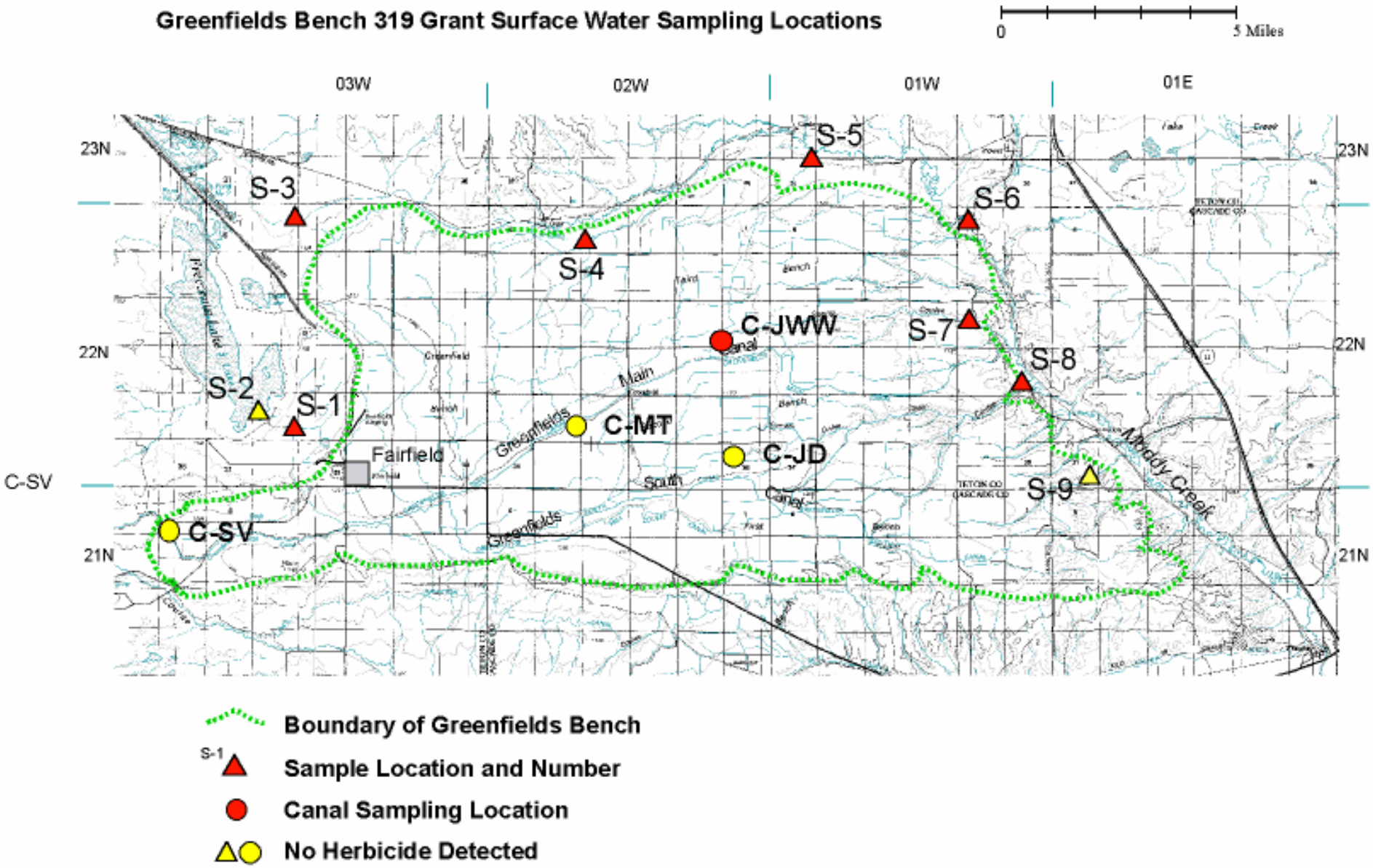
Methods

- Mt. Dept. Agriculture: quarterly pesticide sampling of 16 wells (April 1998-July 1999)
- Measured water levels in 86 additional wells
- Inorganic water-quality analyses
- Aquifer tests
- Surface-water flow measurement and water-quality sampling of selected drains, seeps, and springs

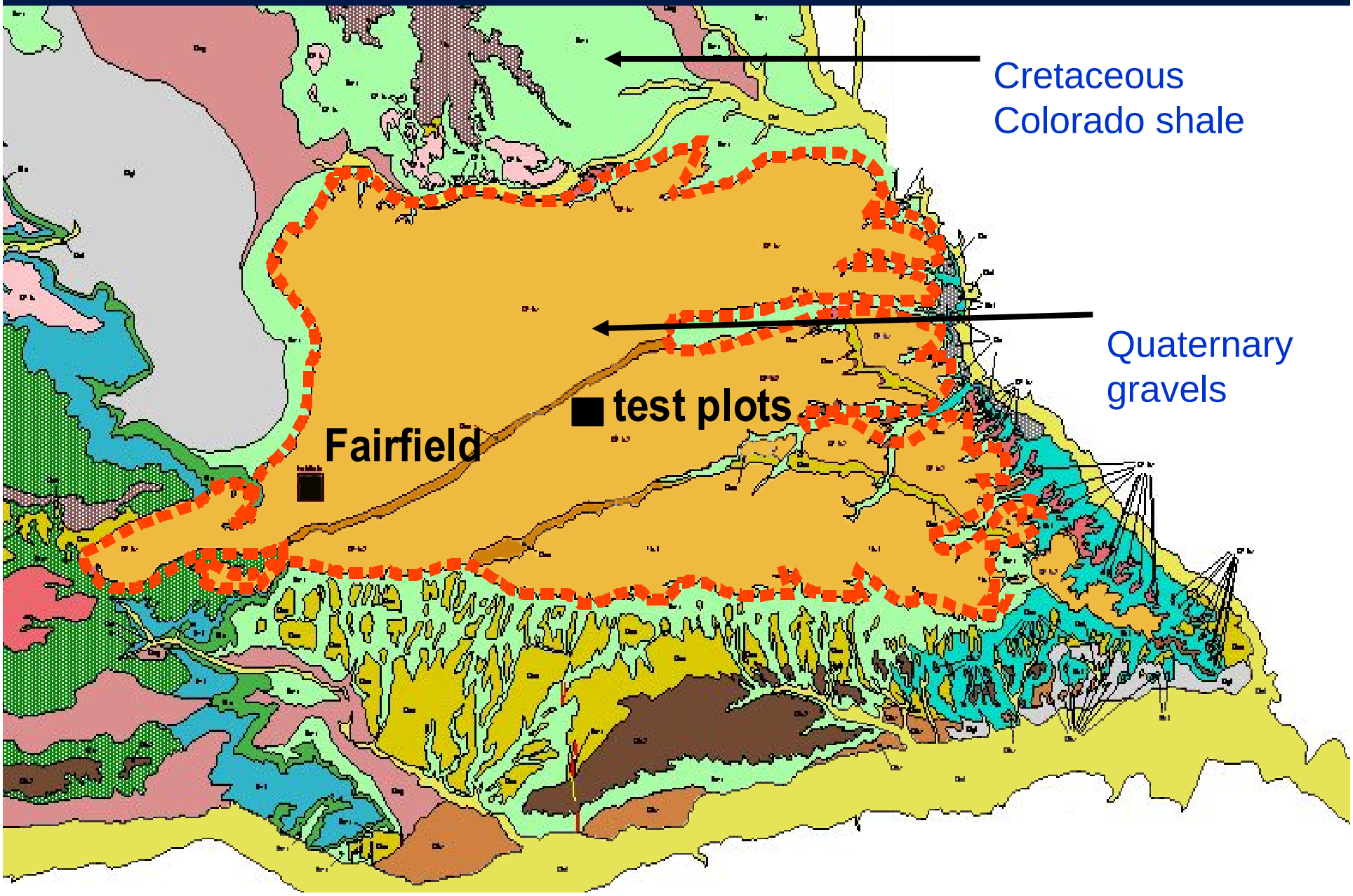
Greenfields Bench
16 Ground-Water Sampling Sites



