LMS/FER/S33849

LM National Lab Network Collaboration: Fernald Preserve, Ohio, Site

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U.S. DEPARTMENT OF ENERGY | Legacy Management

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Abbreviations

CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
COC	constituent of concern
DOE	U.S. Department of Energy
EM	Office of Environmental Management
EPA	U.S. Environmental Protection Agency
EVS	Environmental Visualization System
FRL	final remediation level
FTE	full-time equivalent
GMA	Great Miami Aquifer
IC	institutional control
LAD	liquid acid descaler
LM	Office of Legacy Management
LMS	Legacy Management Support
NLN	National Laboratory Network
Ohio EPA	Ohio Environmental Protection Agency
OU	operable unit
ROD	Record of Decision

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Executive Summary

This report presents recommendations to reduce risk involved with the ongoing aquifer remediation at the Fernald Preserve, Ohio, Site in southwest Ohio. The recommendations are the result of a collaborative effort between the U.S. Department of Energy (DOE) Office of Legacy Management (LM), the Legacy Management Support contractor, and the DOE National Laboratory Network from January 13, 2021, to March 31, 2021. The U.S. Environmental Protection Agency (EPA), Region 5, and the Ohio Environmental Protection Agency (Ohio EPA) also participated in the collaboration. Participation by EPA and Ohio EPA was with the understanding that any official input or endorsement for any of the recommendations would be reserved for if and when DOE actually decides to pursue implementation of a recommendation at the site.

The collaboration focused on how to best maintain the aging wellfield system, how to improve the efficiency and success of the existing aquifer remedy, and how to improve predictions of when remediation objectives will be achieved. Participants were asked to answer the following key questions:

- What are we doing that we should keep doing?
- What are we doing that we should stop doing?
- What are we *not* doing that we should be doing?

The following nine consensus recommendations that are actionable within the next 1 to 5 years (i.e., Short List Actions) resulted from the collaboration:

1. Test the use of automated biofilm and scale control in the extraction wells
2. Test the use of carbon dioxide to rehabilitate extraction wells
3. Enhance rehabilitation contact (i.e., use of satellite wells to deliver treatments)
4. Use alternative mathematical expressions to predict cleanup time frames
5. Conduct targeted data mining of available site information for enhanced understanding of prior fate and transport behavior and improved predictions of future behavior
6. Prepare three-dimensional visualizations of key hydrogeologic and geochemical parameter distributions over time
7. Refine plume metric calculations to reduce uncertainty
8. Continue to port the site groundwater model to a modern hydrologic software platform
9. Conduct algorithm-based optimization for future remedy operation and design

In general, the consensus recommendations focus on reducing risks based on two broad categories of impact: (1) by maximizing the effectiveness and assuring sustainable performance of the existing groundwater remediation in the southern and offsite portions of the plume (recommendations 1–3) and (2) by enhancing the datasets and interpretive tools to support, inform, and improve LM groundwater management decisions (recommendations 4–9). Descriptions, implementation strategies, and rough cost estimates are provided for each of the nine consensus (i.e., short list) recommendations. An additional 15 supplementary

recommendations are also provided to strategically prepare for anticipated future needs or future stages of the aquifer remediation.

Narratives for each of the short list recommendations and actions are provided in Attachment A. Narratives for each of the additional supplementary recommendations and actions are provided in Attachment B, and collaboration team documentation (i.e., schedules, participant lists, working group meeting agendas, and notes) is provided in Attachment C.

1.0 Introduction

1.1 Purpose and Scope

The U.S. Department of Energy (DOE) Office of Legacy Management (LM) is responsible for the stewardship of a growing portfolio of 100 facilities formerly used for defense-related mining, milling, processing, disposal, and program management. LM recently undertook a major effort to rank each site in its portfolio by relative risks related to human health, regulatory compliance, institutional controls (ICs), and stakeholder concerns. The ranking of sites within the four risk categories is a relative ranking (within LM) of potential future risks. A site with a "high" ranking in a given category does not pose an immediate threat; rather, relative to sites ranked "low," it has a greater potential to pose a problem in the future.

Table 1 provides the LM Risk Index as determined in 2019. The table lists the top 10 "at risk" LM sites. The Site Risk Index characterizes the risk for each site in the areas of human health, stakeholders, regulations, and ICs. Sites are ranked from high to low for each weighted factor, which are rolled up into an overall Site Risk Index.

The risk categories are defined as follows:

- Human Health Risk: The possibility that human receptors could be exposed to unacceptable levels of site-related contamination
- Stakeholder Risk: The likelihood that protectiveness of a given site could be affected or questioned in some way based on input from stakeholders (individuals or organizations)
- Regulatory Risk: The likelihood that a site will not attain compliance goals (e.g., groundwater cleanup is ongoing) or that compliance will not be maintained in the future
- IC Risk: An assessment of the effectiveness of an IC to maintain protectiveness of human health and the environment

The director of LM envisioned a partnership—a collaboration among LM, the Legacy Management Support (LMS) contractor, and DOE's national laboratories—working together to help DOE reduce risks at the highest ranked sites, reduce uncertainty, and improve efficiency by strategically leveraging and applying innovative technically-based solutions. LM focused the participants toward developing actionable (i.e., implementable in the 1–5-year time frame), consensus-driven (i.e., lacking dissent among the National Laboratory Network [NLN], the LMS contractor, LM, and other invited participants) recommendations that directly reduce identified risks. For the Fernald Preserve, Ohio, Site, the U.S. Environmental Protection Agency (EPA) and the Ohio Environmental Protection Agency (Ohio EPA) were invited to participate. Participation by EPA and Ohio EPA was with the understanding that any official input or endorsement for any of the recommendations would be reserved for if and when DOE actually decides to pursue implementation of a recommendation at the site.

Five of the highest risk sites were selected for NLN collaborations that would focus on developing recommendations to reduce the identified risks. These sites are the Shiprock, New Mexico, Disposal Site; the Tuba City, Arizona, Disposal Site; the Bluewater, New Mexico, Disposal Site; the Monument Valley, Arizona, Processing Site; and the Fernald Preserve site. This report pertains to the Fernald Preserve collaboration.

As shown in Table 1, Regulatory Risk was identified as the only "high" risk driver for the Fernald Preserve site. This is due to an active ongoing groundwater remediation operation and the risk that the pumping stage of that remediation will need to continue longer than is predicted. As prescribed in the Operable Unit (OU) 5 Record of Decision (ROD), LM is to utilize pump-and-treat technology to conduct a concentration-based cleanup of all areas of the Great Miami Aquifer (GMA) impacted by former plant operations (DOE 1996). As of December 31, 2019, over 48 billion gallons of groundwater have been pumped and 14,645 pounds of uranium removed from the aquifer. Although the current operational remedy remains effective in removing uranium from the aquifer, dissolved uranium concentration data indicate that model-predicted cleanup times for areas of the aquifer will not be met. Model-predicted cleanup times have been missed in the past, resulting in the need to extend the predicted end date for pumping operations.

Table 1. LM 2019 Risk Index

LM Site Information		Site Risk Factor Inputs				Risk Index
LM Site Name	Regulatory Driver/Programmatic Framework	Human Health/ Risk	Stakeholder Risk	Regulatory Risk	Institutional Control Risk	
Shiprock, NM, Disposal Site	UMTRCA Title I	High	High	High	High	1.00
Tuba City, AZ, Disposal Site	UMTRCA Title I	High	High	High	High	1.00
Bluewater, NM, Disposal Site	UMTRCA Title I	Medium	Medium	High	High	0.90
Mound, OH Rollup (8 components)	CERCLA/RCRA	Medium	Medium	High	Low	0.84
Weldon Spring, MO Rollup (5 components)	CERCLA/RCRA	Medium	High	High	Low	0.84
Monument Valley, AZ, Processing Site	UMTRCA Title I	Medium	High	High	High	0.83
Fernald Preserve, OH Rollup (3 Components)	CERCLA/RCRA	Low	Medium	High	Medium	0.79
Monticello, UT Rollup (4 components)	CERCLA/RCRA	Low	Medium	High	Low	0.76
Grand Junction, CO Rollup (2 Components)	UMTRCA Title I	Low	Low	High	Medium	0.75
Pinellas, FL Rollup	CERCLA/RCRA	Low	Low	High	Medium	0.75

Abbreviations:
CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act
RCRA = Resource Conservation and Recovery Act
UMTRCA = Uranium Mill Tailings Radiation Control Act

The OU-5 ROD does not prescribe a time frame for achieving aquifer remediation goals, but it is in the best interest of LM, EPA, and the State of Ohio to achieve cleanup goals as quickly as possible. Uncertainty in achieving aquifer remediation goals fosters a budgeting risk for LM that is directly connected with achieving regulatory approved compliance goals for the site. The focus of the Fernald Preserve NLN collaboration was to recommend actions that could be taken to better maintain and operate the aging extraction well system, improve the efficiency of the ongoing aquifer remedy, and provide better predictive capabilities for managing the remediation to reduce the "high" regulatory risk identified for the site.

1.2 Collaboration Process

The collaboration at the Fernald Preserve site was conducted as follows:

- A kickoff meeting to orient participants to the site and the collaboration objectives was held on January 13, 2021
- Six working group meetings were held, with the first meeting held on January 20, 2021, and the last on March 31, 2021
- Five focus group meetings were held, with the first meeting held on January 27, 2021, and the last on March 24, 2021
- The compilation of this report that summarizes the risk reduction recommendations made by the group

At the recommendation of the Fernald Preserve LM site manager, stakeholders and regulators were invited and encouraged to participate in the collaboration process. For the Fernald Preserve, this included EPA and Ohio EPA. Both EPA and Ohio EPA participated in the kickoff meeting and the six working group meetings by sharing impressions and thoughts about the topics being discussed. Both organizations made it clear that any official input by them would be reserved for if and when any of the recommendations coming out of the collaboration were presented to them as something the site had selected to implement.

The organizations invited to participate included the following:

- LM
- LMS contractor
- NLN:
  - Savannah River National Laboratory
  - Pacific Northwest National Laboratory
  - Sandia National Laboratory
  - Argonne National Laboratory
- Ohio EPA
- EPA, Region 5

Individual names and affiliations of those invited are noted on the meeting agenda included in Attachment C.

This multiorganizational collaboration led to a broad range of topics covered and brought many voices together to formulate the risk reduction recommendations that are detailed within this report. Reference to the NLN collaboration throughout the document refers to the joint effort of

all participants, including those from national laboratories, LM, the LMS contractor, and the regulatory agency representatives.
Further discussed in Section 3.0, two focus groups were organized for the Fernald Preserve collaboration. Each focus group designated both an NLN and an LMS lead. The NLN lead was primarily responsible for coordinating subgroup discussions, compiling the tabulation of recommendations and the implementation details. The LMS lead was primarily responsible for focusing the discussion and ensuring that the recommendations were actionable within the context of the Fernald Preserve project, weighed against work done to date and work already planned. Incremental documentation to support recommendation development was made available to all focus group participants for input and comment. The collaboration achieved major success in that *consensus was achieved among all participants from the various organizations on the final set of recommendations presented in this report*.

2.0 Site Background

2.1 Brief Site History

The Fernald Preserve site (approximately 1050 acres) is in Hamilton and Butler counties, Ohio, approximately 18 miles northwest of Cincinnati. It is a Category 3 LM site with an onsite staff. The Fernald Preserve site is a Category 3 site due to the operation and maintenance of an active remedial system, routine inspections to verify the integrity of engineered facilities and ICs, groundwater and surface water monitoring, and records-related activities. The Fernald Preserve is one of nine Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) sites managed by LM.

The site was established in 1951 by the U.S. Atomic Energy Commission as the Feed Materials Production Center with a mission to consolidate uranium feed production from St. Louis, Missouri; Cleveland, Ohio; and Niagara Falls, New York. Its location was selected because of a favorable nearby work force, access to rail line, and good supply of groundwater. Land was secured through eminent domain. Production started in 1951. The facility produced 500 million pounds of uranium metal from 1951 to 1989.

During production, uranium ore and ore concentrates were converted through wet chemical processes to uranium tetrafluoride, which was heated with magnesium to produce uranium "derbies." The derbies underwent additional processing to generate high purity uranium metal products that were shipped to other sites in the weapons complex. For every pound of uranium product produced, three pounds of waste were generated.

Production ended in 1989, and the site was placed on the National Priorities List due to the presence of waste materials, contaminated soil, and groundwater. The site mission changed from production to remediation in 1991. Remediation of the site took place pursuant to CERCLA and was organized into five OUs:

- OU-1—Waste Pits
- OU-2—Other Waste Units
- OU-3—Production Area

- OU-4—Silos
- OU-5—Environmental Media (i.e., soil, groundwater, and surface water)

With the exception of the aquifer remediation under OU-5, site remediation was completed on October 29, 2006. The site was officially transferred to LM on November 17, 2006. LM manages postclosure responsibilities and ensures protection of human health and the environment. LM scope at the Fernald Preserve includes:

- Completion of the aquifer remediation in accordance with the OU-5 ROD.
- Management of the OSDF.
- Maintaining the site as an undeveloped park with an emphasis on wildlife.
- Ensuring that ICs are in place and remain effective.
- Engaging the community through an onsite Visitors Center, outreach programs, and online content.

2.2 Aquifer Remediation

Completion of the aquifer remedy is a primary focus of LM at the Fernald Preserve site. It constitutes approximately 25% of the site annual operating budget. The OU-5 ROD formally defines the selected aquifer remedy and establishes final remediation levels (FRLs) for 50 constituents of concern (COCs), with uranium being the main COC and the driver for the remediation (DOE 1996). The selected aquifer remedy for the site is a concentration-based cleanup of all impacted areas of the GMA through extraction technology. The OU-5 ROD commits to an ongoing evaluation of innovative remediation technologies so that remedy performance can be improved as such technologies become available; however, any change from extraction technology would involve a ROD amendment.

The Fernald Preserve site is situated over the GMA, which is a regionally important Sole Source Aquifer in southwest Ohio (Figure 1). The aquifer was created by glacial processes during the Pleistocene when an abandoned river valley was filled in with a thick deposit of sand and gravel delivered from the retreating glaciers. The GMA contains approximately 1.5 trillion gallons of fresh water. It is the sole source of drinking water for approximately 1.6 million people, and the City of Cincinnati obtains approximately 12% of its drinking water from the aquifer.

The former Fernald production area was on top of a thick deposit of clay. This thick deposit of clay protected the underlying GMA during production years. Contamination reached the GMA in areas where the clay was not present, impacting approximately 312 acres of the aquifer.

The Fernald Preserve site is unique in LM in that it has an approved Groundwater Certification Plan for the aquifer remedy (DOE 2006). This plan documents the area of the plume that has been impacted by former site operations and establishes a plan for certifying that remediation goals have been achieved. The area of the plume that has been impacted by past operations is referred to as the Target Certification Footprint (Figure 2).

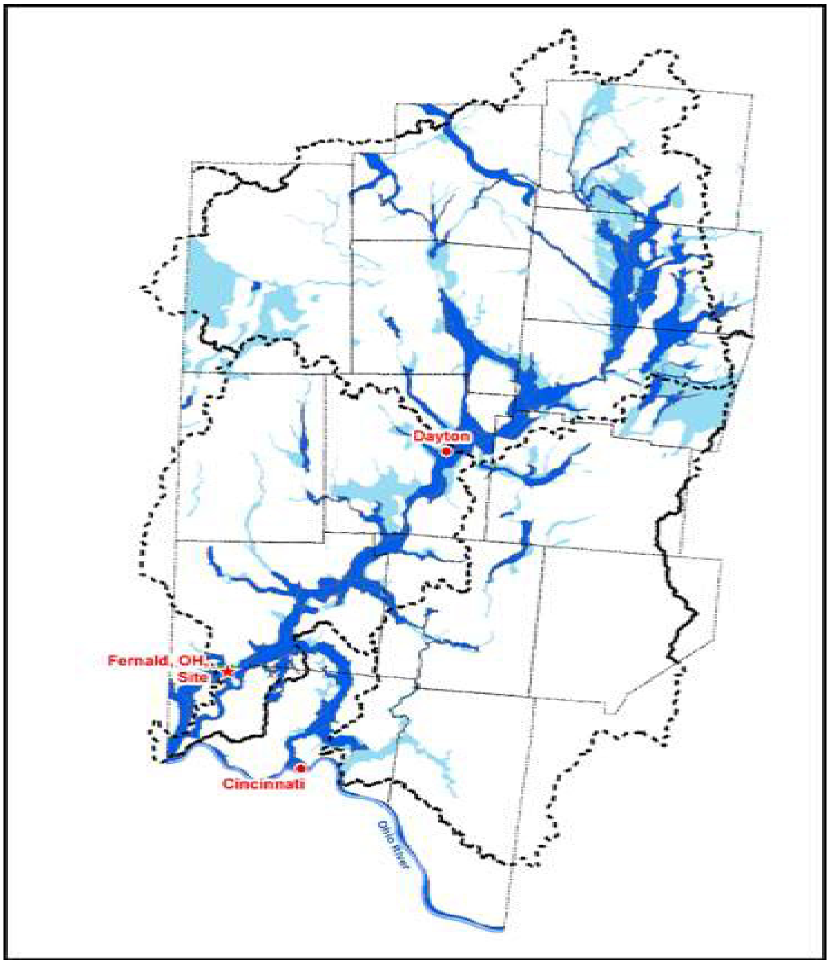

Figure 1. Great Miami Aquifer (Sole Source Aquifer)

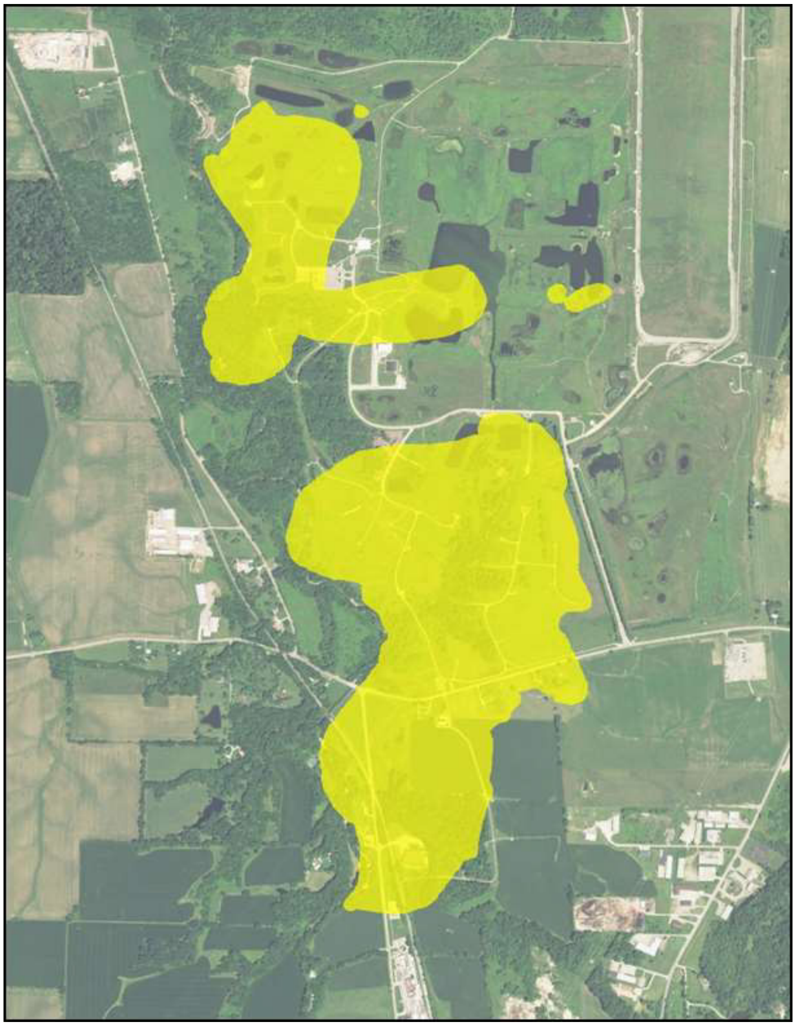

Figure 2. Target Certification Footprint

The main objectives of the aquifer remediation are as follows:

- COC concentration-based cleanup of impacted portions of the aquifer to FRLs defined in the OU-5 ROD
- Focus on the cleanup of off-property portions of the plume first
- Limit further expansion of the plume
- Prevent undesirable groundwater drawdown beyond the site boundary
- Limit impact to private property

The current extraction wellfield consists of 20 extraction wells pumping at a design pumping rate of 4975 gallons per minute. Figure 3 provides the locations of the extraction wells. Also shown in Figure 3 is how the plume is divided into three operational modules: (1) South Plume/South Plume Optimization, (2) South Field, and (3) Waste Storage Area. The final number and location of extraction wells in operation at the site was established through a progressive remedial design process conducted by the DOE Office of Environmental Management (EM) during the CERCLA remediation. The progressive design reports are as follows:

- 1995—*Feasibility Study Report for Operable Unit 5* (DOE 1995)
- 1997—*Baseline Remedial Strategy Report, Remedial Design for Aquifer Restoration (Task 1)* (DOE 1997)
- 2001—*Design for Remediation of the Great Miami Aquifer in the Waste Storage and Plant 6 Areas* (DOE 2001)
- 2002—*Design for Remediation of the Great Miami Aquifer, South Field (Phase II) Module* (DOE 2002)
- 2003—*Comprehensive Groundwater Strategy Report* (DOE 2003)
- 2005—*Waste Storage Area Phase II Design Report* (DOE 2005)

The aquifer remedial design established in 2005 was the design turned over from EM to LM in 2006. That design underwent one operational optimization in 2014 (DOE 2014).

Under LM management, steady progress toward achieving remediation goals has been made. Figure 4 illustrates the decrease in uranium plume area that has been recorded through annual sampling events. From 2006 to 2019, the area of the uranium plume has decreased from 189 acres to 86.5 acres (54.2% decrease). Although the current operational remedy remains effective in removing uranium from the aquifer, dissolved uranium concentration data indicate the following:

- Model-predicted cleanup times in key areas of the plume will not be met
- Additional operational pumping is required beyond the model predicted end dates
- Additional modeling is needed to predict new cleanup times

As previously explained, the OU-5 ROD does not prescribe a time frame for completing the aquifer remedy, but it is in the best interest of LM, EPA, and the State of Ohio to achieve cleanup goals as quickly as possible.

Continued operation of an aging wellfield at the Fernald Preserve site is challenging. Iron biofouling is a constant struggle at the extraction wells (Figure 5). Routine chemical treatments and periodic well rehabilitations are degrading the existing infrastructure. Well rehabilitation efforts are becoming less and less effective and are no longer considered effective at a few of the extraction wells. Specific capacity at the extraction wells (an indicator of well performance) is declining. Although the specific capacity of an extraction well at the Fernald Preserve site generally increases significantly immediately following a well rehabilitation, lately it also has been decreasing rapidly once the well resumes pumping. Routine chemical treatments are corroding cast iron parts, steel bolts used to secure the pumps and motor shafts in place, steel parts of cable connectors, and steel pipe. A better way of managing the long-term care and maintenance of the wellfield and addressing the iron biofouling issue is needed because, as discussed in this section, pumping needs to continue for several more years.

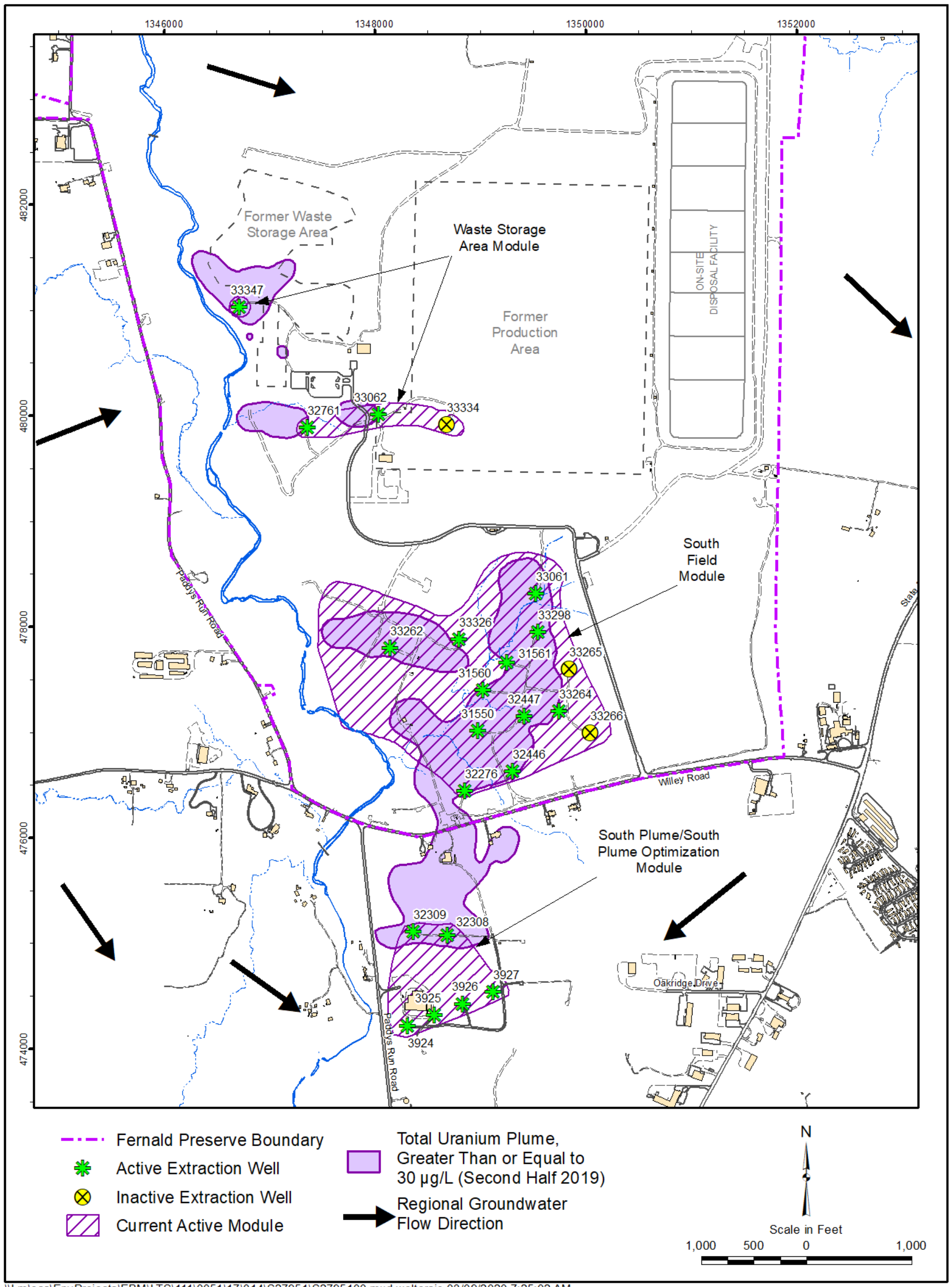

Figure 3. Extraction Well Locations

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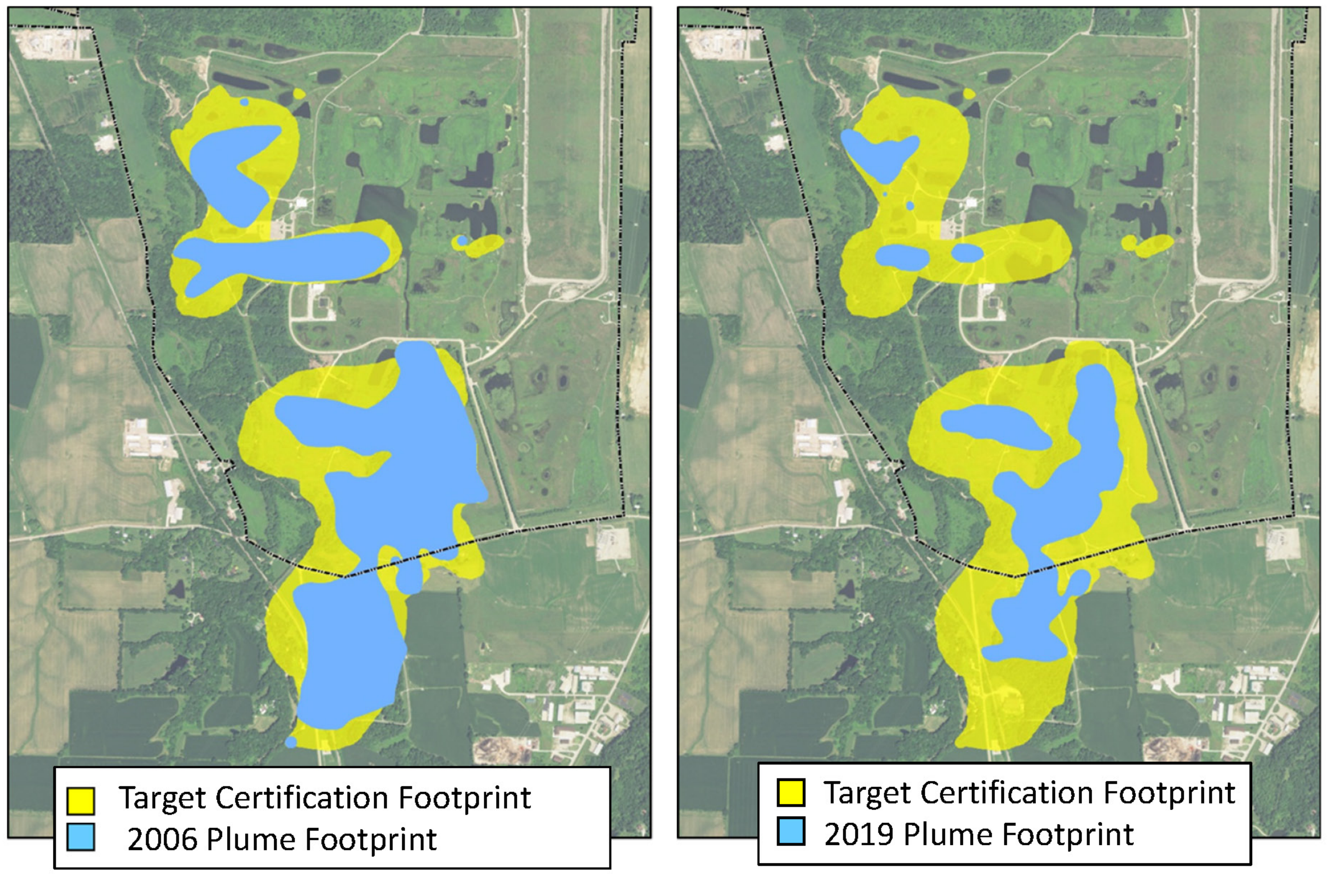
Fernald NLN Collaboration

Current Status of Remediation



Year	Remaining size (acres) of the maximum uranium plume within the target certification footprint
2006	189.3
2007	186.0
2008	186.9
2009	186.0
2010	184.0
2011	144.3
2012	130.3
2013	127.3
2014	110.9
2015	109.5
2016	105.0
2017	94.4
2018	89.3
2019	86.5

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Figure 4. Current Status of Fernald Preserve Remediation

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Figure 5. Clean Pumps (Top Photo) and Iron Fouled Pump (Bottom Photo)

Although the current operational aquifer remedy remains effective in removing uranium from the aquifer, dissolved uranium concentration data indicate that model-predicted cleanup times for key areas of the aquifer will not be met in the predicted time frame. From 1993 through 2019, over 46.8 billion gallons of water have been pumped from the aquifer to remove 14,586 pounds of dissolved uranium. To achieve remediation goals, the model predicts that approximately 1521 additional pounds of dissolved uranium will need to be removed from the aquifer and that this will take until 2033 to achieve. While the overall remedy is predicted to take until 2033, the model predicted that the South Plume and Southern South Field areas (key areas of the plume because they are off-property and near the downgradient site boundary) were predicted to achieve remediation goals by 2022. Uranium concentration data though indicate that this predicted goal will not be met by that time. At the end of 2019, approximately 20 acres of the uranium plume remained off-property. A better understanding of why areas of the plume are not achieving predicted cleanup times is needed, along with better ways of improving cleanup time predictions.

3.0 Fernald Preserve National Laboratory Network (NLN) Collaboration

The Fernald Preserve NLN collaboration effort began on January 13, 2021 and ended on March 31, 2021 (11 weeks). It consisted of a kickoff meeting, six working group meetings, and five focus group meetings. Attachment C contains information pertaining to the process, including:

- A copy of the collaboration schedule.
- A table that lists collaboration participants and roles.
- Working meeting agendas and working meeting notes.

3.1 Scope of the Fernald Preserve Collaboration

Two focus groups were organized for the Fernald Preserve collaboration. Focus Group 1 was challenged with developing recommendations on how to maintain and keep an aging well system operating efficiently. Focus Group 2 was challenged with developing recommendations to improve the efficiency and success of the existing pumping remedy and to improve cleanup predictions for planning purposes. Focus Group 2 was further directed to consider the following site priorities:

- The off-property plume first
- The southern south field plume second
- Recalcitrant areas of the plume in the south field and former waste storage areas third

The overall objective of each focus group was to answer the following three questions:

1. What are we doing that we should keep doing?
2. What are we doing that we should stop doing?
3. What are we *not* doing that we should be doing?

In addressing these questions, recommendations focused on the planned activities and the current status at the site as a starting point. LM also gave recommendation criteria, which required that the recommendations be consensus-driven, be actionable in 1–5 years, and directly address risk.

