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Microbiological, Geochemical and Hydrologic Processes Controlling Uranium Mobility: An Integrated Field-Scale Subsurface Research Challenge Site at Rifle, Colorado

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DOE-LM Site Manager: R. Bush

DOE-SC Program Manager: Todd Anderson

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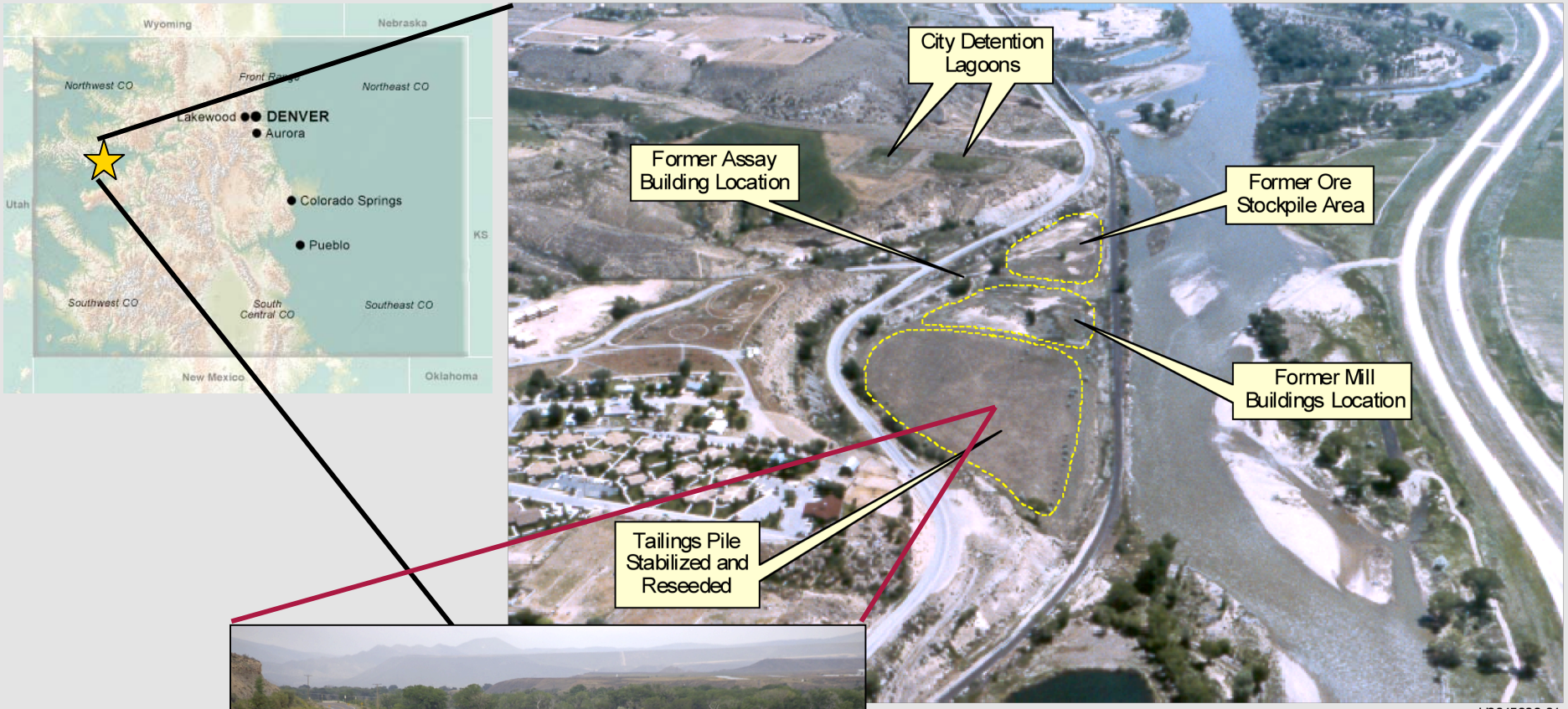