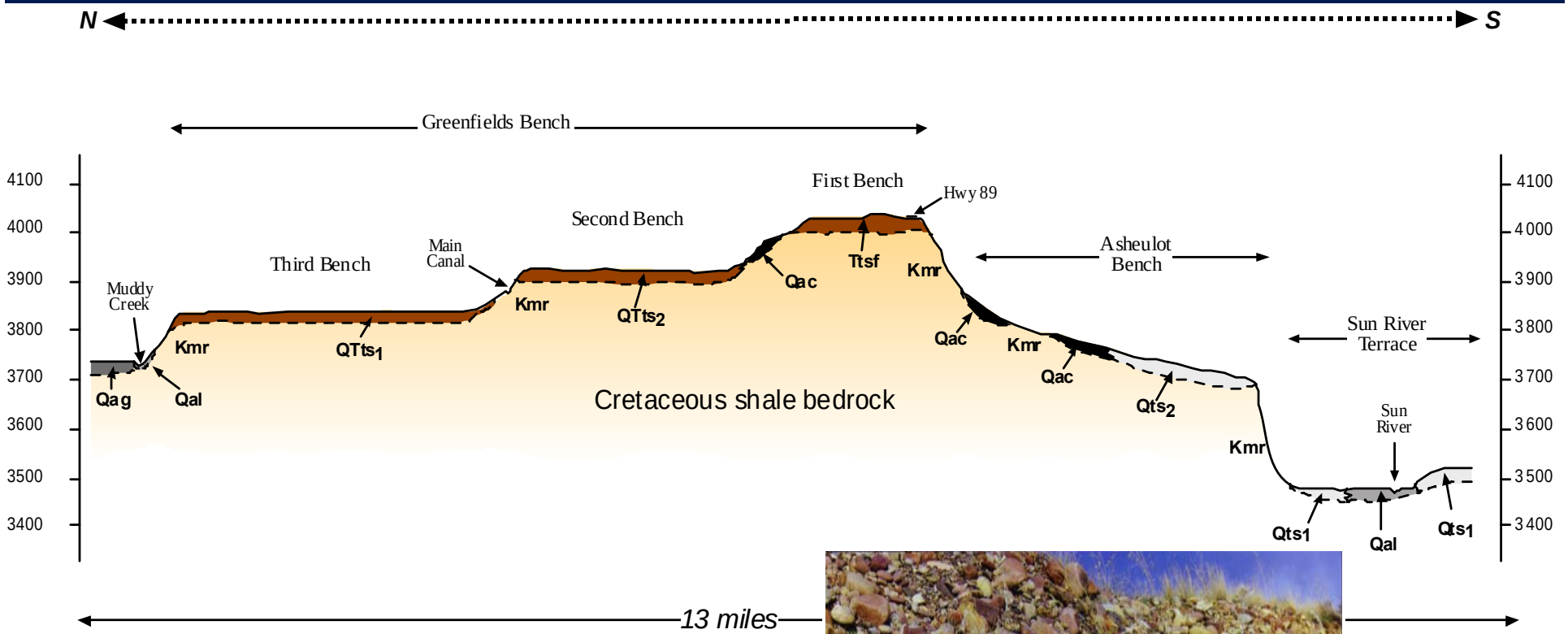
Surface-Water Sampling Sites

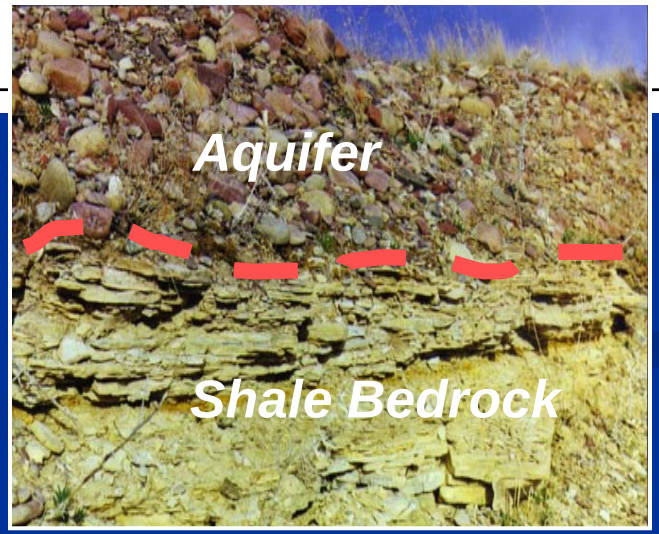


Geology


Cretaceous
Colorado shale
Quaternary
gravels
test plots
Fairfield

Geological Cross-Section



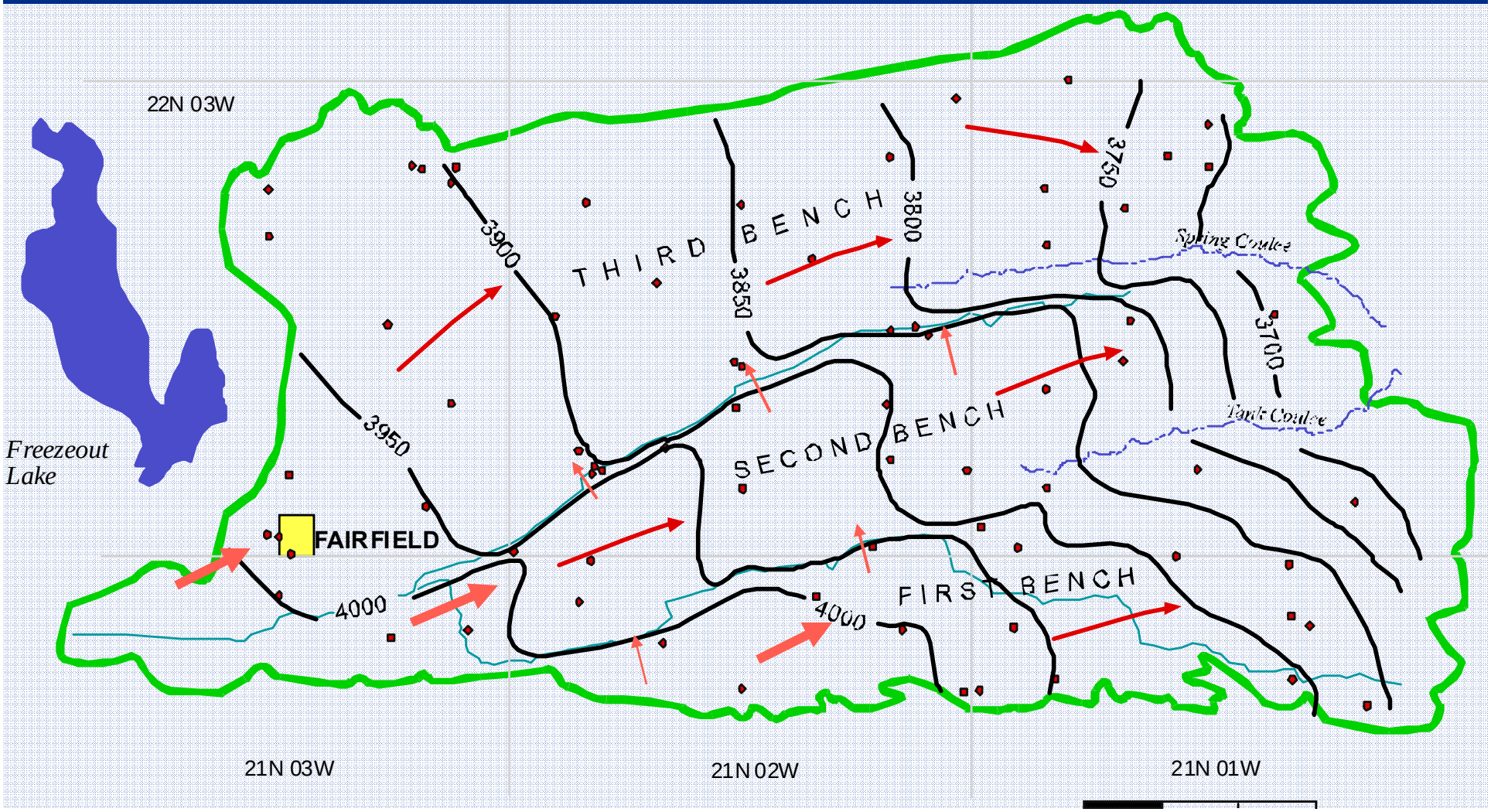


The Soil

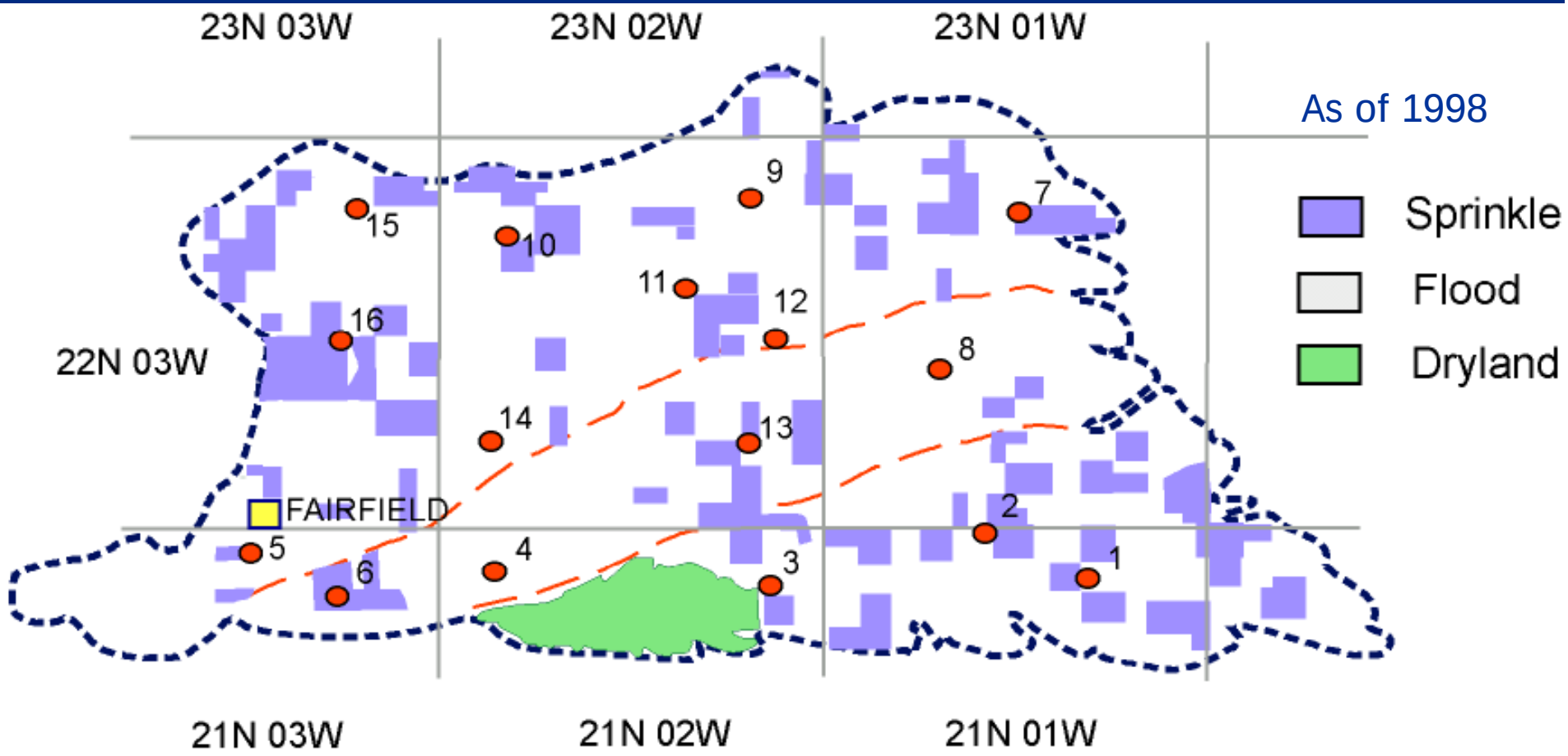
- clay loam
- alluvial in origin, well-drained
- pH 7.4 – 8.6
- Caliche: carbonate buffering significant in Assert transport

Ground-Water Flow Direction

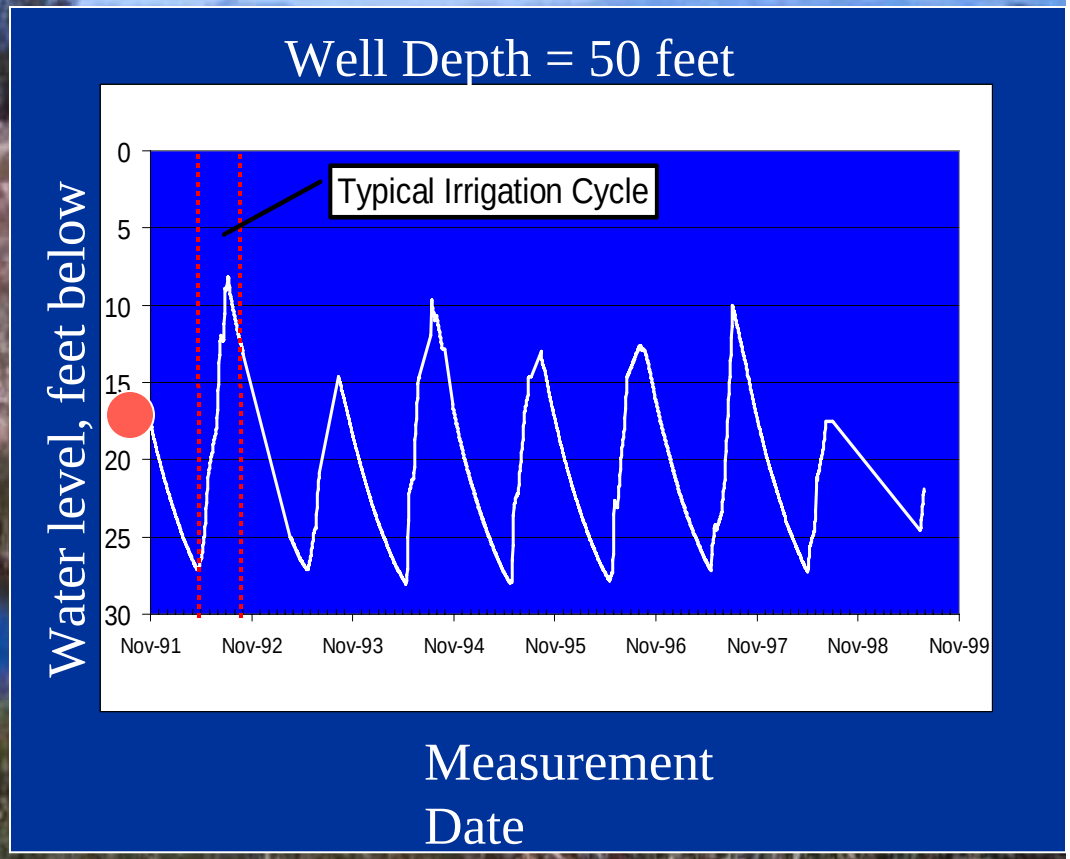
December 1998 - ground water is discharging to Muddy Creek and canals



Canal Leakage and Irrigation Dominates Ground-Water Flow

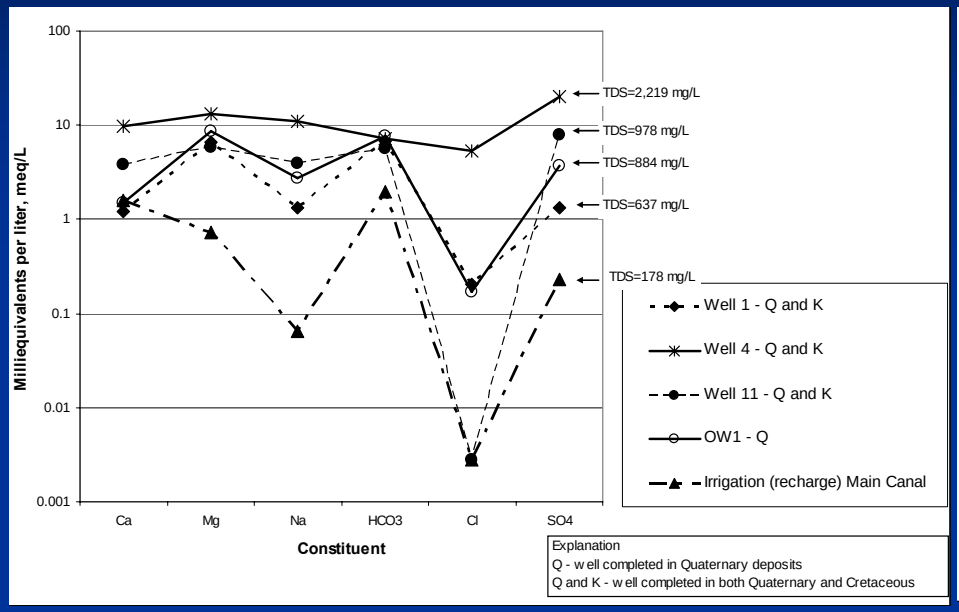


Recharge and Discharge

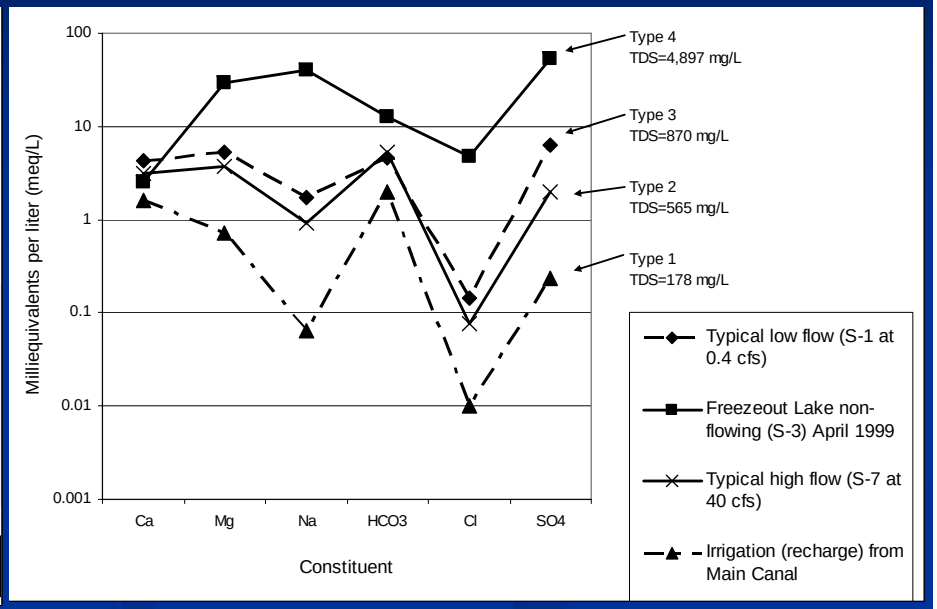


Summary of Inorganic Water Quality

Ground Water



Surface Water

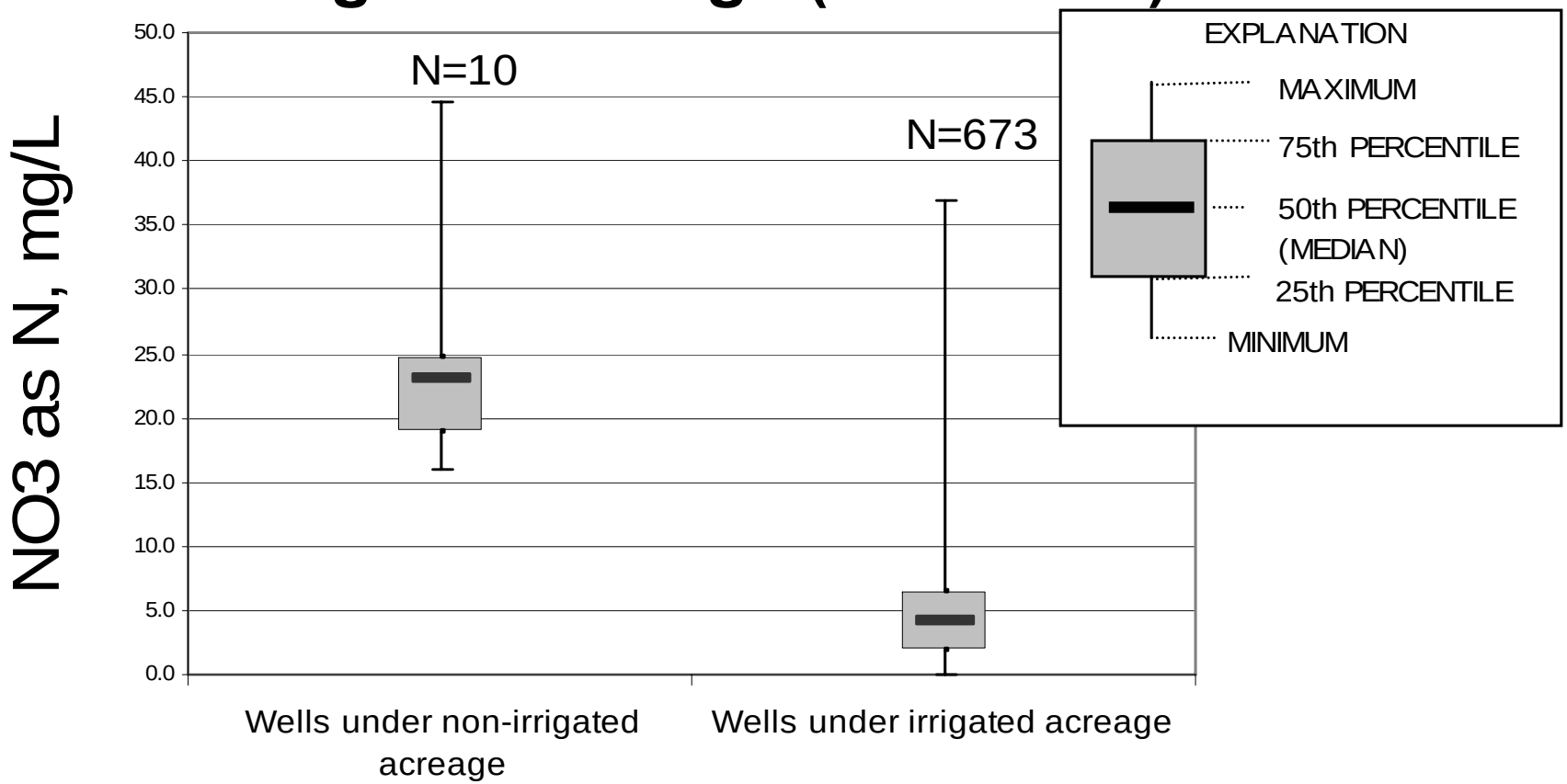


The **Point**:

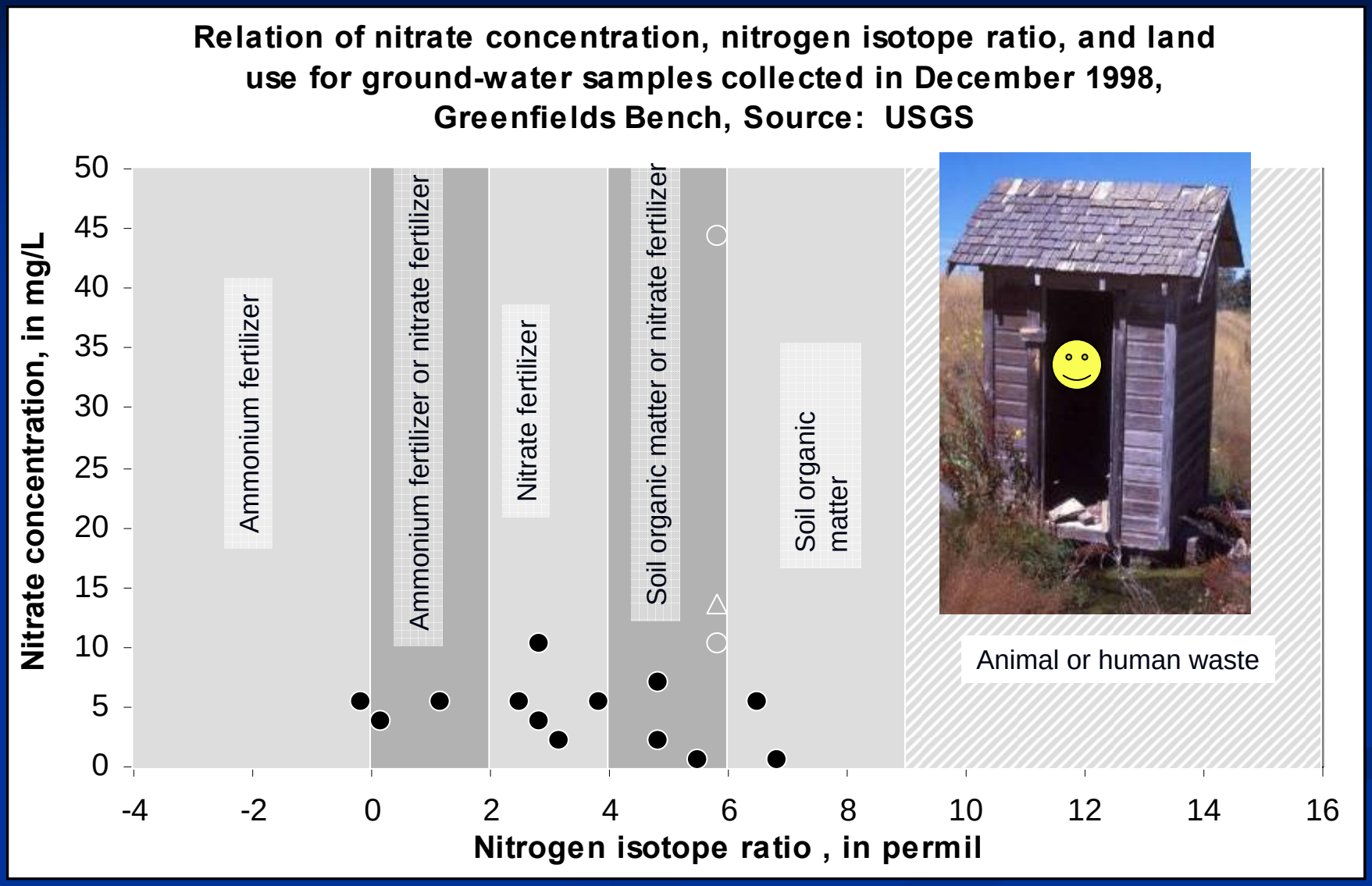
The water-quality signature of the aquifer is almost identical to that of surface water in the Main Canal; surface water affects ground-water quality.