3.2 Process Used to Develop Recommendations and Actions

In general, recommendations and actions focus on reducing risks based on two broad categories of impact: (1) by maximizing the effectiveness and assuring sustainable performance of the existing groundwater remediation in the southern and offsite portions of the plume and (2) by enhancing the datasets and interpretive tools to support, inform, and improve LM groundwater management decisions.

Ideas researched by each of the two focus groups were documented in written narratives. Ideas that were judged as having potential to address focus group challenges became the basis for recommending actions. Actions were organized into two groups: Short List Actions (implementable in a 1–5-year time frame) and Additional Supplementary Actions (based on site priorities or dependent on other actions taking place first).

Short listed actions address the three key questions each focus group was asked to answer. Short listed actions are identified in this report as “Affirm,” “Replace,” and “Supplement,” defined as follows:

1. **Affirm:** What is the Fernald Preserve and LM doing that they should keep doing?
2. **Replace:** What is the Fernald Preserve and LM doing that they should stop doing?
3. **Supplement:** What is the Fernald Preserve and LM *not* doing that they should be doing?

Additional Supplementary Actions for the Fernald Preserve site are identified as “Endorse,” “Conditional,” and “Not Recommended,” defined as follows:

- **Endorse:** What should the Fernald Preserve and LM incorporate into their program to strategically prepare for future needs or future stages of remediation?
- **Conditional:** Are there potential ideas that might benefit the Fernald Preserve and LM efforts depending on various criteria or conditions in the future?
- **Not Recommended:** Ideas that were evaluated and deemed inappropriate for use at the Fernald Preserve site. In some cases, they were deemed inappropriate not because they would not work but because a different idea held more promise.

3.3 Summary of Short List Actions from Focus Group 1

Focus Group 1 was challenged with developing recommendations on how to maintain and keep an aging well system operating efficiently. Operating an aging wellfield system efficiently is somewhat of a “black art” in that there is no one proven method or process that seems to always work. It involves a certain degree of trial and error to determine the most optimal operational practice for any given well. Given the operational challenges at the Fernald Preserve, the current operation and maintenance program is sound. When area experts were contacted for information, the ones familiar with the Fernald program emphasized that they often refer to the Fernald Preserve site when they need an example of how to approach the challenge.

As presented in Table 2, three Short List Actions were identified to address the operation and maintenance of the aging wellfield system. Narratives for each of the Short List Actions are provided in Attachment B.

Table 2. Short List Actions, Focus Group 1

Action	Recommendation
Automatic biofilm and scale control	Supplement
Liquid carbon dioxide well refurbishment alternative	Supplement
Enhancing rehabilitation contact	Supplement

Concerning the wellfield operation and maintenance program, the collaboration did not identify anything that is currently being done that should be discontinued. A "Supplement" recommendation was made for the three Short List Actions noted in Table 2 (i.e., something that the Fernald Preserve is *not* doing that it should be doing). The three Short List Actions are summarized in the following sections. All Short List Actions would require a pilot test to determine if the technology would provide a benefit.

3.3.1 Automatic Biofilm and Scale Control

The objective of this recommendation is to supplement current practices with new techniques. This is a well preventative maintenance strategy that, if successful, holds promise for inhibiting the initial establishment of biofilms in extraction wells as well as limiting additional buildup of biofilms in the extraction wells. The concept is to perform regular and frequent applications of biocide (i.e., shock treatments) to the extraction wells. A weekly, short time shutdown of a well could occur during which time a biocide of appropriate concentration (approximately 50 parts per million) would be administered to the extraction well. After allowing the biocide to interact downhole for approximately four hours, pumping would resume. The most promising candidates for the biocides are peracetic acid and two different forms of stabilized bromine(s).

The benefits of this type of treatment is that the chemicals should be less corrosive and more effective than the liquid acid descaler (LAD) currently used. It would also continuously maintain cleanliness of the well screens and pumps with an added potential benefit of maintaining the cleanliness of the discharge and transfer piping. The disadvantages are that it requires supplemental equipment and some labor to support the operation. A small scale test will be conducted on a couple of select wells to further evaluate the method.

3.3.2 Liquid Carbon Dioxide Well Refurbishment Alternative

The objective of this recommendation is to supplement current practices with new techniques. This is a well rehabilitation and maintenance strategy that holds promise for improving well performance while also reducing the amount of time that the current well rehabilitation effort takes. Liquid carbon dioxide would be used every year to rehabilitate the extraction wells to maintain pumping capacity. Extraction well heads would need to be sealed so that liquid carbon dioxide can be deployed down the well to pneumatically frack the surrounding gravel pack and formation. The process is envisioned to be a 2-day operation.

The benefit of this treatment is that it would take less time than the current well rehabilitation process, which currently takes (on average) 7 days to rehabilitate an extraction well. Wells would be treated every year providing a better chance that their performance would not degrade between treatments. The extraction wells can be configured such that the pump and motor can remain in the well during the procedure, which eliminates the time and expense of removing and replacing the extraction well pumps and motors.

Liquid carbon dioxide is a less harsh chemical than LAD, is less corrosive on the well, and is safer, and less chemical will be required to be discharged into the backwash basin for eventual treatment in the treatment facility. The disadvantage is that the wellheads will need to be reconfigured such that they can be sealed. A regional subcontractor would need to be found who routinely performs carbon dioxide well rehabilitations, and a pilot test would need to be conducted.

3.3.3 Enhancing Rehabilitation Contact

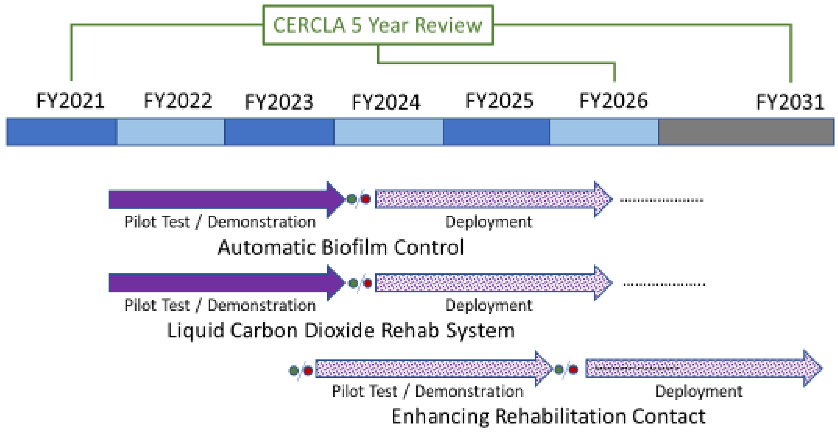
The objective of this technique is to supplement current rehabilitation practices with new techniques. This is a well rehabilitation and maintenance strategy that holds promise for extending the reach of the rehabilitation out into the formation beyond the well screen and filter pack through satellite wells placed around the problematic extraction well. The satellite wells can be used to deliver chemical treatments around the problematic extraction well. These treatments can then be drawn into the problematic extraction wells. This serves as a way to help defeat the buildup of clogged zones surrounding the problematic extraction wells in the areas surrounding the problematic well screen that would otherwise be beyond the reach of the rehabilitation tools used in the problematic extraction wells.

The benefit of the technology is that it would allow the introduction of chemical treatments to portions of the aquifer beyond the reach of current rehabilitation methods. The Fernald Preserve currently has a direct push technology rig that can be used to install the satellite wells.

Fernald Preserve personnel have experience with chemical treatment regimens that could be used in the satellite wells. Successful rehabilitation of failing extraction wells may be more cost effective than replacement wells. The disadvantages are that the technique may not be appropriate due to accessibility and infrastructure constraints (e.g., buried utility lines), and the technique could require contracting. This recommended technique could potentially be combined with the automatic biofilm and scale control method or the liquid carbon dioxide method to provide for a more robust well rehabilitation.

3.3.4 Implementation Strategy

Figure 6 provides a recommended sequencing for implementation of the Focus Group 1 Short List Actions. Implementation details and levels of effort are provided in individual narratives provided in Attachment B. The timeline presented in Figure 6 is subject to availability of resources, stakeholder coordination (as appropriate), and regulatory approval.



Notes:

- Initial focus on high priority offsite and southern plume
- Assumptions for 2026 and beyond
  - Effective progress on offsite and southern plume mitigation (achieved)
  - Shifting focus toward former waste disposal area and onsite residual source contaminants

Hatched durations in figure are dependent upon a precursor activity taking place first.

Figure 6. Implementation Strategy for Focus Group 1

3.4 Summary of Short List Actions from Focus Group 2

Focus Group 2 was challenged with developing recommendations to improve the efficiency and success of the existing pumping remedy and to improve cleanup predictions for planning purposes. Focus Group 2 was further directed to consider the following site priorities:

- Focus on the off-property plume first
- The southern south field plume second
- Recalcitrant areas of the plume in the south field and former waste storage areas third

As presented in Table 3, Focus Group 2 identified six Short List Actions. Narratives for each of the Short List Actions are provided in Attachment B.

Table 3. Short List Actions, Focus Group 2

Action Item	Recommendation
Alternative Mathematical Expressions for Projecting Remedial Time Frame	Supplement
Targeted Data Mining	Supplement
Four-Dimensional Mapping and Interpretation	Supplement
Refine Interpretations of Temporal Plume Footprints and Masses	Affirm + Supplement
Modern Hydrologic Modeling Platform	Affirm + Supplement
Algorithm-Based Optimization	Supplement

Concerning the improvement of the efficiency of the aquifer remedy and predictive capabilities of cleanup times, Focus Group 2 did not identify anything that is currently being done that should stop being done (i.e., “Replace”). Four of the recommendations are identified as “Supplement” (i.e., something that the Fernald Preserve is *not* doing that it should be doing).

Two of the recommendations are identified as “Affirm and Supplement” (i.e., something that the Fernald Preserve is doing that they should keep doing coupled with something that the Fernald Preserve is *not* doing that they should be doing). The six Short List Actions are summarized in the following sections.

Unlike the Short List Actions from Focus Group 1, the Short List Actions recommended by Focus Group 2 do not involve system material costs and pilot testing. Therefore, other than the expense of additional labor, there are no real identified disadvantages.

3.4.1 Alternative Mathematical Expressions for Projecting Remedial Time Frame

The objective of this recommendation is to improve the projection of remediation time frames for key areas of the plume that are currently being made using uranium concentration data. Uranium concentration data at the Fernald Preserve are currently trended using Excel software to determine a best fit trend for the data set. From the data trend, predictions are made on how much more uranium needs to be removed in order to achieve cleanup goals and how much time it will take.

It is recommended that new projection methods be employed to replace the current methods being used. It was further recommended that the Fernald Preserve refine the calculation approach for estimating upper confidence limits to improve bounding projections for remediation time frames.

The benefits of the recommendation are that it provides a clear and understandable approach for stakeholders and regulators and should provide projections that are more stable and will not require frequent modification and revision. The recommendation is also easy to implement because it is an adjustment to the current approach being used and only involves minor additional labor resources.

3.4.2 Targeted Data Mining

The objective of this recommendation is to reduce risk by improving the performance of the current pump-and-treat remedy through maximizing the use of current data, leveraging existing operational and monitoring data relevant to targeted, or prioritized, zones. The focus of the data mining would be on parameters related to contaminant plume distribution, remedial capture zones, and the contaminant geochemistry within the system.

The benefits of the recommendation are that data may be used to hypothesize explanations for identified areas of plume persistence, three-dimensional trench analysis over time, refinement of plume maps, improvement of predictive models, and reoptimization of pumping strategies. Data gaps may be identified in the process, leading to a strategic deployment of monitoring techniques.

3.4.3 Four-Dimensional Mapping and Interpretation

The objective of this recommendation is to reduce risk by reducing uncertainty through leveraging large, existing datasets to enhance and update the site conceptual model utilizing volumetric software (e.g., Environmental Visualization System [EVS]) for four-dimensional mapping and interpretation to create a decision-making tool and to refine the conceptual site model.

The benefits of the recommendation are that it will allow the site to rapidly visualize, interpolate, and extrapolate spatial and temporal data related to three-dimensional geology, dissolved and solid-phase COCs, groundwater elevations, and so on. Visualizations may be used to communicate complex spatial and temporal datasets to a variety of audiences.

3.4.4 Refine Interpretations of Temporal Plume Footprints and Masses

The objective of this recommendation is to reduce risk by leveraging large, existing datasets to refine interpretation of plume distributions by utilizing volumetric software (e.g., EVS) to provide bulk plume metrics (i.e., mass, volume, and average concentration) and calibration targets for fate and transport groundwater modeling.

The technology benefits are that it could provide a greater understanding of remediation progress and interpretation of areas of COC persistence as well as improve upon current calculations of uranium plume metrics (i.e., plume mass, plume area, and plume center of mass position) and provide temporal changes in average plume concentration and plume volume. The technique provides readily compatible datasets for use in updating groundwater models and reoptimizing the current pump-and-treat remedy.

3.4.5 Modern Hydrogeologic Modeling Platform

The objective of this recommendation is to reduce risk through efficient evaluation of uncertainty in predictions of the remedial time frame and evaluation of actions that may be taken to potentially reduce the remedial time frame itself by expanding the current use of a modern modeling software platform (i.e., Groundwater Vistas).

The benefits include providing a more resource efficient, nimble environment to integrate and update Fernald Preserve groundwater flow and contaminant transport models within. This functionality will also allow more nimble consideration of additional wells or optimization of well pumping schemes using quantitative computational analyses. The Fernald Preserve groundwater flow and contaminant transport models consist of a regional model and a smaller, more focused model known as the “zoom” model. The zoom model has already been ported into this tool. Porting the regional model into this tool will allow exploration of impacts at the model boundaries, such as boundary recharge conditions. The recommendation also facilitates the possible use of MODFLOW to run the site model, which will provide an advantage in efficiently coupling with modern optimization algorithms on the Groundwater Vistas modeling platform. Any changes being considered to the currently approved groundwater models being used at Fernald would be discussed with EPA, Ohio EPA, and stakeholders prior to implementation.

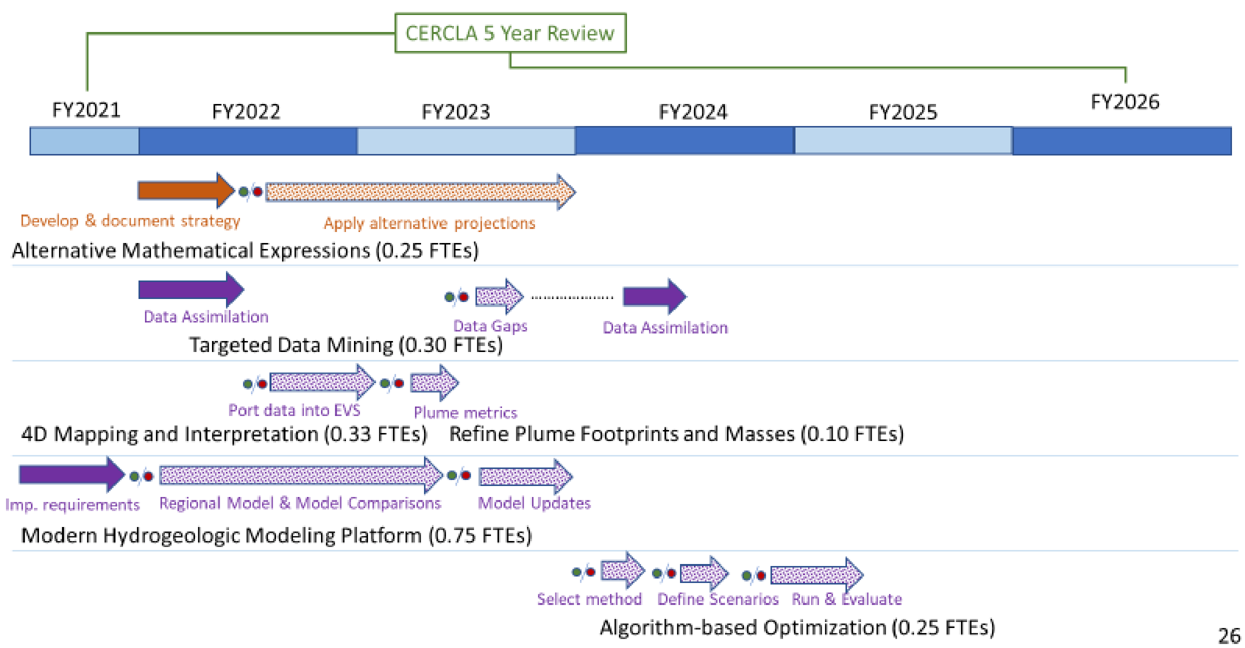
3.4.6 Algorithm-Based Optimization

The objective is to reduce risk by improving the plume containment and uranium mass removal performance of the current Fernald Preserve extraction system by utilizing algorithm-based optimization codes that couple with numerical groundwater flow and transport models to provide a more robust and thorough optimization process than the current trial-and-error optimization process being used at the Fernald Preserve site.

One benefit of algorithmically optimizing the extraction system is to ensure the uranium plume is contained at the southern boundary of the site, resulting in onsite uranium plume concentration decreasing as quickly as possible. Application of algorithm-based optimization codes increases the probability that the "best" wellfield configuration and pumping rates for the assigned design constraints can be identified and selected.

3.4.7 Implementation Strategy

Figure 7 provides a recommended sequencing for implementation of the Focus Group 2 Short List Actions and estimated labor resource requirements (represented as full-time equivalents [FTEs]) for each action. Implementation details and levels of effort are provided in individual narratives provided in Attachment B. The timeline presented in Figure 7 is subject to availability of resources, stakeholder coordination (as appropriate), and regulatory approval.



Note: Hatched durations in figure are dependent upon a precursor activity taking place first.

Figure 7. Implementation Strategy of Focus Group 2

3.5 Additional Supplementary Actions for Focus Group 1

As presented in the Table 4, Focus Group 1 identified seven Additional Supplementary Actions. Five of the Additional Supplementary Actions are potential ideas that might provide benefit in the future depending on various criteria or conditions ("Conditional"). Two of the Additional Supplementary Actions are ideas that were evaluated and deemed inappropriate for use at the Fernald Preserve ("Not Recommended"). It should be noted that "inappropriate for purposes of this report" does not imply that it would not work but that other ideas are considered to be better for the site. Table 5 provides additional discussion on each of the action items. Narratives for each of the seven Additional Supplementary Actions are provided in Attachment B.

Table 4. Additional Supplementary Action Items, Focus Group 1

Action Item	Recommendation
Industrial and innovative maintenance strategies for discharge and transfer piping	Conditional
Antifouling coatings and construction materials	Conditional
Alternative well technologies	Conditional
Delivery of kinetic energy downhole during well rehabilitation to improve extraction well performance	Conditional
Sonication and other innovative downhole maintenance strategies	Conditional
Biofouling assay techniques	Not recommended
Pulse pumping of extraction wells	Not recommended

Table 5. Focus Group 1 Supplementary Topic Discussions

Additional Supplementary Topic	Discussion
Industrial and Innovative Maintenance Strategies for Discharge and Transfer Piping	Could be an option if the extractions well control efforts do not sufficiently protect the discharge and transfer piping.
Antifouling Coatings and Constructive Materials	Not a promising option because coatings may be difficult to apply to the well screens and pumps which are the most active areas of biofouling. Also has the potential to release toxins.
Alternative Well Technologies	Horizontal Wells: Cobbles make install difficult, need for prepacked screen, screen cleaning difficulties, installation costs. Multiple Wells: Pumping infrastructure modifications needed, manifolding flows to pump house. Ranney Wells: Cost constraints.
Delivery of Kinetic Energy Downhole and well rehabilitation to improve extraction well performance	Expensive downhole technology must be purchased by Fernald. Alternatively, if downhole technology can be decontaminated, technologies could be applicable. Local expertise is being developed in these kinetic energy technologies that could benefit Fernald rehab practices in the future.
Sonication and Other Innovative Downhole Maintenance Strategies	Limitations in effectiveness in the well with interfering infrastructure such as pumps, piping, and wires. More uncertainty compared to alternatives such as regular automated biocide application.
Biofouling Assay Techniques	Earlier work under EM reported no success with this approach.
Pulse Pumping of extraction wells	Limited potential for improvement in operation based on past data and compared to other ideas such as pulse pumping in combination with automated biocide application.

3.6 Additional Supplementary Actions for Focus Group 2

As presented in the Table 6, Focus Group 2 identified 12 Additional Supplementary Actions. Four of the Additional Supplementary Actions are actions that should be incorporated into the program to strategically prepare for future needs or future stages of remediation (“Endorse”). Six of the Additional Supplementary Actions are potential ideas that might benefit the site on various criteria or conditions in the future (“Conditional”). Two of the Additional Supplementary Actions are ideas that were evaluated and deemed inappropriate for use at the Fernald Preserve (“Not Recommended”). It should be noted that “inappropriate for purposes of this report does not imply” that it would not work but that other ideas are considered to be better for the site. Narratives for each of the 12 additional supplementary action items are provided in Attachment B.

Table 6. Additional Supplementary Actions, Focus Group 2

Action Item	Recommendation
Geochemical Modeling	Endorse
Groundwater Depth-Profile Sampling	Endorse
Characterization/Sequential Extraction of Core Material	Endorse
Batch/Column Sorption Studies	Endorse
Redox Disequilibrium and Mixing Curves	Conditional
Spectral Gamma Borehole Logging	Conditional
Push-Pull testing	Conditional
In Situ Flushing	Conditional
Permeable Reactive Barrier	Conditional
In Situ Immobilization Approaches to Limit Mobility, Solubility, and Toxicity of Uranium	Conditional
Hydrologic and Boundary Conditions Controls	Not Recommended
Supplemental Modeling Insights using Analytical Solutions	Not Recommended

When and why Additional Supplementary Actions should be considered for the inclusion into the remedy are also important considerations. Table 7 provides this additional information for each of the Focus Group 2 Additional Supplementary Actions.

Table 7. Supplementary Actions, Focus Group 2, Additional Considerations

Action	Recommendation	When	Why
Geochemical Modeling	Endorse	At completion of prior priorities	Identify recalcitrant areas
Groundwater Depth Profile Sampling	Endorse	At completion of prior priorities *or* when feasible to supplement relevant ongoing monitoring activities	Identify and characterize recalcitrant areas
Characterization/Sequential Extraction of Core Material	Endorse	At completion of prior priorities *or* when feasible to supplement relevant ongoing monitoring activities	Characterize recalcitrant areas and can be used as input to additional screening evaluation of remediation options and in flow and transport models

Table 7. Supplementary Actions, Focus Group 2, Additional Considerations (continued)

Action	Recommendation	When	Why
Batch/Column Sorption Studies	Endorse	At completion of prior priorities	To reduce uncertainties associated with the mass flux of uranium into the plume from solid-phase sources along with projected future plume behaviors
Redox Disequilibrium and Mixing Curves	Conditional	Consider post geochemical modeling as an activity to potentially fill geochemical data gaps	To identify the sources and fate of uranium in the aquifer and identify whether fluctuations in uranium concentrations are caused by pH and oxidation/reduction potential disturbances in the local chemical steady state
Spectral Gamma Borehole Logging	Conditional	Consider post geochemical modeling as an activity to potentially fill geochemical data gaps	To reduce uncertainties associated with source(s) of uranium, and to supplement interpretation of results from other characterization studies performed in the same boreholes
Push-Pull Testing	Conditional	Consider post geochemical modeling as an activity to potentially fill geochemical data gaps	To determine if there is a primary sorbed or mineralized source of uranium in the subsurface and to provide insight into the nature of the source
Permeable Reactive Barrier	Conditional	Consider once "Refine Plume Footprint and Masses" has been completed for regional groundwater model and when geochemical modeling has been completed	Passively reduce the toxicity, mobility, and volume of contaminants in groundwater within the Permeable Reactive Barrier
In Situ Flushing	Conditional	Consider if/when recalcitrant pockets are identified and characterized	To enhance remediation of the plume under the former Waste Storage Area; used in conjunction with pump-and-treat
In Situ immobilization Approaches to Limit Mobility, Solubility, and Toxicity of Uranium	Conditional	Consider if/when recalcitrant pockets are identified and characterized	Chemical reductants or bioremediation can be used in conjunction with the current pump-and-treat operations to limit the mobility, solubility, and toxicity of uranium (vapor intrusion)

4.0 Conclusions

Regulatory risk was identified as the only "high" risk driver for the Fernald Preserve site. This is due to an active ongoing groundwater remediation operation and the risk that the pumping stage of that remediation will need to continue longer than is predicted. All of the recommended actions presented in this report address this risk.

Given the aquifer remedy operational challenges encountered at the Fernald Preserve, the current operation and maintenance program is considered to be sound. When area experts were contacted for information, the ones familiar with the Fernald program emphasized that they often refer to the Fernald Preserve site when they need an example of how to approach the challenges. The current program though is trending toward well failures and costly well replacements. Perhaps this is just the result of continued long-term operation and cannot be avoided, but perhaps there are some new and innovative ideas that can be looked at to prolong the life of some of the extraction wells. Three Short List Actions proposed by Focus Group 1 (see Table 2) are presented below to supplement the current operations and maintenance program in an attempt to prolong the useful like of the system. These same ideas could also be applied to new replacement wells and lead to management improvements.

Under LM management (since 2006), steady progress toward achieving remediation goals has been made. The remedy was optimized in 2014 to address declining performance and missed cleanup dates, and, although the current operational remedy remains effective in removing uranium from the aquifer, dissolved uranium concentration data indicate the following:

- Model-predicted cleanup times in key areas of the plume will not be met
- Additional operational pumping is required beyond the model predicted end dates
- Additional modeling is needed to predict new cleanup times

The OU-5 ROD does not prescribe a time frame for completing the aquifer remedy, but it is in the best interest of LM, EPA, and the State of Ohio to achieve cleanup goals as quickly as possible. Six Short List Actions proposed by Focus Group 2 (See Table 3) are presented to supplement the current remedy in an effort to improve the efficiency of the remediation and to provide better estimates of cleanup dates for planning purposes. Four of the proposed six actions are identified for incorporation into the program to strategically prepare for future needs or future stages of the remediation. They are identified as “supplement” in Table 3. The remaining two actions are already in progress, so they are identified as “affirm and supplement” in Table 3.

4.1 What Is the Fernald Preserve Doing that They Should Keep Doing (Affirm)?

- Refine interpretations of temporal plume footprints and masses
- Modern hydrologic modeling platform

4.2 What Is the Fernald Preserve Doing that They Should Stop Doing (Replace)?

- Nothing was identified under this category.

4.3 What Is the Fernald Preserve Not Doing that They Should Be Doing in the Near Future (Next 1–5 years) (Supplement)?

- Automatic biofilm and scale control
- Liquid carbon dioxide refurbishment alternative
- Enhancing rehabilitation contact
- Alternative mathematical expressions for projecting remedial time frame
- Targeted data mining
- Four-dimensional mapping and interpretation
- Refine interpretations of temporal plume footprints and masses (supplement current approach)

- Modern hydrologic modeling platform (supplement current approach)
- Algorithm-based optimization

4.4 What Should the Fernald Preserve Incorporate into Their Program to Strategically Prepare for Future Needs or Future Stages of Remediation?

- Geochemical modeling
- Groundwater depth profile sampling
- Characterization/sequential extraction of core material
- Batch/column sorption studies

4.5 What Should the Fernald Preserve Potentially Consider in the Long Term?

- Industrial and innovative maintenance strategies for discharge and transfer piping
- Antifouling coatings and constructive materials
- Alternative well technologies
- Delivery of kinetic energy downhole during well rehabilitation to improve extraction well performance
- Sonication and other innovative downhole maintenance strategies
- Redox disequilibrium and mixing curves
- Spectral gamma borehole logging
- Push-pull testing
- In situ flushing
- Permeable Reactive Barrier
- In situ immobilization approaches to limit mobility, solubility, and toxicity of uranium

5.0 Implementation Details and Level of Effort Costs

Implementation details and level of effort costs for each recommended action are provided in the individual narratives contained in Attachment A. Table 8 provides a summary of the Short List Actions. The labor and cost estimates below are considered to be very rough in that they were provided by the focus group team members who proposed the action. Detailed cost estimates using a formal DOE cost estimating technique will need to be generated to support implementation decisions. It should be noted that wellfield operation and maintenance actions recommended by Focus Group 1 involve pilot studies, equipment costs, lab costs, and subcontractor costs. Remedy improvement actions recommended by Focus Group 2 involve labor only.

Table 8. Rough Order of Magnitude Estimates for Actions

Action	Labor Hours	Other Direct Costs
Automatic Biofilm and Scale Control (Manual Approach)	640	[redacted]
Automatic Biofilm and Scale Control (Automatic Approach	290	[redacted]
Liquid Carbon Dioxide Rehabilitation	240	[redacted]
Enhanced Rehabilitation Contact	160	[redacted]
Alternative Mathematical Expressions for Projecting Remedial Time Frame	238	
Targeted Data Mining	340	
Four-Dimensional Mapping and Interpretation	627	
Refine Interpretations of Temporal Plume Footprints and Masses	220	
Modern Hydrologic Modeling Platform (supplement current approach)	3488	
Algorithm-Based Optimization	520	

6.0 Lessons Learned

Lessons learned were solicited from working group participants during the last working group meeting that was held on March 31, 2021. The following input was received:

- It was recommended that more hours be allocated to the NLN focus group leads to provide the larger effort they need to make than the other group participants.
- It was noted that the creation of specific topics by site personnel for the focus groups helped.
- One-on-one calls were found to be very effective for focus group work.
- Good collaboration existed between NLN and site personnel, which was needed for efficiency.
- To be successful, the focus groups need to be flexible.
- Technical challenges encounter with use of the WebEx platform could perhaps be resolved by using a different virtual meeting platform.
- Given COVID-19 travel restrictions, site visits could not be made. However, virtual site tours were effective.
- The Fernald Preserve is a mature CERCLA site with decades of available data and a long regulatory history. The collaboration would have possibly benefitted by having more time for data review and assimilation after the kickoff meeting.
- While electronic file transfer works for sharing documents, an easier to use system would have benefitted the collaboration.

7.0 References

DOE (U.S. Department of Energy), 1995. *Feasibility Study Report for Operable Unit 5*, Final, Fernald Environmental Management Project, Fernald Area Office, Cincinnati, Ohio, June.

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DOE (U.S. Department of Energy), 1997. *Baseline Remedial Strategy Report, Remedial Design for Aquifer Restoration (Task 1)*, Final, Fernald Environmental Management Project, Fernald Area Office, Cincinnati, Ohio.

DOE (U.S. Department of Energy), 2001. *Design for Remediation of the Great Miami Aquifer in the Waste Storage and Plant 6 Areas*, 52462-RP-0003, Revision A, Draft Final, Fluor Fernald, Fernald Area Office, Cincinnati, Ohio, April.

DOE (U.S. Department of Energy), 2002. *Design for Remediation of the Great Miami Aquifer South Field (Phase II) Module*, 52462-RP-0001, Revision A, Draft Final, Fluor Fernald, Fernald Area Office, Cincinnati, Ohio, May.

DOE (U.S. Department of Energy), 2003. *Comprehensive Groundwater Strategy Report*, Revision 0, 51900-RP-0001, Cincinnati, Ohio, June 30.

DOE (U.S. Department of Energy), 2005. *Waste Storage Area Phase II Design Report*, 52424-RP-0004, Revision A, Draft Final, Fluor Fernald, Fernald Area Office, Cincinnati, Ohio, June.

DOE (U.S. Department of Energy), 2006. *Fernald Groundwater Certification Plan*, 51900-PL-0002, Revision 1, Final, prepared by Fluor Fernald for the Office of Legacy Management, Cincinnati, Ohio, April.

DOE (U.S. Department of Energy), 2014. *Operational Design Adjustments-1, WSA Phase-II Groundwater Remediation Design, Fernald Preserve*, LMS/FER/S10798, Office of Legacy Management, Cincinnati, Ohio, March.

Attachment A

Narratives for Short List Actions

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Contents

Technology/Strategy: Automatic Biofilm and Scale Control

Summary Information

Accumulation of biofilms in the extraction wells at Fernald – fouling the well screens and pumps –challenges sustainable operation of the groundwater remediation system. The fouling of extraction wells reduces performance and necessitates regular costly and invasive well cleaning and rehabilitation and the need for costly well replacement. Well rehabilitation operations that generated large quantities of aqueous chemical wastes that are transported to the "Backwash Basin" for eventual treatment and that can impact the performance or operation of the groundwater treatments. The LM-NL collaboration recommends consideration of automatic biofilm control strategies that would prevent the establishment of biofilms and contribute to the sustainability and robustness of the remediation system (assuring that the system will reliably operate at pumping rates required to mitigate the offsite groundwater plume and to mitigate regulatory risks and bolster stakeholder confidence).