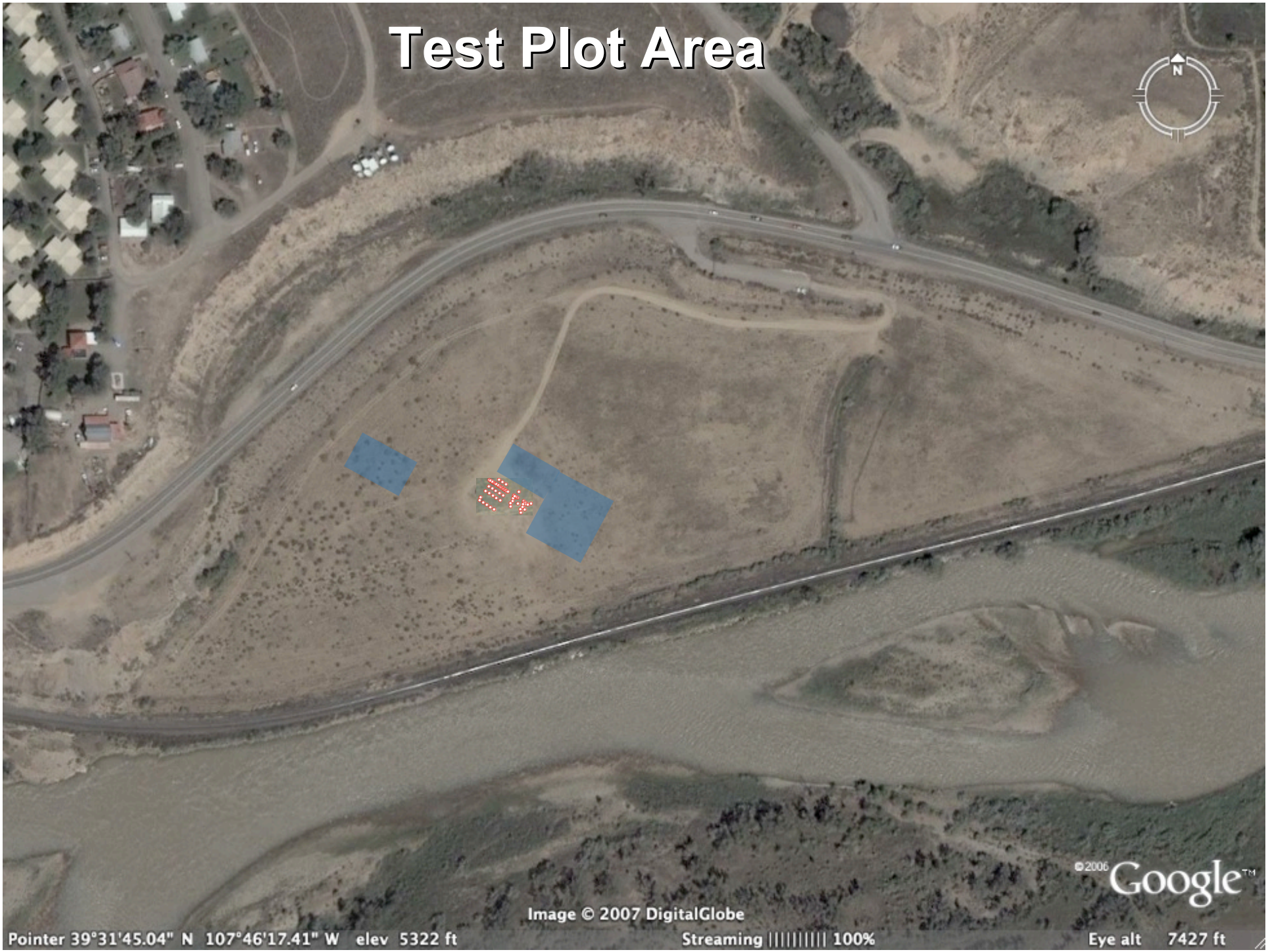
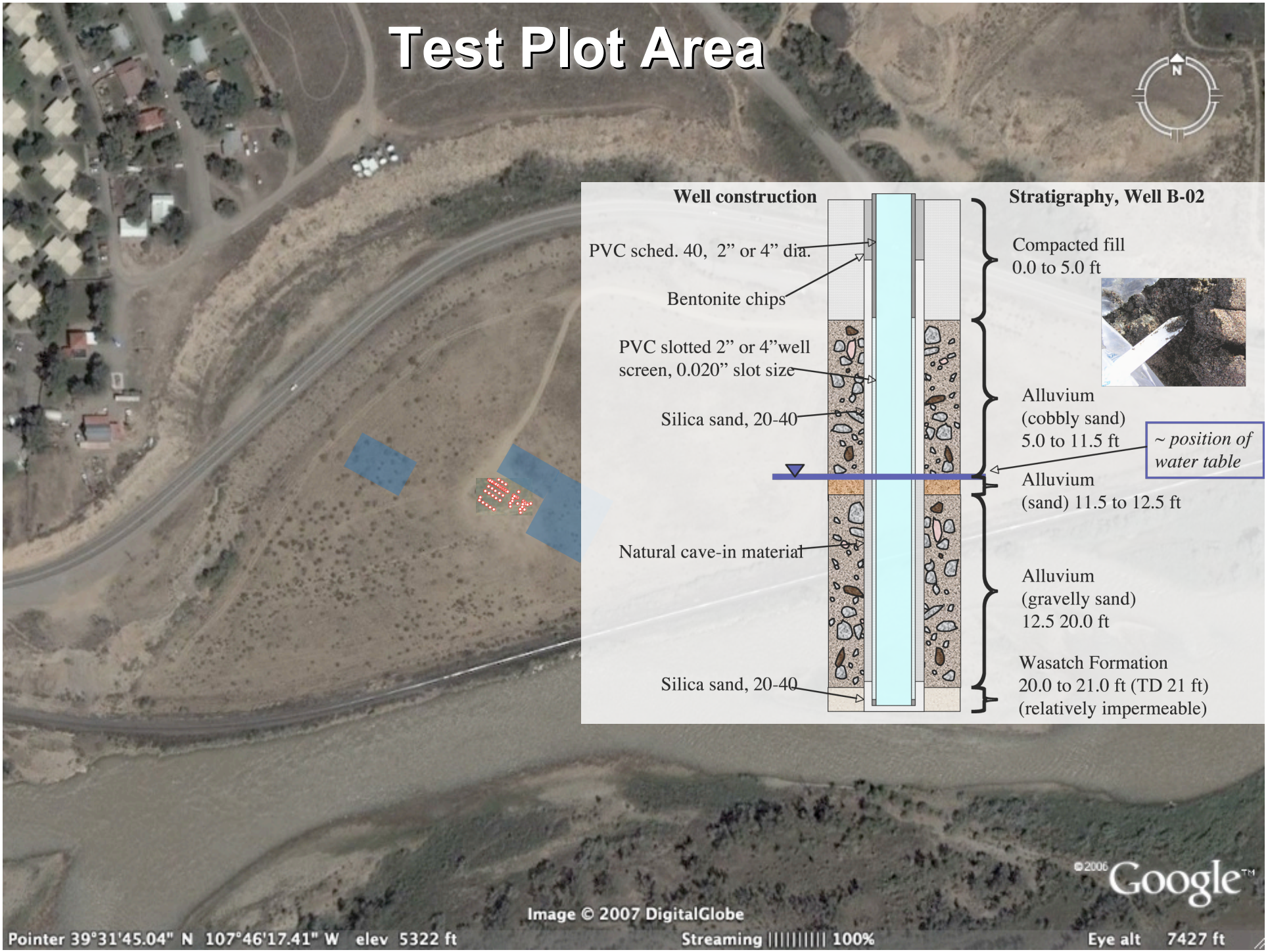
U.S. Department of Energy:
"Problem owner" for a wide range of sites contaminated with metals and radionuclides