Ground-Water Nitrate

Comparison of NO3 concentrations in ground water under irrigated vs. non-irrigated acreage (1980-1999)



Possible Sources of Nitrate in Ground Water



○ Non-irrigated area

● Irrigated area

△ Sample affected by denitrification

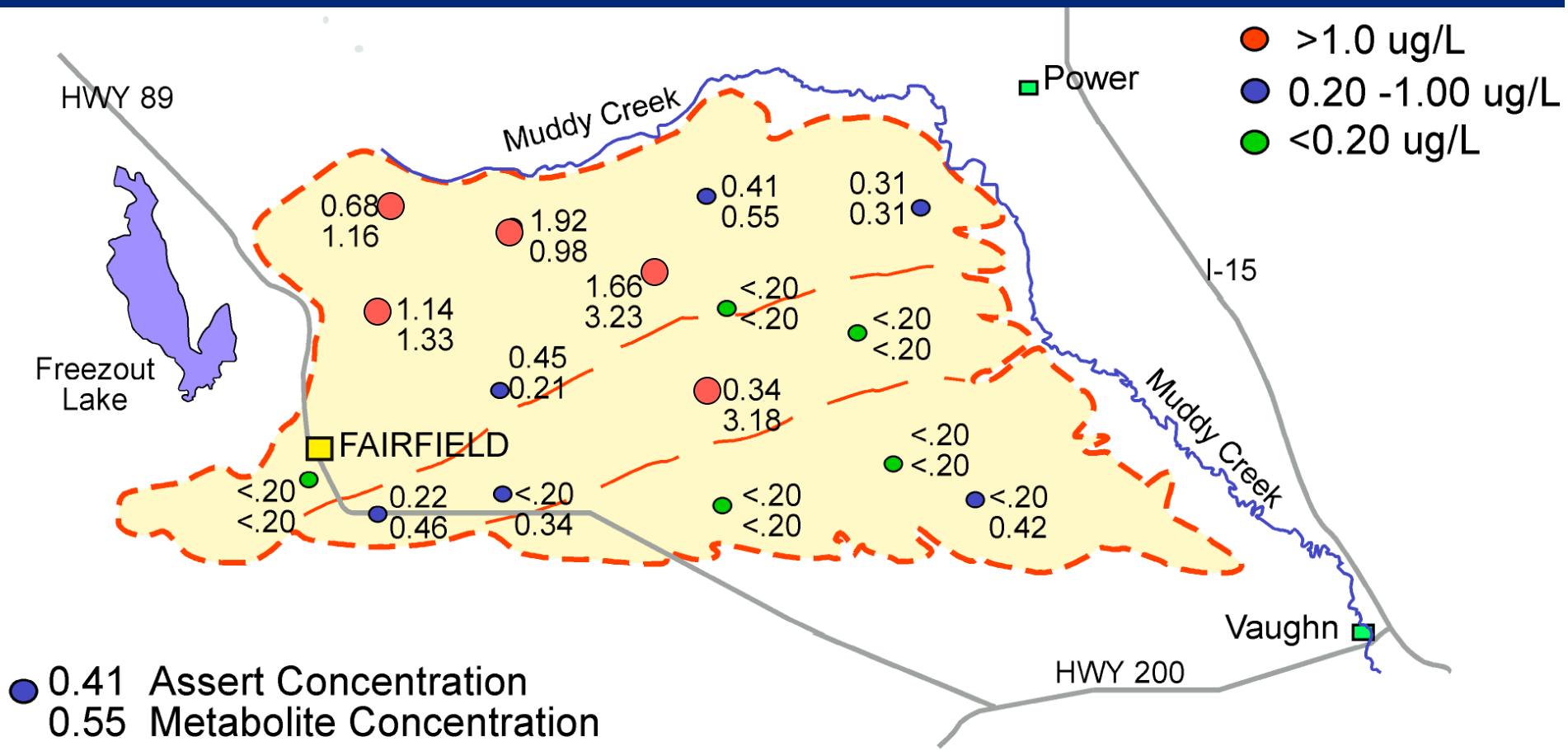
Assert Herbicide

- Widely used on the Bench to control wild oats and other weedy grasses
- Applied as a spray post emergent
- Persistence: half life = 26-45 days
- Leachability: high
- Interim Health Standard: 400 μg/L
- Detection limit in ground water: 0.20 μg/L

Pesticide Sampling Results for Domestic Wells

- **Assert and/or Metabolite**
  - 14 of 16 wells
  - 67 % of samples (62 detections)
  - Maximum: 5.0 μg/L Minimum: <0.20 μg/L
- **Sporadic detections of other chemicals**
  - 2,4-D (1 detection)
  - Picloram
  - Prometon
  - Clopyralid
  - Achieve…?

Assert Concentrations and Distribution in Ground Water

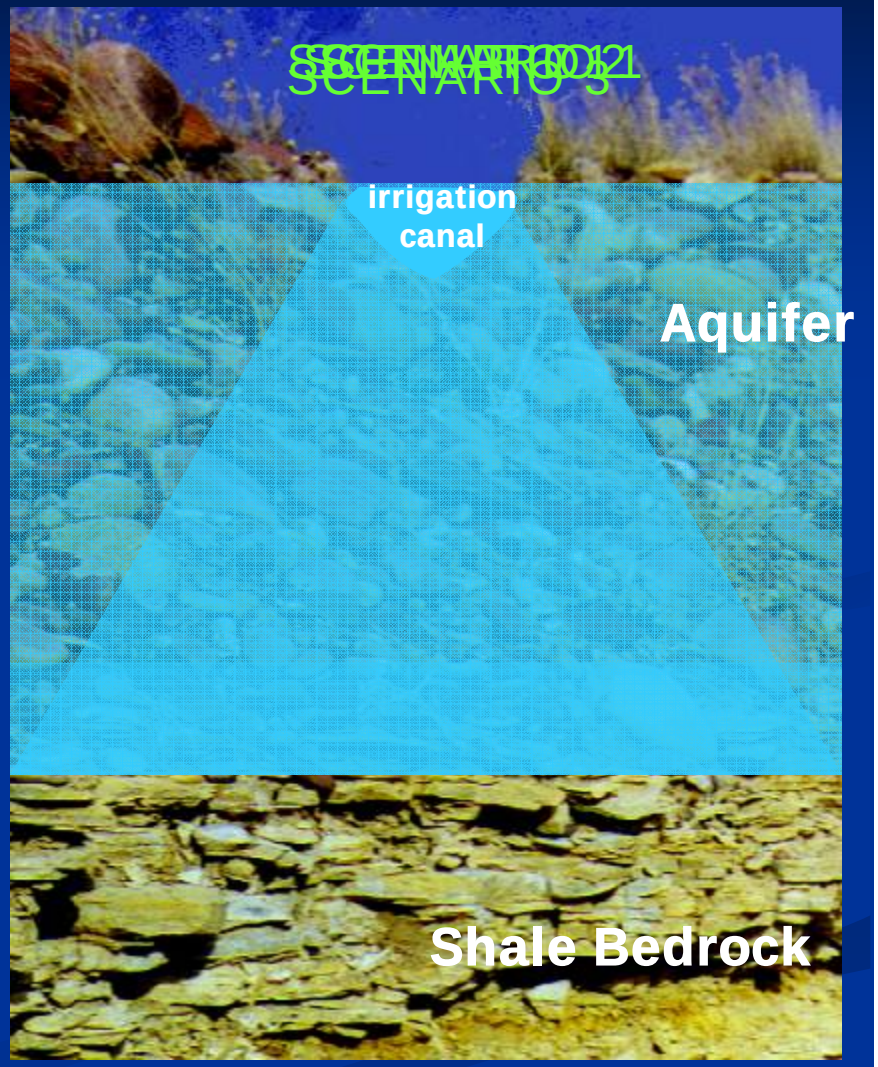


Seasonal Water-Level Fluctuations

SCENARIO 1:
Low water levels
April-May

SCENARIO 2:
Maximum hydraulic gradient
Early May

SCENARIO 3:
Maximum volume flow
Summer-Fall



Hydrogeology Summary

- **A**ssert/metabolite residues were widespread in the aquifer, a non-point source
- **H**ealth risks from Assert not demonstrated
- Hydraulic connection to canals causes contaminant transport problems.
- **A**ssert and metabolite are discharged to receiving streams.
- Correlation between the occurrence of Assert (and/or met.) and the occurrence of nitrate.
- **A**ssert and metabolite was the only pesticide consistently detected