Focus Area(s): Focus Area 1, Tier 2/3 (requires field pilot and potential future extraction well modifications)

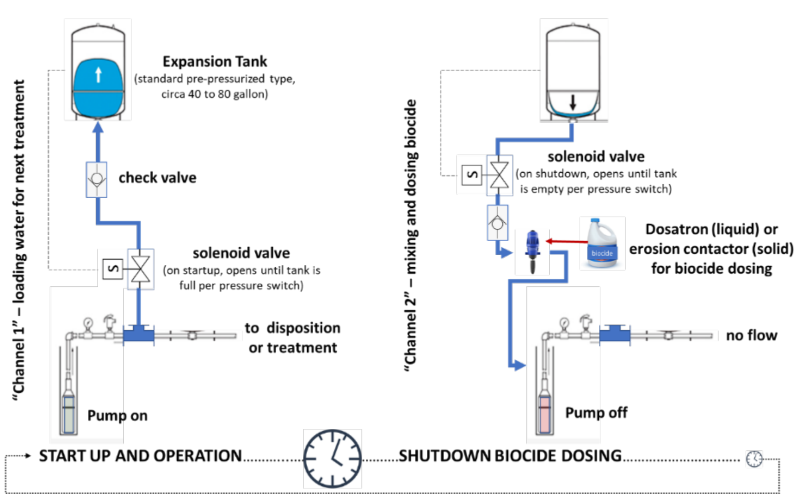
Description:
This recommendation focuses on "continuously" maintaining the sanitation of extraction wells to prevent the establishment of biofilms on the well screens and in/on the pumps. The paradigm relies on a timed sequence of well operation during which the well is regularly shut down for a short period during which a biocide dose ("shock") is added. In the recommended paradigm, dosing is performed on a more frequent basis (e.g., weekly) compared to the baseline in situ pump cleaning (nominally performed one to a few times a year). The objective of automatic biofilm and scale control is to prevent the initial establishment of biofilm so that well fouling is largely mitigated. In situ pump cleaning is performed only after measurable performance degradation is observed, limiting efficacy of the cleaning and requiring aggressive cleaning solutions. Automatic biofilm control is a maintenance strategy that can be performed with less corrosive solutions and lower biocide concentrations.

A number of biocide options are available for consideration by the LM Operations team, including oxidizing biocides, non-oxidizing biocides, chelating and dispersing agents, and various other techniques. Of these, the oxidizing biocides are the class that is most mature and that has been used most frequently in the past for maintaining subsurface pumping wells (water production wells and oil and gas wells). The range of options for biocides are documented in the referenced reports, design guides, and technical information. The following table provides a cursory evaluation (green-yellow-tan) and a synopsis of some of the key determinants for the scoring. Of the choices, peracetic acid (liquid) and stabilized bromine (either liquid or solid) were rated as the most viable and any of these choices should work equivalently. The remaining choices were downgraded (yellow or tan) by relative comparison. For example, sodium hypochlorite (bleach) was downgraded because it is less stable in storage and biocidal effectiveness occurs over a narrower pH range. These factors are important for potential future deployment because only a few cups of biocide will be needed each week and the groundwater is buffered to a pH that might limit the performance of bleach at the projected doses (10 to 50 ppm). Other classes of biocides were rated lower due to limited information on relevant application to wells, or general maturity (low technology readiness level).

Oxidizing Biocides			
Peracetic Acid (liquid)		Relatively stable -- demonstrated effectiveness for biofouling maintenance in wells	Example products: BIOSIDE HS 15% or PERASAN OG (Envirotech); PERACLEAN (Evonik); SANIDATE 15.0 (Biosafe Systems); others
Stabilized Broimine (liquid)		Relatively stable -- demonstrated effectiveness for biofouling maintenance in wells	Example products: BROMAX 10.2 - liquid (Envirotech);
Stabilized Broimine (solid such as hydantoins)		Relatively stable -- demonstrated effectiveness for biofouling maintenance in wells	Example Products: ENVIROBROM or BCDMH - solid (Envirotech);
sodium hypochlorite (liquid)		"bleach" - compared to alternatives… less stable in storage -- less effective at circumneutral pH	Example Products: Standard Bleach (commodity chemical)
hydrogen peroxide (liquid)		compared to alternatives… less stable in storage	Example products: Standard Peroxide Solutions (commodity chemical)
Percarbonate and similar oxidizers		more difficult to handle compared to alternatives	Example products: oxiclean (Church and Dwight), FB 700C (Solvay), OCI PROVOX C (Ravago)
Ozone (gas)		can be generated onsite but more difficult to handle compared to alternatives	Electrochemical generator system using air or oxygen gas as feedstock
chlorine (gas) and chlorine dioxide (liquid)		safety concerns for storage and handling	n/a
Non-Oxidizing Biocides			
Various Options (liquids)		relatively stable -- not demonstrated for biofouling maintenance in wells - limited information on dose	
Chelating and Dispersing Agents			
Various Options (liquids)		relatively stable -- not demonstrated for biofouling maintenance in wells - limited information on dose	
Other Options			
sonication and similar acoustic tools		evaluated separately-not amenable to "chemical" dosing from the surface	
strong acids, dispersents and similar well rehabilitation chemicals		relatively corrosive and not generally suited to maintenance application	
UV light		potentially complex to implement and infrastucture interferences (shaded areas not treated)	
pasturization (heating)		potentially complex to implement - low technology readiness level	
bacteriophage (biological controls)		low technology readiness level (research)	
electrohydraulic discharge and electrical treatments		low technology readiness level (research)	

A hypothetical system for deployment is depicted in the graphic. As shown, the system would have two separate channels: 1) a loading channel (left) that would fill a pre-pressurized tank on start-up and then store the water for a week until needed, and 2) a biocide dosing channel (right) that would add biocide automatically upon well shutdown. A timer would operate the shutdown sequence on a repeated schedule determined by Fernald Operations staff (e.g., continuous pumping with weekly shutdown and dosing for 4 hours).

<u>Graphic</u>:



Simplified depiction of automated system

Development Status: Systems have been deployed for water wells but are not widely used (overall technology readiness level (TRL) 7 to 8). In general, this is a simple system that would be straightforward to implement. A commercially available erosion contactor system (using solid stabilized bromine hydantoins) was on the market in 2016 but does not appear to be available at this time. As depicted in the graphic a liquid biocide or solid (erosion) biocide system can be easily constructed. To pilot the system on a few wells for a limited timeframe, a manual dosing strategy is feasible – this would require Fernald Operations Specialists to manually deploy the biocide (e.g., weekly) with a small tank and pump system.

Fernald Site-Specific Advantages/Disadvantages:
Advantages include:

- Potential to inhibit the initial establishment of biofilms in extraction wells
- Potential to extend the operational timeframe between major rehabilitation and well rework actions
- Potential to extend overall lifetime of the wells (eliminate the need for replacement)
- Potential to reduce export of biofilm organisms to the discharge and transfer piping, minimizing the potential for buildup of biofilms in these lines
- Results in a significant cost savings if above items are demonstrated in pilot deployment
- Uses less corrosive chemical options and lower concentrations of strong acid or base compared to episodic in situ pump cleaning – potential to extend pump service life
- Maintains well sanitation “continuously” – episodic in situ pump cleaning is based on observed degradation in performance which is a lagging indicator (well screen and pump fouling are likely to already be beyond simple maintenance)
- Maximizes pumping rates and system performance and reduces risk that groundwater remediation will underperform and not meet regulatory commitments
- Provides robustness and confidence and the ability to demonstrate a high level of performance to stakeholders

Disadvantages include:

- May not be effective on wells that have already degraded (provides limited ability to address fouling outside the well screen in the gravel pack or formation) – this strategy does not aggressively clean well, but limits the establishment of new biofilms
- Some biocide options are mildly corrosive so that optimal deployment concentrations need to be defined and controlled
- Regulators need to be briefed and informed about the technology and may need to concur and/or affirm planned pilot study and deployment strategies.
- System will require procurement and handling of biocides – many of these chemicals require care for safe handling (similar to bleach)
- Some biocides have limited storage life (e.g., sodium hypochlorite) – chemicals that are more stable for storage should be prioritized since the usage rates are anticipated to be relatively small (e.g., target level in well approximately 50 ppm requiring on the order of <5 cups of liquid biocide per weekly application in a well)

Technology Inter-Relationships: This is a well maintenance technology/strategy and not a well cleaning strategy. Thus, success of "Automatic Biofilm and Scale Control" requires a relatively clean and high performing well as a starting condition (a recently rehabilitated well or a new well). Comprehensive extraction well management protocols will require effective strategies for cleaning/rehabilitation and for maintenance. This recommendation dovetails with efforts to affirm, supplement or replace the Fernald well rehabilitation methods. This technology has the potential to mitigate buildup of biofilms in discharge and transfer lines – optimally, the pilot study would be performed on a well where the discharge piping had been cleaned to provide the most useful information on overall performance.

Short list: Yes -- Relatively low-cost strategy with the potential to improve system robustness and reduce risks of remediation underperformance.

Data Gaps: Need to implement on a few wells (with one or more representative untreated controls) to determine if the technology is viable for general use on Fernald extraction wells.

Example References:

Guidance documents for biofilm controls ESTCP, 2005. A Review of Biofouling Controls for Enhanced In Situ Bioremediation of Groundwater,
available at: https://clu-in.org/download/contaminantfocus/dnapl/treatment_technologies/er-0429-whtpaper.pdf

Paractic Acid and Stabilized Bromine
Array of technical information and design information at:
https://envirotech.com/sdstech-data/

Next Steps: Identify target wells for pilot study deployment of controls (wells that are equivalent wells in terms of historical performance, wells that have required regular rehabilitation and wells and that can be rehabilitated and reworked to a significant and appropriate performance levels). Include identified wells in next scheduled rehabilitation and discharge transfer pipe cleaning. Select biocide and deploy (either manually or automatically) protocols for weekly shutdown and biocide application. Include supplemental biological indicator data (e.g., presence and quantity of biofilm forming organisms) in planning for specific capacity and performance testing. Interpret results. If positive, install automated biocide maintenance controls on wells as appropriate.

Implementation Details and Level of Effort:

LM contractor led effort. Minimal level of effort from NLs

FY 2021–FY 2022 (shift to 2022–2023 if 2021 funding cannot be secured):

- Identify target wells for pilot study deployment of biocide maintenance control
- Include identified wells in next scheduled rehabilitation and discharge transfer pipe cleaning – no added cost
- Select biocide – develop plan and brief regulators (obtain concurrence as needed) – 120 person-hours
- Deploy pilot study
  - (manual option) -- [redacted] for tank and pump rig
  - (automated option) -- [redacted] for equipment and [redacted] for setup and hookup

- Operate pilot study for 18 months –
  - (manual option) – 500 person-hours (assume two-person crew and approximately 3 hours per week
  - (automated option) – 150 person-hours (assume two-person crew and approximately 1 hour per week)
- Collect supplemental biological indicator data during baseline performance pump tests ([redacted] contract lab)
- Pull pumps and compare treated and control wells (crew for 20 hours)

FY 2023–FY 2024 (shift to 2024–2025 if 2021 funding cannot be secured):

- Go No Go -- Incorporate into baseline if appropriate (net future cost savings if go)

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Technology/Strategy: Liquid Carbon Dioxide Well Refurbishment Alternative

Summary Information

Replace current well rehabilitation and refurbishment with simpler liquid CO_2 strategy that allows rehabilitation of wells every year to better maintain pumping capacity. The LM-NL collaboration recommends advancing this technology to the short list and consideration of performing a pilot study and potential future implementation for all extraction well. This approach would preemptively clean wells on a more frequent schedule, reduces waste volume and chemical load to the backwash basin, and can be configured to be performed without removing pumps and downhole equipment. Thus, it is a potentially transformational technology compared to the baseline system.

Focus Area(s): Focus Area 1, Tier 2/3 (requires field pilot and potential future extraction well modifications)

Description:
This recommendation focuses on developing an alternative to the current paradigm of rotating chemical well refurbishments every few years (each well refurbished on a nominal schedule of 1 to 3 years). The current system uses a series of chemical cocktails (strong acids, chelating agents and biocides) and physical surging performed over approximately 7 days. The process results in large quantities of wastewater containing residual chemicals, requiring transfer to the backwash basin. The proposed process streamlined process seals the well and deploys liquid CO_2 to perform the refurbishment over two days. The infused liquid CO_2 rapidly converts to a gas state and generates a large volume of bubbles that physically scrub the screen and pump. The pressure from the generated gas (phase change) pneumatically fractures the gravel pack and formation, and the gas then dissolves to provide a buffered acid. The following day, the produced solids and water are pumped from the well (producing a relatively lesser volume of wastewater containing not residual strong acids or harsh treatment chemicals). Significantly, this technology can be configured for deployment without having to pull the pump and downhole equipment. The net result of these advantages is that system operators are able to rehabilitate and refurbish all wells every year – thus the wells are refurbished prior to measurable degradation of performance so refurbishments are generally more effective. The photos below depict an example deployment and a modified wellhead configuration. This process is commercially available and has been applied to thousands of wells around the country, including in Ohio.

Photos:

Photographs of Liquid $C0^2$ rehabilitation of a well and close up of deployment in well with pump remaining in place (courtesy of Subsurface Technologies, Inc. subsurfacetech.com)

Development Status: Commercially available but not as widely used as chemical rehab baseline methods (overall technology readiness level (TRL) 7 to 9). In general, this system would be straightforward to implement. A pilot test on a few wells for a limited timeframe is recommended.

Fernald Site-Specific Advantages/Disadvantages:

Advantages include:

- Treatment in 2 days versus 7
- Treats wells every year (preventative maintenance) before performance degrades
- Can be configured to leave pump in well – saving labor
- Uses less harsh chemical (less corrosive on well, safer, and less chemicals to backwash basin
- Potential to improve treatment into formation (similar to det cord)
- Potential to extend overall lifetime of the wells (eliminate the need for replacement)
- Results in a significant cost savings if above items are demonstrated in pilot deployment
- Uses less corrosive chemical options and lower concentrations of strong acid or base compared to baseline refurbishment
- Maximizes pumping rates and system performance and reduces risk that groundwater remediation will underperform and not meet regulatory commitments
- Provides robustness and confidence and the ability to demonstrate a high level of performance to stakeholders

Disadvantages include:

- May not be effective on wells that have significantly degraded already
- Requires rework of well and contracting for new method – requires pilot testing
- Regulators need to be briefed and informed about the technology and may need to concur and/or affirm planned pilot study and deployment strategies
- System will require procurement and logistics

Technology Inter-Relationships: This is an alternative rehabilitation/refurbishment method. An optimal scenario would be to use this approach in combination with a "continuous" (e.g., weekly) biocide to provide the most robust protection. If both technologies are selected for pilot testing, then combined deployment (on the same wells) would provide the most useful information.

Short list: Yes -- Potential to improve system robustness and reduce risks of remediation underperformance.

Data Gaps: Need to implement on a few wells (with one or more representative untreated controls) to determine if the technology is viable for general use on Fernald extraction wells.

Example References:

Commercial Product Example: https://www.subsurfacetech.com/aqua-gard/

Next Steps: Identify target wells for pilot study deployment of controls (wells that are equivalent wells in terms of historical performance, wells that have required regular rehabilitation and wells and that can be rehabilitated and reworked to a significant and appropriate performance levels). Include identified wells in next scheduled rehabilitation and also clean discharge transfer pipe. Refurbish one or more wells with liquid CO_2 and one or more wells with standard baseline chemical approach. Perform specific capacity tests to assess relative effectiveness.

Implementation Details and Level of Effort:

LM contractor led effort. Minimal level of effort from NLs

FY 2021–FY 2022:

- Identify target wells for pilot study deployment of biocide maintenance control
- Include identified wells in next scheduled rehabilitation and discharge transfer pipe cleaning – no added cost
- Implement contract for alternative method (new contractor)
    - LM contractor planning and contracting – approximately 240 person hours
    - Contractor -- requires pulling pump for initial setup. Budget costing of approximately [redacted] per well for initial deployment (if wells reconfigures so that future cleanings will not require pulling pump) and [redacted] per well for follow up cleaning or [redacted] per well for refurbishment if pump is pulled and well not reconfigured. Note that these are contractor costs and do not include transfer of wastewater to backwash basin.
- Deploy pilot study
- Compare refurbishment performance (already in baseline)

FY 2023–FY 2024:

- Go No Go -- Incorporate into baseline if appropriate (net cost savings if go)

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Technology/Strategy: Enhancing Rehabilitation Contact (ERC)

Summary Information

Satellite wells can be used to deliver chemical treatments that can be drawn into problematic extraction wells as a way to defeat the buildup of clogged zones otherwise beyond the reach of rehabilitation tools.

Focus Area(s): Focus Area 1, Tier 2/3 (requires field pilot)

Goal: Improve or sustain the specific capacity of problematic extraction wells.

Description

Treatment chemicals designed to reduce well clogging can be injected into the aquifer and drawn into problematic extraction wells to treat the well clog.

In some cases, the specific capacity for some extraction wells is not sustainable because clogged zones in the aquifer appear to be beyond the reach of the rehabilitation tools that are being used. One way to extend the reach of the rehabilitation process is to introduce treatment chemicals into so called "satellite wells" installed adjacent to the problematic extraction well(s). This satellite well approach was proposed to the site in 2014 and is referred to there and here as Enhancing Rehabilitation Contact (ERC). (Ground Water Science 2014).

The NLN team discussed the satellite approach with a site operator in Michigan. The site in question has 12 extraction wells. Each extraction well has a triangular satellite well configuration supporting the introduction of treatment chemicals. The satellite wells have been installed within 7 feet of the extraction well. Satellite wells are 2 inch stainless steel wells with screen lengths identical to the screen lengths in the adjacent extraction well. The contamination scenario differs from the situation at Fernald in that the aquifer being pumped is reportedly predominantly anaerobic. The operator uses what he refers to as a Blended Chemical Heat Treatment method in which the chemical blend is heated and then injected. As reported to the NLN team, the range of rehabilitation frequency is well dependent but can range from 3 to 4 months per well to a year or years per well.

These satellite wells need to be sited based on sampling results. Transects based on the location of the extraction well in question could be established. Samples of aquifer matrix and groundwater could be collected from locations along such transects to establish how far out from the extraction well the aquifer matrix is clogged. Samples could be collected using direct push technology (DPT). DPT technology could also be used to collect biofouling assay samples. Ideally, the DPT sample collection borings could also be used to inject the needed rehabilitation treatment. Should the pilot project show promise, site operators may want to install more permanent satellite wells constructed of stainless steel or PVC for the routine injection of treatment chemicals into the aquifer. In regard to DPT placement, the literature suggests distances from 1 to 7 meters (6.6 to 23 ft) from an extraction well center point. (ACE 2000). The analytical suite for aquifer matrix and/or pore water samples could include Fe^{+2}, Fe^{+3}, Mn, alkalinity, EH, biofouling assays ($BART^{tm}$ or similar), visual examination, etc.

Site staff suggest the approach may be appropriate for a subset of the extraction wells. Three wells would be candidates for the satellite approach: extraction wells 21A, 24 and 25. Reportedly the approach may not be viable at other extraction wells because extraction well infrastructure (pipeline, pipeline chases, power conduit etc.) creates accessibility issues.

Development Status

The approach is mentioned in the literature. A single case study was identified, and the site operator was interviewed as part of this NLN collaboration effort.

Fernald Site-Specific Advantages/Disadvantages

Advantages include:

- Satellite wells allow for the introduction of chemical treatments to portions of the aquifer beyond the reach of the current rehabilitation methods
- The site has a dedicated DPT rig and DPT samples are already being sampled as part of the remedial action. Required DPT sample points could serve a dual purpose: compliance monitoring and aid in the placement of satellite wells for the introduction of treatment chemicals
- The site has experience with chemical treatment regimes that could be used in the satellite wells.
- The successful rehabilitation of failing wells may be more cost effective than extraction well replacement.

Disadvantages include:

- Uncertainty regarding acceptance of the approach because of Underground Injection Control (UIC) regulations.
- Reportedly, installing satellite wells may not be viable for all failing extraction wells because of accessibility issues; to wit: infrastructure precludes placement of direct push points.
- The introduction of treatment chemicals via satellite wells would need to be preceded by a sampling event to delineate the presence/absence of clogged aquifer matrix with the associated costs for sample plan preparation, field deployment, sample collection and analysis and data interpretation. Subject matter experts would need to be funded to assist in developing the plan and interpreting sample results
- The site has had past difficulties with injection well clogging. Satellite well clogging may also occur, although biofouling seems less likely since the chemical treatment being injected has biocide properties.

Technology Inter-Relationships: This is an alternative rehabilitation/refurbishment method. A critical first step is the Go/No Go decision. Ideally, the Go/No Go decision must have, as at least one input, optimization models developed by Focus Group 2. For example, optimization models should be able to weigh the costs/ value of 1) baseline rehabilitation vs 2) extraction well replacement vs 3) implementation of ERC. This is a well cleaning strategy to be implemented only if either the baseline well field rehabilitation approach and/or short list items such as Automatic Biofilm and Scale Control and Liquid Carbon Dioxide Well Refurbishment causes specific capacity to drop below the go/no go decision point as determined by optimization studies. This technology has the potential to reduce or stop the decline in SC.

Short list: YES

Data Gaps:

- Acceptance of injection of treatment chemicals into the Great Miami Aquifer per Ohio EPA re-injection guidelines[1]
- Go/No Go decision for a, yet to be determined, pilot test well
- Delineation of the portions of the aquifer matrix impacted by fouling
- Method(s) to deliver treatment chemicals to targeted portions (aquifer matrix and gravel pack)
- Identification of treatment chemicals
- Whether or not ERC can improve SC

Example References

Ground Water Science, 2014. Letter report to S.M Stoller Aquifer Restoration, from Stuart A. Smith, subject Report to S.M Stoller on well Maintenance, Poland Ohio.

U.S. Army Corps of Engineers, 2000. Operation and Maintenance of Extraction and Injection Wells at HTRW Sites, Engineer Pamphlet 1110-1-127, January.

Email and telephone contact: Charles Graff Senior Geologist, Michigan Department of Environment, (517) 930-3073, graffc@michigan.gov

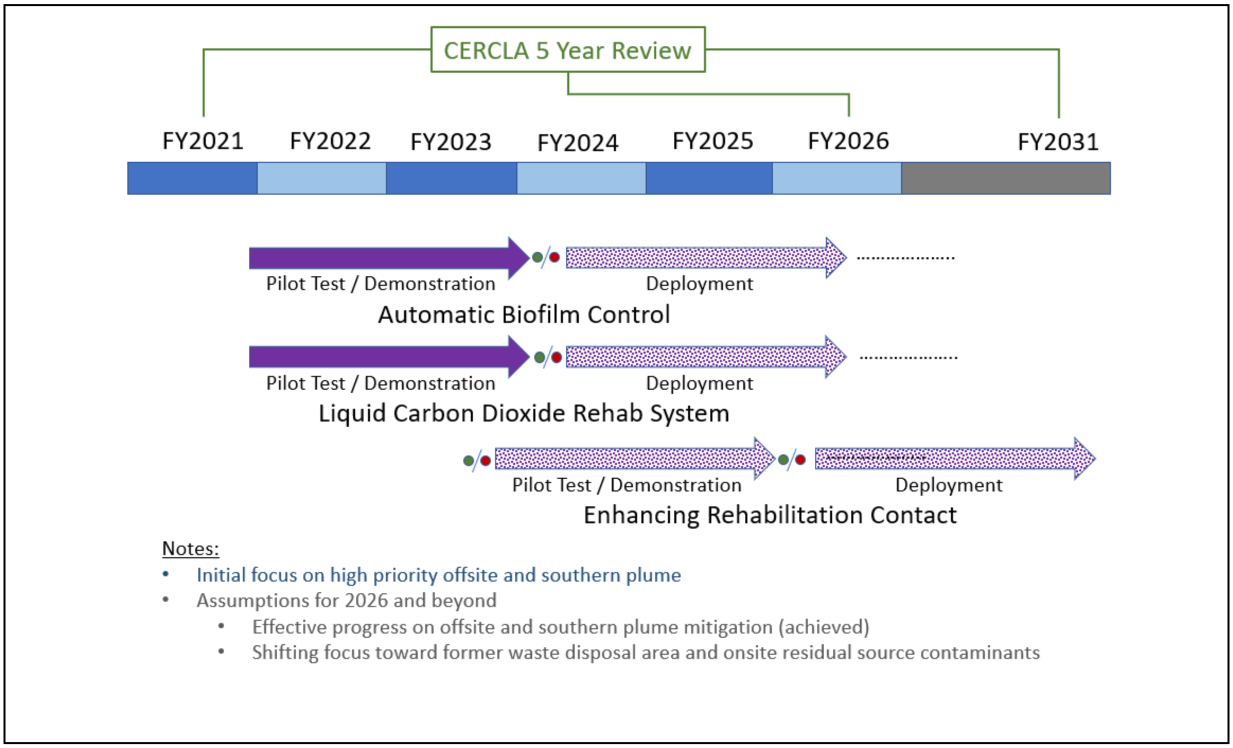
Next Steps: Identify target well(s) for pilot study. Fernald site contractor to team with vendor to:

- Fund the Pilot ERC study
- Prepare sampling plan for State approval
- Implement sampling plan
- Determine optimal satellite well placement
- Install additional DPT points if needed, inject rehabilitation chemical selected
- Assess relative effectiveness using metrics such as specific capacity

Implementation Details and Level of Effort

Per the schedule in the graphic below. This is an anticipated Fernald/LM effort.

[1] **This** guidance **allows** underground injection wells, used for the purpose of remediation, to operate without a permit provided that the injectate does not exceed any Safe **Drinking** Water Act (SDWA) **Maximum** Contaminant Levels_-(MCLs



FY 2023–FY 2024 (dependent on funding):

- Identify well(s) for pilot ERC study based on optimization modeling.
- Implement LM procurement action to select contractor and select contractor-160 person hrs.
- Contractor will develop sampling plan and brief stakeholders (obtain concurrence from State as needed for UIC injection/Pilot ERC Study) – [redacted][2].
- Implement sampling plan- DPT sampling of aquifer matrix and groundwater surrounding targeted pilot well. Sample 30 groundwater and subsurface soil samples from 0-70' below ground level. Sampling and analysis [redacted]. Identify likely injection points for well rehabilitation treatment.
- Perform pilot ERC contractor-led single injection event [redacted].
- Collect the same data from extraction well that is currently collected for the baseline well field monitoring.

FY 2024–FY 2026:

- Decision point, ERC approach is determined to be successful and the is approach is integrated into baseline rehabilitation program for a subset of extraction wells
- For each applicable extraction well, install 3 stainless steel wells for periodic injection of ERC treatment chemicals[redacted] for each extraction well to be treated

  Or,

- Pilot test well should be abandoned and replaced with a new extraction well

[2] All cost estimates are unburdened costs derived from expert system AECOM, 2016, Remedial Action Cost Engineering and Requirements System.

Technology/Strategy: Alternative Mathematical Expressions for Projecting Remedial Timeframe

Summary Information

Accurate projections of the timeframe for groundwater remediation are important to future LM site managing and to providing stakeholders/regulators with transparent and understandable information. Initial and past projections of groundwater remediation timeframe, both from the numerical modeling using a simple exponential analytical expression, have been over-optimistic. The data indicate that the remediation performance is exhibiting a "tail" typical of such systems suggesting that the numerical models are not adequately capturing the complex controlling processes and the simple analytical solutions are not adequately describing the emergent behaviors. Recent literature provides a basis for using alternative analytical expressions that have the potential to improve projections of remediation progress and remediation timeframe. The current process used at Fernald is to plot concentrations over time and use Excel trend functions to fit the best regression curve to the data set based on R^2. The LM-NL collaboration recommends implementation of the new projection methods as an alternative (replacement) for the current exponential and polynomial projections, and further recommends refinement of the current calculation approach for estimating upper confidence limits to provide improved upper bounding projections for remediation timeframes.

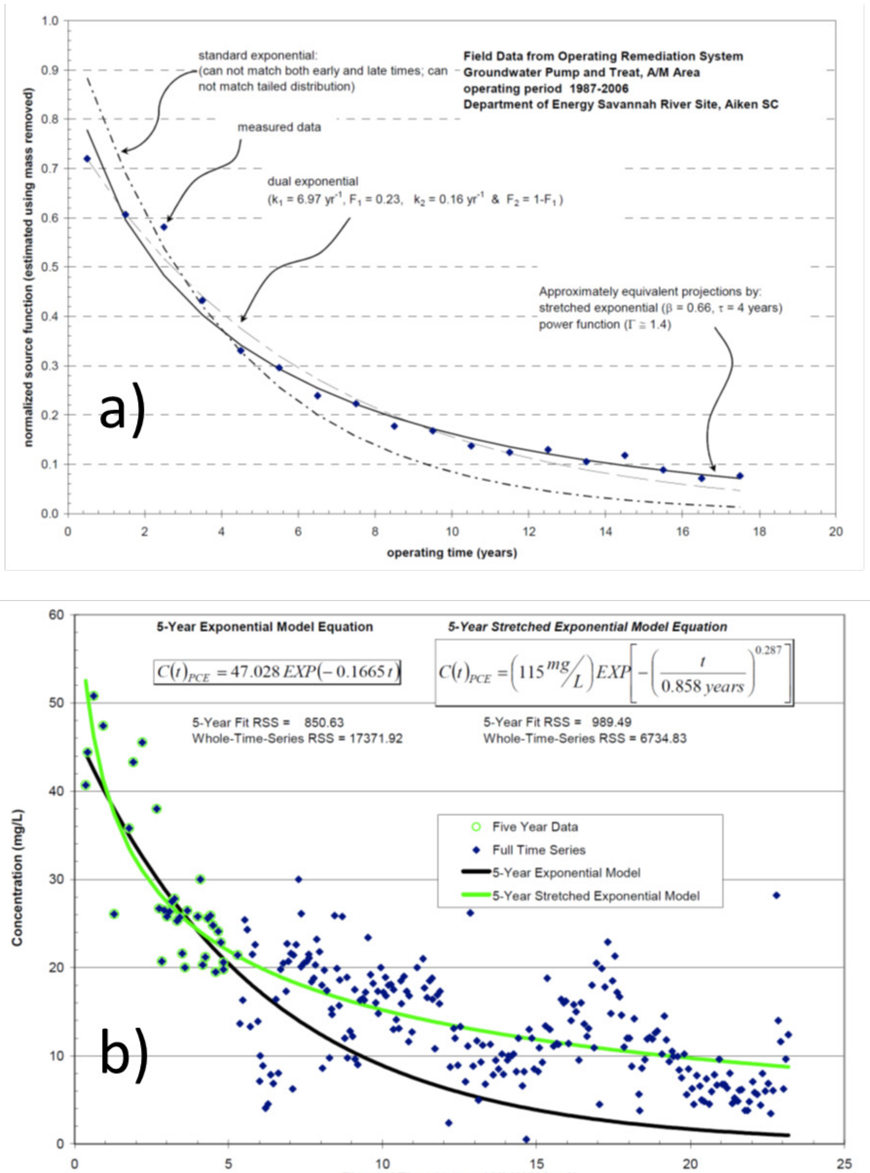
Focus Area(s): Focus Area 2, Tier 1 (uses existing data)

Description:
The observed progression of a groundwater remedy composites multiple, complex and interacting processes, including: the quantity and behavior of primary and secondary sources, aquifer heterogeneity, mass transfer, biogeochemical interactions/processes, and remediation system design. While explicitly and comprehensively modeling such systems is challenging, there has been progress in projecting the emergent behavior of groundwater remediation progress using straightforward analytical expressions. The literature suggests that the simplest expressions (exponential or linear), when calibrated to early remediation system performance, will tend to underpredict remediation timeframe, do not adequately anticipate the typical observed "tail," and will result in projected timeframes that shift (longer) as more data are collected. However, recent applications of power functions and more complex exponential functions (stretched exponential and double exponential) have significantly improved projections of observed-emergent remediation performance and remediation timeframe. The basis for these models is that they account for the residual source material that is present in different forms/settings and provide a theoretical basis for the projection – for example, the stretched exponential is often used to describe the discharge of a capacitor (a process that is somewhat analogous to the flushing of contaminant from a groundwater system).

The graphic depicts an example of these models applied to a groundwater pump and treat system. As shown, the power function, stretched exponential, and double exponential provide a significant improvement in matching the emergent-observed progress of remediation compared to a simple exponential projection. This is shown for the overall system (a - an area with multiple recovery wells) and for individual wells (b – an example well). Improved performance of the enhanced mathematical expressions is most significant when projections are made based only on early performance data (b) but improvement is also observed when calibrating to the entire data period (a).

The primary result of implementing this recommendation would be to provide: a) a tool that has a high potential to improve the projection of remediation timeframes for key areas of the plume (e.g., the southern portion versus the former source areas), b) an approach that is clear and understandable for stakeholders and regulators, and c) projections that are likely to be more stable and not require frequent modification/revision.

Graphic:



Example results for application of alternative analytical expressions for projection of the remediation progress for a groundwater pump and treat system operating in the A/M Area of the DOE Savannah River Site – a) projections for the overall system, and b) projections of a single wells (RWM-1). Note that the simple exponential does not adequately project the "tail". The expressions in graph (a) are calibrated to the entire 18-year period of record while the expressions in graph (b) are calibrated to the first 5 years of data.

<u>Development Status</u>: Mature technology -- application of statistics to existing dataset based on statistical guidance, regulatory guidance, and recommendations in the recent scientific literature.

<u>Fernald Site-Specific Advantages/Disadvantages</u>:

Advantages include:

- Uses existing dataset with little (or minimal) additional labor or effort compared to the baseline calculations already being performed
- Provides demonstrable improvement in projection of concentration and mass removal trends
- Method supported by recent scientific literature on mathematically projecting progress of remediation system performance and source mass depletion
- Model parameters provide insights on the nature of residual subsurface sources contributing to the plume being remediation and how these are being released over time
- Provides a technically based estimate of total mass in the system
- Provides an opportunity to check and refine key statistical calculations (such as upper confidence limit)

Disadvantages include:

- Represents a change in calculation compared to previous reporting to regulators and stakeholders – would require technical documentation and clear communication and may require assent or concurrence

<u>Technology Inter-Relationships</u>: This effort would relate to the baseline program data collection and interpretation, to proposed activities to refine and re-interpret the historical dataset, and to developing strategies for reduced order models.

