Groundwater Remediation at the Fernald Preserve, Cincinnati, Ohio Modeling and Resulting 2014 Well Field Operational Changes − 15324

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ABSTRACT

The Fernald Preserve became a US DOE Office of Legacy Management site in November 2006, for long-term surveillance and maintenance following completion (with the exception of completing groundwater cleanup) of the Comprehensive Environmental Response, Compensation, and Liability Act; environmental remediation; and site restoration. When the site was turned over to the Office of Legacy Management, approximately 76 hectares (189 acres) of the Great Miami Aquifer (GMA) remained contaminated with uranium above the final remediation level of 30 micrograms per liter.

Uranium contamination is being removed from groundwater in the GMA through a pump-and-treat operation that is predicted by groundwater modeling to continue until 2033. Certifying that cleanup objectives have been met and removing the remediation infrastructure after pump-and-treat (P&T) operations are complete will require a minimum of 3 additional years.

The current P&T remedy has operated well. From August 1993 through December 2013 the remedy has been used to remove 5,345 kg (11,784 lb) of uranium from the GMA. A variety of metrics are used to track how the P&T operation is progressing and are reported each year in the Site Environmental Report for the Fernald site. The metrics show that the effectiveness of uranium removal is slowly decreasing (a common observation for P&T remedies) and that operational changes needed to be considered. Several different operational changes were modeled to determine if model-predicted cleanup dates could be shortened and if the effectiveness of the groundwater remediation could be improved.

With the concurrence and support of US EPA, Ohio EPA, and site stakeholders, operational changes were agreed upon and implemented in 2014 that are predicted to increase the effectiveness of the ongoing operation and shorten cleanup times for a portion of the aquifer. Although the overall predicted length of the remediation was not shortened, modeling predicts that key areas of the uranium plume will be remediated sooner.

This paper provides a status of the groundwater remediation under way at the Fernald Preserve near Cincinnati, presents the operational changes that were implemented in 2014, and summarizes the groundwater modeling that supported the changes. This paper also illustrates the

potential benefits that can be gained by proactively managing a pump-and-treat operation and looking for innovative ways to adjust the operation.

INTRODUCTION

Background

The Fernald Preserve (referred to in this paper as the Preserve) is a 425 hectare (ha) site (1,050 acres), approximately 29 kilometers (18 miles) northwest of Cincinnati, Ohio (Fig. 1). The preserve overlies the GMA, which the US EPA has designated as a sole source aquifer.

In 1951, the US Atomic Energy Commission, the predecessor agency to the US DOE, began building the Feed Materials Production Center outside the small farming community of Fernald, Ohio. The facility’s mission was to produce “feed materials” in the form of purified uranium compounds and metal for use by other government facilities involved in producing nuclear weapons for national defense.

The feed materials facility operated from 1952 to 1989, produced more than 226 kilograms (kg) (498 million pounds [lb]) of uranium metal products, and contaminated the soil, surface water, sediment, and groundwater on and around the site. In 1991, the site’s mission was formally changed from uranium production to environmental remediation and restoration under CERCLA. The cleanup project was divided into Operable Units (OU); OU 5 focused on environmental media and biological receptors, including groundwater, impacted by site activities.

With the exception of the GMA, physical completion of the CERCLA remediation was declared on October 29, 2006, and the site was officially transferred to US DOE Office of Legacy Management (LM). By then, all contaminated soils had been excavated and certified to meet final remediation levels (FRLs) (with the exception of certain areas associated with utility corridors and remediation infrastructure left in place to remediate the aquifer); the on-site disposal facility was complete, all required groundwater infrastructure was installed, operational, and secured; and restoration activities were completed within all excavated areas.

The final Record of Decision (ROD) for remedial actions at OU 5 defines a pump-and-treat (P&T) groundwater remedy for Fernald and establishes FRLs for the 50 constituents of concern [1]. Pumping in the GMA began in 1993 from four recovery wells (RW-1 through RW-4) installed in front of the southernmost tip of the uranium plume (Fig. 1). The objective was to capture the leading edge of the uranium plume and prevent it from mixing with off-site industrial plumes known to be present down gradient of the Fernald plume.