Irrigation Practices

Methods

- 20 observation/monitoring wells
- Soil samples and ground-water samples

Inputs:
Sources of Assert in Ground Water

IRRIGATION WATER

VEGETATION

SOIL

UP-GRADIENT GROUND WATER

Outputs:
Losses of Assert from Soil and Vegetation

microbial and chemical degradation

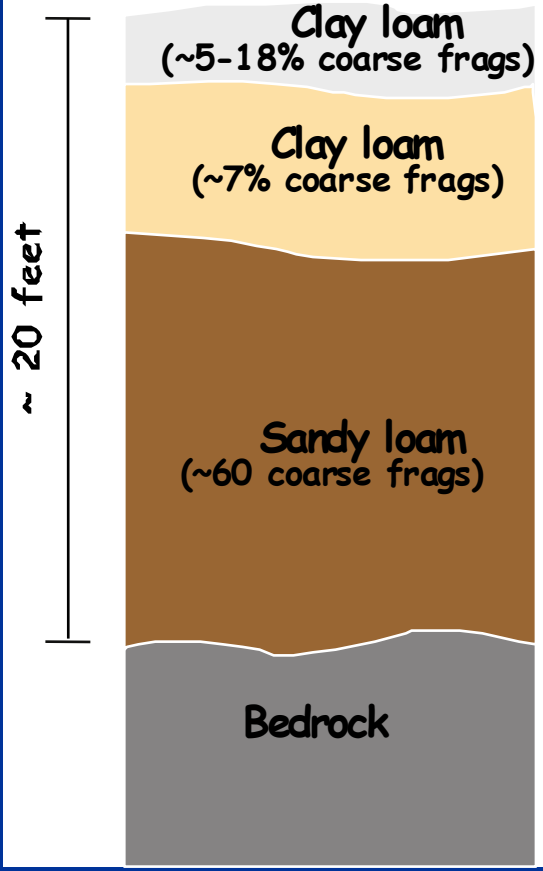
atmosphere

runoff

wild oat control

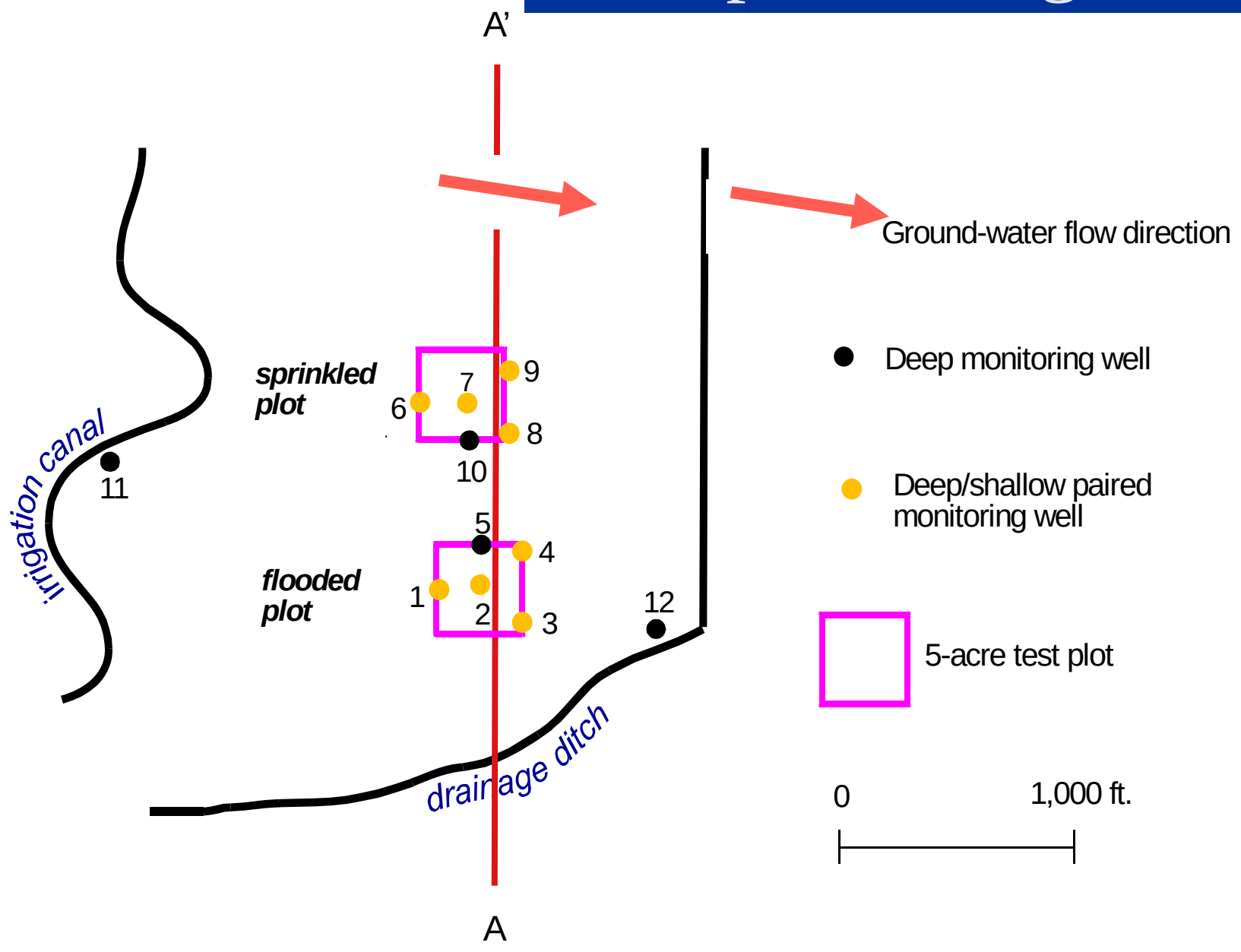
percolation to ground water

Soil Characteristics at the Experimental Site

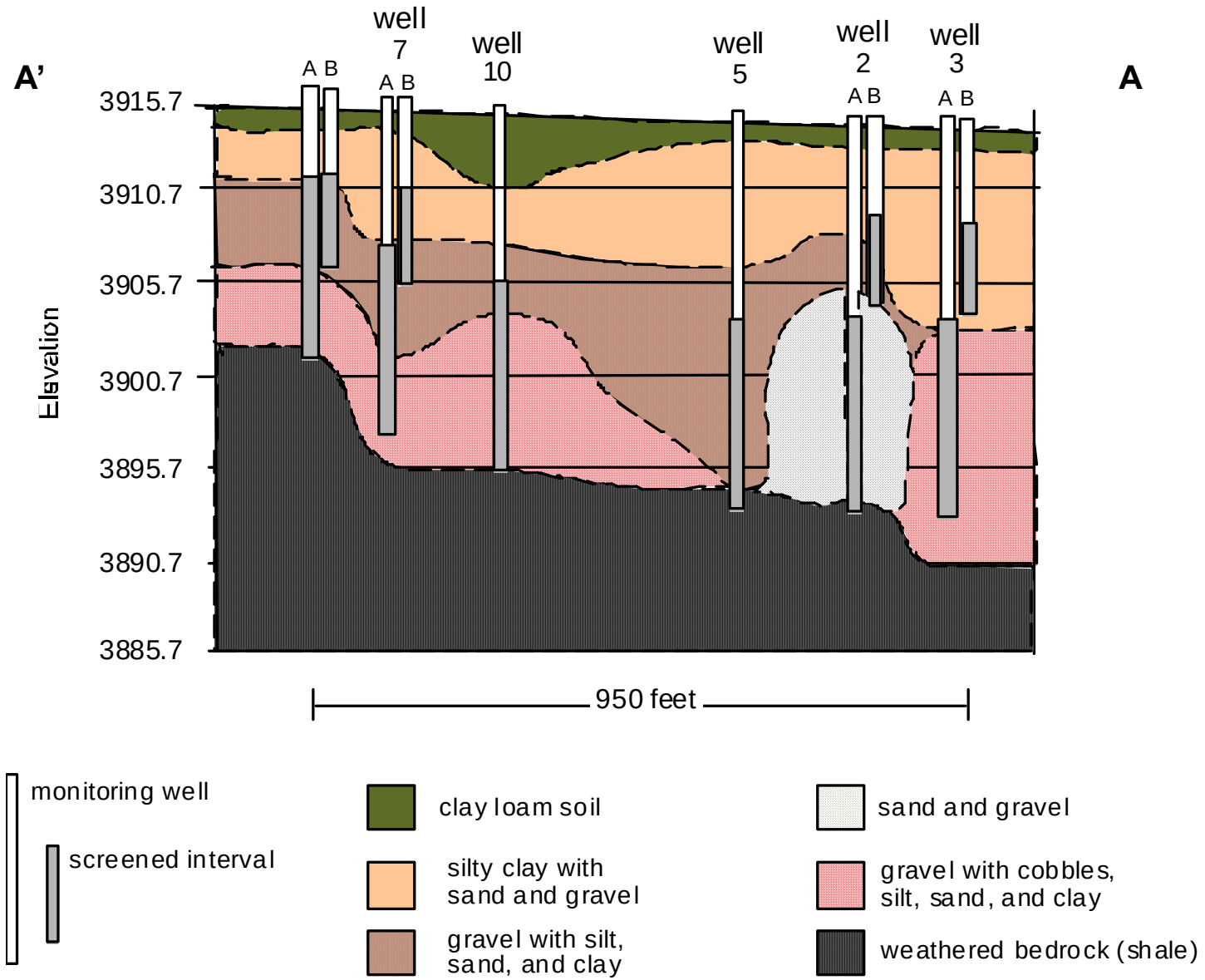


	Flood Plot			Sprinkle Plot		
	pH	Organic Carbon %	Cond., mmhos/cm	pH	Organic Carbon %	Cond., mmhos/cm
"A" Horizon	7.4	2.62	1.02	7.4	2.42	0.54
"B" Horizon	7.7	1.32	0.50	7.8	1.62	0.90
"C" Horizon	8.1	0.27	0.47	8.0	0.23	0.50

Test plot configuration

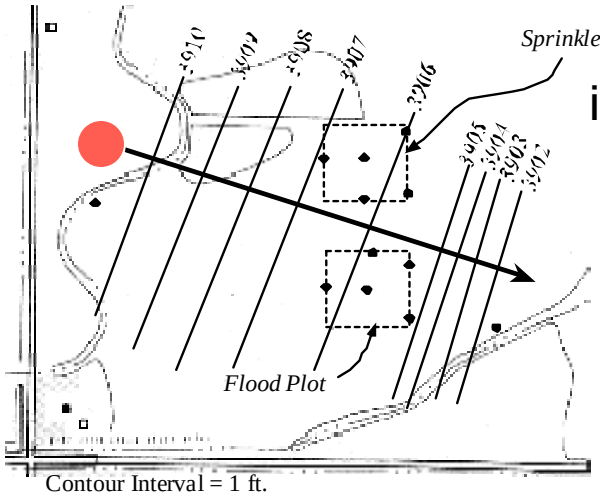


Simplified Cross-Section



Water-Level Contours on Test Plots for Years 2000 and 2001

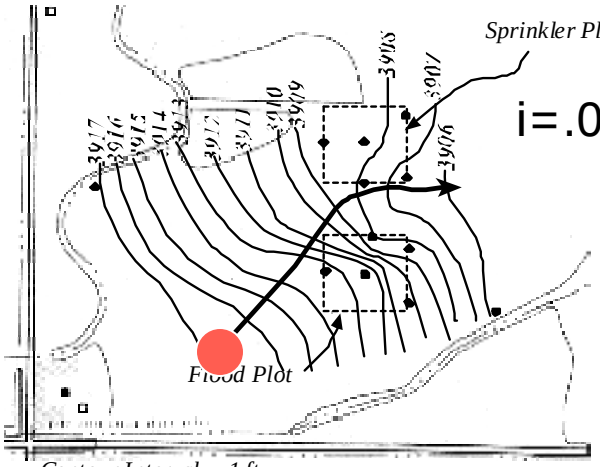
4/14/00 - No Irrigation



i=.004

Contour Interval = 1 ft.

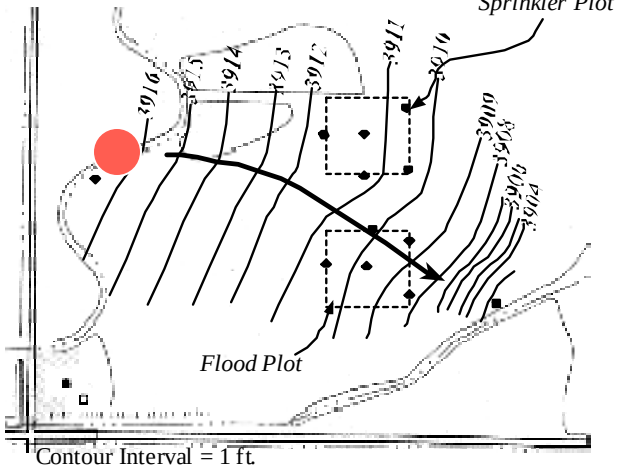
5/26/00 - Flood Irrigation



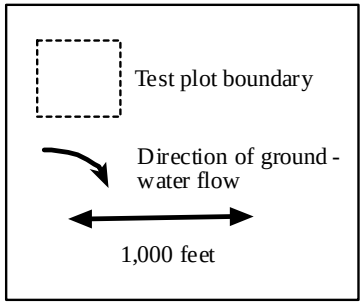
i=.008

Contour Interval = 1 ft.

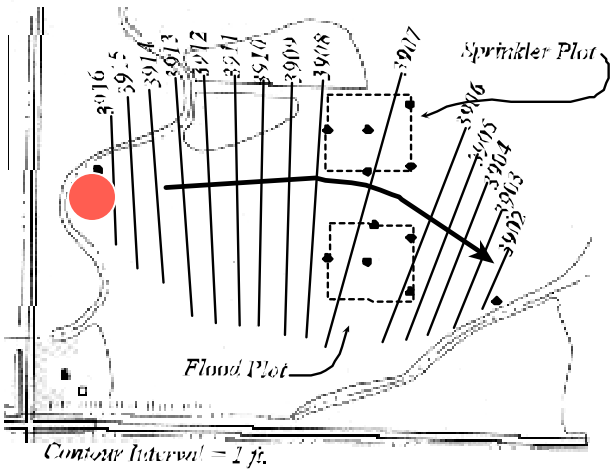
6/22/00 - Wheel Line Irrigation



Contour Interval = 1 ft.

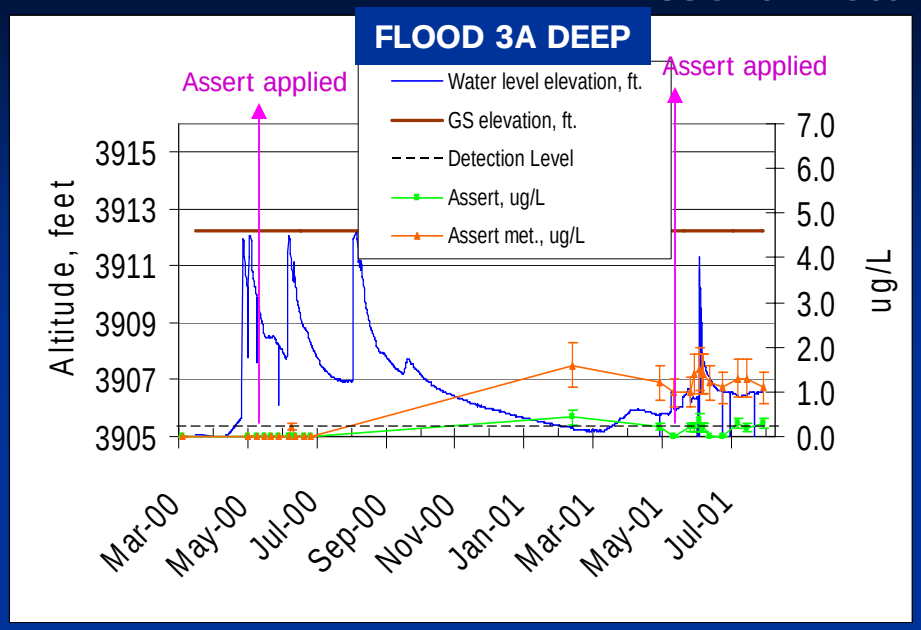


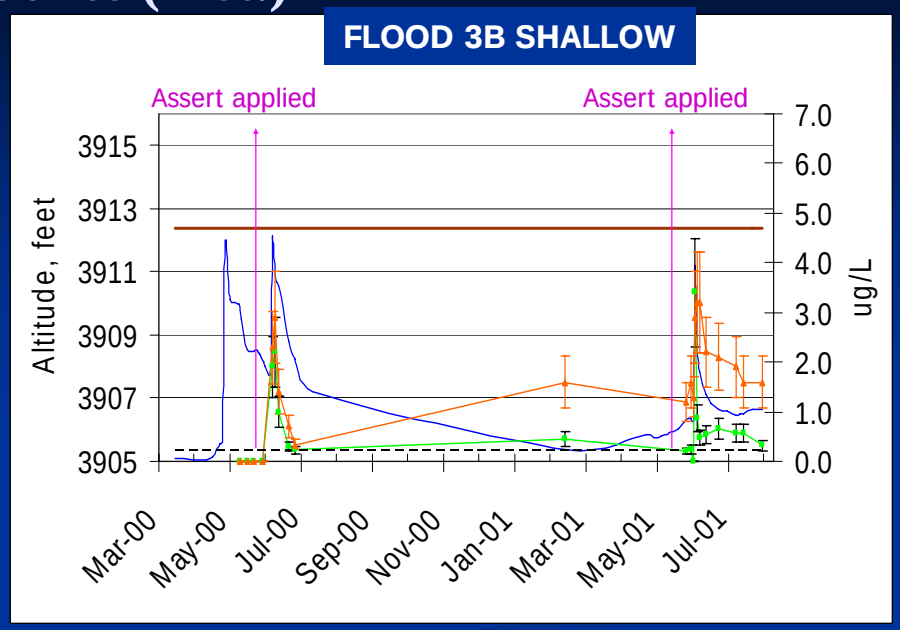
5/28/01 Pivot Irrigation

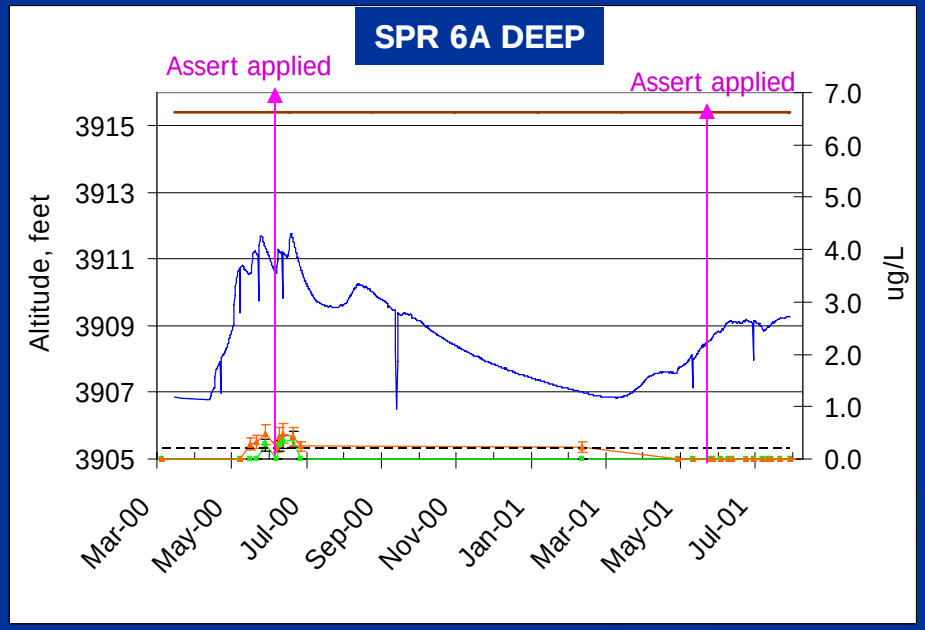


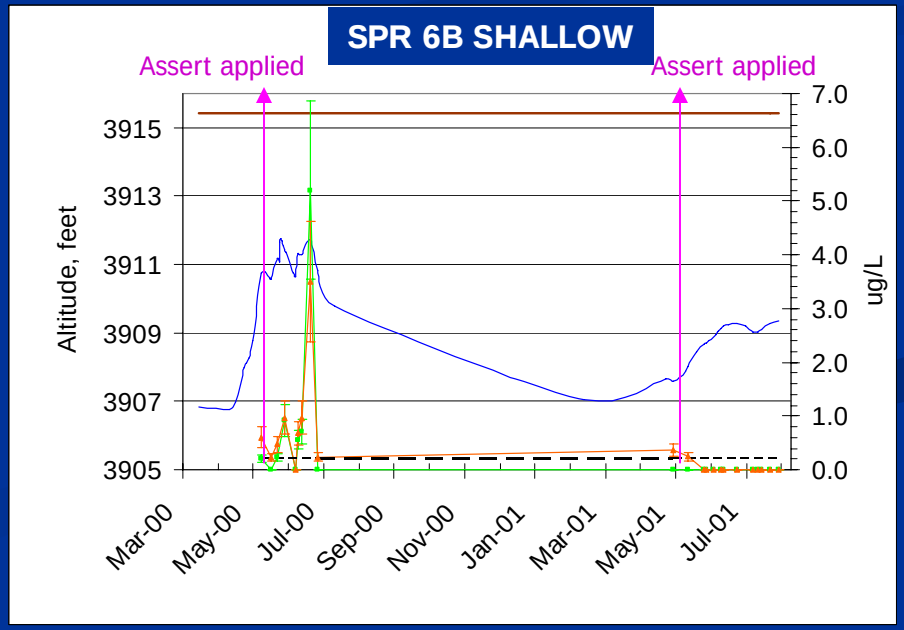
Contour Interval = 1 ft.

Hydrographs showing concentrations of Assert and Assert metabolite (met.)