<u>Short list</u>: Yes – DOE LM should consider implementing an alternative projection strategy (e.g., stretched exponential) in the future as a replacement for the simple exponential or polynomial projections used in the past. Refinement of future upper confidence limit (UCL) projections is recommended as a predecessor step because the performance of current/past statistical approaches to calculate UCL is expected to decline as the remediation progresses. The recommended combination of changes will provide a more realistic best estimate and upper bounding remediation timeframe.

<u>Data Gaps</u>: Uses existing data – for best implementation, some alternative tabulations would be beneficial, such as tabulation of mass removed each year from each of the target areas (to allow separate estimates of remediation progress in each of the areas.

<u>Example References</u>:

Stretched (and Double) Exponential:
Berberan-Santo, M.N., E.N. Bodunov and B. Valeur, 2005. "Mathematical functions for the analysis of luminescence decays with underlying distributions 1. Kohlrausch decay function (stretched exponential)," *Chemical Physics*, Volume 315, pp 171–182.

Krall, A.H. and D.A. Weitz, 1998. Internal Dynamics and Elasticity of Fractal Colloidal Gels, Physical Review Letters, Volume 80, pp 778–781.

Jund, P., R. Jullien, and I. Campbell, 2000. Random walks on fractals and stretched exponential relaxation. arXiv:cond-mat/0010142, Volume 1, 29 Nov 2000, pp. 1–5.

Laherrère, J. and D. Sornette, 1998. "Stretched exponential distributions in nature and economy: "fat tails" with characteristic scales", *Eur. J. Phys*. B, Volume 2, pp 525–539.

Malacarne, L. C., R. S. Mendes, I. T. Pedron, E. K. Lenzi, 2000. Nonlinear equation for anomalous diffusion: unified power-law and stretched exponential exact solution. arXiv:cond-mat/0010142, Volume 1, 10 Oct 2000, pp. 1–3.

Power Function:

Falta, R.W., 2005. "Dissolved chemical discharge from fractured clay aquitards contaminated by DNAPLs, in Dynamics of Fluids in Fractured Rocks," B. Faybishenko, P.A. Witherspoon, and J. Gale, Eds., Geophysical Monograph 162, *Am. Geophys. Union*.

Falta, R.W., P.S.C. Rao and N. Basu., 2005a. "Assessing the impacts of partial mass depletion in DNAPL source zones: I. Analytical modeling of source strength functions and plume response," J*ournal of Contaminant Hydrology* 78(4):259–280.

Falta, R.W., N. Basu and P.S.C. Rao (2005b), "Assessing the impacts of partial mass depletion in DNAPL source zones: II. Coupling source strength functions to plume evolution," J*ournal of Contaminant Hydrology,* 79(1-2):45–66.

Jawitz, J.W., Fure, A.D., Demmy, G.G., Berglund, S., and Rao, P.S.C., 2005. "Groundwater contaminant flux reduction resulting from nonaqueous phase liquid mass reduction," *Water Resources Research*, 41(10):W10408.

Newell, C. J., D. T. Adamson, 2005. "Planning-level source decay models to evaluate impact of source depletion on remediation time frame," *Remediation Journal*, Volume 15, No.4, pp. 27–47.

Rao, P.S.C., Jawitz, J.W., Enfield, C.G., Falta, R., Annabel, M.D., Wood, A.L., 2001. "Technology integration for contaminated site remediation: Cleanup goals and performance metrics," *Ground Water Quality*, Sheffield, UK, pp. 410–412.

Ross, B. and N. Lu (1999), Dynamics of DNAPL penetration into fractured porous media, Groundwater, 37(1), 140-147. SERDP, 2006. Final Report: SERDP and ESTCP Expert Panel.

Workshop on Reducing the Uncertainty of DNAPL Source Zone Remediation, September 2006. U.S. Department of Defense, Washington DC.

General regulatory and statistical Guidance (e.g., for calculating uncertainty and bounding confidence intervals from duplicates or replicates):

EPA (U.S. Environmental Protection Agency), 1983. *Guidelines for Assessing and Reporting Data Quality for Environmental Measurements*, U.S. Environmental Protection Agency Environmental Monitoring and Support Laboratory, Cincinnati OH (lead lab for the Office of Research and Development).

Magnusson, B., T. Näykki, H. Hovind, M. Krysell and E. Sahlin, 2017. *Handbook for calculation of measurement uncertainty in environmental laboratories, Nordtest Report*, TR 537 (ed. 4). Available from www.nordtest.info.

Vaclav Synek, 2008. Evaluation of the standard deviation from duplicate results, *Accred Qual Assur*, 13:335–337, DOI 10.1007/s00769-008-0390-x.

Next Steps: Develop whitepaper to document/describe/plan transition – provide briefing for regulators and stakeholders. If there is concurrence, develop tools and workflow to perform the alternative projections, including: a) refine calculations of upper confidence limit (e.g., using expected sample relative standard deviation [RSD]), b) perform alternative mathematical projections. Apply tools – initial deployment will require extra person-effort; follow-on use will be equivalent to current and panned baseline.

Implementation Details:

FY 2022–FY 2023:

- Develop and document strategy for transitioning to the new mathematical paradigm and develop white paper and technical presentations for regulators.
- If regulators concur with refinements continue (go / no go)
- Refine estimates of upper confidence interval (e.g., using rsd estimated from collected duplicates or similar strategy) for the entire data period and replot UCL data on graphs
- Apply alternative mathematical projections (e.g., stretched exponential to all recover wells and to other wells as appropriate) and generate refined remediation timeframes for each key area of the plume (with near term focus on southern portions).

Level of Effort:

LM Contractor:

- FY 2021–FY 2022 = baseline activity + 5 person weeks
- FY 2023 and beyond = current planned baseline

NLs:

- FY 2021–FY 2022 = 3 person weeks

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Technology/Strategy: Targeted Data Mining

Summary Information

Objective and Potential for Risk Reduction:

The goal of implementing data mining at the Fernald Preserve is to improve the performance of the current pump-and-treat remedy efficiently by maximizing the use of existing data. The site has amassed a wealth of data over its operational lifetime, much of which is publicly available in annual Site Environmental Reports, remedial investigation reports, and via the DOE-LM Geospatial Environmental Mapping System (GEMS) at https://gems.lm.doe.gov. GEMS displays analytical results from samples collected from monitoring wells, surface water locations. Samples collected using direct push technology (i.e., vertical groundwater profiling), soil, and sediment samples are not displayed in GEMS, but are readily available using a database pull. Note there is one primary LM database, EQuIS; additional data may be accessed via the predecessor site (DOE EM database). Operational data is contained in these databases but depending on data needed for this exercise (e.g., site-specific rainfall, individual extraction well pumping rates), additional site-specific spreadsheets may be utilized. These data may be mined to make enhanced operational decisions which may be used to reduce uncertainty in predictions of the remedial timeframe and potentially reduce the remedial timeframe itself (e.g., adapting the remedy, guiding which wells to operate, changing well pumping rates, improving predictions of when pumping can stop).

Focus Area(s): Focus Area 2, Tier 1

Description:
Targeted data mining –in the form of advanced data management (e.g., EVS) and statistical techniques (e.g., linear regression, Mann-Kendall trend analysis, advanced polynomial regression techniques) could enhance the Fernald Preserve's ability to leverage existing operational and monitoring data as well as assimilate and analyze new data, providing insights to manage remediation more efficiently in targeted, or prioritized, zones. Here, data mining efforts may be particularly beneficial in enhancing the understanding of contaminant plume distributions, remedial capture zones, and the contaminant geochemistry within the system.

- With respect to the contaminant plume distributions and remedial capture zones, targeted parameters for data mining may include:
  - COC concentrations in groundwater over time with focus on uranium
  - Hydraulic heads
  - Meteorological data (precipitation, barometric pressure, temperature)
  - Depths and COC concentrations of solid phase masses
  - Well operational data including pumping rates, total gallons pumped/reinjected, and uranium removed over time
  - Any other observed fluxes, physical features, or interactions impacting fate and transport. For example, this data may include:
    - Temporal stage elevation data along Paddys Run
    - Data on grain size distribution and stratigraphic contacts

- ➢ Historical aerial photographs (for use in overlays and stakeholder communication), plant operation era ground surface elevations, and/or plant layout maps showing material and waste storage areas
- ➢ Hydraulic information pertaining to surface reclamation. Specifically:
    - Vertical hydraulic conductivity and thicknesses of compacted soils used in the establishment of the ponds/wetlands
    - Vertical hydraulic conductivity and thicknesses of materials used for the On-Site Disposal Facility liner and cap systems
- ➢ Operational records, pond elevations, or permitted groundwater extraction rates for any nearby operations

  These data may be used to hypothesize explanations for identified areas of plume persistence and may be utilized for 3D trend analyses over time (refer to *4D Mapping and Interpretation* narrative), refinement of plume maps (refer to *Refine Temporal Plume Footprints and Masses* narrative), improvement of predictive models (refer to *Employ Modern Hydrogeologic Software Tools* narrative), and re-optimization of pumping strategies (refer to *Algorithm Based Optimization* narrative).

- Targeted geochemistry data may include:
  - Temperature
  - pH
  - Specific conductance
  - Turbidity
  - Fe^{2+}/Fe^{3+}
  - Dissolved oxygen or oxidation-reduction potential (ORP)
  - Cation/anion for groundwater COCs identified in the ROD
  - Information on chemical tracers, redox couples, etc.

  These data may be used to characterize potential contaminant release from recalcitrant or secondary sources into the aquifer, and determine key geochemical parameters controlling the mobilization and release of uranium.

This task would be carried out with prioritized interest in addressing off-site contaminant plumes and focusing on the most pertinent data.

Ultimately, insights gleaned from targeted data mining may be used to update and improve both the existing hydrologic and geochemical conceptual site models (including groundwater flow, surface water flow, contaminant fate and transport representations). As a result of both data mining focuses, data gaps may be identified leading to the consideration of doing some subsequent actions (refer to supplementary narratives). Maximizing the use of existing data is strongly recommended to improve the remedy optimization process.

Development Status:

Data mining methodologies and implementation frameworks are well established and are regularly being advanced within the environmental field (EPA 2008; Bear and Cheng 2010; Suthersan et al. 2016). Similar approaches to what is recommended for the Fernald Preserve have been successfully applied at other LM sites (incl., Tuba City Disposal Site, Shiprock Disposal Site, Monticello Mill Tailings Site, Monument Valley Processing Site, Durango Processing Site).

Fernald Site-Specific Advantages/Disadvantages:

Advantages include:

- Reduces uncertainty in remedial timeframe predictions and may lead to reduction of the remedial timeframe itself
- Cost efficient method to maximize use of pre-existing data
- Enhances understanding of existing hydrologic and geochemical conceptual site models
- Identification of data gaps for strategic deployment of monitoring technologies

Disadvantages include:

- Data may exist in outdated databases or scanned reports, and would therefore need to be digitized and entered into a database before use

Technology Inter-Relationships:

Data mining is a critical first step in supporting subsequent recommended activities and potential, supplementary activities, including:

- 4D Mapping and Interpretation
- Refine Temporal Plume Footprints and Masses
- Employ Modern Hydrogeologic Software Tools
- Optimization
- Geochemical Modeling

Short list: Yes

Data Gaps: As a result of data mining data, gaps may be identified leading to the consideration of subsequent actions. Refer to supplementary narratives.

References:

Bear, J. and Cheng, A.H.D., 2010. *Modeling groundwater flow and contaminant transport* (Vol. 23). Springer Science & Business Media.

DOE (U.S. Department of Energy), 2019. *Monticello Mill Tailings Site Operable Unit III Annual Groundwater Report, May 2018–April 2019*, LMS/MNT/S26208, October.

DOE (U.S. Department of Energy), 2020. *Draft Tuba City, Arizona, Disposal Site, Groundwater Remedy Performance Report 2002 Through 2018*, LMS/TUB/S28108, June.

EPA (U.S. Environmental Protection Agency), 2008. A systematic approach for evaluation of capture zones at pump and treat systems.

Suthersan, S., Gentile, M., Bell, C., Quinnan, J. and Horst, J., 2016. "Big data and environmental remediation: gaining predictive insights." *Groundwater Monitoring & Remediation*, *36*(2), pp.21–31.

Next Steps: This activity is not dependent on any prior technical action. It may begin as soon as scope and budget are approved.

Implementation Details:

1. Assimilation of electronically available data. [200–400 hours]

   Assumes no digitization of boring logs will be required, but if detailed stratigraphy need to be incorporated and are not electronically available, it may be an additional 5-10 hour per well log [~400 hours total].
2. Port assimilated data into mapping software (e.g., EVS) for implementation of visualization and plume mapping activities [included with those activities' implementation plans]
3. Identification of data gaps based on results of initial mapping. [40 hours]
4. Perform necessary activities (lab, field, or computational) as deemed appropriate for collection of requested data [see relevant supplementary narratives]
5. Assimilate requested data into a useable format to the EVS system for second trend analyses. [100–200 hours. Note this estimate is contingent upon the results of the identified data gaps. This estimate assumed one half the level of effort of the initial phase]
6. Port the updated dataset into mapping software

Level of Effort:

LM Contractor: 340 to 1040 hours

NLs: No effort anticipated.

Technology/Strategy: 4D Mapping and Interpretation

Summary Information

Objective and Potential Risk Reduction:

The goal of utilizing volumetric software for four-dimensional (4D) mapping and interpretation is to create a decision-making tool that can reduce risk and uncertainty at the Fernald Site by (1) leveraging large, existing datasets to enhance and update the site conceptual model; (2) providing a tool that can be used to communicate complex spatial and temporal datasets to a variety of audiences; and (3) creating datasets for use in numerical models to improve the current pump-and-treat remedy. Once constructed, this tool can rapidly visualize, interpolate, and extrapolate spatial and temporal data related to three-dimensional (3D) geology, dissolved and solid-phase constituents of concern, groundwater elevations, etc.

Focus Area(s): Focus Area 2, Tier 1

Description:

Organizing, presenting, and analyzing data with volumetric software (e.g. Earth Volumetric Studio - EVS) allows LM/LMSP to interpret a multitude of datasets for decision support and to effectively communicate results to stakeholders and regulators using four-dimensional (4D) visualization tools (three spatial dimensions and time). DOE Office of Legacy Management Sites - such as Fernald - benefit from having a large quantity of spatial and temporal data. Uranium concentration data at Fernald are currently presented as a conservative, worst case format using maps and multiple two-dimensional (2D) cross sections in the Site Environmental Reports (SER). Cross sections are used to report the third dimension. 3D Kriging is used to load uranium plume conditions into the groundwater model. Often, 2D renderings may generalize site details that fall off of the transect(s) that can lead to subjective estimates of plume mass and volume.

Volumetric software programs allow LM/LMSP to organize, superimpose, correlate, and present complex spatial and temporal datasets synergistically (Figure 1). Two-dimensional slices can be created rapidly and 4D interactive volumetric models can efficiently communicate site complexities and issues to a broad spectrum of audiences. Creating 4D visualizations and performing quantitative analyses of Site data first requires mining that data from existing and supplemental LM databases. To help improve future remedy optimization efforts, volumetric data sets specific to the Fernald Site that can be created include, but are not limited to:

- Three-dimensional (3D) geology of the buried valley aquifer, which can be used to revise the gridding of a numerical groundwater flow and transport model;
- Temporal plumes for uranium and other constituents of interest;
- Temporal maps of equipotentials, water-table fluctuations, and drawdowns;
- Interpolated source mass distribution in the solid phase; and
- Temporal analysis and mapping of pumping well capture zones and hydraulic gradients from observed data.

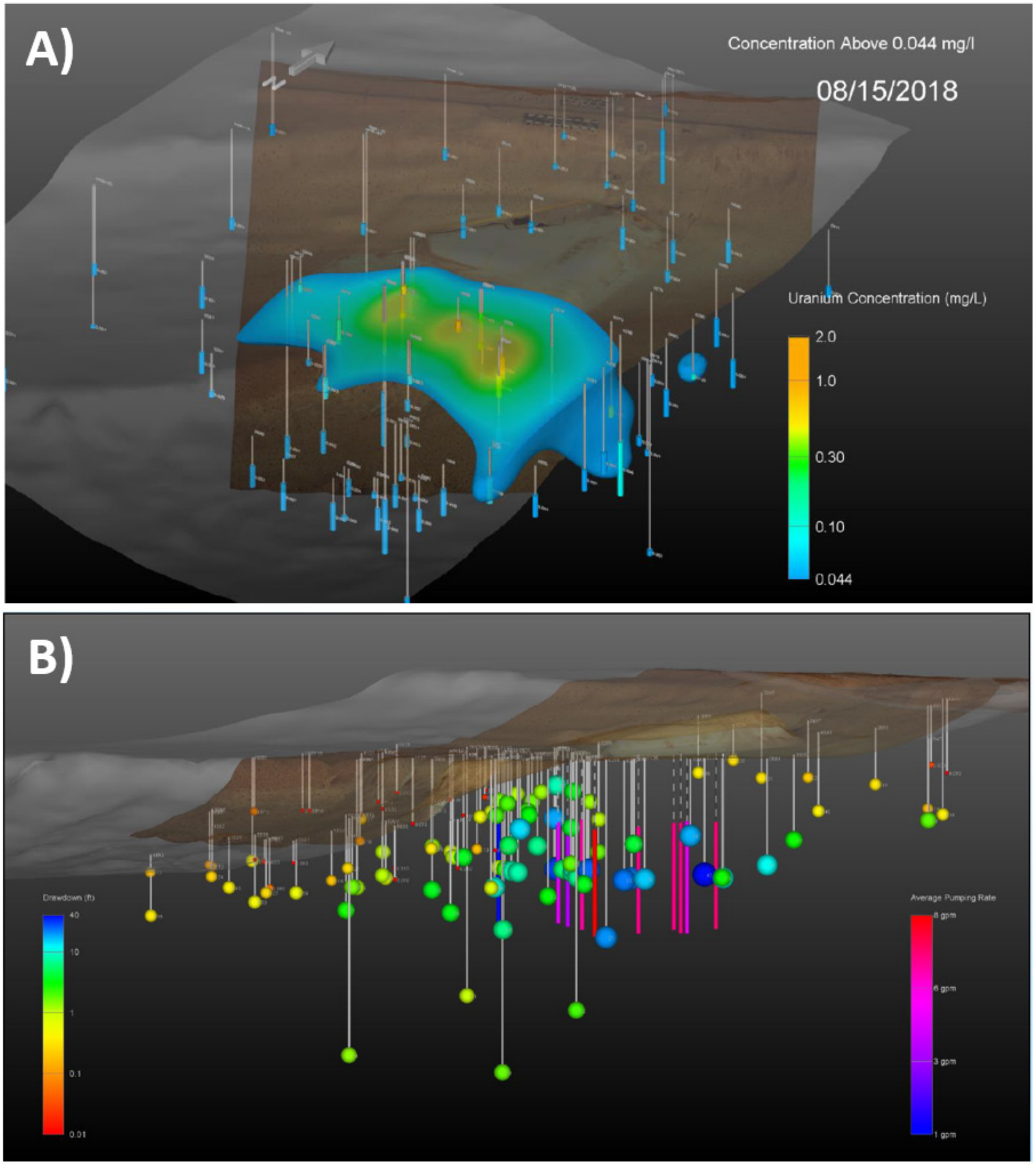

Figure 1: Example 3D data renderings of the 2018 dissolved uranium plume (A) and 90-day drawdowns with steady-state pumping rates (B) at the Tuba City Disposal Site.

Development Status:

Applies commercially available software (C Tech Earth Volumetric Studio) that has been successful at examining other LM sites such as Tuba City Disposal Site, Shiprock Disposal Site, Monticello Mill Tailings Site, Monument Valley Processing Site, Durango Processing Site, and others in development.

Fernald Site-Specific Advantages/Disadvantages:

Advantages include:

- More robust interpretation of the site conceptual model for LM/LMSP, stakeholders, and regulators.
- Easily generate custom cross sections and visualizations of a variety of site data.
  - Provides a useful tool to support future flow, fate, and transport modeling exercises.
  - Can be used to help plan future data acquisition projects.
- Should prove helpful for detailed interpretation of recalcitrant areas.

Disadvantages include:

- No real disadvantages identified.
- Some information identified during the data mining process may require additional resources to produce or format that data before importing into EVS. This could be handled on a case by case effort as deemed appropriate.

Technology Inter-Relationships:

Generally, this software readily interfaces with flow and transport modeling codes and pre/post processors to help establish the grid, boundary conditions, aquifer properties, initial conditions and calibration targets. The effort required to successfully import data generated from EVS into the Site's existing groundwater flow and transport modeling code, VAM3D, is largely unknown and could be substantial.

Short list: Yes

Data Gaps:

Additional needs may be identified from an initial 3D mapping of readily available data and the data mining task. The need for this additional sampling would be evaluated on a case by case basis and conducting it would be based on the perceived benefit provided to the remedy.

References:

DOE (U.S. Department of Energy), 2019. *Monticello Mill Tailings Site Operable Unit III Annual Groundwater Report, May 2018–April 2019*, LMS/MNT/S26208, October.

DOE (U.S. Department of Energy), 2020. *Draft Tuba City, Arizona, Disposal Site, Groundwater Remedy Performance Report 2002 Through 2018*, LMS/TUB/S28108, June.

Next Steps:

This activity builds off the associated "Targeted Data Mining" narrative.

Implementation Details:

Step 1: Input assimilated data into mapping software (e.g., EVS) for implementation of visualization and plume mapping activities (See Implementation Detail #2 from Data Mining Activity Task). Specific information from the Data Mining Task to support this effort includes:

1. Establish coordinate systems and datums;
2. Export known usable information from LM databases to construct pre-geology files (PGFs), Analyte Point Data Files (APDV), and/or Analyte Interval Data Files (AIDV) for Earth Volumetric Studio software. This information *may* include:
    - Stratigraphic contacts (e.g., Ground surface, base of glacial overburden/top of Greater Miami Aquifer (GMA), blue clay layer (where present), base of GMA/top of bedrock);
    - COC concentrations in groundwater over time with focus on uranium;
    - Meteorological data (precipitation, barometric pressure, temperature);
    - Hydraulic heads with barometric corrections applied where appropriate;
    - Depths and COC concentrations of solid phase masses;
    - Well operational data including pumping rates, total gallons pumped/reinjected, and uranium removed over time;
    - Temporal stage elevation data along Paddy's Run;
    - Data on grain size distribution, hydraulic conductivity, and stratigraphic contacts;
    - Historical aerial photographs (for use in overlays and stakeholder communication), plant operation era ground surface elevations, and/or plant layout maps showing material and waste storage areas.
    - Thicknesses and extents of compacted soils used in the establishment of the ponds/wetlands; and
    - Thicknesses of materials used for the On-Site Disposal Facility liner and cap systems.
3. Operational records, pond elevations, or permitted groundwater extraction rates for any nearby operations. Begin interpolating and extrapolating data across the domain.

Step 2: Using interpretative results of Step 1, identify data gaps (e.g. data needed to better evaluate remediation progress overall and in identified recalcitrant areas).

Step 3: Conduct additional data mining for identified data gaps. If data exists, get into an EVS usable format. If data does not exist, consider a task to collect the needed data.

Level of Effort:

Estimates provided herein assume that data are readily available and can be formatted to import into EVS without additional transformations, corrections, or significant manipulation. Data that must be manually entered or extracted from PDF tables will require additional effort than budgeted here. Because the volume of data that would require additional preparation is unknown at this time, any estimates to account for this would be highly uncertain.

LM Contractor:

Step 1: 400 hours. This assumes dissolved and solid-phase concentration data, head (with any appropriately applied barometric corrections), and lithologic/stratigraphic data are within EQuIS such that PGF, APDV, and/or AIDV files can be generated relatively quickly.

Step 2: 80 hours

Step 3: 200 hours. Note this estimate is contingent upon the results of the identified data gaps. This estimate assumed one half the level of effort of Step 1.

NLs: No effort anticipated.

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Technology/Strategy: Refine Interpretations of Temporal Plume Footprints and Masses

Summary Information

Objective and Potential Risk Reduction:

The objective of this task is to utilize volumetric plume software (e.g. Earth Volumetric Studio - EVS) to provide bulk plume metrics (i.e., mass, volume, and average concertation) and calibration targets for fate and transport groundwater modeling. This task builds upon the 4D Mapping and Interpretation task.

Using existing datasets, Fernald Site managers can objectively quantify temporal changes in total plume mass, total plume volume, average plume concentration, and their associated uncertainties. Using bulk plume metrics provides not only a greater understanding of remediation progress to predict remedy completion, but also allows a more robust and quantitative approach to identifying, evaluating, and understanding why and how recalcitrant areas differ from other areas of the plume.

Focus Area(s): Focus Area 2, Tier 1

Description:

This recommendation directly builds upon the 4D Mapping and Interpretation recommendation. DOE Office of Legacy Management Sites - such as Fernald - benefit from having a large quantity of spatial and temporal data of dissolved contaminants of concern.

Uranium plume metrics of total plume area, total plume mass, and plume center of mass position are currently reported each year in the Site Environmental Report using Ricker (2008) Method Calculations. Utilizing more robust 3D mapping interpretations, and volumetric EVS software should greatly improve upon the metrics being currently reported, as well as including temporal changes in average plume concentration and plume volume.

Volumetric software programs (e.g. EVS) allow LM/LMSP to superimpose various data types (e.g. site geology, solid phase concentration data, equipotentials, and dissolved plumes), interpolate concentrations in three dimensions (3D) over time, and provide quantitative analysis of bulk plume metrics. Bulk plume metrics are the temporal quantification and trend analysis of total plume mass, total plume volume, and average plume concentration that 1) provide a greater understanding of remediation progress (Figure 1), 2) allow LM/LMSP to hypothesize explanations for identified areas of plume persistence, and 3) serve as powerful calibration targets for fate and transport models. By leveraging the wealth of Site data contained in existing and supplemental LM databases and incorporating data from the Site's Remedial Investigation, a tool can be developed to provide significantly enhanced spatial and quantitative information needed for successful remedy optimization.

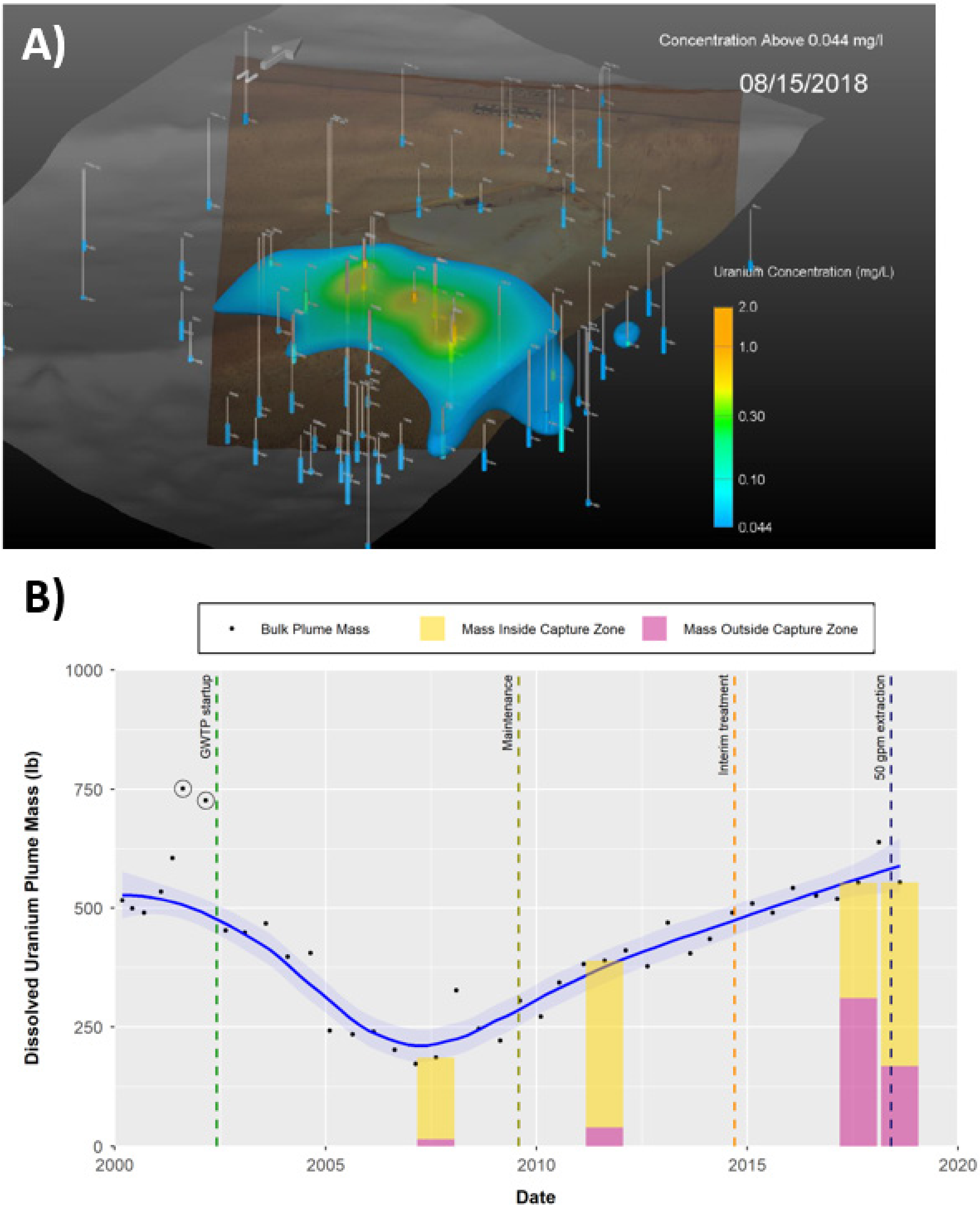

Figure 1: A) Example 3D rendering of the 2018 dissolved uranium plume at the Tuba City Disposal Site. B) Uranium plume mass trend and proportion of mass inside and outside the estimated capture zone of the treatment system wells at the Tuba City Disposal Site.

Development Status:
Applies commercially available software (C Tech Earth Volumetric Studio) that has been successful at examining other LM sites such as Tuba City Disposal Site, Shiprock Disposal Site,

Monticello Mill Tailings Site, Monument Valley Processing Site, Durango Processing Site, and others in development.

Fernald Site-Specific Advantages/Disadvantages

Advantages include:

- Provide a greater understanding of remediation progress and interpretation of areas of COC persistence;
- Improve upon current calculations of uranium plume metrics (plume mass, plume area, and plume center of mass position) and provide temporal changes in average plume concentration and plume volume;
- Could be used to incorporate solid-phase data to better quantify and understand source mass distribution in the subsurface;
- Decision making tool to guide or support any future investigations, extraction well installations, or extraction well pumping changes; and
- Could be used to generate fate and transport model calibration targets.

Disadvantages include:

- No real disadvantages.
- Some information identified during the data mining process may require additional resources to produce or format that data before importing into EVS. This could be handled on a case by case effort as deemed appropriate.

Technology Inter-Relationships:

Generally, this software readily interfaces with flow and transport modeling codes and pre/post processors to help establish the initial conditions and calibration targets. The effort required to successfully import data generated from EVS into the Site's existing groundwater flow and transport modeling code, VAM3D, is largely unknown and could be substantial.

Short list: Yes

Data Gaps:

The need to sample for some additional data may be identified from initial 3D mapping interpretations and the data mining task. The need for this additional sampling would be evaluated on a case by case basis and conducting it would be based on the perceived benefit provided to the remedy.

References:

DOE (U.S. Department of Energy), 2019. *Monticello Mill Tailings Site Operable Unit III Annual Groundwater Report, May 2018–April 2019*, LMS/MNT/S26208, October.

DOE (U.S. Department of Energy), 2020. *Draft Tuba City, Arizona, Disposal Site, Groundwater Remedy Performance Report 2002 Through 2018*, LMS/TUB/S28108, June.

Ricker, J.A., 2008. "A Practical Method to Evaluate Ground Water Contaminant Plume Stability," *Groundwater Monitoring and Remediation* 28(4):85–94.

Next Steps:

Proceed with EVS model to compute bulk plume metrics using data that is already available in a user-friendly format for EVS Identify what data is not readily available and coordinate with data mining task to obtain it.

Implementation Details:

Step 1: Use plume data that is in EVS (4D Mapping and Interpretation Task) to calculate bulk plume metrics (mass, volume, and average concentration).

Step 2: Using interpretation from Step 1, identify any additional data needs that would improve 1) the bulk plume metrics, 2) interpretation of recalcitrant areas, and/or 3) assessment of remedy performance.

Step 3: Once fate and transport calibration needs have been identified, use EVS to prepare quantified calibration targets.

Step 4: Long term maintenance and update of Fernald EVS model.

Level of Effort:

LM Contractor:

Step 1: Estimated to be 80 hours and assumes no further data analyses are required.

Step 2: Estimated to be 80 hours This task is contingent upon the interpretation needs for recalcitrant areas or assessment of remedy performance. This task assumes that extraction rate and mass recovery data are in a readily usable electronic format that does not require additional data manipulation. This estimate further assumes that extraction well capture zones have been sufficiently defined with the observed data and no further evaluation will be required.

Step 3: 40 hours This task assumes that calibration targets will be imported into the Groundwater Vistas modeling pre/post processor for use with MT3D or PHT3D family of transport codes. This task further assumes that required data is available.