Context for field bioremediation research at the Old Rifle Uranium Mill Tailings Site

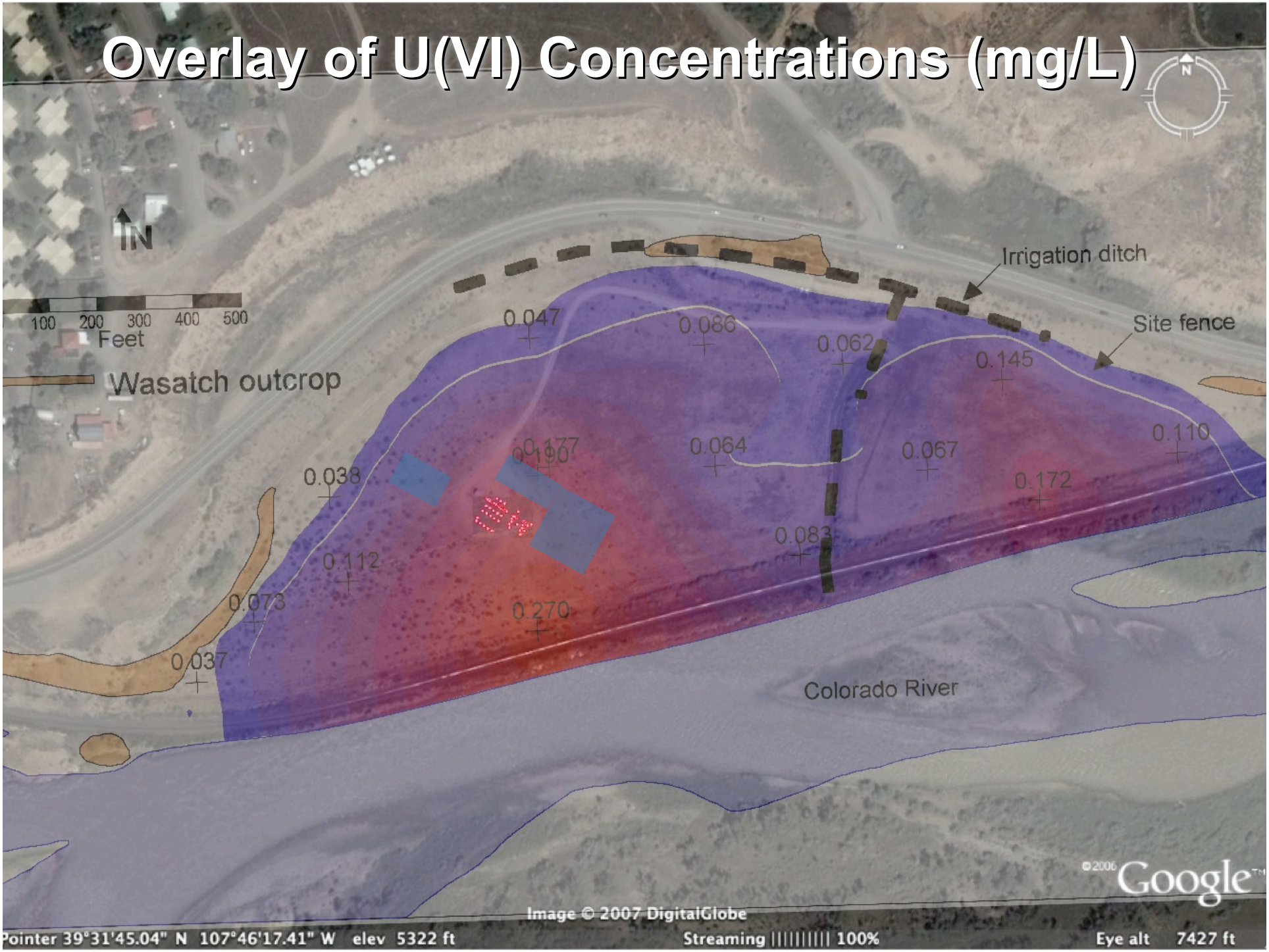



Test Plot Area
N
©2006 Google™
Image © 2007 DigitalGlobe
Pointer 39°31'45.04" N 107°46'17.41" W elev 5322 ft
Streaming 100%
Eye alt 7427 ft

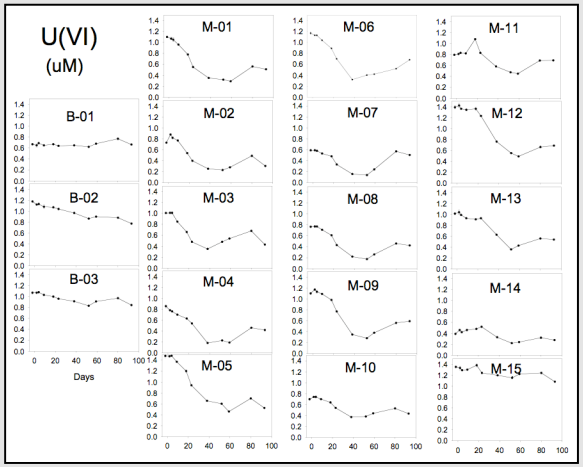
Test Plot Area



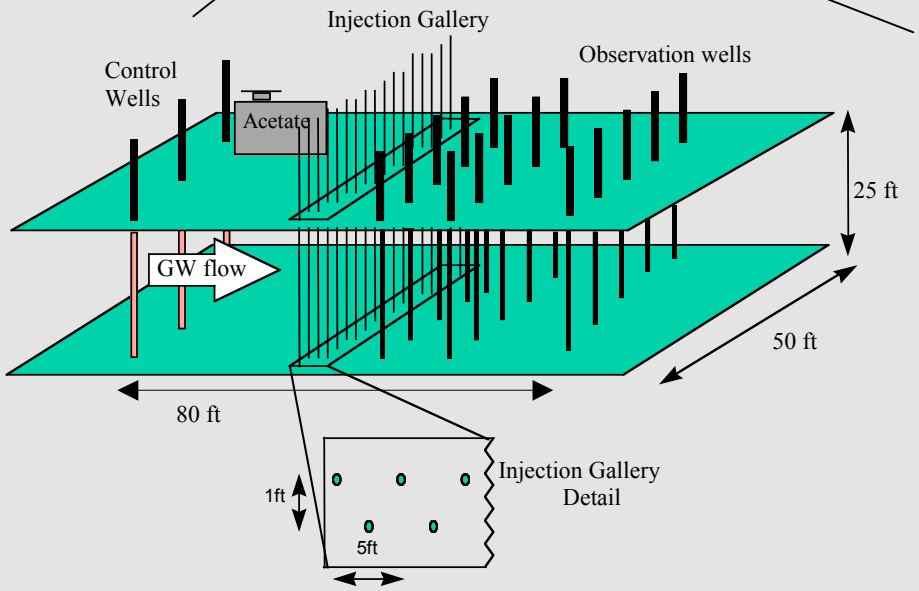
Overlay of U(VI) Concentrations (mg/L)