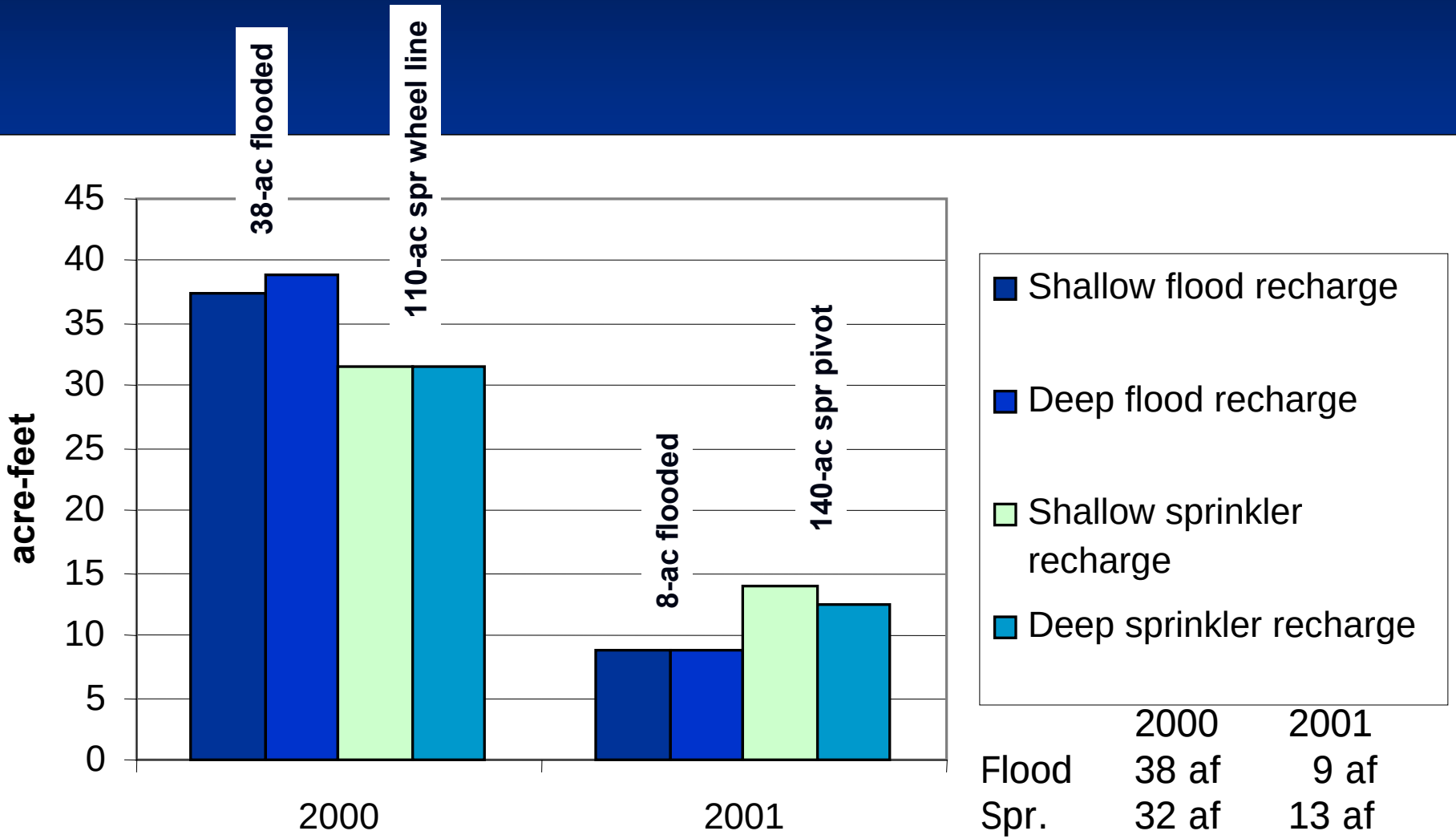






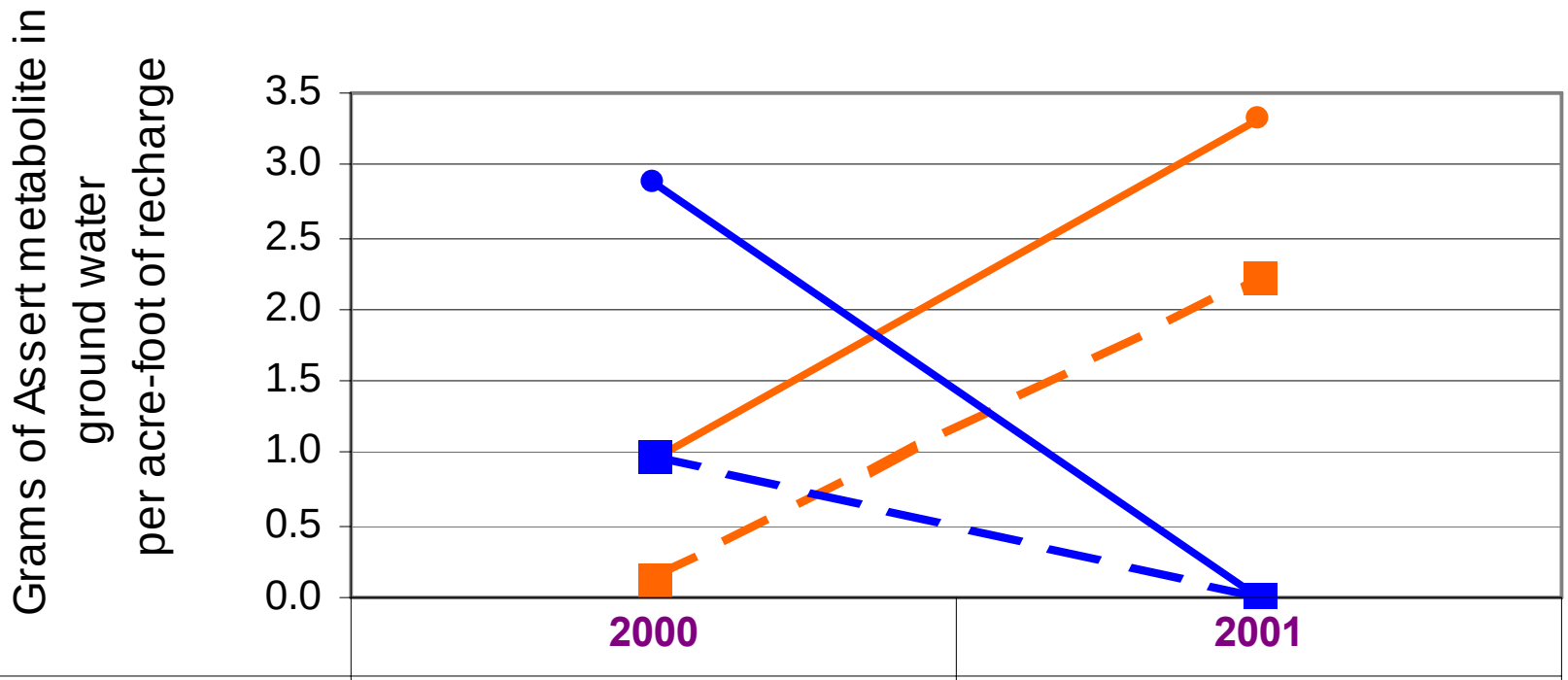


A Comparison of Recharge between Flood and Sprinkler Plots



	2000	2001
Flood	38 af	9 af
Spr.	32 af	13 af

Comparison of 2000 and 2001 Mass Flux : Recharge Ratios between Deep and Shallow Wells



	2000	2001
deep flood wells	1.0	3.3
shallow flood wells	0.1	2.2
deep sprinkler wells	2.9	0.0
shallow sprinkler wells	1.0	0.0

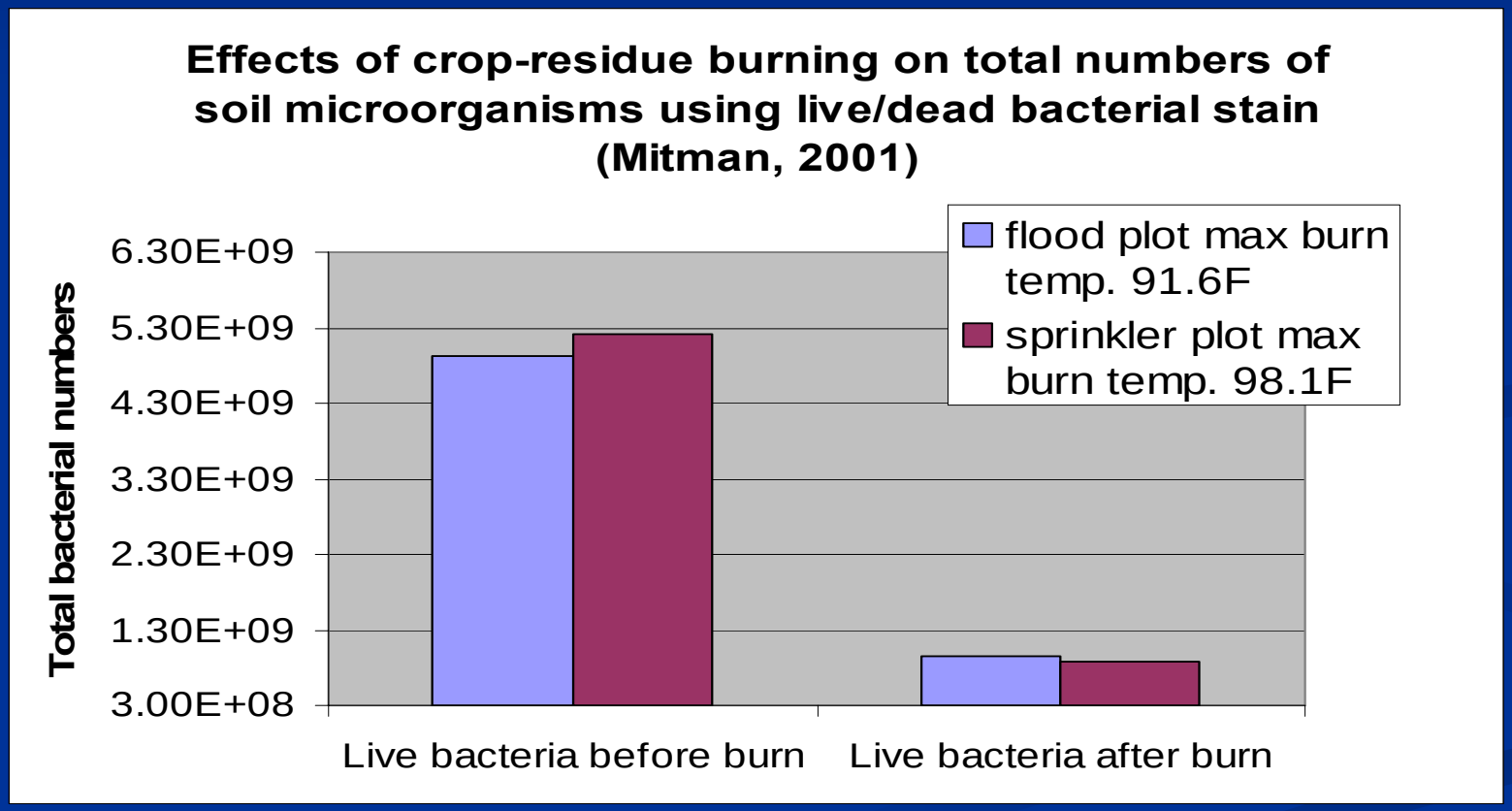
Assert Residuals in Soils

Date	Event	Flood plot		Sprinkler plot	
		Assert µg/kg	Met. µg/kg	Assert µg/kg	Met. µg/kg
8-Mar-00	Background, pre-application	70	5	120	8
10-Jun-00	2-day post-application	1,400	53	1,800	32
3-Jul-00	24-day post-application	810	110	730	56
24-Jul-00	45-day post-application	310	21	270	55
3-Mar-01	Pre-application	110	39	230	37
6-Aug-01	66-day post-application	480	36	320	24

Note:

- About 100 µg/L found after 2 years
- In 2000, within 24 days, about 50% lost to:
  - plant or microbial metabolism,
  - hydrolysis,
  - photo-degradation, and/or,
  - saturated zone

Effects of Burning on Soil Microorganisms…?



Conclusions

1. Soils on the Greenfields Bench appear to be functioning as a "reservoir" for Assert and metabolite.

2. Due to persistence and favorable environmental factors, low levels of Assert can be expected under any type of irrigation system, with the possible exception of center pivot.

3. A minimum threshold of hydraulic flux is required to transport Assert metabolite into the ground-water system. But at high levels of hydraulic loading, such as the flood irrigation event in 2000, dilution may result in low concentrations.

Recommendations

1. Balance the need for improving ground-water quality with water-supply demands.

   On a per-acre basis,

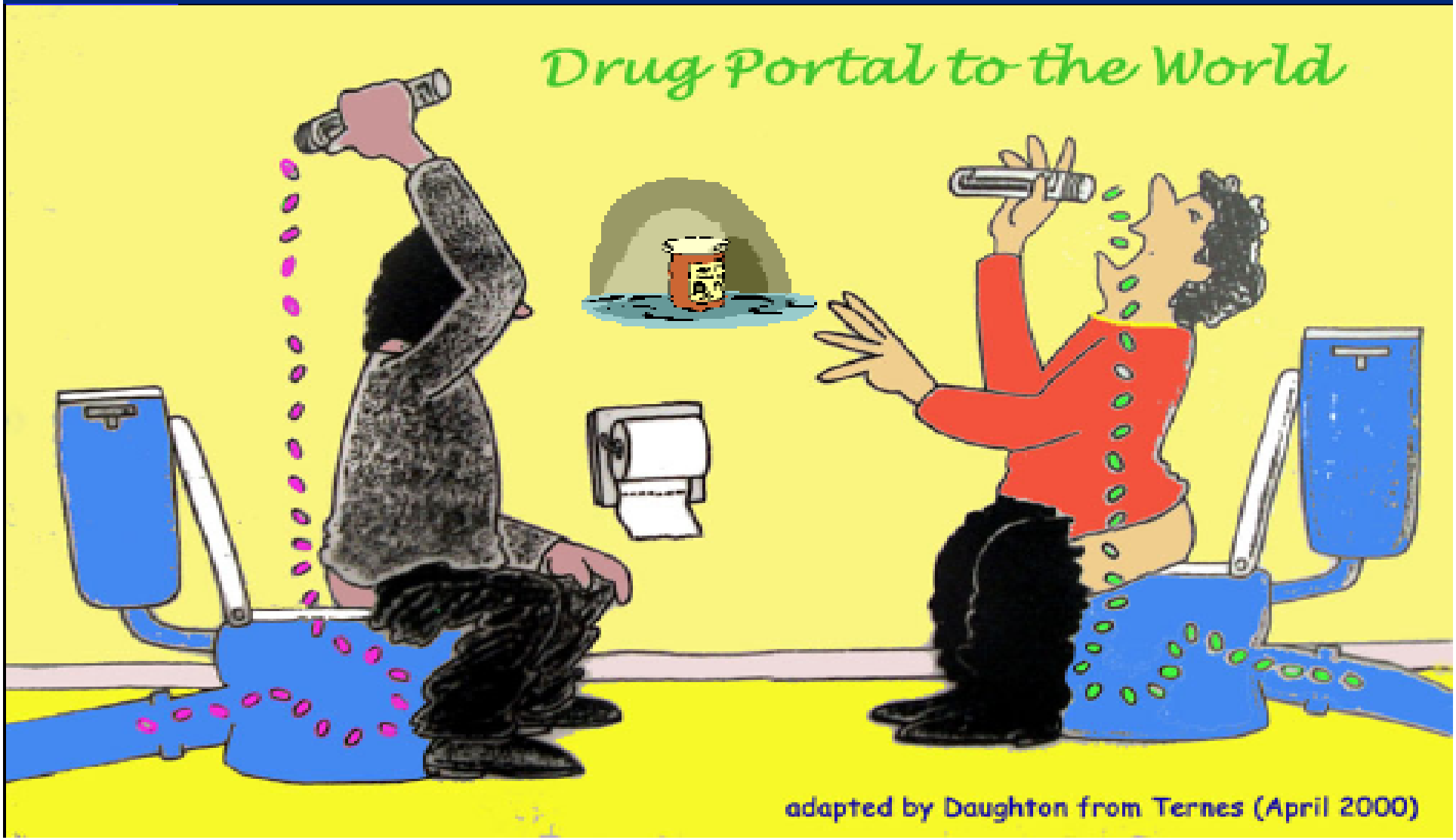
   - Wheel line provides 1/3 of the GW recharge of flood irrigation (0.3 ft. vs. 1.1 ft.)
   - Center pivot provides 1/10 the GW recharge of flood irrigation (0.1 ft. vs. 1.1 ft.)

2. Additional soil Assert concentration data should be collected to more fully characterize flux rates through the "A" horizon.

3. A comprehensive evaluation should be performed to determine the effect of agricultural practices, such as crop-residual burning and chemical fertilizer treatment, on soil health and microbial ecology.

In short…a very *“sensitive”* system…

Environmental Exposure to Pharmaceuticals, Endocrine Disruptors and Personal Care Products (PPCPs)



Pharmaceuticals and Personal Care Products (PPCPs)

- FACT: Certain PPCPs occur in the environment, especially the aquatic environment
- ORIGINS: Domestic sewage, hospitals, CAFOs
- ISSUE: Fate and effects are poorly understood

Exposure to Multiple, Trace-Level Compounds Below Known Effects Levels

- Additive effects
  - Multiple agents sharing common mechanisms actions (MOAs).
  - Individual concentrations combine to exceed an effects level
- Interactive effects
  - Synergism, where combined action exceeds the sum of individual effects
- Toxicant-Induced Loss of Tolerance (TILT)
  - Initial exposure sensitizes and subsequent exposures to levels below those previously tolerated trigger symptoms.

