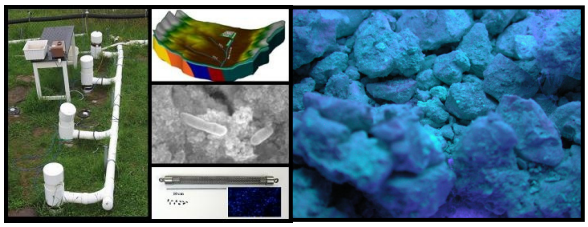
U. S. Department of Energy Office of Science

Subsurface Biogeochemical Research

OVERVIEW

Oak Ridge Integrated Field Research Challenge



Advancing the understanding and predictive capability of coupled hydrological, geochemical, and microbiological processes controlling the *in situ* transport, remediation and natural attenuation of metals, radionuclides, and co-contaminants at multiple scales

The Oak Ridge Integrated Field Research Challenge (ORIFRC) supports the U.S. Department of Energy's (DOE's) Subsurface Biogeochemical Research Program goal of understanding the complex physical, chemical, and biological properties of contaminated sites for new solutions to environmental remediation and long-term stewardship. In particular, the ORIFRC promotes understanding of the processes that influence the transport and fate of subsurface contaminants, the effectiveness and long-term consequences of existing remediation options, and the development of improved remediation strategies. Research is conducted at a series of contaminated and uncontaminated sites in which investigators and students conduct field research or collect samples for laboratory analysis. ORIFRC research also spurs the development of new and improved characterization and monitoring tools. Additionally, the ORIFRC hosts external investigators and ships groundwater and sediment samples to scientists around the globe.

Historical research, development, and testing associated with weapons production and related activities resulted in subsurface contamination that has been identified at over 7,000 discrete sites within the DOE complex. DOE currently is responsible for remediating 1.7 trillion gallons of contaminated groundwater, an amount equal to approximately four times the daily U.S. water consumption, and 40 million cubic meters of contaminated soil, enough to fill approximately 17 professional sports stadiums – a legacy of these past activities.* To help achieve this goal DOE sponsors research to improve or develop remediation technologies, especially for difficult, currently intractable contaminants or conditions.

The ORIFRC is not unique among DOE sites in having a mixture of contaminant plumes and difficult hydrogeochemical conditions.

For example, buried wastes in contact with a shallow water table have created large reservoirs of contamination. Rainfall patterns affect the water table level seasonally and over time. Furthermore, the hydrogeology of the area, with its fractures and karst geology, affects the movement of contaminants. Plumes have migrated long distances to surface discharge points through preferred flow paths created by the fractures and karst conditions.

Remediation options are limited, especially for contaminated groundwater. Moreover, current remediation practices for the source areas can affect biological, chemical, and physical processes that, in turn, may influence the movement of subsurface contaminants in unknown ways.

For more information about the ORIFRC

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* Status Report on Paths to Closure, DOE/EM 0526, U.S. Department of Energy, Washington, D.C., March 2000.

Anatomy of the ORIFRC: Watershed-wide effects

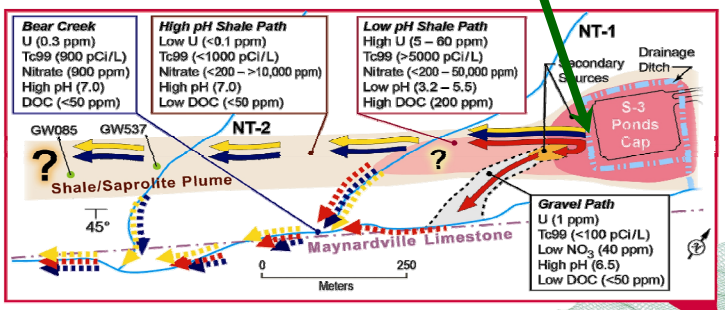
S-3 Ponds during operation (above), now capped and serving as a parking lot (right)