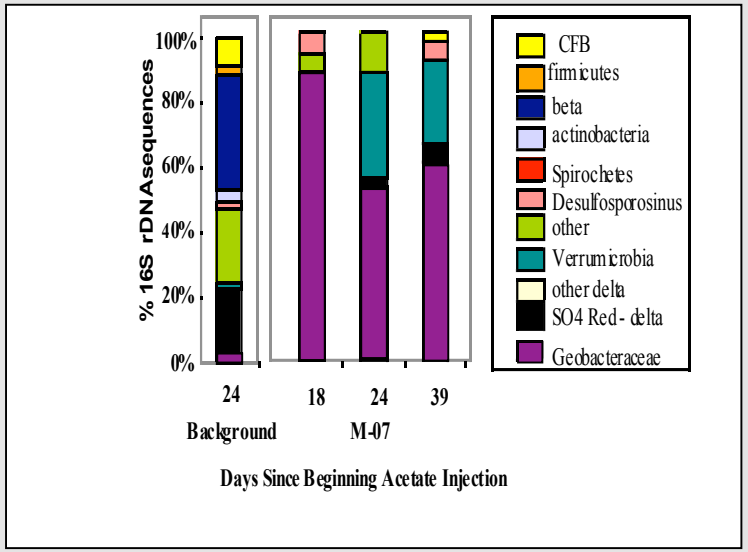


Test Plot Design(s)



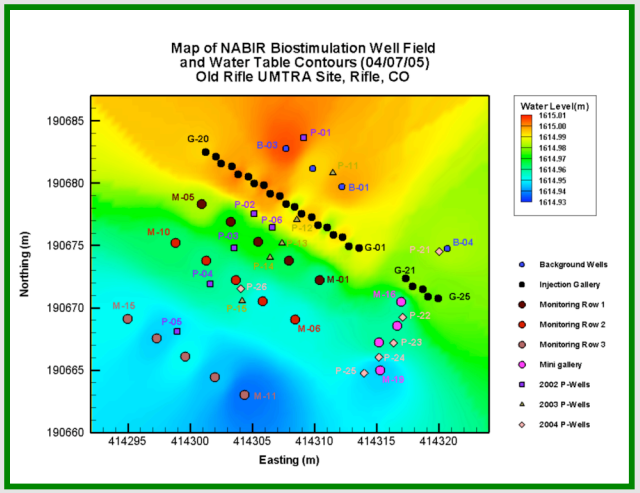
Conceptualized Test Plot

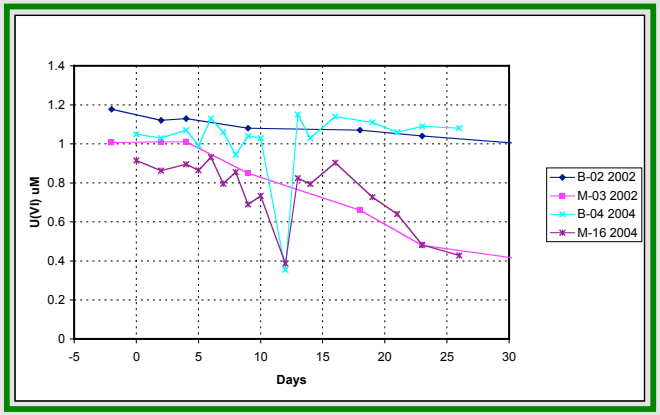




Summary of Previous Work

- Amendment with acetate stimulated metal reduction and loss of soluble uranium from the groundwater
- Loss of soluble uranium correlated with a substantial shift in the subsurface microbial community towards members of the Geobacter family
- Geobacteraceae are known to couple acetate oxidation to the reduction of Fe(III) oxides and U(VI)
- Loss of soluble uranium is attributed to the stimulation of Geoabacteraceae and enzymatic reduction of soluble U(VI) to insoluble U(IV)
- Continued acetate addition caused shift towards sulfate reduction decreased loss of U(VI) from groundwater
- Unexpected removal of U(VI) continued after stopping addition of acetate