Excerpted from Daughton, 2005

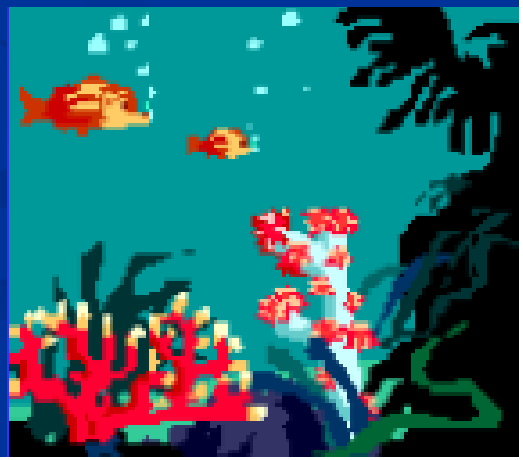
Exposure to Multiple, Trace-Level Compounds Below Known Effects Levels, continued

- Extremely low concentrations (nM-pM and below)
  - Some agents have ability to impart previously unrecognized effects at "ultra-trace" concentrations. Little research...
- Non-target species receptor repertoires
  - Across species and unknown overlap with humans. Not well characterized...
- Genetic outliers
  - Susceptible within species.
- Modes of Action
  - Not fully understood. Most drugs can each have a multitude of effects.

PPCPs in Receiving Waters: A Global, Ubiquitous Process with Unique Local Expression

- ALL municipal sewage, regardless of location, will contain PPCPs
  - Issue is not unique to any particular municipal area.

- Each geographic area will differ only with respect to the types, quantities, and relative abundances of individual PPCPs.
  - E.G. Europe vs USA



Aquatic Organisms are Captive to Continual, Life-Cycle Chemical Exposures

- Aquatic Exposure is Key:
  - Continual multigenerational exposure for aquatic organisms.

- Re-evaluation of "Persistence:"
  - Even if a chemicals' half-lives are short- their supply is continually replenished. These can be referred to as *pseudo-persistent chemicals (P2s).*

Subtle, Difficult-to-Detect Effects: *some examples*

- SSRI and tricyclic antidepressants (ppb levels)
  - Profound effects on the development, spawning, and wide array of other behaviors in shellfish, ciliates, and other aquatic organisms
- Calcium-channel blockers (regulate blood pressure, etc.)
  - Dramatic inhibition of sperm activity in certain aquatic organisms
- Antiepileptic drugs (phenytoin, valproate, carbamazepine)
  - Neuroteratogens, triggering neurodegeneration
- NSAIDS, glucocorticoids (steroid hormones), anti-fibrotics
  - Affect collagen metabolism in bony fish, leading to defective/blocked fin regeneration
- And we haven't established potential effects on humans...

KAPUT
JACOB A. F.
JOHN

Pharmaceuticals, Personal Care Products, Endocrine Disruptors (PPCPs) and Microbial Indicators of Fecal Contamination in Ground Water in the Helena Valley, Montana, USA

Kate Miller

Montana Department of Environmental Quality

2006

kmiller2@mt.gov

Introduction

- 22 PPCPs detected in ground water in the Helena Valley, both private and public supplies
- Associated with discharge from domestic wastewater
- Ground Water Rule: Multiple Microbial Fecal Indicators for public water supplies
  - Coliphage, *E.coli*, enterococci

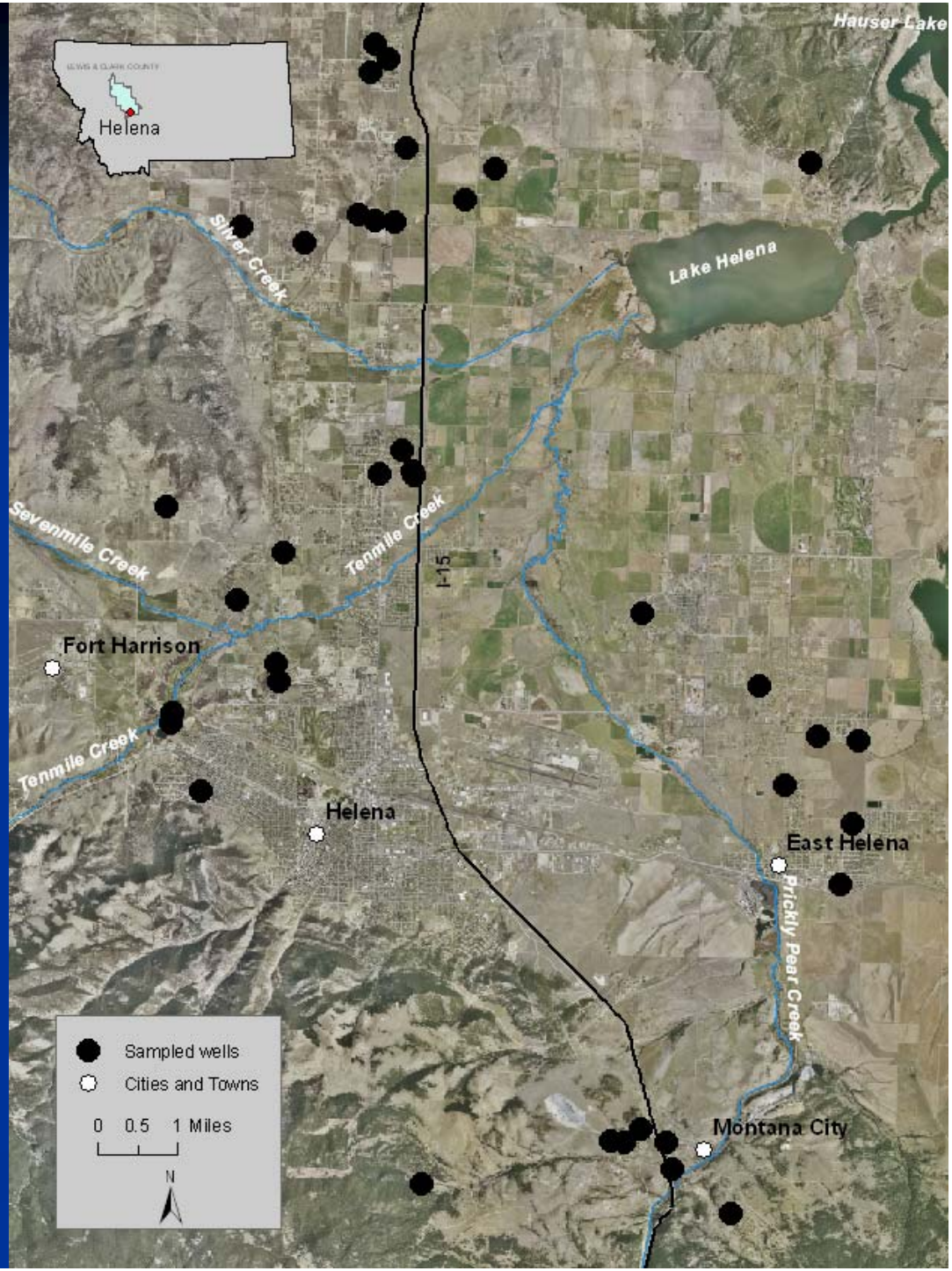
Residential Development on the Valley Fringe

Selected Previous Investigations on PPCPs and Coliphage in Ground Water

- **Hinkle et al, 2005, LaPine, OR**
  - Of 45 compounds found in wastewater only 9 found in GW - too reactive to serve as GW tracers
  - Also found sulfamethoxazole (SMX), acetaminophen and caffeine in GW
  - Coliphage detected 8 samples (considered to be field or lab contamination) but absent in replicate and repeat samples; probably attenuated before reaching sampled wells
- **Heberer, 2004, Berlin, Germany**
  - PPCPs are likely attenuated in ground water
  - Loading rates between wastewater systems could be highly variable
- **Seiler, 1999, Reno, NV**
  - Caffeine (up to 0.23 ug/L) and PPCPs as fecal indicators in GW– unambiguous evidence of fecal contamination
  - But caffeine is not conservative; probable nearly complete catabolism of caffeine in bacteria-rich septic system…
  - Also found carbamazepine (anti-seizure), chlorpropamide (treats diabetes) and phensuximide (anti-seizure)
- **Godfrey and Woessner, 2004, Missoula MT**
  - Acetaminophen, caffeine, nicotine, codeine, trimethroprim (antibiotic) and carbamazepine in wastewater

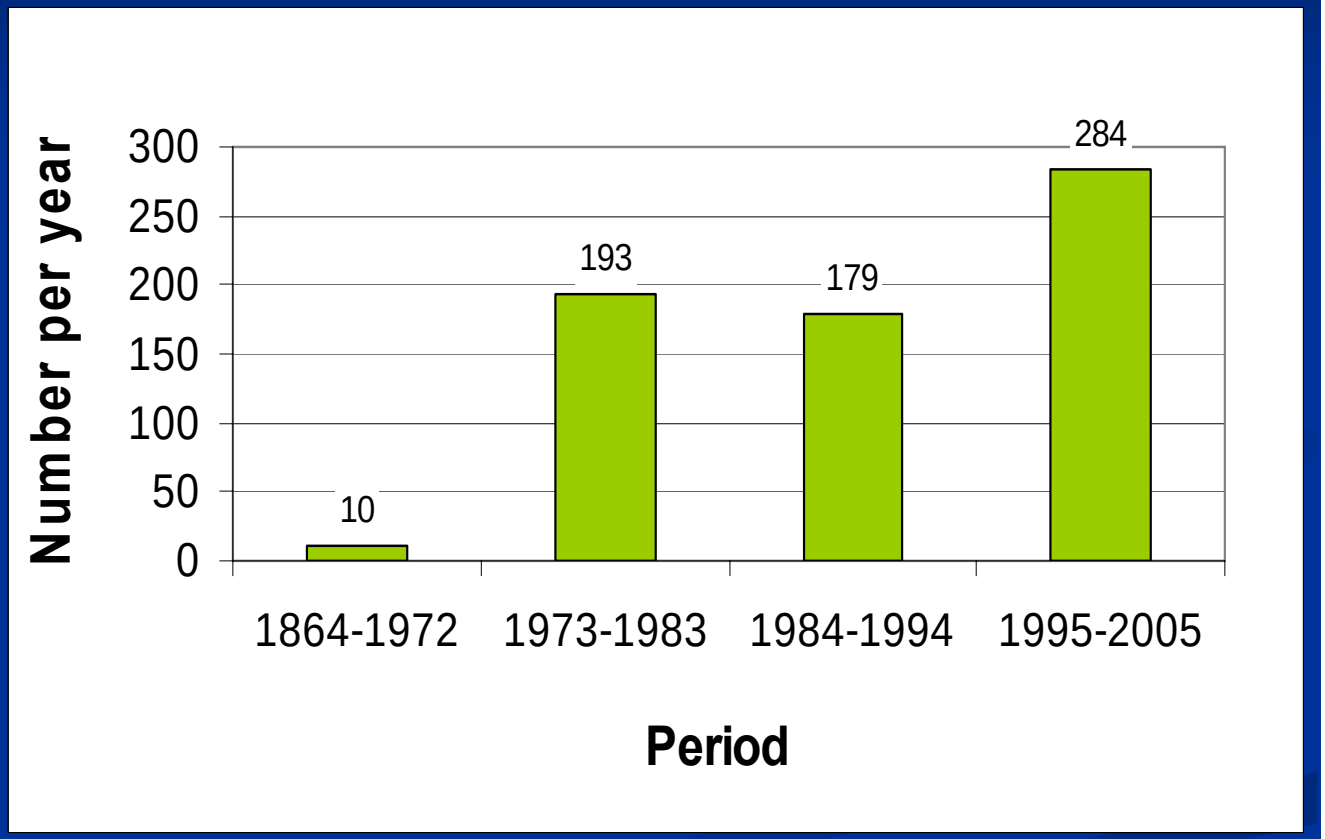
The Helena Valley

- Rocky Mountain Foothills
- 330 sq. mi.
- City limits pop. 28,000
- State Capital
- Previous investigators:
  - Coliphage in 10 of 19 samples
- Mixed-use
  - Current: residential
  - Previous: Agriculture and metals-mining