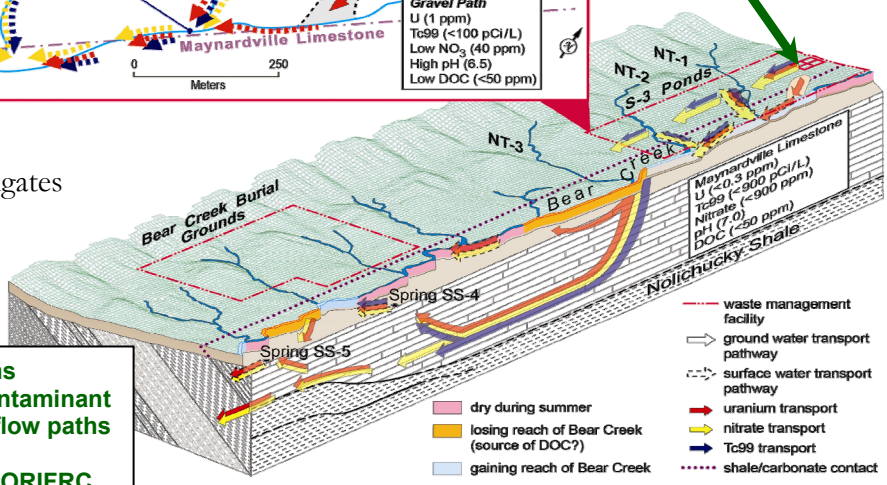
Site Setting

- Liquid wastes (nitrate, metals, radionuclides such as uranium and technetium, other chemicals) were disposed of in four unlined ponds – the S-3 Ponds – from the 1950s until 1983
- Contaminants flowed underground from the Ponds, creating large secondary sources of contamination
    - Ponds now are capped by an asphalt parking lot – capping prevents rainwater from directly infiltrating Ponds and releasing contaminants into surface and groundwater
- Rainwater infiltration (recharge) outside the cap (e.g., drainage ditch around Ponds), makes subsurface contaminants mobile in the watershed

Watershed-wide problems created by disposal are subject of ORIFRC research

- Wastes travel through two main pathways in the subsurface
    - Each pathway has different geological, hydrological, and microbial characteristics
    - Wastes discharge to Bear Creek and Maynardville Limestone, with its karst characteristics, then migrate further down the watershed
    - Shale saprolite: main pathway for nitrate and technetium
    - Gravel: main pathway for uranium
- pH matters – uranium is highest where pH is low (pink in diagram at right) but more mobile in gravel where pH is high
- No other field research facility investigates the subsurface fate and transport of contaminants on such a large scale using a real-world, contaminated site





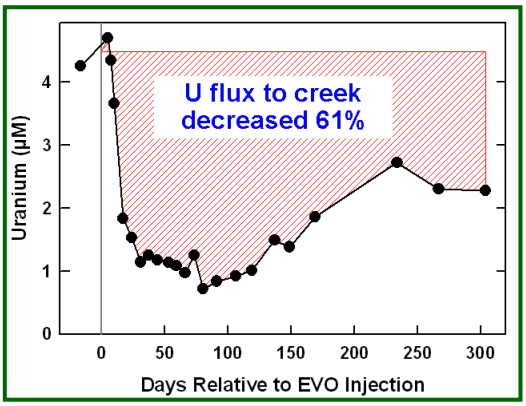
Schematic diagrams depicting major contaminant source zones and flow paths in the watershed encompassing the ORIFRC

ORIFRC findings to date

The Oak Ridge IFRC comprises an integrated multi-disciplinary, multi-institutional research program whose goal is to provide an improved scientific understanding and predictive capability of subsurface contaminant fate and transport through experiments and observations at scales ranging from the molecular to the watershed. A few of our research results and approaches are summarized below.