Underlying constraints on application of *in situ* bioremediation of uranium

Incomplete understanding of:

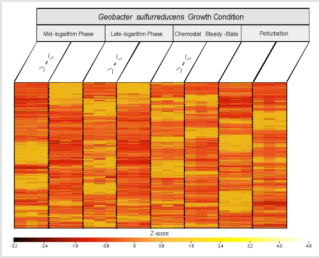
- Function and growth of subsurface microbial communities
- Microbial community succession in the subsurface
- Relative importance of enzymatic reduction of U(VI) to other potential immobilization mechanisms:
  - Sorption
  - Mineralization
  - Relative potential for abiotic reduction
- Long-term stability of immobilized uranium
- Methods to monitor stimulated metal reduction and microbial communities in the subsurface

Objective of the Rifle IFC

- Provide a “comprehensive and mechanistic understanding of the microbial factors and associated geochemistry controlling uranium mobility in the subsurface”
  - Such understanding of the coupled biotic and abiotic factors affecting uranium mobility is relevant to DOE’s cleanup and long-term stewardship missions

Overall Science Themes

- Mechanisms of U bioreduction illuminated by protein expression
- Relative contribution of biotic processes and abiotic uranium immobilization processes evaluated (e.g. U bioreduction and U sorption)
- Correlation of subsurface geochemical processes with geophysical monitoring of subsurface redox status associated with bioreduction
- Comprehensive reactive transport modeling of uranium mobility in the subsurface.



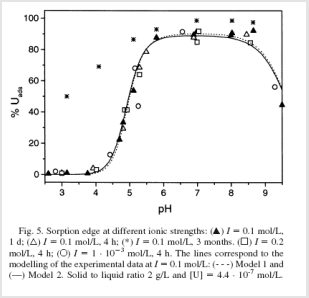
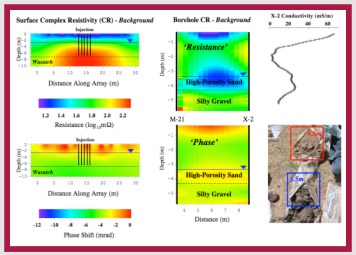


Fig. 5. Sorption edge at different ionic strengths: (▲) $I = 0.1$ mol/L, 1 d; (△) $I = 0.1$ mol/L, 4 h; (*) $I = 0.1$ mol/L, 3 months. (□) $I = 0.2$ mol/L, 4 h; (○) $I = 1 \cdot 10^{-2}$ mol/L, 4 h. The lines correspond to the modelling of the experimental data at $I = 0.1$ mol/L: (- - -) Model 1 and (—) Model 2. Solid to liquid ratio 2 g/L and [U] = 4.4 · 10^{-7} mol/L.



Hypothesis 1: Extending microbial Fe reduction in the subsurface

- HYPOTHESIS 1: In the presence of mM sulfate concentrations in groundwater, the transition from Fe(III) to sulfate reduction during acetate amendment will occur when the readily bioavailable Fe(III) is depleted. Iron reduction (and concomitant U(VI) reduction) can be extended in time through:

  1) the addition of nanoparticulate or soluble Fe(III) to the subsurface, and

  2) introduction of acetate at concentrations sufficient to support iron-reduction but not sulfate-reduction.

Hypothesis 2: Impact of reducing conditions on U(VI) sorption

- HYPOTHESIS 2: The sorption of U(VI) under reduced conditions is decreased overall in comparison to more oxic conditions, but is still large enough to retard U(VI) transport in the Rifle aquifer relative to groundwater flow.

Quantifying the impact of U(VI) sorption on groundwater U(VI) concentrations under Fe-reducing conditions is a crucial part of numerical modeling of aquifer conditions during and after biostimulation experiments.

Hypothesis 3: Long-term post-biostimulation removal of U(VI)

- HYPOTHESIS 3: Long-term post-biostimulation removal of U(VI) is dependent on ferrous sulfide minerals precipitated during sulfate reduction. After cessation of acetate amendment, these minerals become electron donors for a ***post-biostimulation microbial community*** capable of using low ambient concentrations of oxygen and nitrate as terminal electron acceptors. U(VI) is sorbed on to;

  1) biopolymers specific to the post-biostimulation microbial consortia, and/or,

  2) freshly oxidized Fe(III) mineral surfaces.