Step 4: 20 hours/year are assumed to be required to incorporate new annual data and update reporting figures only. Additional effort may be required subject to new findings or requests.

Technology/Strategy: Modern Hydrogeologic Modeling Platform

<u>**Summary Information**</u>

Objective and Potential for Risk Reduction:

Expanding the current use of a modern hydrogeologic modeling software platform (Groundwater Vistas) will provide a more resource efficient, nimble environment to interrogate and update Fernald Preserve groundwater flow and contaminant transport models within. This functionality would allow efficient evaluation of uncertainty in predictions of the remedial timeframe and evaluation actions that may be taken to potentially reduce the remedial timeframe itself (e.g., adapting the remedy, guiding which wells to operate, changing well pumping rates).

Focus Area(s): Focus Area 2, Tier 1

Description:

Observations reviewed in the *Fernald Preserve 2019 Site Environmental Report* (SER) indicated that pumping operations in the South Plume and the Southern South Field would need to continue past 2022, and that additional modeling should be conducted to optimize the performance of the system again. The governing equations for subsurface flow and transport have remained consistent since the Regional and "Zoom" Fernald groundwater models were developed with VAM3D; however, both Regional and Zoom Fernald models consist of thousands of lines of ASCII data. When changes need to be input, the exact lines need to be located and changed, which is very labor intensive. Since the initial site groundwater model development, hydrogeologic modeling technology has significantly advanced in terms of (1) speeding up solution and computational time and (2) making sophisticated analysis, optimization options, and modern pre- and post-processing methods available within a single software platform.

Between 2019 and 2020, the Zoom groundwater model was ported into a user-friendly, modern hydrogeologic modeling platform, Groundwater Vistas[1], to make the process of modeling pumping changes more efficient. The continued use of Groundwater Vistas is recommended with expanded application. The recommended additional effort will result in a version of the Regional Fernald groundwater model translated into Groundwater Vistas. Groundwater Vistas is model-independent, meaning the immediate outcome of this effort will result in use of the same geomodels with flexibility to be numerically solved by MODFLOW or VAM3D, without having to rebuild geomodels from scratch. By porting both geomodels into this modern hydrogeologic modeling platform, the Fernald site will be enabled to efficiently run algorithmic optimizations (refer to *Algorithm Based Optimization* narrative), test out well-system design strategies, recalibrate the models as a function of observations, and benefit from the use of modern post-processing and visualization tools.

Development Status: This recommended action is fully mature and has already been demonstrated on one of the two existing site groundwater models of interest.

[1] http://www.groundwatermodels.com/

Fernald Site-Specific Advantages/Disadvantages:

Advantages include:

- Makes the groundwater models more transparent and portable.
- Allows for more nimble consideration of additional wells and/or optimization of well pumping schemes.
- Updating the Regional model using this tool would allow efficient exploration of impacts of boundary conditions not currently considered
- Use of Groundwater Vistas facilitates the possible use of the MODFLOW code to run the site model. Running the site model using the MODFLOW code would be an advantage given that most modern optimization algorithms are configured to run seamlessly with MODFLOW on the GWVV platform.

Disadvantages include:

- Need to engage regulatory stakeholders on any major model updates. For instance, if the choice of running MODFLOW is recommended, it may impact the speed at which it can be implemented.
- Additional coding may have to be performed to format raw VAM3D files to work with the optimization algorithms. This may be addressed by running the model using MODFLOW, which is discussed above under advantage.

Technology Inter-Relationships:

The recommended activity is an extension of already ongoing work. The flexibility allowed from this relatively quick activity is critical to carrying out additional recommended actions to evaluate the current remedy in a cost effective and time efficient succession. This activity will also benefit from the simultaneously occurring data mining, 4d mapping, and plume refinement recommended activities.

Short list: YES

Data Gaps:

The activity of porting the regional model into Groundwater Vistas may begin as soon as approved. It is recommended that re-evaluations of optimal pumping schemes using this platform be held off until the *Data Mining* recommended activity is complete.

References:

DOE-LM (U.S. Department of Energy, Office of Legacy Management), 2020. *Fernald Preserve 2019 Site Environmental Report* (LMS/FER/S28948), Appendix A, Supplemental Groundwater Information, U.S. Department of Energy Office of Legacy Management (United States).

Next Steps: Expand upon the completed activity porting the Fernald Zoom groundwater model into Groundwater Vistas by porting the Fernald regional VAM3D model into Groundwater Vistas.

Implementation Details:

FY 2021

Evaluate the implementation requirements for employing recommended analysis and optimization efforts using either code (VAM3D or MODFLOW) to determine which is more cost and time efficient and technically sound to pursue and make recommendation for which code to use (see *Algorithm Based Optimization* narrative).

FY 2022

If MODFLOW is selected for optimization efforts, run the ZOOM and Regional models with both VAM3D and MODFLOW to demonstrate consistencies and identify any significant differences. For example, VAM3D handles dispersivities using a 4 × 4 dispersivity matrix that accounts for near vertical flow around pumping wells due to partial penetration effects. This prevents artificial contaminant halos from appearing beneath the extraction wells. Need to verify MODFLOW can handle near vertical flow with respect to dispersivities. If not, then level of effort to modify MODFLOW code should be discussed.

Using ongoing incoming results of the data mining efforts (refer to *Data Mining* narrative), recommend what updates should be made to the model(s) for the purposes of (1) reducing remedial timeframe uncertainties and (2) evaluating remedy changes or enhancements to reduce the remedial timeframe first in the South Plume and Southern South Field areas.

FY 2023

Using results of the data mining efforts, make any changes deemed appropriate to improve the Fernald Regional groundwater model before making further optimization runs.

Conduct groundwater modeling to optimize the remedy.

Level of Effort:

LM Contractor: 9 full-time equivalent months

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Algorithm-Based Optimization

Summary Information

Objective and Potential for Risk Reduction:

The objective of algorithm-based optimization is to improve the plume containment and uranium mass removal performance of the current Fernald Preserve extraction system. Optimizing the extraction system will ensure the uranium plume is contained at the southern boundary of the site and result in onsite uranium plume concentration decreasing as quickly as possible.

Focus Area(s): Focus Area 2, Tier 1

Description:

Use of algorithm-based optimization codes that couple with numerical groundwater flow and transport models will provide a more robust and thorough optimization process than the current trial-and-error optimization process being used at the Fernald site. Algorithm-based optimization codes determine the well locations and extraction rates to satisfy combinations of drawdown, aquifer restoration duration, plume containment, maximum number of extraction wells and minimum and maximum pumping rate constraints.

The remedial extraction well field is being operated to restore aquifer water quality at the Fernald Site, but restoration progress is lagging relative to expectations and alternative extraction well field designs are sought to increase aquifer restoration progress. Application of algorithm-based optimization codes should result in extraction well field designs that achieve aquifer restoration sooner than that achieved by the current extraction well field. Design considerations will include, use of existing extraction wells, replacement extraction wells and combinations of existing and replacement extraction wells; horizontal extraction wells; and combinations of existing and replacement well types coupled with injection wells. Hydraulic performance of the various extraction and injection designs will be coupled with economics to determine the most cost-effective, well field design to achieve aquifer restoration.

Development Status:

Application of algorithm-based optimization codes is a mature technology. Starting in the 1990s, well field optimization algorithms have been used at the DOE Kansas City Plant, DOE Paducah Gaseous Diffusion Plant and the LM, Monument Valley, AZ, Processing Site to design and evaluate various extraction well field configurations.

Fernald Site-Specific Advantages/Disadvantages:

Advantages include:

- Use of algorithm-based optimization codes that couple with numerical groundwater flow and transport models will provide a more robust and thorough optimization process than the current trial-and-error optimization process being used at the Fernald site does.
- Application of algorithm-based optimization codes increases the probability that the “best” well field configuration and pumping rates for the assigned design constraints can be identified and selected.

- Costs associated with undertaking an optimization design and evaluation effort are typically minimal compared to the savings realized following optimization.

Disadvantages include:

- Most algorithm-based optimization codes were designed to work seamlessly with MODFLOW and MT3D, USGS groundwater flow and transport codes, respectively. Coupling algorithm-based optimization codes with VAM3D, the model currently used to simulate groundwater flow and transport at Fernald, will require coding to allow information to be exchanged between VAM3D and the optimization codes. Any coding effort will require vetting using simple models to ensure that the optimization results are as expected. This disadvantage could be addressed by using MODFLOW and MT3D to simulate Fernald site groundwater flow and contaminant transport rather than using the current VAM3D model. This is discussed further in the narrative titled: “Modern Software Tools.”

Technology Inter-Relationships:

The alternative to algorithm-based optimization is numerical model trial-and-error simulations of various well field configurations and extraction rates. Because there is no algorithm guiding extraction well placement and determination of pumping rates, trail-and-error simulations may not yield the best solution for desired design criteria.

Short list: Yes

Data Gaps:

Algorithm-based optimization codes require, above all else, calibrated, numerical groundwater flow and, depending on the algorithm, transport models that reasonably replicate site groundwater flow and transport conditions as described by the groundwater flow and transport conceptual site models. The current VAM3D model does not reasonably replicate contaminant transport as evidenced by the model’s inability to predict cleanup times. Before algorithm-based optimization can be applied at Fernald, the transport model will need to be updated to better match observed concentration trends. Additionally, algorithm-based optimization codes require 3-D knowledge of plume geometry and concentration distributions. The Fernald uranium plume is currently depicted using map views and cross-sections. Before algorithm-based optimization can be used at Fernald, 3-D plume representations need to be developed. This is discussed further in the narrative titled: “4D Mapping and Interpretation”

References:

Becker, D. et al, 2006. “Reducing Long-Term Remedial Costs by Transport Modeling Optimization,” *Groundwater*, 44(6):864-75, November.

Peralta, R.C. and Kalwij, C.M, 2012. Groundwater optimization handbook: flow, contaminant transport, and conjunctive management, CRC Press & International Water Association.

Next Steps:

This activity is dependent on completion of data mining activities, transitioning the Fernald numerical groundwater flow and transport model to a platform that couples with algorithm-based optimization codes, and development of calibrated groundwater flow and numerical transport models.

Implementation Details:

Estimates provided herein assume that data mining is complete and that the current VAM3D model is converted to groundwater flow and transport code (e.g. MODFLOW and MT3D) that couples with algorithm-based optimization codes. The estimate also assumes that an adequately calibrated groundwater flow and transport model is available to couple with the algorithm-based optimization codes.

Step 1: Select algorithm-based optimization code.

Step 2: Determine design scenarios and criteria for optimization.

Potential design scenarios could include:

1) Existing extraction wells;

2). New extraction wells;

3) New and existing extraction wells;

4) Horizontal wells;

5) Combinations of above with injection wells;

Design criteria could include:

1) Plume capture requirements expressed as a percentage of total plume mass;

2) Plume capture durations expressed as time to reach standards;

3) Minimum and maximum individual extraction well pumping rates;

4) Maximum cumulative extraction rates;

5) Individual extraction well maximum allowable drawdowns;

6) Maximum allowable off-site drawdowns;

7) Maximum allowable number of extraction and injection wells.

Step 3: Configure optimization effort.

1) Locate candidate well locations within the model domain;

2) Assign minimum and maximum extraction pumping ranges and maximum allowable drawdown;

3) Assign maximum allowable drawdown at areas of concern within the model domain;

4) Assign plume capture and duration criteria;

Step 4: Run optimization simulations.

Step 5: Evaluate and report on optimization effort.

1) Routine briefing meetings;

2) Draft report;

3) Final report.

Level of Effort:

LM Contractor: Total 520 hours

Step 1: 20 hours. Includes time for technical and management briefing meetings and meeting preparation time.

Step 2: 100 hours. Includes time for technical meetings to determine optimization designs and constraints and management briefing meetings and meeting preparation time.

Step 3: 40 hours. Assumes one senior and one junior staff participation.

Step 4: 160 hours. Assumes one senior and one junior staff participation.

Step 5: 200 hours. Includes hours for report and presentation preparation, document management and senior review.

NLs: National Laboratory support is not anticipated.

Attachment B

Narratives for Additional Supplementary Actions

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Contents

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Technology/Strategy: Industrial and Innovative Maintenance Strategies for Discharge and Transfer Piping

Summary Information

Consider implementing industrial processes to inhibit the biofouling and build-up of solids on the walls of the discharge and transfer piping with the goal to improve reliability, performance and longevity between cleaning events. There are a wide range of available options including regular use of biocides, sonication, uv light and others. There is significant scientific literature on these options. This is a viable concept that has significant potential to benefit the Fernald operations team – however, other recommended actions (notably regular use of biocides in the extraction wells, has the potential to limit the export of biomass to the transfer piping and may eliminate the need for separate control actions. The LM-NLN triage of this process did not advance the concept to the short list but recommends keeping the technology class as a future option if the extraction well control efforts do not sufficiently protect the discharge and transfer piping.

Focus Area(s): Focus Area 2, Tier 2/3 (requires modifications to site infrastructure)

Description:
This narrative focuses on deploying and operating industrial processes to inhibit the biofouling and to limit the accumulation of bio solids on the walls of the discharge and transfer piping. The objective is to maintain system efficiencies and reduce the requirements for periodic disconnection, and physical cleaning and flushing. A number of options are available, including regular use of biocides (either continuous or shock treatments), physical disruption of the flocculation or attachment processes (e.g., sonication), energy based disinfection (e.g., UV light), or materials selection (e.g., biocidal coatings). Of these, the simplest to implement would be use of sonication since there are available systems that clamp on the discharge piping and operated as needed to disrupt the attachment of biofilms and to keep any microbial and filamentous cells in solution. Such systems are also used to minimize the attachment of biofilms to the hulls of boats (reducing the need for using biocidal coatings that contain toxins such as organotin compounds). Notably, the LM-NL collaboration has recommended a series of actions to limit the establishment of biofilms in the extraction wells -these actions are anticipated to have a downstream benefit of limiting the delivery of biomass to the discharge and transfer piping and providing significant benefit toward keeping the piping clean. Thus, we recommend a staged consideration of this technology option. LM-NLN triage of this process did not advance the concept to the short list at this time. However, these technologies, particularly sonication, remain potentially viable for future consideration by the Fernald team if needed.

Graphic: no graphic included in this narrative

Development Status: Potentially viable strategy that generally uses commercially available components. (TRL 6 to 9).

Fernald Site-Specific Advantages/Disadvantages:

Advantages include:

- Potentially viable system that could be incorporated into operations
- Widely used in industry – commercial systems are available

Disadvantages include:

- Objectives are redundant with potential benefits of alternative recommendations for automated biofilm control in the extraction wells.

Technology Inter-Relationships: This is an available technology that can be considered by the Fernald team if needed in the future.

Short list: No

Data Gaps: n/a.

Example References: n/a

Next Steps: n/a

Implementation Details and Level of Effort: n/a

Technology/Strategy: Antifouling Coatings and Construction Materials

Summary Information

Consider use of construction materials (well screens, pumps and casings) that inhibit or minimize the growth of biofilms for better maintaining the hygiene of Fernald extraction wells with the goal to improve extraction well operations and longevity between cleaning events. The LM-NLN triage of this process did not advance the concept to the short list for a variety of reasons, including: some materials would provide only incremental improvements (e.g., polished stainless steel), some materials or coatings would be expensive (e.g., elemental silver), some materials or coatings would have potential for releasing toxins (e.g., organotin marine paints), and most applied paints and epoxies have the potential for flaking or wearing over time. Further, coatings might be difficult to apply to the well screens and pumps which are the most active areas of biofouling. The LM-NLN triage of this process did not advance the concept to the short list for a variety of reasons and believes that this concept has limited potential for future consideration.

Focus Area(s): Focus Area 2, Tier 2/3 (requires modifications to site infrastructure)

Description:
This narrative focuses on minimizing biofilm formation and fouling by selecting materials and coatings that resist the establishment of the biological community. Common and widely recognized technologies such as microban™ have been documented for maintaining the hygiene of surfaces and these concepts have been applied to the selection of piping and equipment in industry. Scientific literature documents a number of materials that provide incremental benefits (i.e., they slow the establishment of biofilm attachment because of smoothness) – these materials include electropolished stainless steel, epoxy coatings, and industrial coatings such as SkotchKote. Other materials include biocides that inhibit growth—these materials include biocidal metal elements (silver or copper), marine paints that contain organotin compounds, and other applied liquids or solids. The primary sections of the extraction wells where biofouling is occurring are the screen zone (stainless steel wire wrap) and the pumps (currently cast iron and mild steel). The casing and riser piping are areas of less biofilm growth (although these materials would be the easiest to coat or modify in future construction. As described below, materials that provide incremental improvement may not significantly benefit Fernald operations and there are limitations with many of the candidate materials (potential for wear of flaking, expense, etc.). Thus, the LM-NLN triage of this process did not advance the concept to the short list.

Graphic: no graphic developed for this narrative

Development Status: Potentially viable strategy that generally uses commercially available components. (TRL 6 to 8).

Fernald Site-Specific Advantages/Disadvantages:

Advantages include:

- Can be incorporated into design for future wells or for replacement components (such as pumps)

Disadvantages include:

- May not provide fully effective control of biofouling
- Paints, epoxies and similar coatings may wear, flake and fail over time
- Special ordered coatings will increase the cost and lead time for well components such as pumps (and may not be available)
- Some materials may leach toxic compounds (e.g., marine paints)
- Not as effective as other recommended alternatives

Technology Inter-Relationships: This is an available technology that may have limited applicability -- but this concept has limited potential for future consideration as a primary biofouling control strategy by the Fernald team.

Short list: No

Data Gaps: n/a

Example References: n/a

Next Steps: n/a

Implementation Details and Level of Effort: n/a

Technology/Strategy: Alternative Well Technologies

Summary Information

Alternative well technologies offer the potential to reduce the amount of well rehabilitation required for the current version of vertical extraction wells used at the Fernald site. Alternative technologies also may be more efficient at extracting groundwater from all or some portions of the existing plume. Technologies described here include horizontal wells, Ranney wells and multiple small vertical extraction wells used to supplant a single existing large vertical well.

Focus Area(s): Focus Area 1

Goal: Reduce or eliminate the need for extraction well chemical treatments while maintaining baseline pumping rate.

Description

Groundwater can be extracted using alternatives to the vertical wells that are currently being used. Alternatives to the current approach (20 vertical extraction wells: hereafter the "baseline well configuration") include the following"

- Horizontal Direction Drilling (HDD) Technology (Blind drilled or continuous)
- Ranney-Type vertical and horizontal collector Technology
- Multiple vertical collector wells

HDD technology can be used to install utilities, to extract oil and natural gas and install horizontal wells. The technologies use a specialized rig to install a horizontal well within a curved borehole. Locating technologies (such as a signaling sonde or a compass-like sensor), can be used to map the drill-head location, depth and orientation. If sensors exceed communication range gyroscopic steering tools can be used as a locating technology. The borehole can be created with either a single-entry point (a.k.a. blind hole) or with both an entry and exit point (a.k.a. surface to surface, continuous or double ended well). Blind wells may be resorted to when there is insufficient real estate to locate both an entry and exit hole. Successful installation of well components is less certain when using the blind well method and borehole completion can be complicated by the presence of rock and cobbles. At issue is difficulty in maintaining an open borehole and the inability of well construction materials to withstand pushing the well pipe and screen into the borehole (EPA 2017). Cobble blockage can be addressed potentially by dual rotary rigs that push a large diameter casing ahead of the drill string. Centralizers then permit the installation of a casing with screen, a sand pack and then the casing is withdrawn. However, large cobbles could block the casing while it is being advanced.

Surface-to-surface have been installed to depths in excess of 200 ft and with lengths in excess of 2,800 feet (ft). Unlike the blind installation method, the drill head is removed at the exit hole and a back reamer can be attached to the drill string. The reamer and the well casing and screen (and in some cases, a pre- installed sand pack) can be pulled back through the borehole (vs being pushed in the blind installation method). Reportedly a zone of influence (ZOI) can be about 40 to 80 ft around the well (Figure 1) (EPA 2017).

The selection of drilling fluids, casing and well screen types, is critical. The well screen has to be robust enough to withstand well installation (damage during pushing/pulling, sufficient tensile strength, overlying forces that could lead to screen collapse) able to prevent excess infiltration of aquifer matrix into the well. Wells can be designed with segmented sections of differing screen slot size to account for head losses due to pipe/screen length. A key point is that the well riser must be of sufficient diameter to accommodate the pump or pumps required to achieved desired pumping rates. (EPA 2017).

Horizontal wells can be developed using over pressuring the whole well, over pressuring segments using inflatable packers and jetting. Reportedly, horizontal well require less maintenance than vertical wells. However, since there is no filter pack, infiltration of fine grain sediments into the well may necessitate recurring maintenance (EPA 2017).

Ranney Wells

Ranney wells were first used to drill for oil in the 1920s. A Ranney well, A.K.A a Ranney Collector is a patented approach for extracting water from an aquifer. A series of caissons are installed into the subsurface. The caissons are installed in “lifts”. Soil/aquifer sediment is excavated from within the caisson. Once the caisson settles into the subsurface the next lift is placed on the buried caisson (with tongue and grove linkage) and excavation continues until the target installation depth is achieved. At the target depth, horizontal laterals can be extended out from the caisson column. (Wikipedia)

By way of example, horizontal laterals 12 ft in diameter with a total length of about 1,200 ft were pushed out from a central collector installed to 100 ft below ground level as part of a water supply project (Osgood 2010). As reported during the Fernald orientation, Ranney wells are being used to supply public water supply systems that draw from the Great Miami Aquifer.

Ranney wells still require periodic well maintenance. A Ranney well that was constructed in 1960 had obstructions and heavy scale by 1998 and required cleaning. (Western Groundwater Services LLC 2007). Krieter Water and Environmental company also writes about how horizontal collector wells can suffer from the clogging of screen. http://krieter.com.my/?page_id=122 (advanced horizontal well screen).

Multiple Vertical Collector Wells

This alternative involves using the same vertical well construction technology that was used to install the existing extraction wells at Fernald. What makes this approach different from the existing groundwater extraction approach is that several vertical wells, for example five or six wells could be used to supplement or replace a single existing extraction well.

Development Status:

Thousands of horizontal wells have been installed in the U.S. Ranney wells are currently used to withdraw water from the Great Miami Aquifer. Vertical collector well installation would rely on readily available equipment and commonly understood well installation techniques.

Costs for Ranney Wells and horizontal wells were assessed in CERCLA documents in the past. For comparison, the cost to install an “on property” vertical extraction well, including piping and pumping is [redacted]. A single Ranney well (including pump and piping) was estimated to cost 7.5 to 10 times more than an “on-property” vertical extraction well. A horizontal well installed by directional drilling (including pump and piping) was estimated to cost between 1.5 to 6 times more than an on property vertical extraction well. (FEMP1997)

Fernald Site-Specific Advantages/Disadvantages:

Advantages of horizontal wells include:

- The well can be placed under existing infrastructure including the waste disposal area, sensitive ecological habitats in the preserve, adjacent property, etc.;
- The HDD can be oriented with the major axis of a contaminant plume;
- The HDD well can be installed at the leading edge of a plume;
- A horizontal well installed in a continuous boring would allow for well redevelopment/well cleaning from the entry and exit point of the well.

Disadvantages of horizontal wells include:

- Costs and risk associated with horizontal wells were described as high, and difficulties in properly developing horizontal wells are described in FEMP 1997.
- Cobbles are present at the Fernald site. Cobbles can make drilling using HDD technology uncertain.
- HDD technology may require the use of prepacked screens to prevent screen failure.
- Volumes of solid waste and development water.
- Installation costs may be greater than a series of vertical wells.
- Pumping infrastructure would have to be modified. Flows from multiple horizontal wells may need to be manifolded to pump houses, CAWWT, etc.
- New pumps and pump controllers would have to be purchased and maintained.

Advantages of Ranney Wells

- Potential for less frequent well cleaning than current baseline of 20 extraction wells.
- Caissons could potentially be fitted with ports. The Ranney caisson could be repurposed as the component of a PRB. Once extraction is completed, the ports could be opened, and the caissons could be filled with reactive media such as ZVI.
- Ranney wells can be thought of as a series of horizontal wells and thus an extraction well with an expansive radius of influence.

Disadvantages of Ranney Wells

- Required length of horizontal laterals would likely be much longer than in typical Ranney well applications. Significant amounts of soil would need to be excavated and disposed of as described in FEMP 1997.
- Cost to construct the Ranney well and horizontal collector wells.
- Ranney wells still require cleaning of the horizontal laterals (although less frequent well cleanout than experienced with the 20 current extraction wells at Fernald.

Advantages of multiple collector wells

- Collector wells would be smaller diameter wells and less costly to install than larger wells
- Collector wells could be used to target any portion of the remaining plume
- New wells could be constructed to ensure well screens remain submerged
- Pumping from several wells, rather than just one well, would reduce the potential for a single well to experience excessive drawdown.

Disadvantages of multiple collector wells

- Pumping infrastructure would have to be modified. Flows from multiple wells would have to be manifolded to pump houses, CWAT etc.
- New pumps and pump controllers would have to be purchased and maintained

Short list: NO

The disadvantages noted above for each of the alternate extraction well approaches outweigh the advantages noted. Disadvantages can be grouped as follows: installation-related difficulties, cost constraints, and O&M constraints.

References

EPA (U.S. Environmental Protection Agency). 2017. *How To Evaluate Alternative Cleanup Technologies For Underground Storage Tank Sites A Guide For Corrective Action Plan Reviewers*.

FEMP (Fernald Environmental Management Project), 1997. *Baseline Remedial Strategy*, Fernald, Ohio.

Report Remedial Design for Aquifer Restoration.
http://kreiter.com.my/page_id=122
(advanced horizontal well screen)

Osgood, D., 2010. "Collector Wells Supply Award Winning Water," *Water and Wastes Digest* Collector Wells Supply Award-Winning Water | WWD (wwdmag.com).

Western Groundwater Services, 2007. *Design Report, Ranney No. 5 Well Cleaning Project, City of Kennewick*, Washington, June, HDR Engineering Inc.

Williams, D.E., 2008. Research and Development for Horizontal/Angle Well Technology, U.S. Department of the Interior, Bureau of Reclamation, May, https://en.wikipedia.org.wiki.Ranney_collector, updated on October 20, 2020, accessed on 2/15/2021.

Technology/Strategy: Delivery of Kinetic Energy Downhole During Well Rehabilitation To Improve Extraction Well Performance

Summary Information

The current well rehabilitation process relies on a combination of chemical additives and a mechanical surging process. Several technologies offer the potential to augment the delivery of treatment chemicals into the gravel/sand pack and the aquifer formation. The technologies described include detonation cord, the use of pressurized air or inert gas and the use of high pressure jetting. Fundamentally, the well rehabilitation procedure would be augmented by using one or several of these methods.

Focus Area(s): Focus Area 1, Tier #

Goal: Delivery of energy downhole as a component of well cleaning to improve the specific capacity of extraction wells.

Description

Delivery of energy downhole may increase the reach of the rehabilitation process out into the aquifer material. The current well rehabilitation process relies on a combination of chemical additives and a mechanical surging process. At this time, it appears that chemical/physical/biological plugging is occurring beyond the reach of the energy being delivered downhole. Either the gravel pack around the outside of screen or aquifer material in immediate contact with the screen or both are not being effectively cleaned by the mechanical surging approach. The operating history of Well EW-21A is illustrative. The well has undergone 4 rehabilitations, 14 chemical treatments and has had 3 different pumps and motors.

Three approaches have been considered by the site as documented in a paper authored by Navarro staff (March 1, 2017): (1) detonation cord, (2) Airburst® Technology, and (3) WellJet https://hydropressure.com/welljet/. The detonation cord (a.k.a "det cord") process involved setting off a small explosion within the well screen.

Airburst® Technology uses pressurized air or inert gas. The release of pressurized air/gas creates bubbles that expand and collapse (cavitate) creating the desired energy needed to increase the porosity and permeability of the aquifer material surround the well screen. The entire submerged portion of the screen is treated up to 3 times. The Airburst method is a fluid percussive method based on a pulse generated by a gas gun. A similar method known as Airshock was developed by Flow Industries. https://groundwaterscience.com/resources/tech-article-library/94-recent-innovations-in-well-rehabilitation.html#force

The WellJet process uses pressured water in a laminar flow to remove obstruction from the perforated area of the well screen and to penetrate into the gravel pack.

The use of approach (2) and (3) have been recommended by the long-time well field operations consultant. The consultant also referenced a tool analogous to the Airburst tool: Flow Industries Air Shock (Groundwater Science 2018).

<u>Fernald Site-Specific Advantages/Disadvantages</u>

Advantages of the det cord approach**:**

- Detonation cord can be easily integrated into the current Fernald Preserve site-well rehabilitation procedure.
- Moody's of Dayton Inc. (Fernald Preserve's current wellfield subcontractor) is experienced with the use of det. cord.
- The detonation-cord service provider, Torpedo Services, is local and has a good working relationship with Moody's.
- Detonation cord has a proven safety-and-success record in other similar aquifers in Ohio.
- Continued long term use of det. cord could be easily coordinated with our well-maintenance subcontractor.
- Cost estimate of [redacted] which includes the baseline rehabilitation cost ([redacted]) and the det cord application cost ([redacted]).

Disadvantages of the det cord approach:

- Energy waves created by the detonation-cord process follow the path of least resistance out into the aquifer formation. Energy emitted from the detonation could bypass some areas of the surrounding formation resulting in a non-uniform dispersal.
- The method was applied in July 2017 with short-term improvement only (Groundwater science 2018).
- The energy application is a one-time pulse, versus a more sustained energy delivery provided by Airburst® and WellJet.

Advantages of Airburst approach:

- Airburst® is considered to be highly efficient because the Airburst® gun can be slowly raised and lowered across the length of the well screen, allowing the energy released to be evenly distributed across the entire length of the submerged portion of the well screen.
- The devices can provide a highly efficient action of a shock wave effect coupled with strong surging without using explosive. The devices can be fired in discrete intervals up and down a screen.
- It can be used in conjunction with or instead of chemical treatment O&M.

Disadvantages of the Airburst approach:

- The service provider and equipment may not be local.
- No proven track record of success in unconfined buried valley aquifers.
- Maximum submergence of the Airburst tool is 2−3 feet. Since the well screen in well EW-21A, for example, is located at the water table, an upper portion of the well screen will not be affected by this method.
- Reportedly, case histories demonstrating effectiveness are not readily available for review.
- Cost-estimate of [redacted].

Advantages of the WellJet approach:

- WellJet is considered to be highly efficient because the WellJet gun can be slowly raised and lowered across the length of the well screen allowing the energy released to be evenly distributed across the entire length of the submerged portion of the well screen.
- The method can provide steerable and focused force application.

Disadvantages of the WellJet approach:

- WellJet must have at least 6 wells to justify the travel costs from California.
- No proven track record of success in unconfined buried valley aquifers.
- In general, the process works well in deep well under high hydrostatic pressure. This is not the case for all wells at the Fernald site.
- Cost estimate of [redacted].

Example References

Navarro, 2017. Selection of a Well Rehabilitation Enhancement Method at the Fernald Preserve, Task Assignment 101 LTS&M- CERCLA/RCRA Sites, D&D sites and Other Sites. March

Groundwater Science, 2018, Review and Commentary on Draft Selection of a Well Rehabilitation Enhancement Method at the Fernald Preserve. July.
Copyright 1998-2015, Stuart A. Smith, All rights reserved. Copying is permitted but please credit the source. Original version (since repeatedly updated) presented at el XV Congreso Nacional del Agua, La Plata, Argentina, April 1994.
https://groundwaterscience.com/resources/tech-article-library/94-recent-innovations-in-well-rehabilitation.html#force

Short list: No

There are two primary factors that detract from the technologies described above: uncertainty about effectiveness and cost. There is potential added value for delivering kinetic energy downhole if the effects of rehabilitation can be extended beyond the extraction well and gravel pack. Intuitively, delivering additional energy downhole would seem to provide for rehabilitation beyond the radius of influence of the baseline approach. However, disadvantages of the above noted approaches appear to outweigh the advantages. The WellJet approach, or similar technologies, would require the purchase of the equipment because of Fernald-specific uranium contamination concerns. Cost of the technology is approximately 10 times the cost of the baseline rehabilitation cost ([redacted]). The Airburst tool, which would also have to be purchased costs about 2 times the cost of baseline rehabilitation, but there is a need to take advantage of economies scale and perform the process on multiple wells. The det cord approach appears to be cost effective (adding approximately [redacted]) to the baseline well rehabilitation cost but the Fernald experience with the approach provided only a short-term improvement.

Nevertheless, expertise with Airburst tool-like and/or the WellJet-like approaches may be developed by local vendors/well field maintenance practitioners and the approaches may become viable in the future. These approaches may have value especially if the site can work out decontamination procedures so equipment does not have to be purchased but can rather be applied in a vendor turn-key type scenario.

Technology Inter-Relationships: Other approaches suggested by the NLN collaboration, in particular the introduction of CO_2 into extraction well systems will likely extend the influence of well rehabilitation beyond the baseline radius of influence.