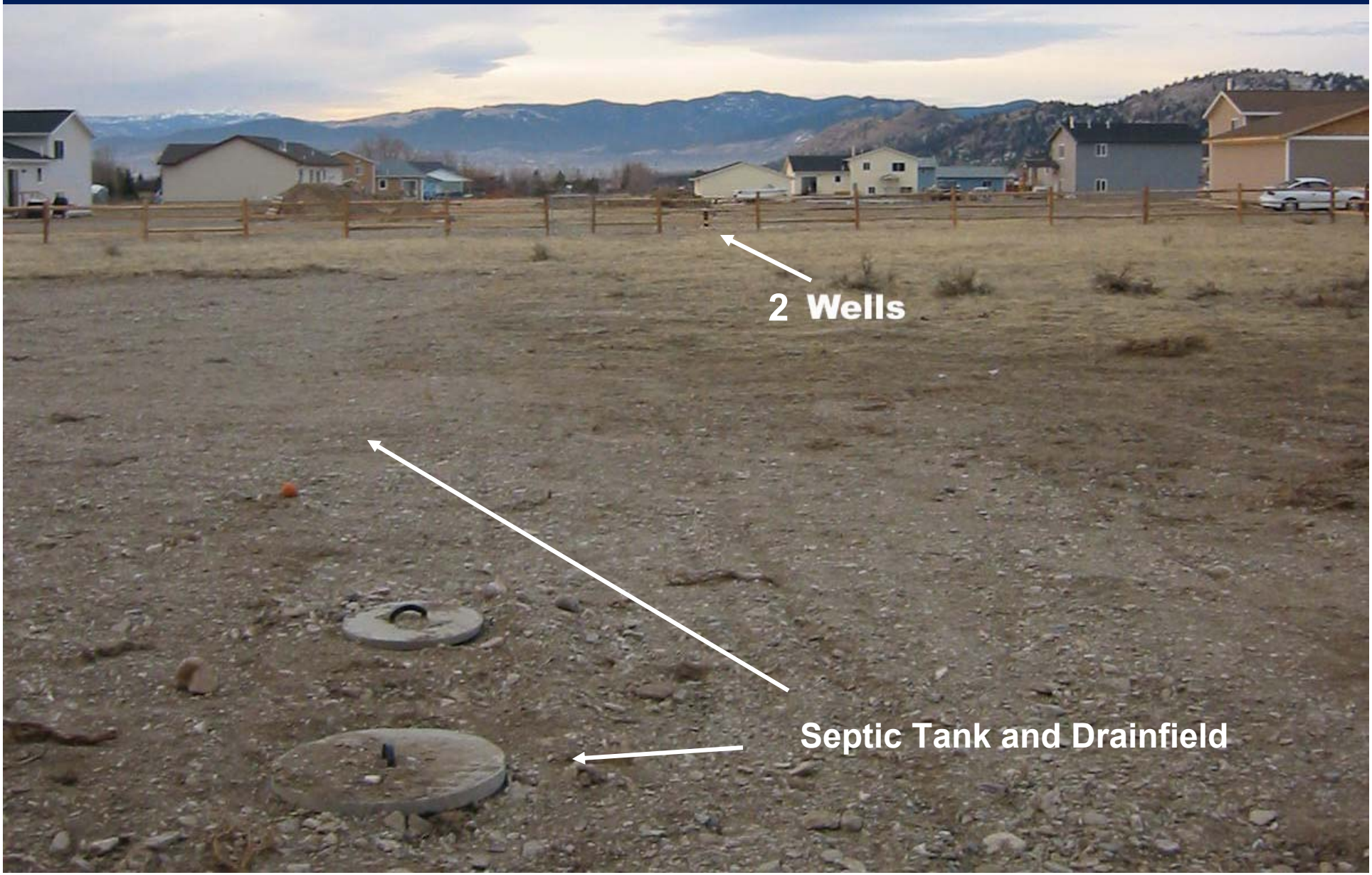


Number of New Well Installations Per Year

- Residential development into areas with no central water or sewer

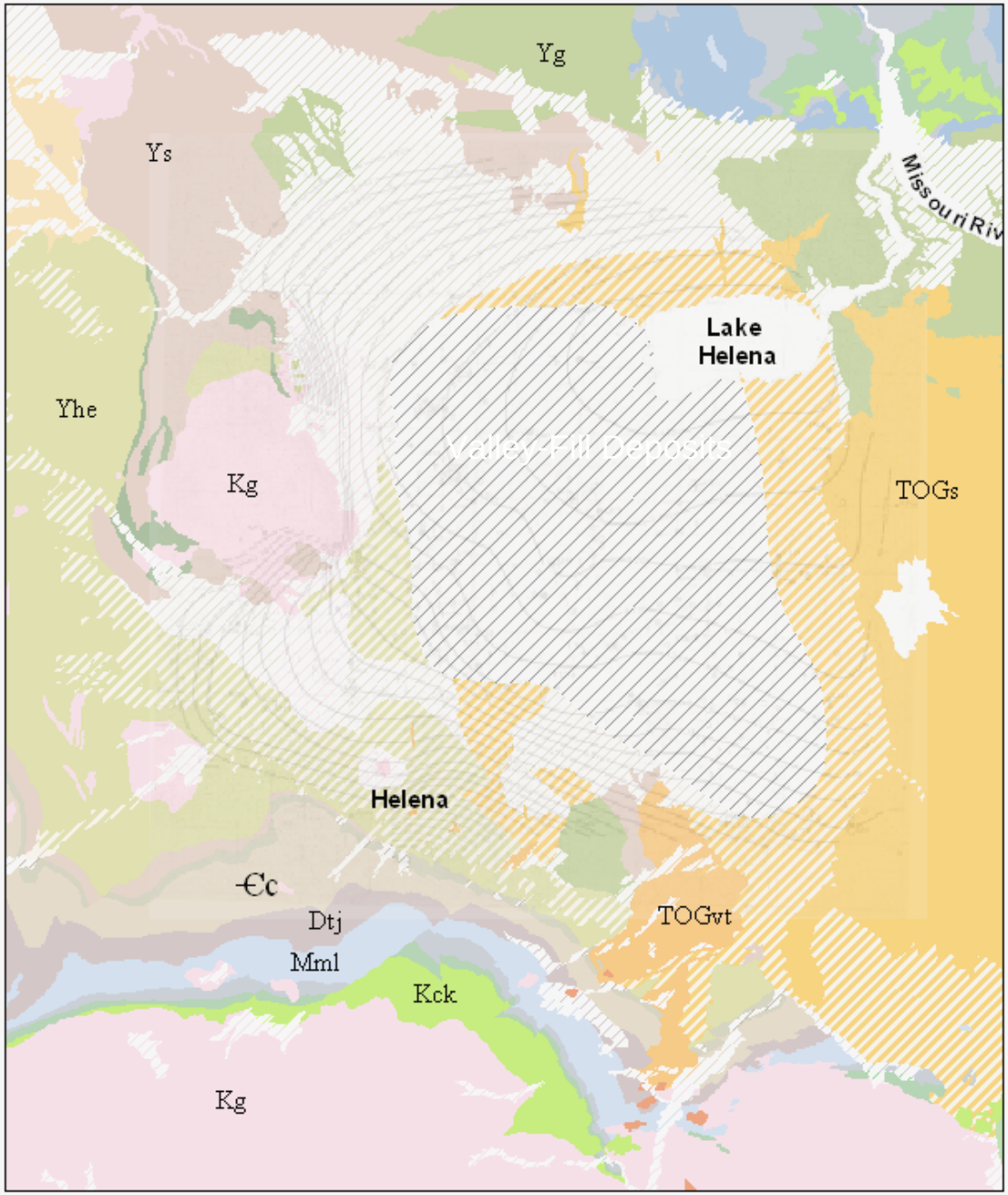


Onsite Wastewater Systems and Drinking-Water Wells



Helena Valley Hydrogeology

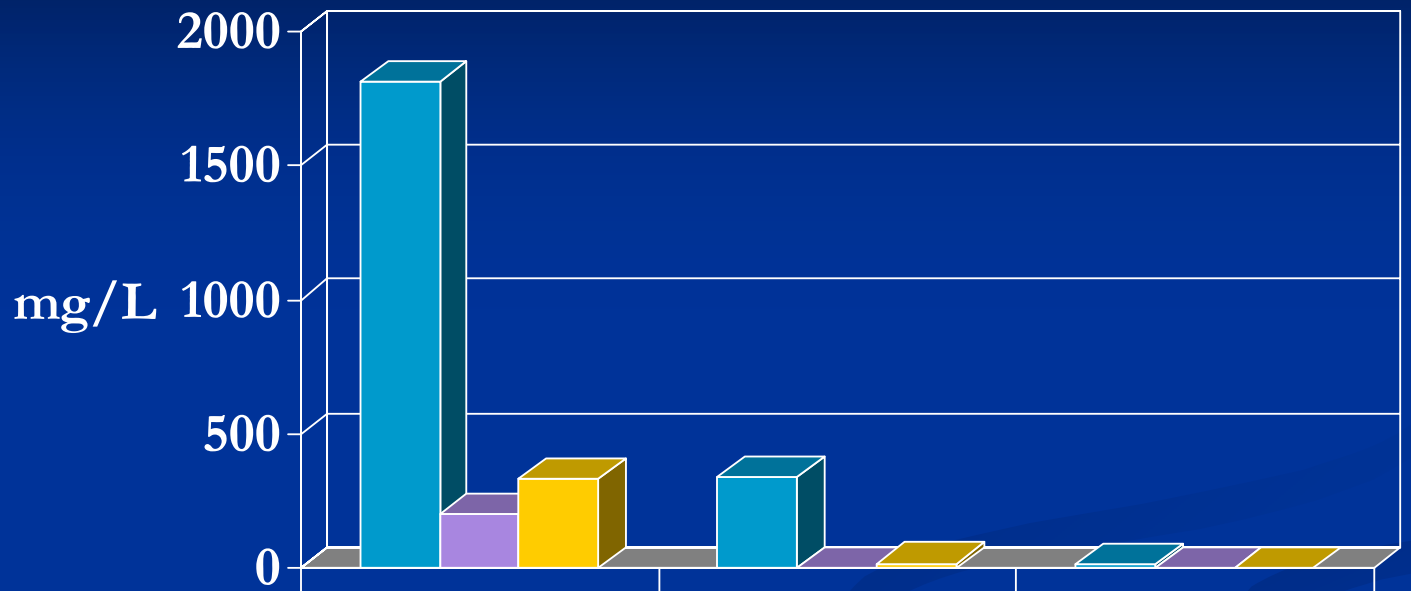
- Bedrock is Precambrian to Cretaceous age, folded and fractured, sedimentary, metamorphic and igneous
- Valley-fill deposits (Q/T age) function as one complex aquifer system
- Irrigation with imported Missouri River water
- Ground-water flow from south, west, and north margins to Lake Helena
- Calcium bicarbonate type ground-water quality



Methods

- April, June, November 2005
- 35 wells sampled for PPCPs
- 38 wells sampled for microbial indicators
  - 12 wells completed in bedrock aquifers
  - 26 wells completed in valley fill deposits
- 18 public water supplies
- Wells flushed until stable field parameters
- Analytical;
  - Coliphage – EPA 1601 Male specific and somatic coliphage by two-step enrichment procedure
  - PPCPs – Sample prep by EPA Method 3535, used LC/MS/MS
- Each well site assigned unique GWIC ID number referenced to the Montana Ground-Water Information Center
- Well depths range from 39 – 425 ft

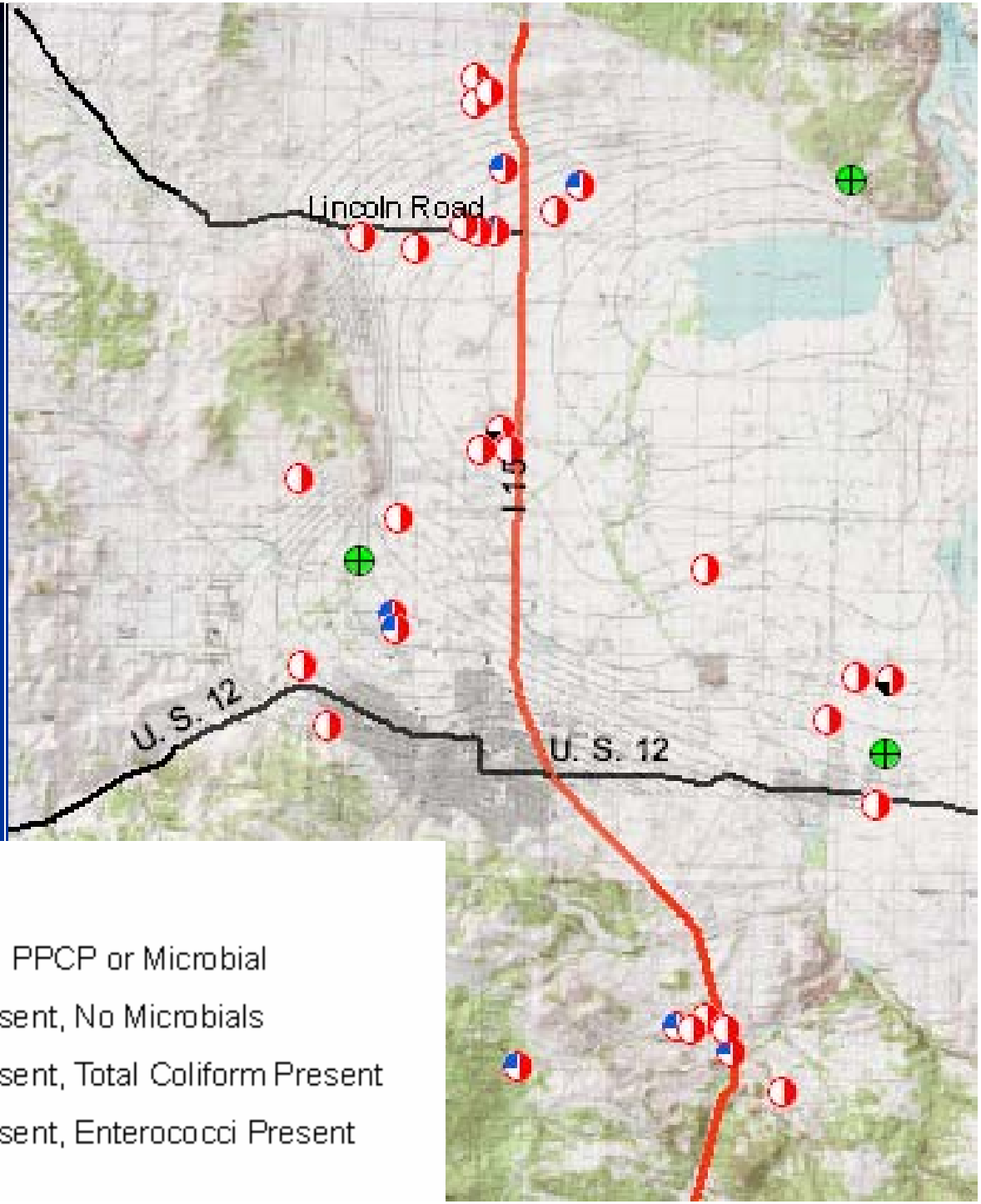
TDS, Chloride and Nitrate Occurrence



	TDS	Chloride	Nitrate
Maximum	1810.8	342	12.4
Minimum	199	1.1	0
Median	333.8	17.1	2

PPCP and Microbial Results

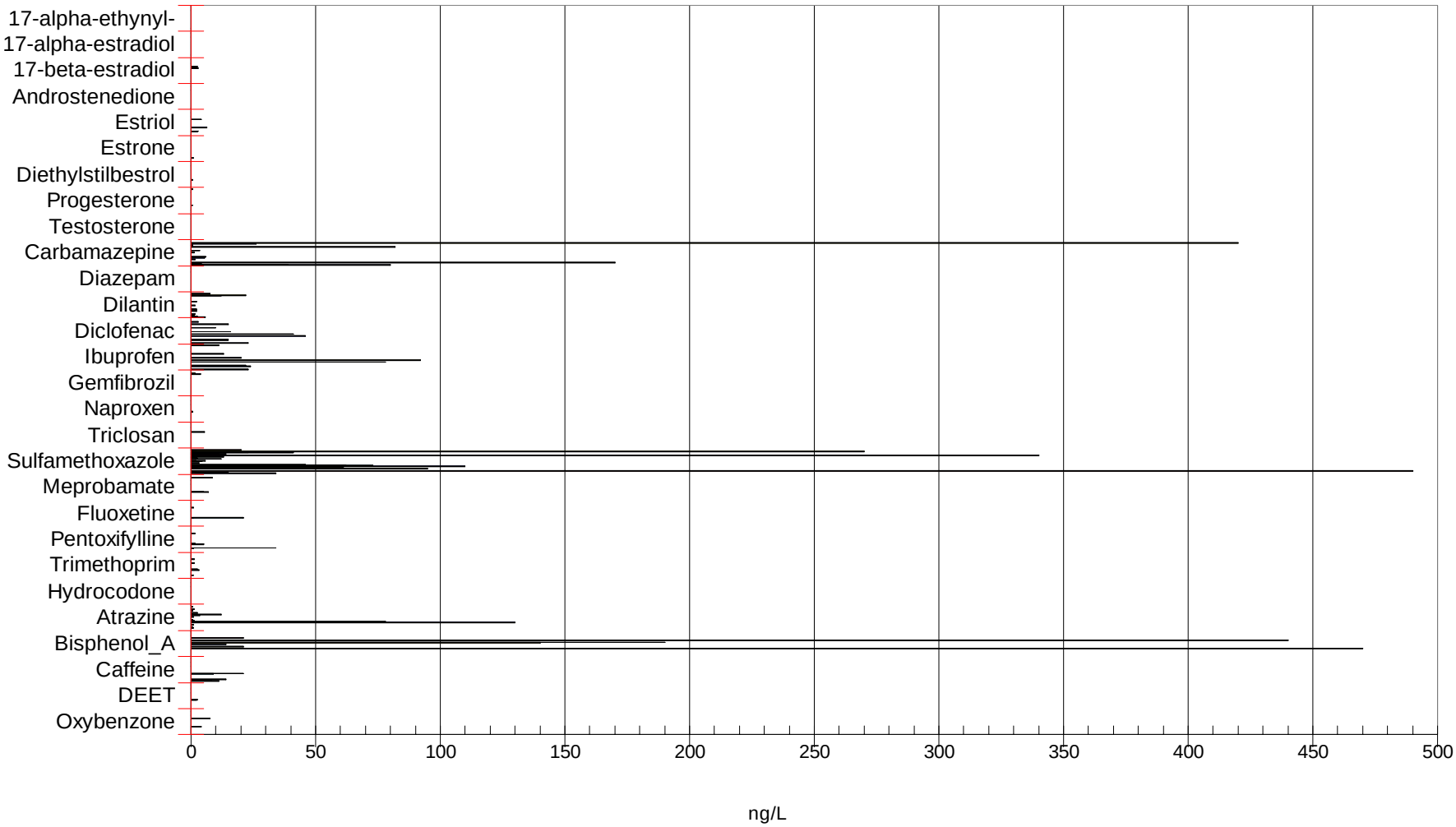
- PPCPs detected at 32 of 35 sites
- Zero coliphage detected
- Zero *E.Coli* detected
- 8 sites positive for total coliform in the presence of PPCP
- 2 sites positive for enterococci in the presence of PPCP