Hypothesis 4: Naturally occurring rates of U(VI) reduction

- HYPOTHESIS 4: Slow, naturally occurring rates of microbially mediated U(VI) reduction can be estimated (low, medium, high) using molecular biomarkers in Rifle samples by comparing the lowest acetate amendment in Hypothesis 1 with samples from other Rifle locations with no electron donor amendment.

Innovative Approaches and Techniques

- ***Proteomics***
- ^{13}C labeling
- Detailed analysis mineralogic changes,
- ***Lab and field sorption experiments under reducing conditions***
- ***Geophysical monitoring (especially ERT, complex resisitivity)***
- Detailed monitoring of hydraulic conductivity before, during, and after biostimulation
- CATs (cellularly adsorptive tracers)
- Instrumented in situ incubators
- Integration of diverse data sets via joint inversion
- ***Comprehensive reactive transport modeling***

FY-07 Schedule

- Kick-off Meeting in Grand Junction, CO Feb 27-Mar 1, 2007
- Mid- to late-May 2007: Electromagnetic survey of entire flood plain
- May 15, 2007: Geophysics and backhoe sampling for assessing experimental site locations
- June 15, 2007: Well installation for 2007 experimental site
- July 30 to August 15, 2007: Initial field experiment starts
- October 1, 2007: Initial field experiment ends

Old Rifle Data Availability on DOE-LM Web Site

Office of Science
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Geocortex Internet Mapping Framework (IMF) - Mozilla Firefox

File Edit View Go Bookmarks Tools Help

http://gems.lm.doe.gov/imf/imf.jsp?site=rifleoldprocessing&title=Rifle%20Old,%20CO,%20Processing%20Site

Getting Started

Geospatial Environmental Mapping System
GEMS: Rifle Old, CO, Processing Site

About Layers Legend Locate Selection Key Map Environmental Reports View Log Bookmarks Create PDF Help Exit

Office of Legacy Management

Scale: 1:3,568 go Map Tool: Select by Rectangle Active Layer: General Location - Existing Well

Done

MONITORING WELL COMPLETION LOG RFO01-0655

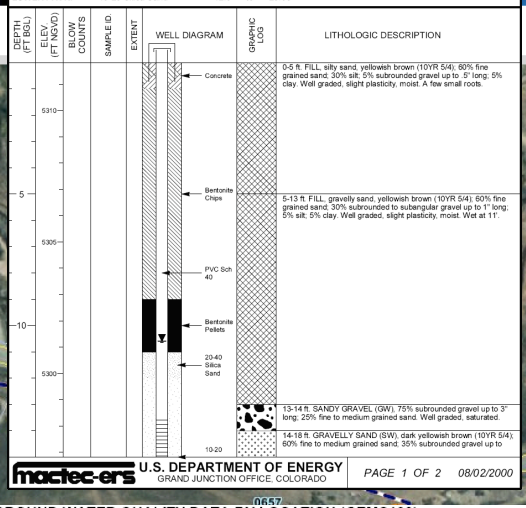
PROJECT UMTRA GROUND WATER
LOCATION RIFLE, CO
SITE RIFLE (OLD)
WELL NUMBER 0655

NORTH COORD. (FT) 625706.33
EAST COORD. (FT) 1359344.17
HOLE DEPTH (FT) 24.00
WELL DEPTH (FT) 23.93

DATE DRILLED 04/23/1998
SURFACE ELEV. (FT NGVD) 5311.82
TOP OF CASING (FT) 5312.87
MEAS. PT. ELEV. (FT) 5312.87
SLOT SIZE (IN) 0.020
BIT SIZE(S) (IN) 9.34

WELL INSTALLATION		INTERVAL (FT)		
SURFACE CASING:				
BLANK CASING:	4 in. PVC Sch 40	-1.05	to	13.6
WELL SCREEN:	4 in. Vee Wire Wrapped	13.6	to	23.6
SUMP/END CAP:	4 in. PVC Sch 40	23.6	to	23.93
SURFACE SEAL:	Concrete	0.0	to	1.0
GROUT:	Bentonite Chips	1.0	to	9.0
SEAL:	Bentonite Pellets	9.0	to	11.0
UPPER PACK:	20-40 Silica Sand	11.0	to	12.0
LOWER PACK:	10-20 Silica Sand	12.0	to	23.93

DRILLING METHOD ODEX - CASING ADVANCE
SAMPLING METHOD
DATE DEVELOPED 04/24/1998
WATER LEVEL (FT BTOC) 11.64 on 04/23/1998
LOGGED BY L. Spencer
REMARKS No samples collected



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Selection Set

HELP

Layer:
General Location - Existing Well

Selection:
1 features selected.