Technology/Strategy: Sonication and Other Innovative Downhole Maintenance Strategies

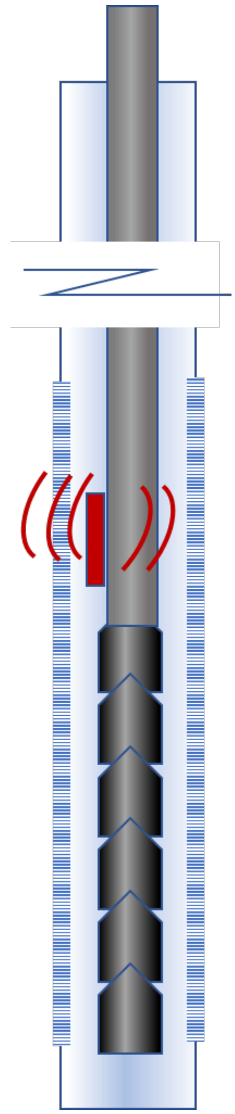
Summary Information

Consider regular or continuous use of sonication, UV light or similar innovative downhole (energy disinfection) strategy for maintaining the hygiene of Fernald extraction wells with the goal to improve extraction well operations and longevity between cleaning events. The LM-NLN triage of this process did not advance the concept to the short list for a variety of reasons, including limitations in effectiveness in the well with interfering infrastructure such as pumps, piping and wires, and more uncertainty compared to alternatives such as regular automated biocide application.

Focus Area(s): Focus Area 2, Tier 2/3 (requires modifications to site infrastructure)

Description:
This narrative focuses on deploying and operating downhole equipment for continuous or semicontinuous well disinfection and maintenance to minimize the initial establishment and growth of biofilms. The deployed technology options include sonication, UV light or similar energy-based disinfection tools. Both sonic tools and UV light have been used and proven effective for inhibiting biofouling in and maintenance of above-ground industrial piping systems. The benefit of the approach at Fernald would be improved extraction well operations and increased longevity between rehabilitation and reworking of the wells. These methods would be challenged by the configuration of the extraction well and potential interferences in the wellbore. For examples: a) there is limited space for deploying transducers for sonication, and b) UV light would not treat areas of the well that are “shaded” by the pump and associated piping and power cables. Further, use of these technologies for well maintenance is not widely used or documented in the literature, increasing development and pilot testing needs. As a result of the potential limitations and the availability of more promising maintenance alternatives (such as automated biocide application), the LM-NLN triage of this process did not advance the concept to the short list at this time. However, these technologies, particularly sonication, remain as potentially viable and for future consideration by the Fernald team if needed (if other maintenance methods do not prove effective).

Graphic:



Simplified depiction of extraction well modified to include innovative downhole energy-based disinfection such as continuous sonication

Development Status: Potentially viable strategy that generally uses commercially available components. (TRL 6 to 7).

Fernald Site-Specific Advantages/Disadvantages:

Advantages include:

- Potentially viable system that could be incorporated into operations

Disadvantages include:

- Requires additional control infrastructure to be deployed in well house buildings and adds to equipment and complexity of downhole infrastructure
- Need to assure that operations would not physically impact long term pump operation (e.g., sonication) or exposed seal materials (e.g., UV light)
- More development needed for implementation compared to automated biocide application.

Technology Inter-Relationships: This is an available technology that can be considered by the Fernald team.

Short list: No

Data Gaps: n/a

Example References: n/a

Next Steps: n/a

Implementation Details and Level of Effort: n/a

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Technology/Strategy: Biofouling Assay Techniques

Summary Information

Biofouling assay techniques may be able to provide an early warning that extraction wells need to be rehabilitated. For newly installed extraction wells, modify existing maintenance monitoring approaches to include biological assay methods.

Goal: Reduce or eliminate the need for extraction well rehabilitation.

Description

Water sample results for microbes present in the groundwater can be used to help determine when or whether an extraction well needs to be cleaned. Existing well field monitoring and management practices include the parameters summarized in Table 6 of the IEMP. The existing maintenance monitoring program is appropriate for the existing extraction wells.

Should new extraction well be installed, the existing practices used to monitor the well field can be augmented to measure biological activity. The primary factor in production and hydraulic efficiency loss on US Army Corps of Engineer projects is biological activity. Biofouling has been identified as a primary cause of well performance problems for both water supply and contaminant plume control scenarios (ACE 2000 and California Rural Water Association 2019). Given the role of biofouling, it makes sense that biological testing is considered an essential component of a maintenance monitoring program for extraction wells. However, whether or not biofouling monitoring results can be used to predict future extraction well performance at the Fernald site is unknown.

The literature suggests that biofouling assay techniques can have a role as an advance signal that well performance is going to suffer. Authors have indicated that the results of biofouling potential in a maintenance monitoring program can provide an advance signal that specific capacity will eventually decrease (ACE 2000). The monitoring of biological activity can also have a role in helping to gauge the success of chemical treatments and/or pulsed pumping strategies as well. Biofouling assay techniques can be combined with a suite of analytes considered to have a role in biofouling such as iron+2 , iron +3, alkalinity and manganese. Including biofouling monitoring in an analytical suite with inorganic analytes thought to have a role in well fouling such as iron and manganese can be performed in tandem with well performance testing to 1) establish baseline extraction well characteristics and 2) identify deviations from the baseline that may be indicative of the future loss of performance. However, the value of biofouling assay techniques as a predictive tool in well field management may be strongly dependent on site-specific conditions. Operators would need to establish a baseline of biofouling monitoring results to assess the value of the monitoring parameter.

Laboratory and near real-time monitoring methods can provide insight into the potential for biofouling (and biocorrosion) to influence system operations. Laboratory methods include: light microscopy of visible samples of bacteria sampled by collector surfaces strategically placed within an extraction well casing Hetrotrophic plate count (HPC) methods; and, Adenosine tri phosphate-based methods to assess biological activity.

Laboratory methods can also be supplemented and/or supplanted with methods that can be used in the field (Groundwater Science (undated). Other, near real-time monitoring methods can provide rapid information about the organisms causing biofouling and give feedback about whether or not well management practices exacerbate or reduce biofouling.

The near-real time monitoring methods (in combination with laboratory methods if needed) could be used to determine if biofouling is occurring and then to determine what niches bacteria occupy in the subsurface (for example: within iron reducing, sulfate reducing, slime forming microbial consortia). The BART™ Method biological activity reaction test (Droycon Bioconcepts Inc. 2003) is one such technique. (Method 9240. Standard Methods) .

The BART TM method includes specific tests for several types of bacteria including:

- Iron Related Bacteria (IRB)
- Sulfate Reducing Bacteria (SRB)
- Heterotrophic Aerobic Bacteria
- Slime Forming Bacteria (SFB)

The method identifies the biological consortia present in a sample and a provides qualitative sense of the population numbers of the microorganisms present in the biological consortia. Results are revealed by visual cues that report on the concept of "aggressivity" which relates to the time lag between the start of a test and when a reaction is observed. The shorter the time lag, the more aggressive the nuisance bacteria.

Fernald has experience using the BART ™ method. The method was used as part of a reinjection well study. Samples were tested for IRB, SFB, and total aerobic bacteria. BART sampling was conducted to see if bacterial changes could be detected in injection wells. Results were inconclusive. Samples collected indicated aggressive growth of all types of bacteria tested for. Results were inconclusive. No predictive pattern was observed. A decrease in biological activity following well rehabilitation was not observed (FEMP 2020).

<u>Fernald Site-Specific Advantages/Disadvantages</u>

Advantages:

- Biofouling assay methods focus on what is likely the primary causal factor in the deterioration of well performance: microbes.
- Many biofouling assay methods are cost effective. By way of example (a combination piece test package that can assess IRB, SRB, and SFB × 3 costs [redacted][1].
- Some biofouling assay methods can be performed in the field and provide near-real time results.
- Biofouling assay method results, along with water chemistry results could be used to establish well profiles. The success of well maintenance interventions (any method that makes it to the short list, for example) can then be assessed.

[1] https://www.hach.com/bart-test-combination-package-iron-related-bacteria-sulfate-reducing-bacteria-slime-forming-bacteria-3-each/product-details?id=7640250884

Disadvantages:

- Uncertainty that biofouling monitoring would be predictive of future extraction well performance failure
- Uncertainty that biofouling monitoring can be used to measure the success of well rehabilitation technologies
- The site may need to combine laboratory and near real time measurement methods to adequately measure biofouling patterns
- Biofouling assays would need to performed over a long period (quarters or years) to develop criteria for triggering well cleaning
- Adding biofouling assay monitoring to the current maintenance monitoring program would require increased staff time for procurement, sampling, data evaluation and reporting
- Experts (with associated vendor costs) would need to be consulted to help interpret the initial sets of biofouling assay results

Short list: No

Given the experience gained while implementing the injection well demonstration, it does not appear the biofouling assays alone can be used as a way to 1) predict future extraction well performance or 2) evaluate the efficacy of well rehabilitation techniques. Site operators would need to close that data gap by adding biofouling monitoring to the analytical suite already being used to asses well performance. Well profiles would need to be developed necessitating sample collection for several months, quarters or years and the value of results are uncertain. Adding biofouling assay monitoring would require increased staff time and may require the retention of subject matter experts to aid in data interpretation.

References

U.S. Army Corps of Engineers, 2000, *Operation and Maintenance of Extraction and Injection Wells at HTRW Sites*, Engineer Pamphlet 1110-1-127, January.

Droycon Bioconcepts Inc. 2003, *Biological Activity Reaction Test BART ™ User Manual*, Regina, Saskatchewan, Canada. January

California Rural Water Association, 2019. *Well Asset Management Report, El Macero Well # 3* El Macero County Service Area, El Macero, California,

Ground Water Science https://groundwaterscience.com/resources/tech-article-library/96-primer-on-microbial-problems-in- accessed on 2/21/2021.

Standard Methods, accessed on 2/22/2021, https://www.standardmethods.org/action/doSearch?AllField=BART&ConceptID=

FEMP (Fernald Environmental Management Project) 2020. *Re-Injection Demonstration Test Report for the Aquifer Restoration and Wastewater Project*.

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Technology/Strategy: Pulsed Pumping of Extraction Wells

Summary Information

Consider pulse pumping (used alone) to improve extraction well operations and longevity between cleaning events. The LM-NLN triage of this process did not advance the concept to the short list for a variety of reasons, including limited potential for improvement in operation (based on past data and compared to other ideas such as pulse pumping in combination with automated biocide application).

Focus Area(s): Focus Area 2, Tier 2/3 (requires modifications to site infrastructure)

Description:
This narrative focuses on operating the extraction well in pulse mode to improve system performance. In the current paradigm, pumps are operated continuously, and in situ pump cleaning is not performed until degradation in pump performance is already measured. In this case, considerable biofilm has already established on the pump and in the well prior to cleaning. As a result, in situ cleaning is only partially effective. An alternative operating strategy would be to pulse the wells to help flush the screen by surging the water level oscillations on startup and shutdown. Puls pumping used alone has the potential to provide some benefits (see separate narrative for pulse pumping with automatic biocide application). For the past several years, some of the twenty groundwater extraction wells have been operated in a pulse pumping mode. These wells are pumped for 300 gpm for 8-hours a day which is equivalent to operating at 100 gpm for 24-hours a day. Under this scheme, these wells are idle for 16-hours every day. The data suggest that there is potential for some limited benefit in using pulse pumping alone (although the quantitative benefit varied from well to well and was relatively small). Based on the net assessment of advantages and disadvantages listed below, the LM-NL collaboration does not recommend advancing this concept to the short list as a significant initiative at this time. However, the team recommends considering pulse pumping in combination with automated biocide application (short list item) and considering pulse pumping alone as a potential engineering option/practice that is available to the Fernald team.

Graphic:
no graphic provided for this narrative

Development Status: Available engineering practice (TRL 8 to 10). In general, this is a simple system that would be straightforward to implement.

Fernald Site-Specific Advantages/Disadvantages:

Advantages include:

- Simple approach system that could be incorporated into operations

Disadvantages include:

- Requires additional control infrastructure to be deployed in well house buildings for pulse pumped wells
- Limited benefit observed in wells that were pulse pumped in the past

- Reduces the amount of water pumped from the well (need to make sure that sufficient water can be pumped to meet overall pumping/design requirements and to support remediation objectives

Technology Inter-Relationships: This is a standard technology that can be considered by the Fernald team.

Short list: No

Data Gaps: n/a

Example References: n/a

Next Steps: n/a

Implementation Details and Level of Effort: n/a

Technology/Strategy: Geochemical Modeling

Summary Information

Objective and Potential for Risk Reduction: Goal is to identify whether an ongoing source zone exists. Risk reduction is use of existing data to better define the source zone and long-term liability. Geochemical modeling of groundwater data can identify the possible existence of upgradient minerals (uranium source minerals and/or controlling minerals). Overall, this task will reduce risk by better understanding influences on downgradient plume concentrations that may remain above drinking water standards.

Focus Area(s): Focus Area 2

Description: Existing well data can be input into a geochemical modeling program (like PHREEQC or Geochemist's Workbench) and evaluate output (mineral saturation indices) for minerals that are near equilibrium or supersaturated. For best results, any redox data (such as Fe^{2+}/Fe^{3+}, dissolved oxygen, or oxidation-reduction potential [ORP]) should be included. Also, data can be plotted as stability diagrams (see graphic) to evaluate if uranium minerals are soluble, likely to precipitate, or near equilibrium. Additional stability diagrams can be completed as Eh/pH diagrams or evaluations of mineral solubility changes with varying Eh (see graphic), if enough redox data are available. The result will be an ability to characterize how contaminant release from secondary sources into the aquifer.

Graphic:

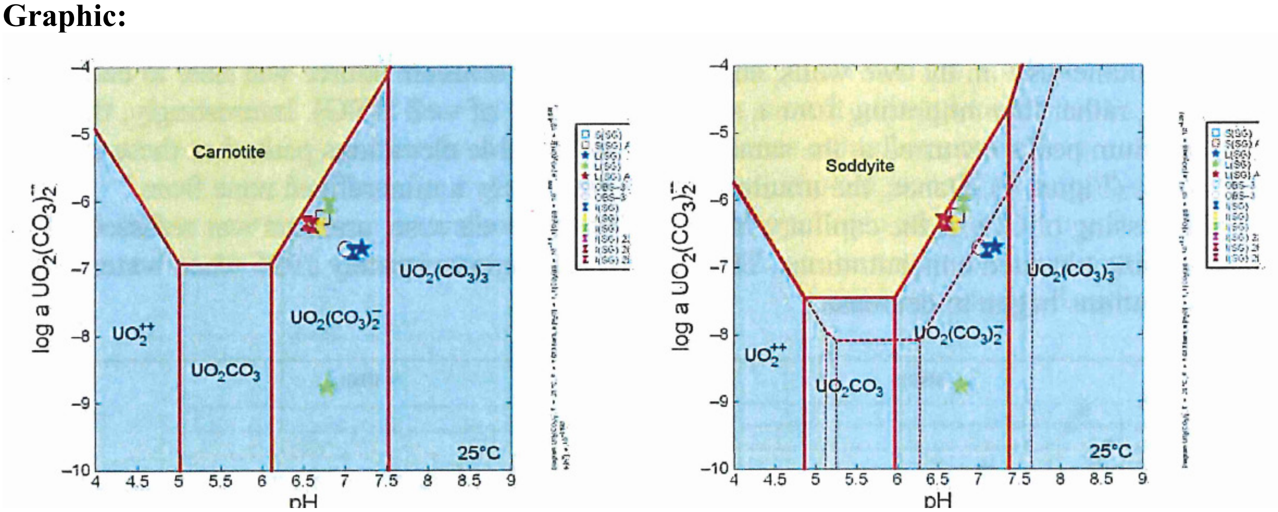

Figure 1. Plot of stability diagrams for two uranium minerals (Denham et al. 2014)

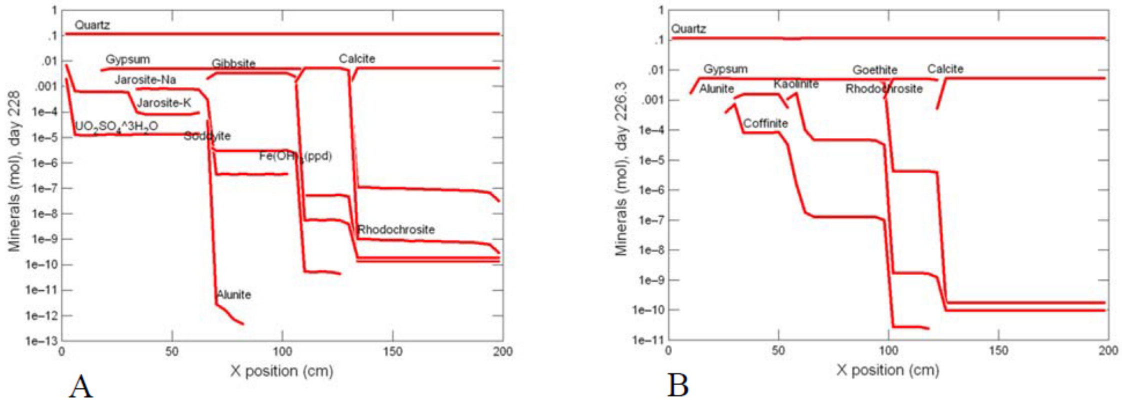

Figure 2. Simulations of the Mineralized Zone under (A) Oxidizing Conditions and (B) Reducing Conditions (Denham et al. 2014)

Development Status: Mature, can apply immediately

Fernald Site-Specific Advantages/Disadvantages:

Advantages include:

- Relatively easy to implement
- Generates actionable interpretations using existing data
- Geochemical modeling programs already exist
- Simple and relatively inexpensive to implement and interpret

Disadvantages include:

- Not a direct indicator of mineral presence
- May have to make some assumptions on the geochemical conditions between the source zone and downgradient wells
- Can be somewhat uncertain, depending on the thermodynamic database being used

Technology Inter-Relationships: Results of analysis will be stronger if coupled with other existing data analysis tools such as review existing sediment and GW data, redox disequilibrium

Short list: Not to be included in the short list due to not addressing near term priorities of the southern portion of the plume. However, this recommendation could be useful to identify secondary sources in the vicinity of the former waste disposal areas and to support future CERCLA reviews.

Data Gaps: The implementation of this recommendation will depend on the data gaps identified in the Targeted Mining Data Tasks. Immediately actionable. Some unique uranium minerals may need thermodynamics added to the geochemical modeling database. Not all wells will have necessary geochemistry data. Can consider additional data collection, as needed, especially redox information (like Fe^{2+}/Fe^{3+}, dissolved oxygen, and ORP).

Next Steps: Will need to decide on what minerals to evaluate in detail, what geochemical modeling program to use, and what thermodynamic database to use. Decide on whether collection of additional redox data is necessary. Decide on geochemical modeling output approach (stability diagrams, Eh/pH diagrams, solubility changes with geochemical changes, etc.).

Implementation Details: Would be part of any updated conceptual site model. Immediately actionable and provides general information on past, current, and future risk of contaminant release from the source zone based on geochemical conditions.

Personnel (person months):

- Year-1 "Assess adequacy of historical and groundwater data" – 0.5 per-month each LM and NL
- Year-1/Year-2 "Develop geochemical model" – 2.0 per-month LM; 2.0 per-month NL
- Year-2/Year-3 "Finalize geochemical model and generate results (run PHREEQC, evaluate redox data, evaluate mineral saturation indices and updated database, as needed)" 3.0 per-month LM; 2.0 per-month NL

Additional Assumptions: Assumes appropriate data sets for geochemical modeling are available.

References:

Denham, M.E., B.B. Looney, C.A. Eddy-Dilek, 2014. Independent Technical Review and Qualitative Risk Assessment of the Department of Energy Office of Legacy Management Bluewater UMTRCA Site.

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Technology/Strategy: Groundwater Depth-Profile Sampling

Summary Information

Objective and Potential for Risk Reduction: Multilevel sampling of groundwater (GW) is conducted in new or possibly existing boreholes and coupled with geochemical modeling to identify the existence of uranium source minerals, solubility-controlled secondary sources, and/or dominant soluble complexes. Vertical sampling of GW will support the development and application of geochemical models. Multilevel sampling provides well-scale information about the geochemistry as input to interpreting GW geochemistry on a larger scale through geochemical modeling. The technology will reduce uncertainties associated with the source(s) of uranium. This technology addresses human health, regulatory, and stakeholder risks.

Focus Area(s): Focus Area 2

Description: Where data are unavailable, a "Waterloo" multilevel sampler system (Figure 1) could be deployed to obtain the necessary geochemical depth-profile data. The objective is to measure vertical profiles of uranium and the full suite of geochemical parameters (pH, ORP, full cation/anion analysis including NO^{2-}, chemical tracers, redox couples, and so on) necessary to support development of the geochemical model as well as other technologies being deployed (e.g., chemical tracers as proxies, redox disequilibrium, GW mixing).

Existing and/or newly collected well data would be analyzed with a geochemical modeling program such as PHREEQC or The Geochemist's Workbench® to calculate mineral saturation indices, dominant aqueous complexes impacting uranium solubility/mobility, and redox speciation. Model results can be interpreted using various stability diagrams (Figure 2) and Eh/pH diagrams (Figure 3) to evaluate the impact of aqueous composition, pH, and ORP on uranium speciation. "What if" scenarios can be analyzed once the model is developed (e.g., changes in alkalinity, dissolved organic carbon, etc. on uranium solubility). For Fernald, the presence of higher uranium concentrations deeper in the aquifer versus near the water table would assist in a multiple lines of evidence approach to help resolve alternative conceptual models of contaminant distribution and type of source.

Graphic:

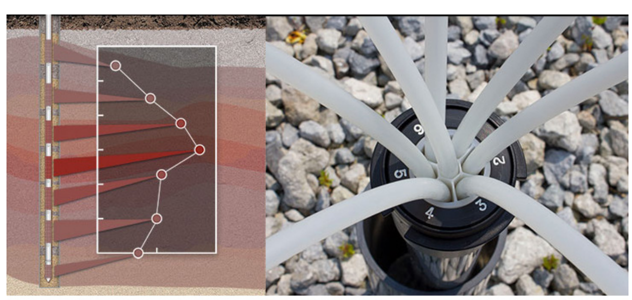


Figure 1. Solinst Multilevel Sampler System (https://www.solinst.com/products/multilevel-systems-and-remediation/)

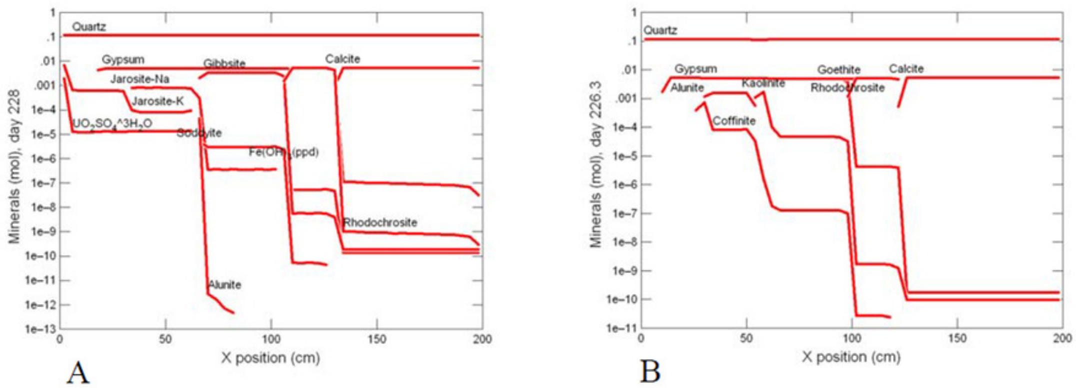


Figure 2. Simulations of the Mineralized Zone under (A) Oxidizing Conditions and (B) Reducing Conditions (Denham et al. 2014)

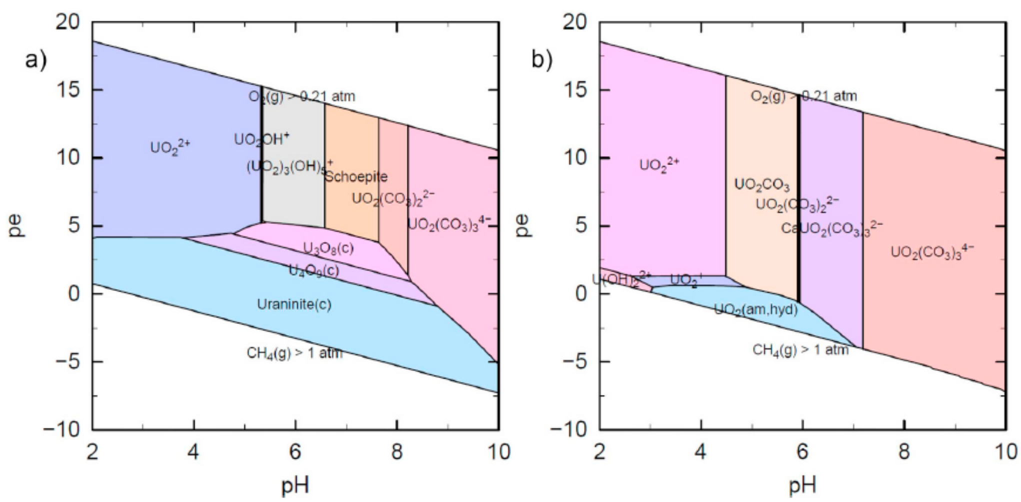


Figure 3. Predicted pe vs. pH Diagrams (Müir-Ebert et al., 2019) for 10^{-5} M Uranium in Synthetic Water Sample 2_2 using Thermodynamic Databases by (a) Ball and Nordstrom (1991) and (b) Müir-Ebert et al. (2019)

Development Status: Technology is mature and can be applied immediately as part of an integrated field sampling program.

Fernald Site-Specific Advantages/Disadvantages:

Advantages include:

- Generates actionable data using both existing and new GW data.
- Geochemical modeling software is available commercially (The Geochemist's Workbench®) and in the public domain (PHREEQC).
- Simple and relatively inexpensive to deploy and interpret, especially if an existing well can be used and/or if existing data is already available.
- Helps interpretation of other well sampling and testing efforts.

Disadvantages include:

- Need full suite of cation/anion data and geochemical parameters for the geochemical model, preferably including redox data.
- Not a direct indicator of mineral presence.
- May need to make some assumptions on geochemical conditions between the source zone and downgradient wells.
- Uncertainties could be introduced depending on the quality of the thermodynamic database employed in the geochemical model.

Technology Inter-Relationships: The approach will also provide input to better plan other characterization and monitoring approaches such as redox couple disequilibrium, mixing ratios and push-pull testing.

Short list: Not to be included in the short list due to not addressing near term priorities of the southern portion of the plume. However, this recommendation could be useful to identify secondary sources in the vicinity of the former waste disposal areas and to support future CERCLA reviews.

Data Gaps: The implementation of this recommendation will depend on the data gaps identified in the Targeted Mining Data Tasks. If currently available groundwater characterization data are not adequate, then a field effort will need to be planned to collect additional samples.

Next Steps:

- Assess adequacy of historical and groundwater data to gain insights and to develop a functional geochemical model for evaluating uranium speciation and potential mitigation strategies.
    - Full suite of geochemical parameters (pH, ORP, complete cation/anion analyses, etc.) necessary to support development of the geochemical model
    - Vertical profiles of GW data
- If data appear adequate, develop a preliminary geochemical model using PHREEQC or The Geochemist's Workbench® (GWB) software.
    - Assess and, if necessary, update thermodynamic database, especially for uranium speciation.
    - Build and execute chemical equilibrium and/or redox models.
    - Identify data gaps that require additional field sampling.
    - Summarize initial insights, if any.
- If data are not adequate, develop and execute field sampling plan to collect vertical groundwater profile data in new/temporary or existing wells using Waterloo multilevel sampler.
    - Need wells screened over wide interval.
    - Detailed work plan must be developed with scope, schedule, and field and laboratory sampling plan.

- Finalize geochemical model
  - Evaluate mineral saturation indices, dominant aqueous complexes impacting uranium solubility/mobility, and redox speciation.
  - Generate stability and E_h/pH diagrams to evaluate the impact of aqueous composition, pH, and ORP on uranium speciation.
  - Perform "what if" simulations (e.g., changes in alkalinity, dissolved organic carbon, etc. on uranium solubility).

Implementation Details:

Personnel (person month):

- Year-1 "Assess adequacy of historical and groundwater data" – 0.5 per-month each LM and NL
- Year-1/Year-2 "Develop preliminary geochemical model" – 2.0 per-month LM; 2.0 per-month NL
- Year-2/Year-3 "Develop and execute field sampling plan" – 6.0 per-month LM; 2.0 per-month NL
- Year-2/Year-3 "Finalize geochemical model and generate results" – 3.0 per-month LM; 2.0 per-month NL

Additional Costs: Laboratory analyses of GW samples (full suite of geochemical parameters and cations/anions). Assume [redacted]/sample × 2 wells × 20 samples per well = [redacted].

References:

Ball, J. W., Nordstrom, D. K., 1991. WATEQ4F Database. U.S. Geological Survey.

Denham, M. E., Looney, B. B., and Eddy-Dilek, C. A., 2014. Independent Technical Review and Qualitative Risk Assessment of the Department of Energy Office of Legacy Management Bluewater UMTRCA Site.

Müir-Ebert, E. L., Wagner, F., and Walther, C., 2019. "Speciation of uranium: Compilation of a thermodynamic database and its experimental evaluation using different analytical techniques," *Applied Geochemistry*, 100: 213-222. https://doi.org/10.1016/j.apgeochem.2018.10.006.

Technology/Strategy: Characterization/Sequential Extraction of Core Material

Summary Information

Objective and Potential for Risk Reduction: The goal of source zone characterization with sequential extraction studies in soil core samples at the Fernald site is to directly identify areas with significant elevated sediment-associated uranium and evaluate uranium chemical forms/susceptibility to mobility. The characterization approach for soil core and sequential extraction provides geochemistry information that can be used as input to additional screening evaluation of remediation options and flow transport models. Opportunity for risk evaluation exists by directly measuring potentially mobile contaminant mass and testing on what conditions could change that mobility. Overall, this task will reduce risk by better understanding past, current, and future source influences on downgradient plume concentrations that may remain above drinking water standards.

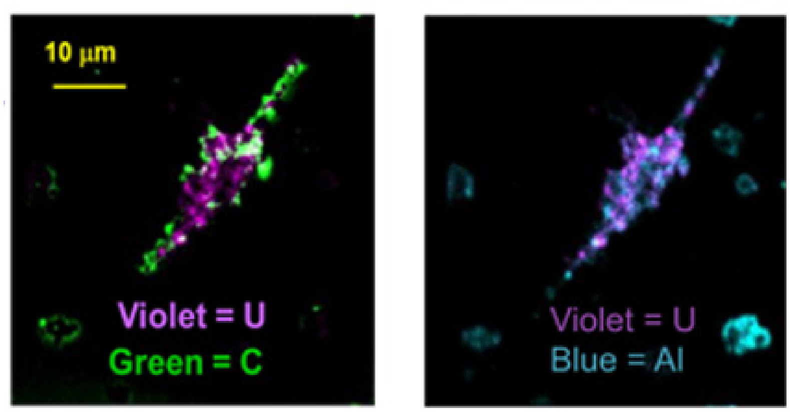
Focus Area(s): Focus Area 2

Description: Mine existing data (previously collected soil core) to help in the planning and selection of additional soil cores collected in areas of the preferential transport zone. Samples with depth will be evaluated by using x-ray fluorescence (XRF) to determine the elemental composition and x-ray diffraction (XRD) to determine the primary minerals present. Field screening of soil core material with XRF and 5% nitric acid uranium extraction can be used to down-select samples for sequential extractions and possibly X-ray spectroscopy for uranium oxidation states.

Sequential chemical extractions of sediments from suspected primary and secondary sources evaluates its susceptibility to mobilization as follows: (i) water soluble – weakly sorbed (MilliQ Water); (ii) Exchangeable – strongly sorbed U (O_2-free Na-bicarbonate); (iii) U-mineral sensitive to the oxidation (O_2 Na-bicarbonate); (iv) U-evaporate sensitive to dissolution (sodium Acetate); (v) resistant (1M HCl). In addition, leaching of core material using column tests can be used to get quantitative data on uranium release concentrations and rates (see batch-column sorption studies narrative).

Graphic:

Selective Extractions



X-ray Spectroscopy

Development Status: All analytical methods are well established with detailed protocols provided in peer-reviewed literature.

Fernald Site-Specific Advantages/Disadvantages:

Advantages include:

- Direct analyses of the source zone. Relatively direct identification of potential U-minerals, U-bearing minerals, or desorption as a long-term source to the aquifer.
- Provides direct measurement of potential uranium release.

Disadvantages include:

- Needs to be paired with existing and future geochemical conditions (oxidizing or reducing, high or low pH) to fully determine contaminant release rates.

Technology Inter-Relationships: This approach dovetails with batch/column sorption studies.

Short list: Not to be included in the short list due to not addressing near term priorities of the southern portion of the plume. However, this recommendation could be useful to identify secondary sources in the vicinity of the former waste disposal areas and to support future CERCLA reviews.

Data Gaps: Will depend on the data gaps identified in the Targeted Mining Data Tasks. If currently available core samples are not adequate, a field effort will need to be planned to collect additional cores.