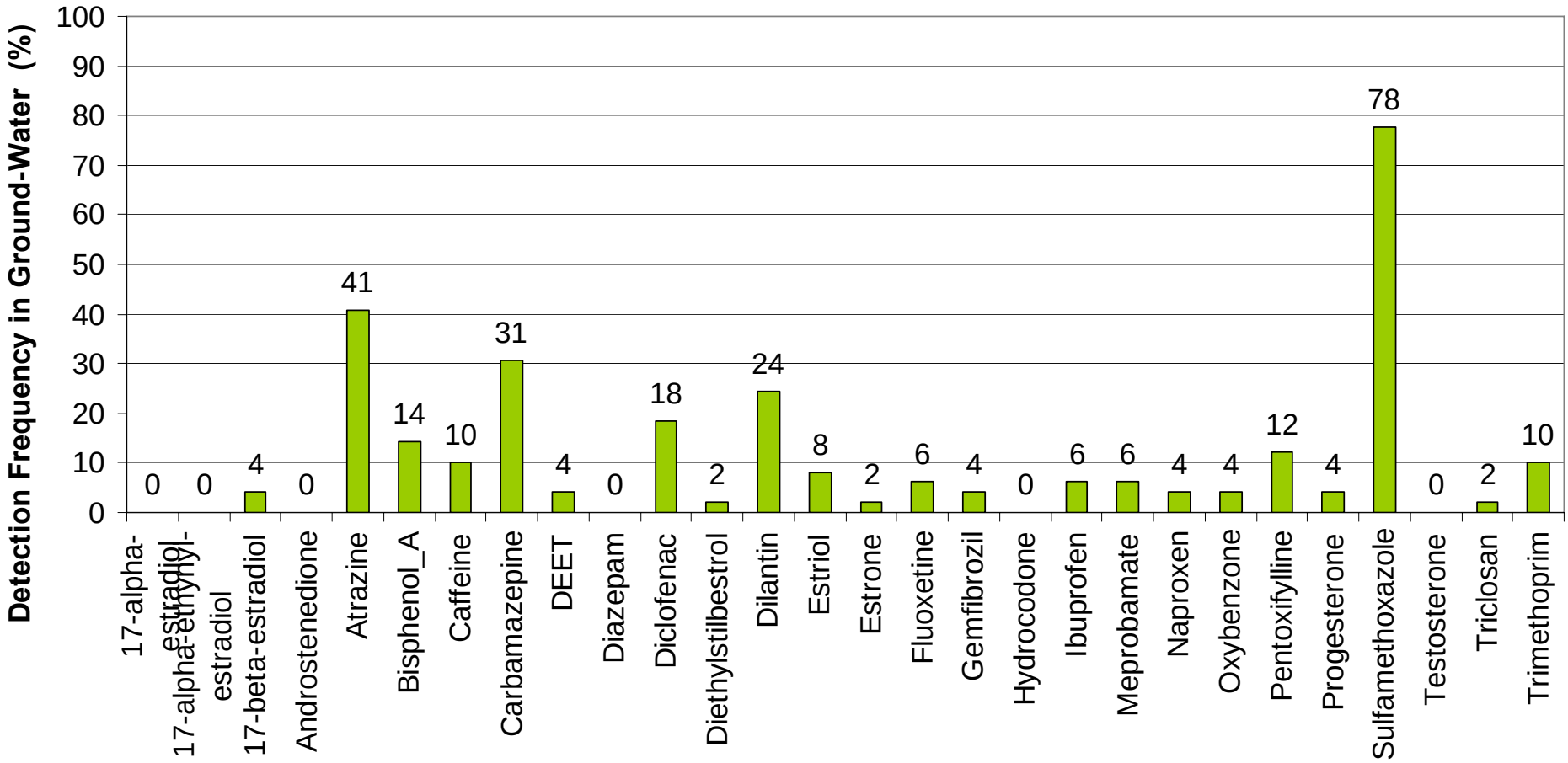
Legend

- No Detect: PPCP or Microbial
- PPCP Present, No Microbials
- PPCP Present, Total Coliform Present
- PPCP Present, Enterococci Present

PPCP Concentrations in Helena Valley Ground Water, 2005



Detection Frequencies of 28 PPCPs



Dictionary of PPCPs found in Helena Valley ground water

- **17-beta-estradiol**: hormone
- **Androstenedione:** hormone
- **Atrazine:** herbicide
- **Bisphenol_A:** ingredient of bottles, food wrapping and can linings (prostate cancer?)
- **Caffeine:** stimulant
- **Carbamazepine:** anti-seizure
- **DEET:** insect repellent
- **Diclofenac:** Voltaren, Cataflum, anti-inflammatory
- **Diethylstilbestrol:** DES, once prescribed pregnancy prevent miscarriages and premature delivery
- **Dilantin:** Anti-convulsant
- **Estriol:** hormone
- **Estrone:** hormone
- **Fluoxetine:** Prozac, anti-depressant
- **Gemfibrozil:** lipid and cholesterol treatment
- **Ibuprofen:** Advil, Motrin, Nuprin, etc. Anti-inflammatory
- **Meprobamate:** anti-anxiety
- **Naproxen:** Aleve, Anaprox, etc., analgesic and anti-flammatory
- **Oxybenzone**: sunscreen agent
- **Pentoxifylline:** improve circulatory problems
- **Sulfamethoxazole:** Gantanol, anti-biotic, malaria, conjunctivitis, UTI
- **Triclosan:** antibacterial, soaps, detergents, additive in plastics and textiles
- **Trimethroprim:** anti-biotic, UTI, combine with SMX to treat pneumocystis infections

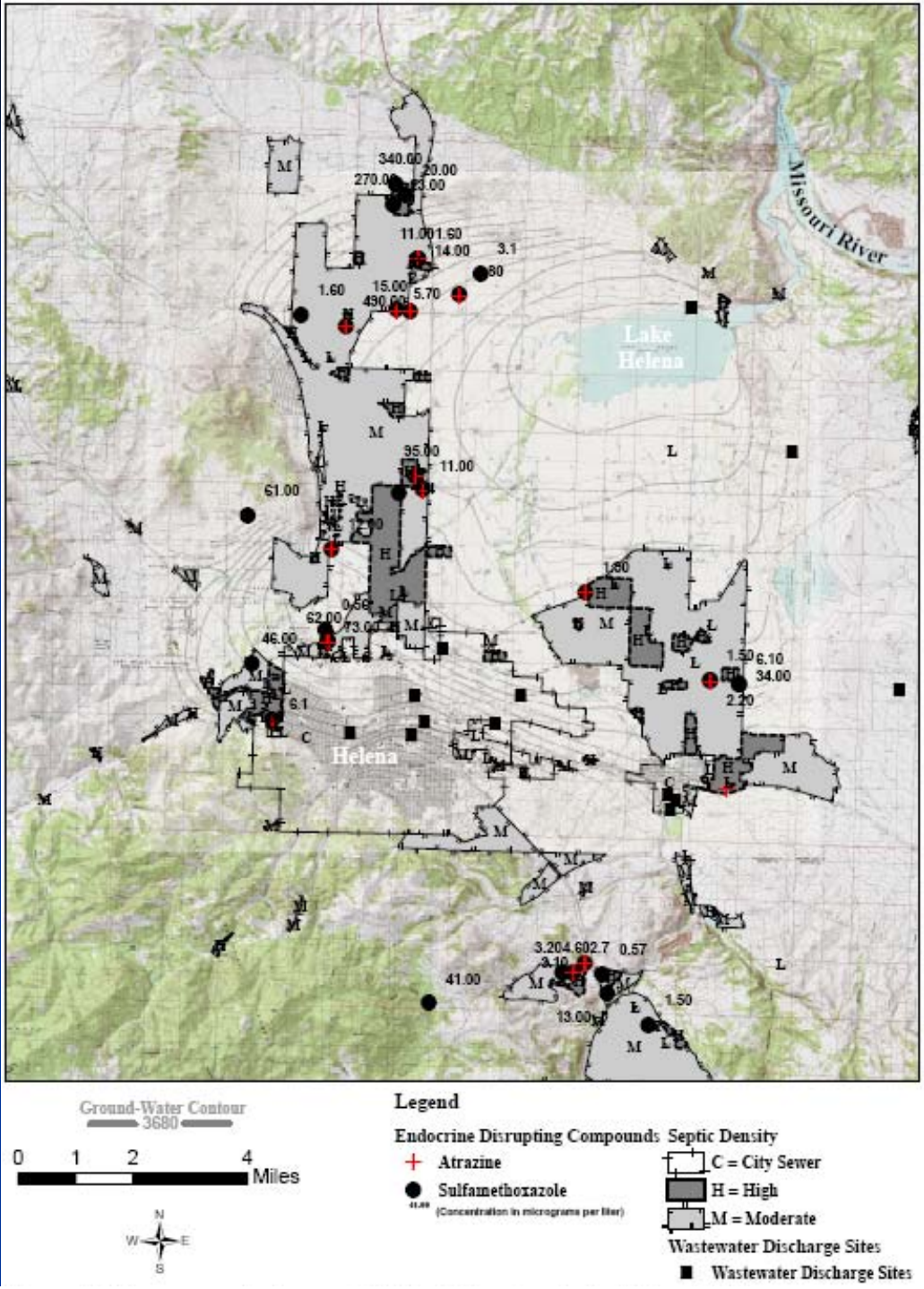
PPCP Concentrations

Five Most Frequently-Detected PPCPs	Maximum Concentration (ηg/L)
Sulfamethoxazole (SMX)	490
Atrazine	130
Carbamazepine	420
Dilantin	22
Diclofenac	46

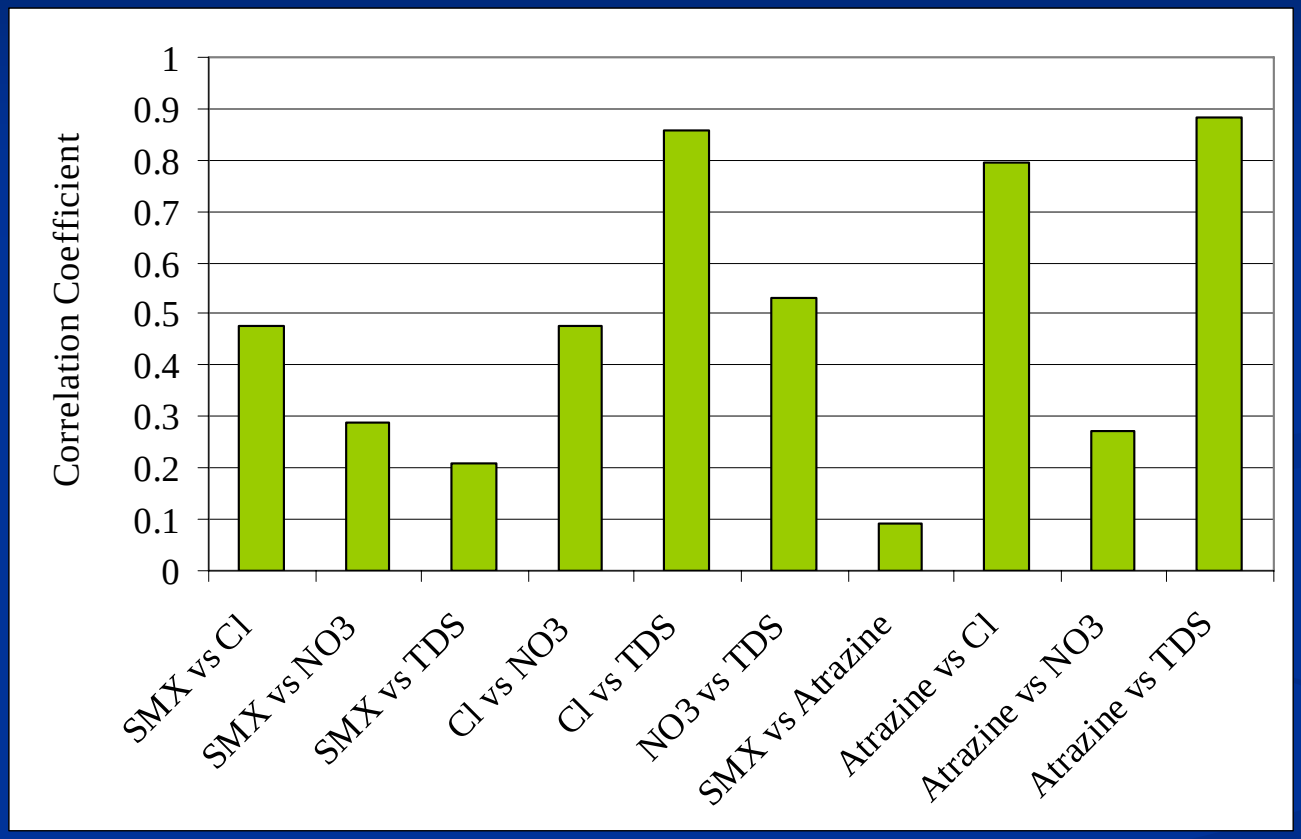
SMX, Atrazine and Types of Wastewater Discharge

<u>Septic Tank Density</u>

- **High:**
  - >300 septic tanks /mi^2
- **Moderate:**
  - 50-300 septic tanks /mi^2



Correlation Between Sulfamethoxazole (SMX), Atrazine, Chloride (Cl), Total Dissolved Solids (TDS) and Nitrate (NO_3)



- Question:
  - Is there a point source component to atrazine occurrence?

Summary

- PPCP findings are consistent with those of other investigators of ground water affected by onsite wastewater disposal

- Coliphage , E.coli and enterococci results present implications for suitability as indicators of fecal contamination in regional ground-water settings

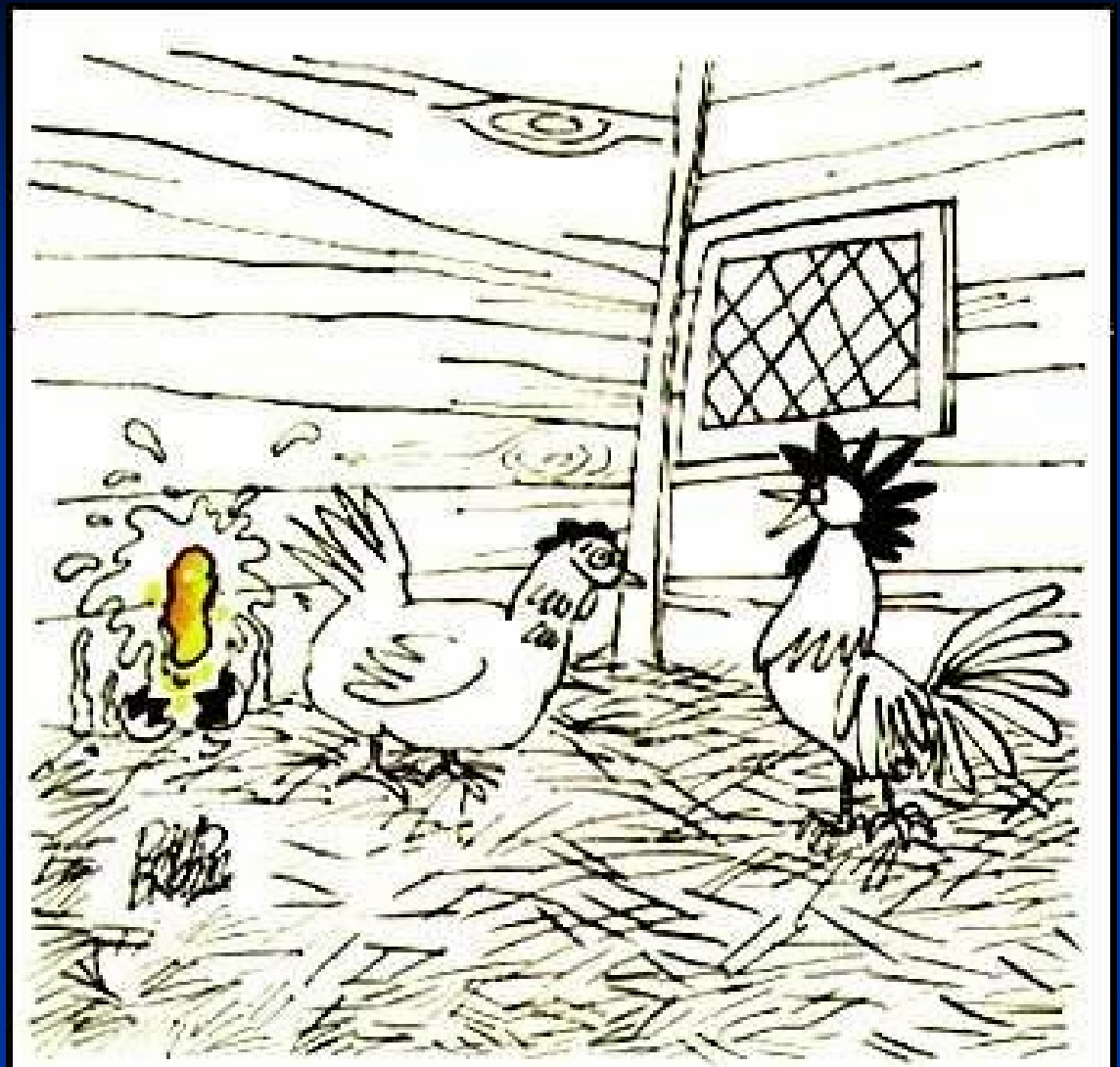
Questions Deserving Attention…

- **Role of aquifer properties and water quality in controlling PPCP sorption, degradation and indicator survival and attenuation in subsurface**
  - Investigate occurrence of atrazine
- **Is there cause for concern regarding impact to non-target organisms?**
  - Many of which do not possess the same suite of receptors as humans
- **Can multiple PPCPs sharing the same mode of action combine to reach threshold-effects levels?**
- **Is this a special exposure case since biota are exposed continually, through multiple generations?**

continued

Questions Deserving Attention…

- Acute toxicity, carcinogenesis, and mammalian endocrine disruption are highly visible concerns for many environmental pollutants –
  - Should more attention be paid to other, less overt toxicological endpoints, such as immuno-disruption, neurobehavioral change, and other subtle effects?
- Should practices be discouraged?
  - Direct disposal of excess/expired PPCPs to domestic sewage (flushing)
  - Over-prescribing of various drugs
- Can consumption by humans lead to significant exposures?
- Role of CAFOs?
  - Antibiotic and hormone use in domestic livestock and poultry



"Gesundheit!"