Options:

Launch GEMS Reporting	Launch Geospatial Environmental Reporting System
Default Report	Show the default report for the selected features
Tabular Report	Show a tabular report for the selected features.
Zoom to Extent	Zoom the map to the extent of the selected features.

This layer is defined as a selected set type of layer. You may use the selection tool to refine your selected set so that it contains the desired features before executing the reporting routines.

GROUND WATER QUALITY DATA BY LOCATION (GEMS100)

REPORT DATE: 4/6/07 12:06:33PM

SITE: RFO01, Rifle Old Processing Site

LOCATION: 0655

View Log

PARAMETER	UNITS	SAMPLE DATE	SAMPLE ID	DEPTH RANGE (FT BLS)	RESULT	QUALIFIERS LAB	QUALIFIERS DATA	QUALIFIERS QA	DETECTION LIMIT	UNCERTAINTY	
Nitrate as NO3	mg/L	05/18/1998	0001	13.60 - 23.60	3.500			#			View Graph
Oxidation Reduction Potential	mV	05/18/1998	N001	13.60 - 23.60	-75			#			View Graph
pH	s.u.	05/18/1998	N001	13.60 - 23.60	6.91			#			View Graph
Polonium-210	pCi/L	05/18/1998	0001	13.60 - 23.60	0.07		U	#	0.06	± 0.09	View Graph
Radium-226	pCi/L	05/18/1998	0001	13.60 - 23.60	0.20			#	0.1	± 0.07	View Graph
Radium-228	pCi/L	05/18/1998	0001	13.60 - 23.60	0.69	U		#	0.69	± 0.4	View Graph
Selenium	mg/L	05/18/1998	0001	13.60 - 23.60	0.0398			#			View Graph
Sodium	mg/L	05/18/1998	0001	13.60 - 23.60	152.000			#			View Graph
Specific Conductance	umhos/cm	05/18/1998	N001	13.60 - 23.60	1870			#			View Graph
Sulfate	mg/L	05/18/1998	0001	13.60 - 23.60	743.000		J	#			View Graph
Temperature	C	05/18/1998	N001	13.60 - 23.60	10.9			#			View Graph
Thorium-230	pCi/L	05/18/1998	0001	13.60 - 23.60	0.80	U		#	0.80		View Graph
Turbidity	NTU	05/18/1998	N001	13.60 - 23.60	10.0			#			View Graph
Uranium	mg/L	05/18/1998	0001	13.60 - 23.60	0.177			#			View Graph
Vanadium	mg/L	05/18/1998	0001	13.60 - 23.60	0.595			#			View Graph

SAMPLE ID CODES: 000X = Filtered sample (0.45 um). N00X = Unfiltered sample. X = replicate number.

Available Site materials

- Groundwater samples under background and biostimulated conditions
- Filtrates of groundwater samples
- Sediment samples under background and biostimulated conditions
- Large volumes of U-contaminated sieved sediment <2mm (RABS)
- Mineral separates on an as-requested basis (small volumes)

Opportunities for collaboration or augmentation of existing science team

- Groundwater organic carbon fractions
- Sedimentary structure and architecture
- Sediment geochemical properties
- Alternate electron donors
- Sampling techniques that preserve sedimentary structures
- Others…

Summary

- The four hypotheses are inter-related and elements of all four will be examined in each of the laboratory and field experiments planned for the site
- Please visit the Rifle IFC poster this evening
- Selected Co-PIs will now discuss the key approaches to investigating these hypotheses

Rifle IFC Presentations:

- DOE-LM Perspective on science needs and the Rifle IFC. ***Rich Bush*** (5 minutes)
- Biogeochemistry and reactive transport modeling of in situ biostimulation experiments at the Rifle site. ***Steve Yabusaki*** (20 minutes)
- Rifle IFC geochemistry and abiotic U(VI) reactions under iron-reducing conditions. ***Jim Davis*** (25 minutes)
- Protein measurement for assessment of subsurface microbial activity under biostimulated conditions. ***Jill Banfield*** (25 minutes)
- Hydrogeophysics and electrical methods for monitoring TEAPs at the Rifle IFC. ***Ken Williams*** (25 minutes)

Acknowledgements

- Funding: ***Environmental and Remediation Sciences Program (ERSP), Biological and Environmental Research (BER), Office of Science, U.S. Department of Energy***
- Thanks for Cooperation:
  - ***City of Rifle, Colorado***
  - ***Colorado Department of Public Health and Environment***
  - ***U.S. Environmental Protection Agency, Region 8***

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