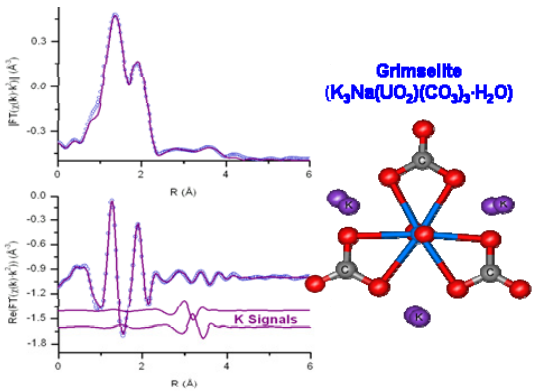
Contaminants can be made less mobile in the subsurface

- Demonstrated that microbes found in subsurface can transform uranium into chemical forms that are less mobile in groundwater
- Maintained decreased uranium concentration in groundwater approximately 1 year following single injection of carbon source
- XAS analysis shows the immobilized U exists as mononuclear U(IV) not particulate uraninite



Factors influencing site biogeochemical dynamics

- Discovered that contaminants from secondary sources play an important role in FRC contaminant fate and transport
- Massively parallel pyrotag sequencing at the watershed scale confirmed that pH is a master variable driving bacterial community composition and activity in the groundwater at the ORIFRC site
- Uranium naturally attenuated on carbonate gravel



Detailed understanding of complex subsurface environment

- Completed the first ever joint inversion of surface seismic and wellbore data to quantify aquifer zonation over plume-relevant scales
- Stable isotope analysis distinguishes microbial denitrification from plume dilution
- Employ massively parallel computer models to study and predict contaminant dynamics in groundwater

New site characterization and monitoring tools made available to other scientists

- PELCAPs provide unprecedented and low cost *in situ* measurement of attenuation rate and extent
- For the first time, detailed time-lapse seismic refraction tomography has been used to track subtle changes in infiltration-related soil moisture content
- CXTFIT/Excel (Tang et al. 2010) has been made publicly available with detailed information and tutorials http://www.ornl.gov/~t6g/cxtfit/index.cfm

Future ORIFRC research opportunities

Research at the ORIFRC has focused on active interventions to achieve accelerated microbially mediated bioreduction and immobilization of subsurface contaminants. It clearly is important to understand the ways in which multiple contaminants behave and move in the subsurface. However, it also is important to understand, monitor, and predict the long-term effectiveness of existing and new remediation technologies in real-world conditions, and at meaningful scales. The ORIFRC and other sites on the Oak Ridge Reservation lend themselves to watershed-scale analyses. These sites constitute an excellent resource for research on persistent questions about the course and long-term effectiveness of attenuation (nature taking its course with or without interventions to speed that process) and other extant remediation practices (placing an impermeable cap over the surface of a contaminated area, pumping-and-treating contaminants in groundwater, etc.). This research could, for the first time, help to track the movement of entire contaminant plumes in the subsurface over time, thereby providing new kinds of information that can help in remediation and monitoring decision making. For example, the ability to integrate data across the width of a plume over time provides information key to identifying important monitoring locations. Below are some of the many research topics associated with long-term stewardship that could be the subject of future field research at the ORIFRC or laboratory research using ORIFRC samples.

Watershed issues and processes

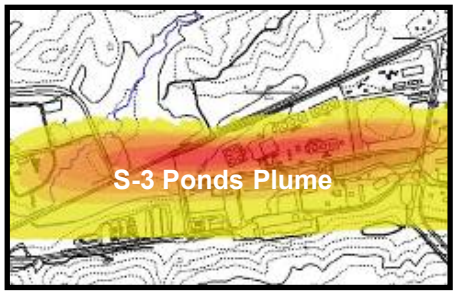
- Variations among watersheds
- Watershed responses to large-scale remediation
- Surface water-groundwater-biogeochemical dynamics
- Plumes from multiple—primary and secondary—sources
- Mercury cycling in the environment and biological communities

Active remediation strategies to reduce long-term stewardship costs

- New, potentially revolutionary remediation techniques and processes
- Abiotic, biotic, mechanical methods
- Enhancements to capping technologies
- Identifying and cutting off migration of contaminants in preferred flow paths

Natural and enhanced attenuation of large, diffuse, mixed waste contaminant plumes and sources

- Interdependent biological, chemical, and physical processes
- Interactions between contaminants (U, Tc, nitrate, other inorganics, and organics) and microorganisms
- Impact of scale and heterogeneity on transport processes and predictive models

Characterization, sensors, monitoring tools, and model predictions

- Techniques for reliably monitoring the progress of long-term attenuation and remediation
- Techniques for anticipating when remediation will or will not achieve goals
- Testing theoretical models in the field