Next Steps:

Assess availability of sediment core samples (location, depth, age, sample mass) and identify if new core sediment samples are needed

- Develop and execute a detailed work plan defining the scope, schedule, and laboratory testing plan for the core characterization and sequential extraction
  - In-house vs. contract lab vs. university?
- Incorporate sediment data into geochemical models

Implementation Details:

- Year-1/ Year-2 - Work plans: 2 LMS FTEs and 0.5 NLN FTEs (LMS time includes review by environmental compliance, safety and health, etc.). Significant effort, not to be overlooked.
- Year-2/ Year-3 - Field work: 5 LMS FTEs (LMS time includes safety and health presence)
- Year-3 Lab work: 3 LMS FTEs and 1 NLN FTE (could be quite variable depending on number of)
- Year-3/ Year-4 - Reporting: 3 LMS FTEs and 1 NLN FTE

References:

Bryan, C.R., Du Frane, S.A., Moir, D., Schloesslin, C., and Davis, K.M. *Selective Sequential Extraction Analysis in Great Miami Aquifer Sediment Samples, Fernald DOE site, Ohio*, Prepared for U.S. DOE, Submitted by Sandia National Laboratories, April 2003.

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Technology/Strategy: Batch/Column Sorption Studies

Summary Information

Objective and Potential for Risk Reduction: The goal of batch and/or column sorption studies of soil core samples at Fernald is to interrogate the nature, extent, and leachability of sorbed uranium as secondary contaminant sources. Batch/column sorption studies will focus on reducing uncertainties associated with the potential for and rate of mass flux of uranium into the plume from solid-phase sources along with projected future plume behaviors and, therefore, would address human health, regulatory, and stakeholder risks.

Focus Area(s): Focus Area 2

Description: The Leaching Environmental Assessment Framework (LEAF) developed for the U.S. EPA consists of four leaching methods designed to work individually or together to assess the release of inorganic constituents of potential concern for a wide range of solid materials. The LEAF Methods consider the effect of key environmental conditions (pH, L/S ratio, time) and waste properties on leaching. The LEAF How-To Guide (U.S. EPA 2019) describes how the LEAF method results can be used to develop screening level assessments of constituent release or to develop more accurate estimates of release in specific use or disposal scenarios. The LEAF Methods (U.S. EPA 2020) are described below:

- Method 1313 – Liquid-Solid Partitioning as a Function of Extract pH Using a Parallel Batch Extraction Procedure –evaluates the partitioning of constituents between liquid and solid phases at or near equilibrium conditions over a range of pH values.
- Method 1314 – Liquid-Solid Partitioning as a Function of Liquid-Solid Ratio for Constituents in Solid Materials Using an Up-Flow Percolation Column Procedure – evaluates constituent release from solid materials as a function of cumulative liquid-to-solid ratio.
- Method 1315 – Mass Transfer Rates of Constituents in Monolithic or Compacted Granular Materials Using a Semi-Dynamic Tank Leaching Procedure – determines the rate of mass transport from either monolithic or compacted granular materials as a function of time using deionized water. Leaching of a sample occurs in a bath with periodic renewal of the leaching solution at specified cumulative leaching times.
- Method 1316 – Liquid-Solid Partitioning as a Function of Liquid-Solid Ratio Using a Parallel Batch Extraction Procedure – is an equilibrium-based leaching test consisting of five parallel batch extractions of a particle-size-reduced solid material in reagent water over a range of liquid-to-solid ratios.

One or more of these methods could be used as is or adapted to address specific questions related to Fernald. For example, a leaching solution of “synthetic groundwater” or actual groundwater could be used in addition to or in place of deionized water.

Graphic:

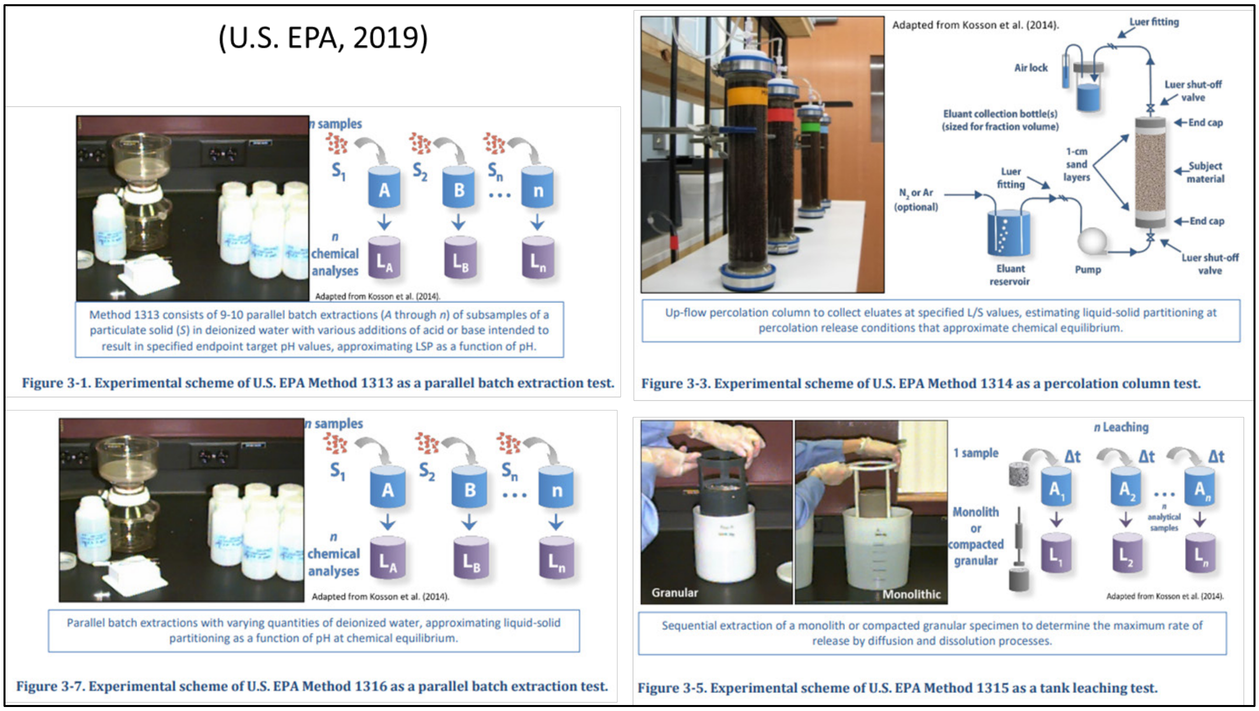

Figure 3-1. Experimental scheme of U.S. EPA Method 1313 as a parallel batch extraction test.

Figure 3-3. Experimental scheme of U.S. EPA Method 1314 as a percolation column test.

Figure 3-7. Experimental scheme of U.S. EPA Method 1316 as a parallel batch extraction test.

Figure 3-5. Experimental scheme of U.S. EPA Method 1315 as a tank leaching test.

Development Status: The LEAF testing protocols are standard EPA methods with detailed written procedures that are available in commercial laboratories.

Fernald Site-Specific Advantages/Disadvantages:

Advantages include:

- Generates actionable data using existing or new soil core samples.
- Suite of test methods considers both equilibrium and rate processes.
- Standard test methods with established written procedures that can be deployed as is or modified to suit specific hypotheses being tested.
- Available from commercial labs or can be performed in house.

Disadvantages include:

- Would not preserve native redox state.
- Potentially expensive if a large number of core samples are to be analyzed.

Technology Inter-Relationships: n/a

Short list: Not to be included in the short list due to not addressing near term priorities of the southern portion of the plume. However, this recommendation could be useful to identify secondary sources in the vicinity of the former waste disposal areas and to support future CERCLA reviews.

Data Gaps: Will depend on the data gaps identified in the Targeted Mining Data Tasks. Characterization and sequential extraction of core material would be done first to identify column/batch experiment needs.

Next Steps:

- Assess availability of sediment core samples (location, depth, age, sample mass), recognizing that if the redox state has not been preserved, then it could potentially impact speciation and mobility. If preserving the native redox state is deemed important, then consider collecting new core samples.
  - If new sediment samples are needed, it would make sense to collect a sediment core as part of an integrated Groundwater Depth-Profile Sampling. This would provide colocated groundwater data at multiple depths
- Develop and execute a detailed work plan defining the scope, schedule, and laboratory testing plan for the batch and column studies
  - In-house vs. contract lab vs. university?
  - Identify which LEAF methods or equivalents are most relevant for Fernald samples (batch, column, or both)
  - Identify the number of sediment samples to be analyzed for each LEAF method
- Incorporate sediment data into geochemical models.

Implementation Details:

- Year-1 – "Assess suitability of existing sediment core samples" – 0.5 per-month each LM and NL
- Year-1 / Year-2 – "Develop detailed work plan for LEAF testing" – 2.0 per-month LM; 1.0 per-month NL
- Year-2 – "Conduct LEAF tests or equivalent batch/column sorption studies on <u>existing</u> sediment samples" - 6.0 per-month LM; 3.0 per-month NL (in-house) or 2.0 per-month LM; 1.0 per-month NL (commercial lab or university)
- Year-2/ Year-3 – "<u>If necessary</u>, develop and execute sediment coring plan" – 2.0 per-month LM; 1.0 per-month NL
- Year-3 – "Conduct LEAF tests or equivalent batch/column sorption studies on <u>new</u> sediment samples" - 6.0 per-month LM; 3.0 per-month NL (in-house) or 2.0 per-month LM; 1.0 per-month NL (commercial lab or university)
- Year-3 – "Finalize geochemical model and generate results" – 3.0 per-month LM; 1.0 per-month NL

<u>Additional Costs:</u> Batch/column studies on sediment samples. Assume [redacted]/batch sample × 6 wells × 5 sediment samples per well = [redacted]) + ([redacted]/column sample × 6 wells × 2 sediment samples per well = [redacted]) = [redacted].

References:

U.S. EPA, 2019. Leaching Environmental Assessment Framework (LEAF) How-To Guide: Understanding the LEAF Approach and How and When to Use It. SW-846 Update VII, Revision 1. U.S. EPA Office of Land and Emergency Management and Office of Research and Development. May 2019. https://www.epa.gov/sites/production/files/2019-05/documents/final_leaching_environmental_assessment_framework_leaf_how-to_guide.pdf

U.S. EPA, 2020. Leaching Environmental Assessment Framework (LEAF) Methods and Guidance. Hazardous Waste Test Methods / SW-846. Accessed on December 7, 2020 from https://www.epa.gov/hw-sw846/leaching-environmental-assessment-framework-leaf-methods-and-guidance

Technology/Strategy: Redox Disequilibrium and Mixing Curves

Summary Information

Objective and Potential for Risk Reduction: Evaluate redox disequilibrium and groundwater (GW) mixing curves as approaches to help identify the sources and fate of uranium in the aquifer at Fernald and identify whether fluctuations in uranium concentrations are caused by pH/ORP disturbances in the local chemical steady state. The information will provide an additional line of evidence. The technology will reduce uncertainties associated with fluctuations in uranium concentrations as well as the interpretations of test results from other technology studies performed in the same boreholes. This technology addresses human health, regulatory, and stakeholder risks.

Focus Area(s): Focus Area 2

Description: *Redox Disequilibrium*. Calculate the state of redox disequilibrium at and upgradient of wells to identify whether the system is transitioning between dominant redox couples (e.g., Fe^{3+}/Fe^{2+}, SO_4^{2-}/S^{2-}, NO_3^-/NO_2^-, NO_3^-/NH_4^+, O_2/H_2O). The calculations can help to identify whether the system is at steady state or in flux. At GW temperatures, many redox reactions will not reach equilibrium due to kinetic constraints. Lindberg and Runnells (1984) compiled more than 600 analyses of 30 GW streams that included a minimum of two measures of oxidation state and calculated redox couple species distributions for each sample (see Figure 1). Next, they calculated E_h/pE values for the different redox couples using the Nernst equation. Figure 1 confirms that redox couples in a sample are generally in a state of disequilibrium with each other. GWB (Geochemist's Workbench) Online Academy (2020) describes how redox disequilibrium can be accounted for in geochemical models, such as The Geochemist's Workbench® (Bethke et al. 2020), by disabling one or more redox coupling reactions. All coupled redox reactions reflect the Master E_h for the system, while disabled redox couples behave independently based on their Nernstian E_h (see Figure 2). Identifying whether there is a redox transition, and which redox couples are controlling the transition, can help to identify controls on U geochemistry: local chemical changes and U release due to an influx of new fluids from other regions, or new transport of U to the well zone. Coupling the redox disequilibrium analysis with the mixing curve calculations below will assist in identifying processes controlling U geochemistry.

Mixing Curves. In this technique, one plots expected mixing ratios for different chemical species from the source area to different monitoring wells to identify whether the elevated concentrations are a system-wide or well-specific event. New wells may be required if data coverage is not sufficient. Gardiner et al. (2020) coupled $^{234}U/^{238}U$ data with $^{87}Sr/^{86}Sr$ data (Figure 3) to identify uranium sources for Chimayo, NM GWs and to improve upon Chimayo GW mixing models. The $^{234}U/^{238}U$ ratio can be employed to trace (1) hydrologic mixing processes because of its considerable variation in GWs and (2) the variability in uranium concentration in natural systems. While geologic materials have a uranium AR ($^{234}U/^{238}U_{meas}$ / $^{234}U/^{238}U_{equil}$) close to 1.0, weathering, redox conditions, and alpha-recoil effects can disrupt the decay chain during interaction of water with rock, and ground and surface waters commonly have AR > 1.0 (Figure 3). For example, the high uranium concentration and high $^{234}U/^{238}U$ of GW sample CHM-5 is likely derived from a deep GW with a long residence time (Figure 3). Combining the mixing models with redox disequilibrium calculations, Gardiner et al. (2020) determined that GW sample CHM-2 is under more oxidizing conditions than GW sample CHM-3. Oxidizing conditions facilitate the release of uranium from the solid phase (Figure 4, CHM-2 vs. CHM-3), effectively diluting ^{234}U and lowering $^{234}U/^{238}U$ ARs closer to 1.0, as observed for CHM-2 in Figure 3.

Graphic:

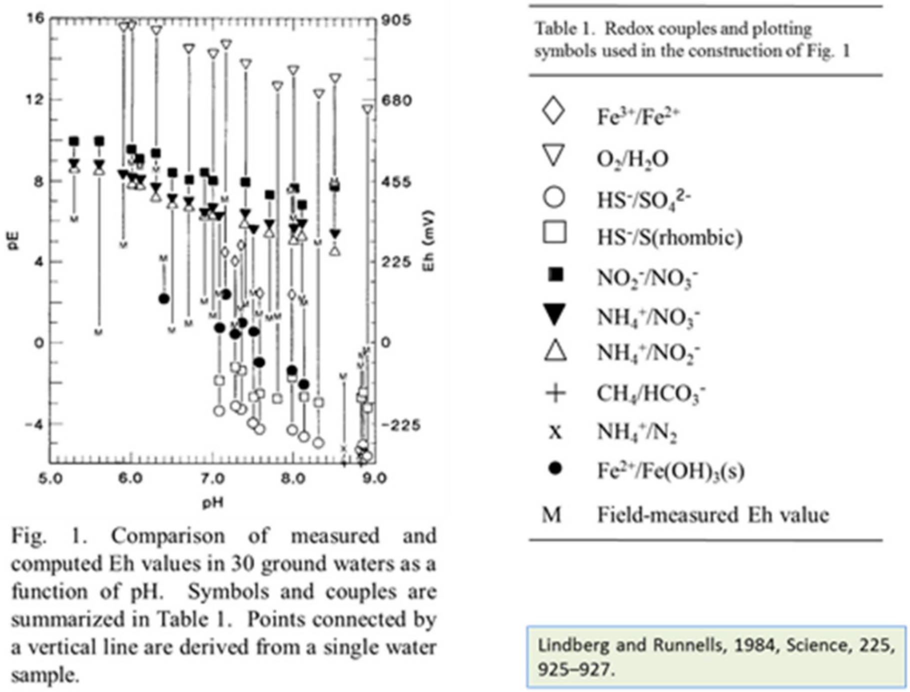

Figure 1. Comparison of Measured vs. Computed Eh values in 30 Groundwaters as a Function of pH (Lindberg and Runnells 1984).

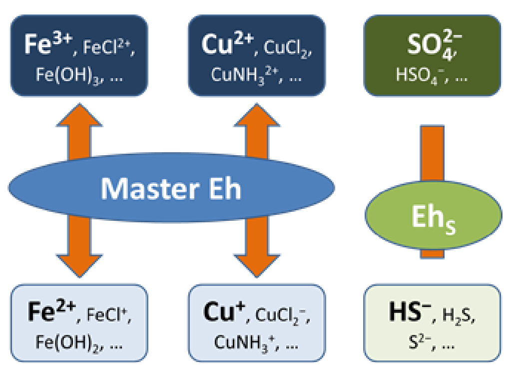

Figure 2. Schematic showing Coupled and Uncoupled Redox Reactions in a Geochemical Model (GWB Online Academy 2020).

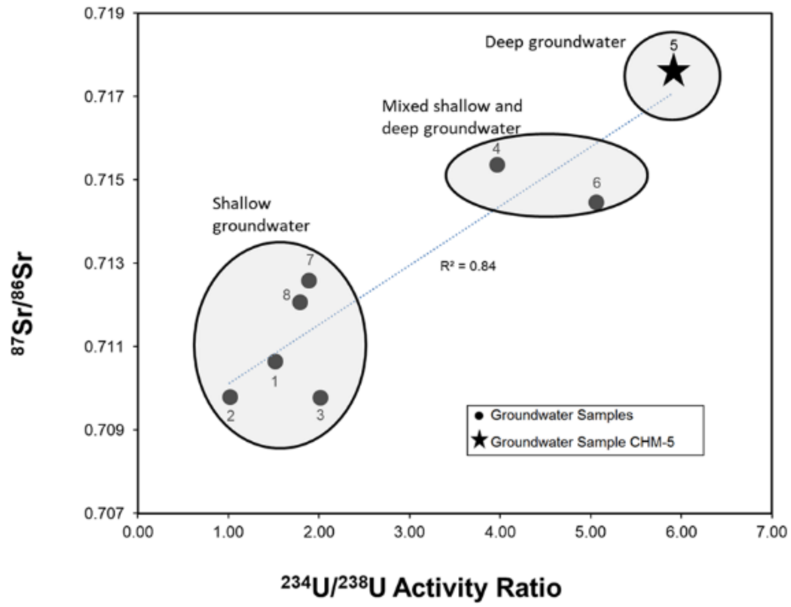

Figure 3. Chimayo, New Mexico groundwaters are plotted using $^{87}Sr/^{86}Sr$ and $^{234}U/^{238}U$ activity ratio data. $^{234}U/^{238}U$ indicates the artesian well (CHM-5) is a deep groundwater sample and supports proposed $\delta^{13}C$ and $^{87}Sr/^{86}Sr$ mixing models that display this deep groundwater (CHM-5) mixing to various extents with shallower groundwater samples [label numbers in figure correspond to groundwater samples CHM-1 through CHM-8] (Gardiner et al. 2020).

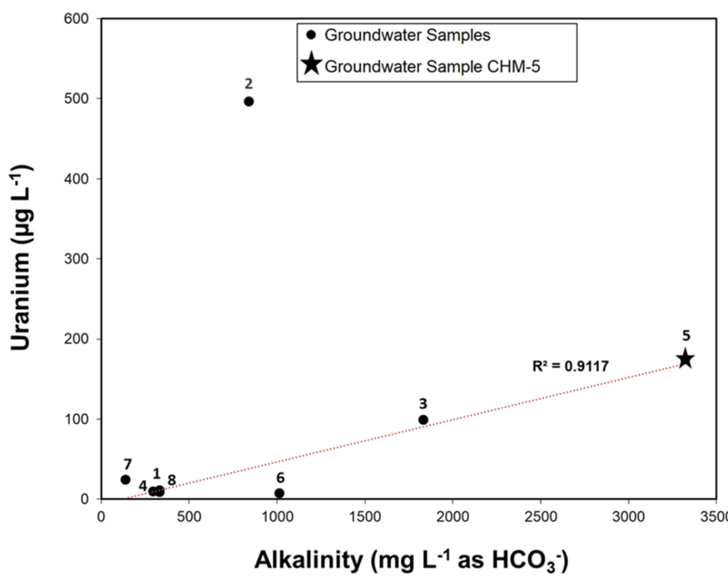

Figure 4. Soluble uranium vs. alkalinity in Chimayo, NM groundwaters [label numbers in figure correspond to groundwater samples CHM-1 through CHM-8] (Gardiner et al., 2020).

Development Status: The analysis approach is well developed. Existing chemical and isotope data may be reevaluated to identify any new insights. If new GW data must be collected, then a more focused effort would be required.

Fernald Site-Specific Advantages/Disadvantages:

Advantages include:

- Provides actionable interpretations using existing data.
- Simple and relatively inexpensive to implement and interpret.
- Provides opportunity to confirm changes in the general nature of uranium sources to GW near and upgradient of wells using inexpensive cation/anion sample analyses (for newly collected GW samples) and geochemical calculations.

Disadvantages include:

- Additional well samples and analytes would require time/financial investment.

Technology Inter-Relationships: Results of analysis will be stronger if coupled with data mining.

Short list: Not to be included in the short list due to not addressing near term priorities of the southern portion of the plume. However, this recommendation could be useful to identify fluctuations in uranium concentration as well as secondary sources in the vicinity of the former waste disposal areas and to support future CERCLA reviews.

Data Gaps: The implementation of this recommendation will depend on the data gaps identified in the Targeted Mining Data Tasks. If currently available groundwater characterization data is adequate, then don't implement this recommendation.

Next Steps: Existing data from monitoring wells will be evaluated to gauge the current chemical information useful for performing the redox disequilibrium and mixing curve calculations.

- If enough data are available to perform calculations, results from initial calculations will reveal which data gaps may require field sampling or may inform how to perform targeted field sampling as part of regular monitoring of the site.
- If current data is inadequate, further data collection will be added to future, planned field efforts.

Implementation Details:

- Year-1 "Assess applicability of existing data and evaluation of redox disequilibrium and mixing curves" – 0.5 per-month each LM and NL
- Year-1/Year-2 "If current data is inadequate, field effort planning and implementation to collect more data." This can be combined with other field effort planning.

References:

Bethke, C.M. (2008) *Geochemical and Biogeochemical Reaction Modeling*, Cambridge University Press, New York.

Bethke, C.M., Farrell, B., and Yeakel, S., 2020. *The Geochemist's Workbench®, Release 14: GWB Essentials Guide*, Aqueous Solutions LLC, Champaign, IL.

Gardiner, J.B., Capo, R.C., Newell, D.L., Stewart, B.W., Phan, T.T., Keating, E.H., Guthrie, G.D., and Hakala, J.A., 2020. “Tracking natural CO_2 migration through a sandstone aquifer using Sr, U and C isotopes: Chimayó, New Mexico, USA” *International Journal of Greenhouse Gas Control*, 104, 103209, https://doi.org/10.1016/j.ijggc.2020.103209.

Lindberg, R. D., and Runnels, D. D., 1984. “Groundwater Redox Reactions: An Analysis of Equilibrium State Applied to Eh Measurements and Geochemical Modeling,” *Science* 225: 925–927.

Phan, T. T., Hakala, J. A., and Sharma S., 2020. “Application of isotopic and geochemical signals in unconventional oil and gas reservoir produced waters toward characterizing in situ geochemical fluid-shale reactions,” *Sci. Total Environ,* 714, 136867, “https://doi.org/10.1016/j.scitotenv.2020.136867.

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Technology/Strategy: Spectral Gamma Borehole Logging

Summary Information

Objective and Potential for Risk Reduction: The spectral gamma borehole logging proposed would focus on new or existing boreholes. The goal would be to generate additional supporting information (i.e., are the ratios/signatures of U-Th-K different in key zones) to reduce uncertainties associated with the source(s) of uranium as well as the interpretation of results from other characterization studies performed in the same boreholes. This technology addresses human health, regulatory, and stakeholder risks.

Focus Area(s): Focus Area 2.

Description: Spectral gamma borehole geophysical methods measure the natural gamma energy spectra caused by the decay of uranium, thorium, potassium-40, and anthropogenic radioactive isotopes (USGS 2020). Each isotope has a unique spectral signature that enables its presence to be identified during post-processing of the logging data. While regular natural gamma tools provide a total count of natural gamma emissions from these isotopes, the spectral gamma tool measures the energy of the gamma emissions and counts the number of gamma emissions associated with each energy level. For this reason, spectral gamma logging permits not only identification but also quantitative analysis of the radioisotopes that contribute to the gross count rate that is recorded on a regular gamma log (Keys 1990). The gamma spectral method has a high vertical resolution and can be used in boreholes that are air-, water-, and mud-filled as well as plastic- and steel-cased (USGS 2020).

Data can be collected at a fixed depth in the borehole or by logging at very slow speeds. The logging time or speed depends on the rate of gamma emissions, where a low emission rate requires a longer logging time or a slower logging speed (USGS 2020). Data collected at a single depth are typically presented in a plot displaying the counts of emissions for each channel in the spectrum (Figure 1). Data collected while moving the tool in the borehole are generally shown as the total count of emissions falling within the energy windows for potassium, uranium, and thorium (Figure 2, left side).

Figure 2 (right side) displays a spectral gamma borehole logging tool sold by Mount Sopris Instruments (QL40-SGR-2G - Spectral Gamma - Mount Sopris Instruments) that is designed as part of a modular platform and can be outfitted with either a BGO (Bismuth Germanium Oxide) or CeBr3 (Cerium Bromide) scintillation crystal.

In some studies, isotope data have been analyzed to determine the dominant clay mineral types present in the alluvial aquifer (Klaja and Dudek 2016). For example, Figure 3 shows how spectral gamma borehole logging data for Th and K can be used to infer the dominant clay mineral types in a particular borehole location.

Graphic:

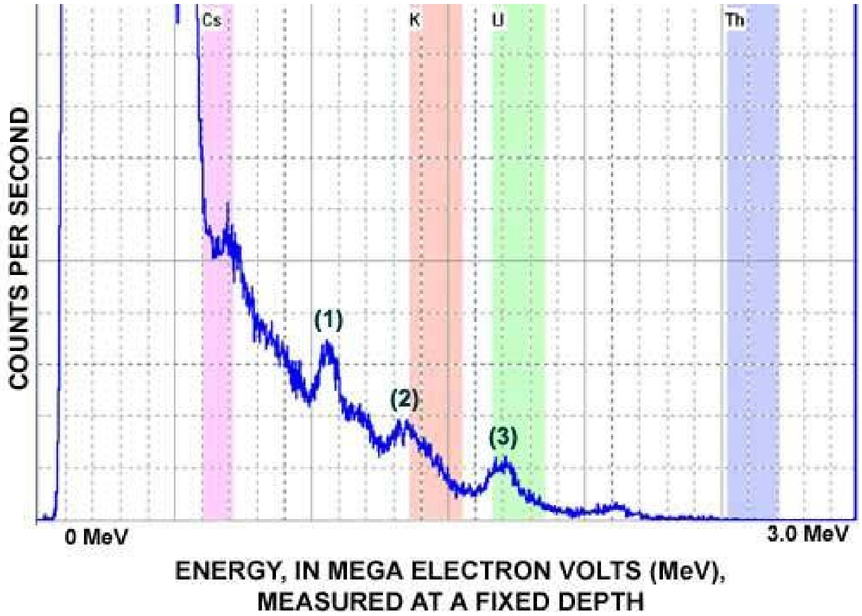

Figure 1. Example Gamma Energy Spectrum for Sample at a Fixed Depth highlighting the Energy Windows for Cs, K, U, and Th (USGS 2020). [The peak between the Cs and K windows (1) corresponds with Bi, a decay product of U and Th. The energy ranges from 0.1 MeV to 3.0 MeV and is divided into 1024 channels.]

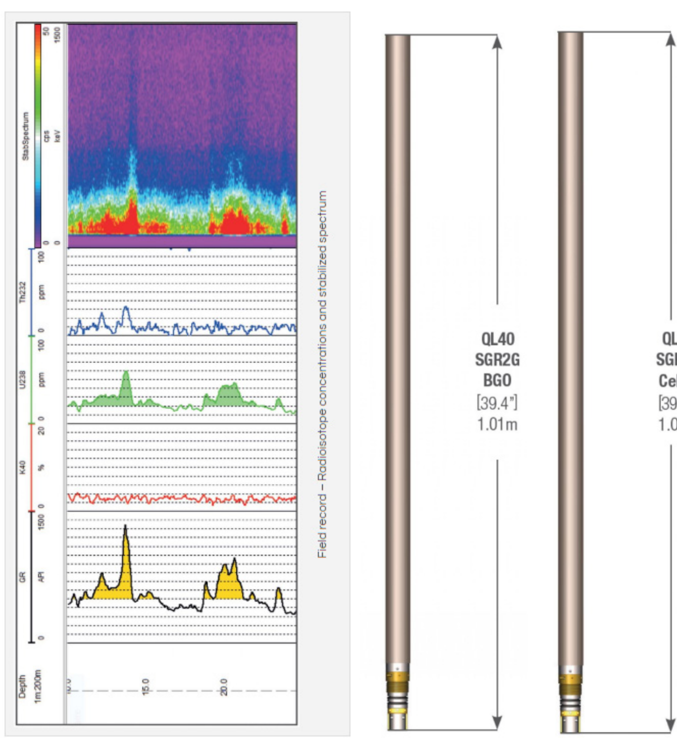

Figure 2. Example Field Record for Moving Spectral Gamma Log (left). QL40-SGR-2G Spectral Gamma Borehole Logging Tool (right) by Mount Sopris Instruments, Denver, CO (QL40-SGR-2G - Spectral Gamma - Mount Sopris Instruments).

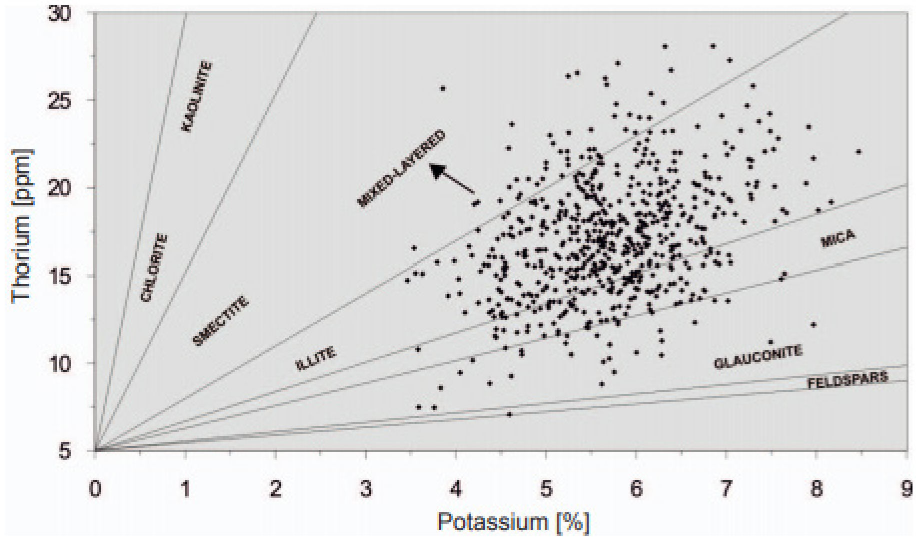

Figure 3. Example of using Spectral Gamma Borehole Logging Data to infer the Dominant Clay Mineral Types (Klaja and Dudek 2016).

Development Status: Spectral gamma logging is a proven and widely used geophysical method that can differentiate between shales and potassium salts, recognize and estimate percentages of mineral types in bedrock surrounding a borehole, compute shale percentages, determine clay mineral types, identify clay depositional environments (detrital: high thorium/low uranium ratios; marine: low thorium/high uranium ratios), study water-rock interactions, and map clay content (USGS 2020).

Fernald Site-Specific Advantages/Disadvantages:

Advantages include:

- Provides actionable data using new or existing boreholes.
- Downhole probes are often stackable, meaning that the spectral gamma probe can be stacked together with electrical resistivity and fluid temperature/conductivity probes, for example.
- Commercial geophysical method.

Disadvantages include:

- Provides point data (i.e., spatial information is representative only of area immediately adjacent to well).
- New boreholes would require time/financial investment.

Technology Inter-Relationships: Results of spectral gamma logging will be more meaningful if performed together with one or more of the following studies: source zone characterization and sequential extraction studies of soil core samples, push-pull testing, and/or batch column sorption studies.

Short list: Not to be included in the short list due to not addressing near term priorities of the southern portion of the plume. However, this recommendation could be useful to identify secondary sources in the vicinity of the former waste disposal areas and to support future CERCLA reviews.

Data Gaps: The implementation of this recommendation will depend on the data gaps identified in the Targeted Mining Data Tasks for collection of additional information.

Next Steps:

- Identify existing candidate wells and/or desired locations of new boreholes
- Develop and execute a detailed work plan defining the scope, deployment strategy, and schedule for existing/new wells. The testing can be sequentially deployed to multiple wells once the equipment and crew have been assembled.
- Consider phased approach targeting existing wells in Year-1/Year-2 and new boreholes in Year-2/Year-3.

Implementation Details:

- Year-1 – "Identify existing candidate wells and/or desired locations of new boreholes" 0.5 per-month each LM and NL.
- Year-1/Year-2 – "Develop a detailed work plan" – 1.0 per-month LM; 0.5 per-month NL.
- Year-2 – "Deployment of spectral gamma logging test on existing wells" – 1.0 per-month LM; 0.5 per-month NL.
- Year-3 – "Deployment of spectral gamma logging test on new wells" - 1.0 per-month LM; 0.5 per-month NL.

References:

Keys, W. Scott, 1990. Borehole Geophysics Applied to Ground-Water Investigations. In *Techniques of Water-Resources Investigations of the United States Geological Survey*, Book 2 (Collection of Environmental Data), Chapter E-2. United States Geological Survey, Reston, VA. Accessed December 29, 2020 from TWRI 2-E2 - Part 5 (usgs.gov).

Klaja, J., and Dudek, L., 2016. Geological Interpretation of Spectral Gamma Ray (SGR) Logging in Selected Boreholes. *Nafta-Gaz*, 72(1): 3-14, accessed December 29, 2020, from NAFTA_2016_1.indd (researchgate.net).

USGS, 2020. Spectral Gamma Borehole Logging, accessed December 29, 2020, from Spectral Gamma Borehole Logging (usgs.gov).

Technology/Strategy: Push-Pull Testing

<u>Summary Information</u>

Objective and Potential for Risk Reduction: The goal of a push-pull test at Fernald would be to interrogate the subsurface to determine if there is a primary, sorbed, or mineralized source of uranium in the subsurface and to provide insight into the nature of the source. The technology would focus on reducing uncertainties associated with the timeframe of mass flux into the plume and projected future plume behaviors; it would address human health, regulatory and stakeholder risks.

Focus Area(s): Focus Area 2

Description: A push-pull test involves the injection ("push") of a prepared test solution into an aquifer, followed by a pause for reactions to occur ("shut-in"), and extraction ("pull") of the test solution/groundwater mixture from the same location (Figure 1). The test solution can be an extractant (water or specialized solution) or a reactive tracer such as a redox reagent, nutrient or other biogeochemical modifier. For Fernald, a push-pull test would interrogate the presence of different matrix contaminant phases using alternative extractants or lixiviants for the test solution. The push-pull test is essentially a sequential extraction performed in situ under field conditions using existing wells for access. The test could also be extended to test potential mobilization remedial strategies on a small (field) scale.

Graphic:

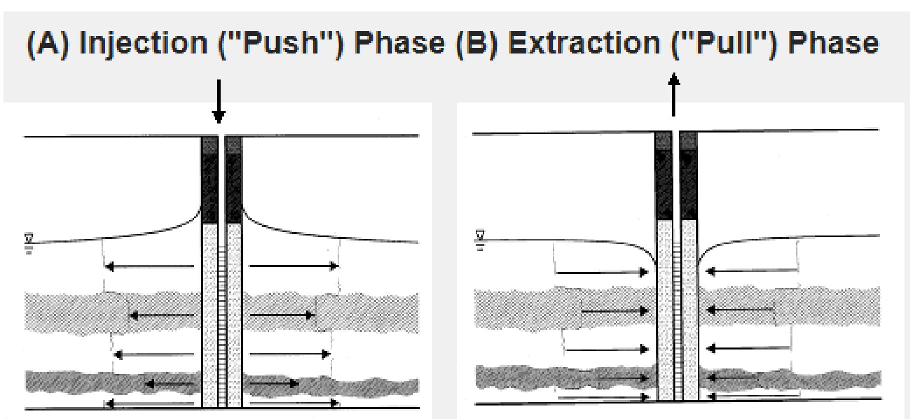

Figure 1. Push-Pull Testing Schematic
(*https://cce.oregonstate.edu/groundwater-research-push-pull-test*)

Development Status: Push-pull tests have been used in the oilfield for characterizing sites and planning for enhanced oil recovery operations and for full scale enhanced recovery. For environmental characterization, the technology has been deployed for characterizing the presence and character of contaminants, assessing geochemistry, quantifying contaminant reduction kinetics, and similar objectives. Much of the research has focused on organic contaminants. To date, research related to uranium has focused on potential for biological reduction and associated kinetics.

Fernald Site-Specific Advantages/Disadvantages:

Advantages include:

- Generates actionable data using existing wells. Could also be implemented with a multilevel sampler for depth profiling.
- Simple and relatively inexpensive to deploy and interpret.
- Provides data similar to sequential extraction under field conditions (eliminates collection and handling of core).
- Provides opportunity to rapidly confirm presence and general nature of residual contaminant sources in the near-field shallow groundwater without waiting for new coring (or if archived core is not available).

Disadvantages include:

- Provides point data (spatial information is only representative of area immediately adjacent to well)
- Influences by heterogeneity within well screen interval - potential for false negatives and does not provide vertical detail that is available in core
- Injection of test solutions may adversely impact validity of future water samples – this is a significant disadvantage at a site with limited well coverage and with high costs for well replacement

Technology Inter-Relationships: Potential alternative to coring and sequential extraction. Could also couple with spectral gamma logging, geochemical modeling (redox couple disequilibrium, isotope mixing, chem. equil. models), and/or strategic coring.

Short list: No for the shortlist. The push pull test could be used in the groundwater plume on the onsite area as an alternative to core/column studies to obtain Kd values. The limitations would be that only groundwater could be used as an injection fluid to avoid regulatory issues. The push pull test is not to be used in the vicinity of source zones.

References:

DOE push-pull test using extractant to assess presence of DNAPL - Field test of single well DNAPL characterization using alcohol injection/extraction – available from DOE OSTI: https://www.osti.gov/biblio/468515-field-test-single-well-dnapl-characterization-using-alcohol-injection-extraction.

Oregon State – archive containing numerous environmental push-pull test case studies and journal articles: http://web.engr.oregonstate.edu/~istokj/grl/grl-manuscripts.htm.

Technology/Strategy: In Situ Flushing

Summary Information

Objective and Potential for Risk Reduction: There are three locations within the Fernald Preserve that are still undergoing remediation: 1. The South Plume (a plume of about 20 acres by 2020), 2. The South Field (a plume of about 52 acres by 2020), and 3. The Waste Storage Area (a plume of about 8.5 acres by 2020). The overall objective for the Fernald Preserve is to complete remediation and move into the monitoring phase. Remediation will be complete when the groundwater in each of the three areas has reached a concentration below the limit specified in the OU5 ROD. For uranium this concentration limit is 30 µg/L.

Of particular concern is the area of the South Plume which resides underneath land south of DOE property (privately owned property). Much progress has been made in reducing the area of the South Plume using a pump and treat technology with six extraction wells.

In the last 10 years, the South Plume Area has decreased by approximately 30 acres. The volume of water extracted from the plume (the sum of water extracted using these six wells) has remained fairly steady over this time period with a high value in 2016 of approximately 670 million gallons of aquifer water extracted that year (see Figure 1). The low value occurred in 2013 and again in 2019 with approximately 563 million gallons pumped in 2013 and 567 million gallons pumped in 2019. In contrast, the uranium removal index has shown a significant reduction in 2016, 2017, 2018, and 2019 when compared to the previous years.

A conclusion one can draw from this analysis is that increasing the volume of water extracted each year from the South Plume will not accelerate reduction in the size of the plume because cleaner water is being pulled into the extraction wells as the area of the plume shrinks. Another conclusion that can be drawn is that there are no recalcitrant pockets of uranium in the South Plume. It appears that all of the uranium is in a mobile form and is being removed as the aquifer water is extracted.

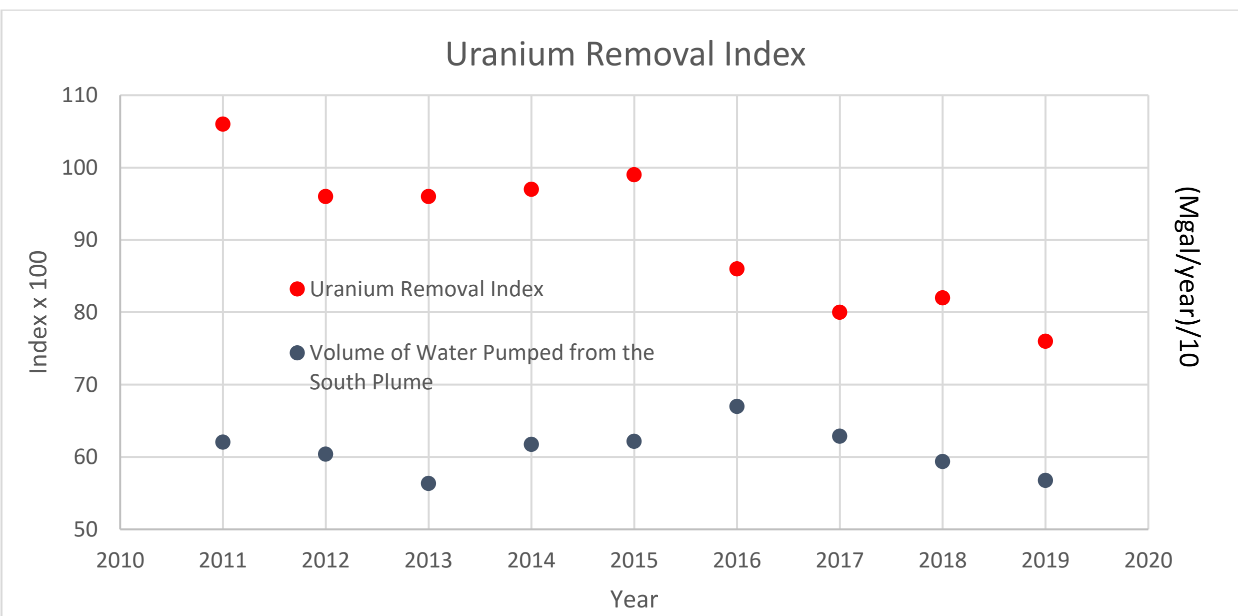

Figure 1. Performance Indicators for the Six Extraction Wells Targeting the South Plume (Well 3924, 3925, 3926, 3927, 32308, 32309).

Focus Area(s): Focus Area 2

Description: In situ flushing is a contaminant removal method that uses a reagent applied directly to the contaminated zone. The reagent is generally injected into the contaminated zone, allowed to react with the existing water and soils, and then withdrawn bringing the contaminants with it. In situ flushing works well when the contaminant of concern (CoC) is more soluble in the reagent solution than it is in the unaltered water/soil system. The outcome of flushing is removing contaminants that have not been removed with a pump and treat remediation technology. In particular, removal of [sediment-associated inventories of adsorbed metals (U, V, Mo) and metalloids (Se, As) through desorption and complexation reactions (U) and ion exchange (V, Mo, Se, As)] is achievable. Oxidants, such as nitrate added at levels below the EPA MCL, are used to promote oxidation of reduced, immobilized forms of contaminant metals especially uranium to soluble forms that can be removed from the system. Two approaches may be combined (e.g. using both a complexation agent plus an oxidant in the reagent solution).

Development Status: In situ flushing is a mature technology that uses standard reagents and infrastructure. Implementation at Fernald would not require a large development effort but would require geochemical analyses to determine the optimum reagent to use for uranium at the site.

Fernald Site-Specific Advantages/Disadvantages:

Advantages include:

In general, in situ flushing has the potential for effective and rapid (accelerated) removal of contaminants. Injection of oxidants at concentrations below drinking water standards has been demonstrated to oxidize and solubilize refractory mineralized contaminant phases. It is a technology that is amenable to unconsolidated alluvial systems with moderate to high permeability and homogeneous systems or well understood systems with only moderate heterogeneity. Treatment of fully saturated conditions is readily tractable with vadose zone applications presumed likely.

Disadvantages include:

In general, in situ flushing must be performed at or very near the contaminant source or its recharge location. Enhanced desorption and/or oxidation and solubilization occurring at more distal locations is effective for short periods of time but re-equilibration can occur rapidly following cessation of active remediation. It is not a technology that lends itself to contaminant source terms in low permeability sediments, or high heterogeneity and/or fractured bedrock systems dominated by crystalline materials.

For the three remaining plumes of uranium at the Fernald Preserve, implementation of in situ flushing would best be used to target recalcitrant pockets of the metal that are believed to be located under the former waste storage area. Application in the South Field and/or the South Plume is believed to be less promising for the following reasons: 1. Injection of an oxidant (even at concentration below the drinking water standard) into the South Plume would be an instant regulatory issue because the land above the plume is not part of the Preserve, 2. The contamination in the South Plume appears to be uniformly spread, without any particular “hot spots” that could be targeted. Thus, implementation of in situ flushing in the South Plume would be a large scale project that would likely to involve new injections wells and millions of gallons of oxidant pumped into the plume, 3. Because of the natural flow of water under the South Plume, a new set of extraction wells would likely be needed to pull the oxidant (against the natural water flow) towards the Preserve for extraction, 4. Progress in reducing the area of the South Plume has been good. It is likely that small improvements in the current pump and treat strategy will result in the desired goal of eliminating the South Plume altogether.

Technology Inter-Relationships: As previously mentioned, in situ flushing is likely not a preferred remediation strategy for the South Plume or the South Field at the Fernald Preserve. The existing pump and treat strategy will accomplish the final goal of completing remediation with less substantial changes in the technology to increase the speed of uranium recovery.

Application of in situ flushing to the plume under the former waste storage area is an option to consider in conjunction with the current pump and treat technology. The closest potential injection well is 2046 which may not be close enough to the extraction wells in that plume to make a difference. New injection wells may be required, but existing extraction wells are likely to prove viable for extraction of the newly-oxidized aquifer water.

Short list: No based on the high priority given for remediation of the South Plume. However, in the longer term, if enhanced remediation of the plume under the former waste storage area becomes a higher priority, the use of in situ flushing should be reconsidered.

Data Gaps:

Before proceeding with in situ flushing at the Fernald Preserve, information is needed about the location of potentially recalcitrant pockets of uranium under the former waste storage area. Ideally one would like to understand how many locations are involved, how the locations fall in line with one another and where they lie on the overall water flow path.

References: n/a

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Technology/Strategy: Permeable Reactive Barrier

<u>Summary Information</u>

Objective and Potential for Risk Reduction: The goal of implementation would be to use a permeable active barrier (PRB)- approach to treat portions of the impacted aquifer being treated with pump and treat technologies.

PRB technology has been used to treat both organic and inorganic contaminants. A permeable "wall" or barrier containing active treatment medium to "treat" groundwater contaminant(s) is constructed perpendicular to groundwater flow path. The barrier can be installed using several placement approaches. Excavation techniques, injecting techniques are examples potentially applicable at the site. Typically, the technology is passive, in that the design relies on natural hydraulic gradients to carry groundwater through the PRB, where the treatment occurs. The thickness of the PRB must be sufficient so that groundwater passes through with adequate residence time for treatment or removal of the contaminants (EPA 2002). The fundamental point is that the PRB must be able to intercept the plume and treat or immobilize contaminants in the plume without contamination going around or under the barrier.

Construction methods used to install PRBs include conventional excavation, continuous trenching, slurry wall techniques; deep soil mixing; caissons, horizontal or large-diameter boring; hydraulic fracturing; and injection. The depth limit for installation is basically the depth limit for excavation and trenching techniques or the depth limit for augers used to introduce reactive media through a hollow stem type system as the auger is withdrawn. Reportedly, a continuous trencher can reach depths of 45 feet (ft), but the ideal depth for a PRB is about 40 ft, (40 ft to the depth of contamination layer being treated (ITRC 2011). The caisson install approach can achieve depths of 60 ft. Caisson install is followed by excavation, then placement of the reactive media, then removal of the caisson. Reportedly, depths of 100 ft can be achieved with injection approaches (ITRC 2011).

By way of example, at the West Valley Demonstration Project Site, NY, the PRB used to prevent the off-site migration of strontium is 865ft long, 3ft wide and 19 to 30 ft deep (AMEC 2011). The install for the 100-NR-2 Operable Unit at Hanford is an injection approach, (DOE 2019). The apatite PRB is formed by injecting a calcium-citrate-phosphate solution into the aquifer through a network of vertical wells. Strontium-90 (and strontium) ions in groundwater substitute for calcium ions via cation exchange and eventually become trapped as part of the mineral matrix during apatite crystallization (Section 1.3 of PNNL-16891, Hanford 100-N Area Apatite Emplacement. The permeable barrier at the Hanford site is 760 meters long and is installed to a depth of 10–20 ft.

Where applicable, PRB technology is capable of reducing the toxicity, mobility, and volume of contaminants in groundwater. Since contaminant reduction takes place only within the PRB itself, this passive remedial approach would have no effect on groundwater contamination downgradient of any constructed PRB.

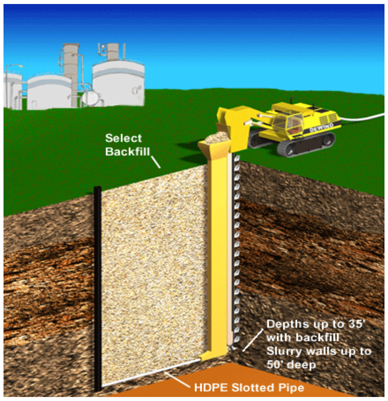

Figure 1. Representation of Excavation Approach for Installation

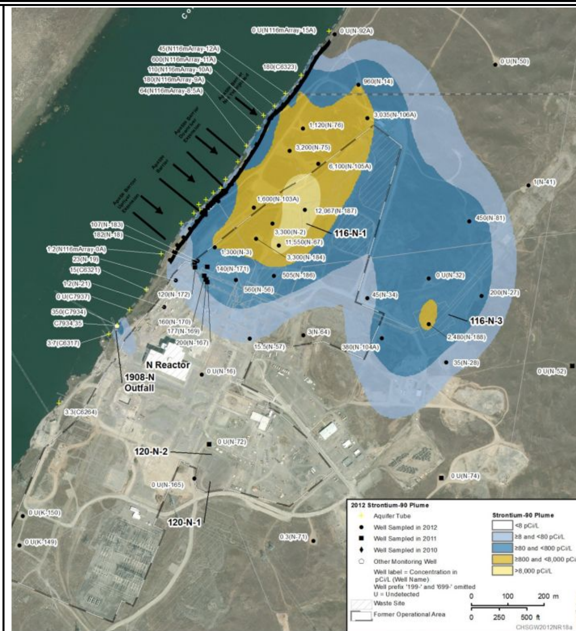

Figure 2. Apatite Permeable Reactive Barrier at Hanford Site

PRBs are being used to treat U in groundwater at two sites including Fry Canyon, Utah, and a system installed at the DOE Oak Ridge National Laboratory site. Mechanisms for the treatment of uranium (at least U (VI)) include reductive precipitation, sorption onto hydrous ferric oxide and co precipitation with iron oxides. The Fry Canyon demonstration site is designed with ZVI as the reactive matrix (ITRC 2011). Noteworthy is the fact that ZVI has been used as the reactive matrix in a number of PRB-like applications for the treatment of several types of compounds.

The development status of the technology is mixed with respect to the Fernald scenario. There are numerous instances where PRBs have been installed and operate successfully per the ITRC document (ITRC 2011). The number of instances in which ZVI has been used to treat uranium-contaminated groundwater is limited to two U.S. case studies. However, there are numerous examples of ZVI used as a treatment media for other contaminants. Typically, in either the excavation-install scenario, or the injection scenario, the PRB would be keyed into an impermeable or less permeable layer. The concept is that groundwater would migrate through the PRB and not under because of placement on the impermeable layer.

Fernald Site-Specific Advantages/Disadvantages:

Advantages include:

- Elimination or reduction of pumping, and associated utility, well rehab, operations costs with control on the off-site migration of uranium preserved.
- May have applicability on recalcitrant plume portions suited for risk reduction via institutional controls.

Disadvantages include:

- Depth to the base of contamination at Fernald may exceed ideal depth limits for the best install technology: excavation techniques. Excavation install would be limited by the practical limit of excavation.
- Cannot be implementable in the conventional configuration ("flooring' the PRB with an impermeable layer in the subsurface.) given the known CSM for Fernald.
- Implementability of the injection approach is not known. Uncertainties are achievability of injection depth, distribution of ZVI in the subsurface post injection, whether injection points would need to be "refreshed" and whether injection points would provide needed barrier to contaminant migration.
- Uranium would remain at the Fernald preserve immobilized in any PRB placed vs being discharged to off-site surface water.

Technology Inter-Relationships: Development of a 3 d representation of the subsurface may help identify impermeable layers that could be used to "floor" placement of PRB technologies. Groundwater modeling may help identify sections of the plume that can be directed into a PRB.

Short list: No for the shortlist.

References:

AMEC Geomatrix Inc., 2011. *Permeable Treatment Wall Post-Construction Baseline Monitoring Report*, March.

(DOE/RL-2010-29, Design Optimization Study for Apatite Permeable Reactive Barrier Extension for the 100-NR-2 Operable Unit).

EPA, 2002. *Evaluation of Permeable Reactive Barrier Performance*, prepared for the Federal Remediation Technologies Roundtable by the Tri-Agency Permeable Reactive Barrier Institute (U.S. Department of Defense, U.S. Department of Energy, U.S. Environmental protection Agency, and Interstate Technology and Regulatory Council), December 9 (http://www.epa.gov/tio/download/rtdf/2-prbperformance_web.pdf).

ITRC, 2011. Permeable Reactive Barrier: Technology Update. June.

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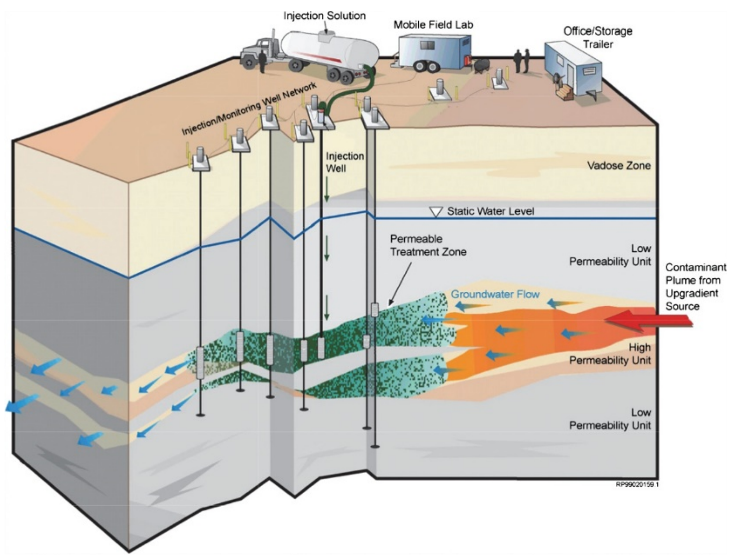
Technology/Strategy: In situ Immobilization Approaches to Limit Mobility, Solubility, and Toxicity of Uranium

Summary Information

Objective and Potential for Risk Reduction: The goal of this approach is to enhance the cleanup and mitigate the expansion of the on-site and off-property plume in the South Field of the Fernald Reserve. The evaluation of alternative remediation strategies can help in the determination of the most appropriate course of action for the ongoing aquifer restoration to potentially reduce the cleanup time and cost. Ideally, recommended approaches can be used in conjunction with the current pump and treat operations. However, some in situ immobilization approaches would require an implementation strategy separate from the current pump and treat operations. Below is a description of each of the in situ amendments that could potentially be applied to limit the mobility, solubility, and toxicity of U(VI).

Focus Area(s): Focus Area 2

Graphic:



Description: Chemical reductants (Zero valent iron, Sodium Dithionite ($Na_2S_2O_4$), Ferrous Sulfate ($FeSO_4$)…)

In this approach, the injection of a reducing agent (S(-II) or Fe(II)) can be used to create a permeable reactive barrier/zone that will alter the chemistry of the aquifer from oxic to reducing conditions to promote the reduction and sequestration of mobile U(VI). This would leave uranium immobilized in a small, contained subsurface area for long-term sequestration or soil removal.

Advantages include:

- Reduction/sequestration can be relatively rapid.
- Potential for recovery of U from soils after immobilization.
- Even upon reoxidation, formation of hydrous ferric oxide may enhance U(VI) sorption.
- Possible to combine with other technologies.
- Slow groundwater velocities eliminate kinetic controls on reaction effectiveness.

Disadvantages include:

- Potential for reoxidation upon introduction of oxic groundwater
- Introduction of reduced S species can introduce unwanted aqueous species (H_2S, SO_4^{2-})

Short list: Not to be included in the short list due to not addressing near term priorities of the southern portion of the plume. However, It can be considered as a potential remediation technology to address the plume in the vicinity of the former waste disposal areas.

Description: Bioremediation

In this approach, an organic carbon is introduced in the subsurface, along with inorganic reductants, oxidants, and/or micronutrients to stimulate enzymatic pathways of indigenous microbial communities to immobilize uranium as insoluble precipitate following enzymatic reduction. This approach would limit offsite transport, reduce source zone contributions, and reduce downgradient stakeholder risks through conversion of uranium to an insoluble form.

Advantages include:

- For uranium, reductive immobilization can lower groundwater concentrations rapidly and to low levels.
- Sub-oxic to anoxic aquifer redox conditions would favor the long-term stability of uranium immobilized as insoluble precipitates.

Disadvantages include:

- Uranium is not removed from the system being instead converted to insoluble mineral end-products that remain available for eventual re-release to the system.
- Biofouling can induce large decreases in injection well permeability leading to decreased efficiency with time.

Short list: Not to be included in the short list due to not addressing near term priorities of the southern portion of the plume. However, It can be considered as a potential remediation technology to address the plume in the vicinity of the former waste disposal areas.

Description: In situ apatite injection

This approach is used to intercept persistent contaminant plume or source zone areas with an injection well network by injecting calcium citrate, sodium phosphate and/or micronutrients to stimulate enzymatic pathways of indigenous microbial communities to precipitate hydroxyapatite. During the formation of hydroxyapatite, uranium can be incorporated into the mineral structure as well as it can be sorbed to its surface after precipitation. The implementation of this technology would limit offsite transport, reduce source zone contributions and regulatory risks by removing uranium from the groundwater through sorption and uptake into insoluble hydroxyapatite.

Advantages include:

- For uranium, immobilization in hydroxyapatite can lower groundwater concentrations rapidly and to low levels for regulatory significant periods of time.
- Potential for recovery of uranium from soils after immobilization.
- Under sub-oxic to anoxic aquifer redox conditions and moderate pH the hydroxyapatite is likely to remain stable.
- Can be applied at the surface to mitigate near surface contamination or at depths of up to several hundred feet through the use of an injection well network.
- Can be very effective and economical for remediating small to medium sized plumes and hot spots.

Disadvantages include:

- Uranium is not removed from the system but instead the uranium is sorbed and/or incorporated into insoluble hydroxyapatite and phosphate minerals that remain in place for the regulatory period and beyond. Hence regulator and/or stakeholder concerns could require the eventual removal of the barrier by excavation.
- Substantial changes to groundwater chemistry over time particularly pH reductions to 4 and below may increase hydroxyapatite solubility and the subsequent release of uranium.

Short list: Not to be included in the short list due to not addressing near term priorities of the southern portion of the plume. However, It can be considered as a potential remediation technology to address the plume in the vicinity of the former waste disposal areas.

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Technology/Strategy: Hydrologic and Boundary Conditions Controls

Summary Information

Actively managing the hydrologic boundary conditions on-near the Fernald site has the potential to accelerate contaminant mass removal and reduce overall remediation timeframe. In general, this concept would alter or control where water enters/recharges (or exits/discharges) the subsurface with the goal of contacting and leaching residual contaminant sources. In the simplest sense, this strategy uses recharge water as a lixiviant. If successful, this strategy would provide for a low-cost, simple and sustainable adjunct to improve the performance and robustness of the groundwater remediation. The LM-NLN triage of this process did not advance the concept to the short list for a variety of reasons, including: water is a poor leaching fluid for residual uranium sources, primary onsite benefit would be in former waste disposal area which is targeted as a future regulatory effort, groundwater remedy goals are set based on concentration targets and no firm timeframe is established, DOE LM has limited control on offsite boundary conditions such as pumping and gravel pit dewatering, and alternative leaching/flushing strategies may provide higher performance if timeframe acceleration is determined to be necessary in the future.

Focus Area(s): Focus Area 2, Tier 2/3 (requires field pilot and potential future modifications to site infrastructure)

Description:
This narrative focuses on beneficially altering the boundary conditions and water balance to aid in achieving DOE-LM remedial action objectives. For Fernald, the most likely implementation would be diverting infiltration to areas where it would move through areas of residual source contamination in the vadose zone and shallow groundwater – flushing the uranium toward extraction wells for removal. This is a straightforward concept that has already been considered, and is being held in reserve, by the LM Fernald team. In general, the technology would be implemented by recontouring and trenching to allow water to naturally flow to areas of desired infiltration. The diversion channels could be lined with commercially available polymer lining, however, this may not be needed at Fernald because of the fine-grained clayey material that underlies much of the site. The potential benefit of the technology would be to improve source mass removal by increasing mass flux to the remediation system, thus reducing remediation timeframe. This technology primarily addresses residual secondary sources in the central part of Fernald (near the former waste disposal operations); implementation would be less impactful to the near-term objective of controlling and mitigating the southern portions of the plume offsite and near the site boundary. Further, the strategy uses water as a flushing fluid, and would be less effective in removing uranium source mass compared to documented lixiviants. Based on the net assessment of advantages and disadvantages listed below, the LM-NL collaboration does not recommend advancing this concept to the short list at this time. However, the team recommends keeping this technology in mind in the future when the remediation focus shifts to the former waste disposal area – in particular, this concept could be combined with other flushing technology ideas by adding chemicals that would facilitate uranium mobilization. The team affirms the strategy of the LM Fernald team to hold this concept in reserve.

Graphic:
no graphic provided for this narrative

Development Status: Systems have been widely deployed for water diversion (TRL 8 to 10). In general, this is a simple system that would be straightforward to implement

Fernald Site-Specific Advantages/Disadvantages:

Advantages include:

- Simple passive system that could be incorporated into long term remediation plans

Disadvantages include:

- In general, does not address leading edge and southern portions of the plume that are near term LM and stakeholder priorities
- Limited ability to influence uranium mobility (water alone is a poor lixiviant for uranium)

Technology Inter-Relationships: This is an innovative remediation adjunct that should be considered in the future if a flushing paradigm for accelerating uranium removal from the vadose zone and shallow groundwater near the former waste disposal area is selected.

Short list: No – Does not focus on current DOE and stakeholder priorities.

Data Gaps: n/a

Example References: n/a

Next Steps: n/a

Implementation Details and Level of Effort: n/a

Technology/Strategy: Supplemental Modeling Insights using Analytical Solutions

Summary Information

Projections of the remedial progress, evaluation of alternative designs and operational paradigms, and estimation of remediation timeframe generally rely on modeling. There is potential benefit in deploying some of the available analytical solutions to provide insights and semiquantitative estimates of parameters to better support the more rigorous physics-based numerical models that provide the baseline support for the Fernald team. While a number of analytical solution models are available (e.g., REMChlor MD), the consensus of the LM-NL collaboration is that the baseline numerical modeling is well developed for Fernald and that the numerical model (particularly if it is ported to a more modern and nimble interface/platform for ease of use) is a preferred strategy at this site. Therefore, the LM-NL collaboration did not recommend advancing this to the short list.

Focus Area(s): Focus Area 2, Tier 1 (uses existing data)

Description:
A number of interesting and potentially valuable analytical solutions related to contaminant plume behavior and remedial design have been documented in the literature. Typically, each of these is built around a few key concepts or controlling features – for example REMChlor focuses on the source mass flux and how that key boundary condition changes over time (the source mass is released into an ensemble of flow paths to statistically represent dispersion). A variant of this model, REMChlor-MD, extends the model to include matrix diffusion to better model the leading edge (plume expansion) and trailing edge (plume cleanup) stages in the lifecycle of a plume. Remediation performance in these particular analytical models is calculated by simplistic removal of mass from different broad zones – so these do not provide specific insights for design or practical operation of a remediation system (well location, well geometry, pulse pumping, etc.). Analytical models are adept at providing semi-quantitative insights related to the key concepts/features that underpin the model – and this information can be useful in constructing and bounding physics-based numerical models. Importantly, the existing physics-based numerical model (currently in VAM-3D) is generally well documented and already developed for Fernald. The LM-NL consensus is to migrate the existing site numerical model to a more modern and nimble software platform over the next few years—providing for simpler updating with new characterization information, as well as to support front-end and back-end visualization (graphical user interfaces) and a wide range of statistical tools for assessing model performance/sensitivity and optimization of remedial designs. The consensus recommended action will result in improved confidence and communication with regulators and stakeholders, will reduce programmatic and regulatory risks, will save time and labor, and will allow more diverse uses of the baseline numerical modeling platform. The determination to not advance analytical models from the long list to the short list is predicated on the important core consensus recommendation related to an existing and available Fernald numerical model and the fact that the analytical model development would address the same risks.

Graphic:
no graphic provided for this narrative

Development Status: Systems have been widely deployed for water diversion (TRL 8 to 10). In general, this is a simple approach that would be straightforward to implement

Fernald Site-Specific Advantages/Disadvantages:

Advantages include:

- Simple reduced order models can provide insights and semiquantitative information to guide and improve numerical models.

Disadvantages include:

- Would require significant effort to select and deploy models for use (identify target key topics to explore such as matrix diffusion, develop and configure data, run model and interpret results, determine if any information could be used as insights for baseline numerical model).
- Unlikely to provide specific design or optimization information for remediation system.
- May not provide information that will be convincing to regulators (i.e., likely need to run numerical model as the official tool for projecting plume behavior and remediation progress).

Technology Inter-Relationships: This idea is related to other modeling long list items.

Short list: No – Redundant with key-alternative LM-NL recommendation (migrate the existing site numerical model to a more modern and nimble software platform); the analytical models address similar DOE and stakeholder priorities and programmatic risks.

Data Gaps: n/a.

Example References:

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Next Steps: n/a

Implementation Details and Level of Effort: n/a

Level of Effort: n/a

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Attachment C

Collaboration Team Documentation

Schedules
Participant Lists
Working Group Meeting Agendas and Notes

Attachment C was removed before posting on the U.S. Department of Energy Office of Legacy Management website.

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