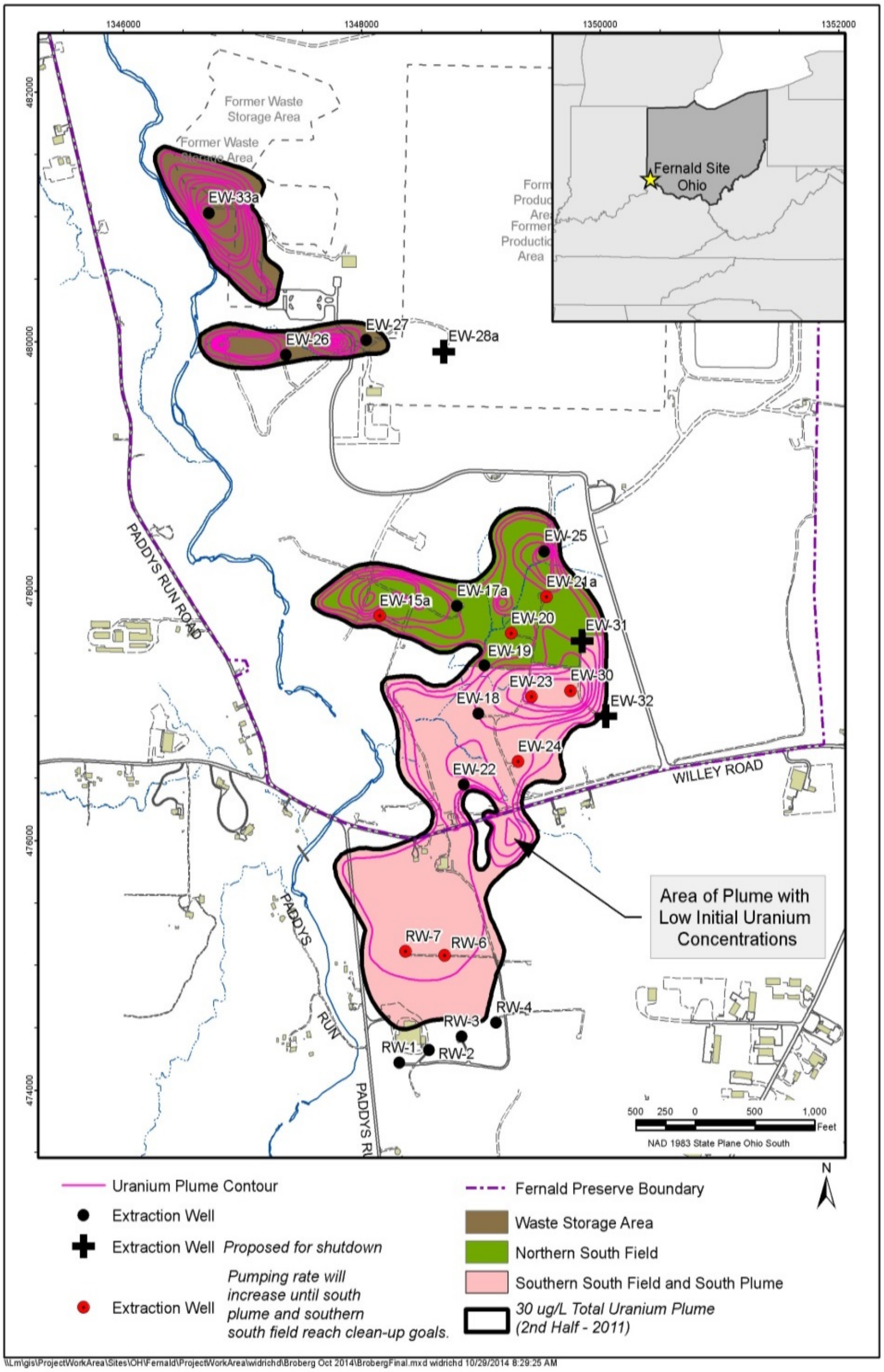

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Fig. 1. Location of the 425 ha (1,050 acre) site, the uranium plume, and extraction wells involved in the pump-and-treat remedy.

The restoration strategy focused primarily on the removal of uranium, but it is also designed to:

- Limit the further expansion of the plume
- Remove all targeted contamination to concentrations below FRLs
- Prevent undesirable draw-down impacts beyond the Fernald property
- Prevent contamination in down gradient industrial plumes from being pulled into the Fernald plume.

2005 Groundwater Remediation Design

The OU 5 ROD commits to the “extraction of contaminated groundwater from the GMA to the extent necessary to provide reasonable certainty that final remediation levels have been attained at all affected areas of the aquifer” [1]. The cleanup ROD identifies 50 constituents for the groundwater remedy. Uranium is the principal constituent of concern. The final remediation level for uranium in groundwater in the GMA is 30 micrograms per liter (µg/L) and is based on US EPA Primary Drinking Water Standards.

When the Preserve was turned over to LM in 2006, a P&T groundwater remediation system was operating to a design that was finalized in 2005 using the site groundwater model [2]. The site groundwater model uses a numerical code for modeling flow and transport in groundwater called VAM-3D (Variable Saturated Analysis Model in 3 Dimensions). The code was developed by HydroGeoLogic, Inc.

The 2005 design consisted of 23 extraction wells pumping groundwater at a system target pumping rate of 18,073.4 liters per minute (Lpm) (4,775 gallons per minute [gpm]) (Fig. 1). From 2005 through June 2014, the groundwater remediation has operated to pumping rates defined for the 2005 design.

In 2012, the decision was made to rerun the site groundwater model to address two issues: 1) discovery in 2011 (through groundwater sampling) that an area of the uranium plume had been initially loaded into the groundwater model at concentrations that were lower than what were actually present in the aquifer, and 2) decreasing operational effectiveness of the P&T operation.

Uranium Concentration Data from 2011

In 2011, uranium concentration data was collected (using direct push technology) in an area of the plume located just off of DOE-property that indicated that the initial plume conditions loaded into the groundwater model in 2005 were lower than they should have been (Fig. 1). Direct push sampling utilizes a temporary sampling borehole to collect a groundwater sample. It is used at the Preserve to supplement groundwater sampling at fixed monitoring well locations. An advantage of direct-push sampling is that groundwater samples can be collected from the same location at different vertical depths, providing a profile of the plume.

Based on the uranium concentration data that were available in 2005, the uranium concentrations in the subject area of the plume were correctly loaded into the groundwater model. The 2011 data, though, indicated that uranium concentrations were actually higher. The model was, therefore, providing unrealistically short cleanup time predictions for this area of the plume.

Modeling Results with Updated Uranium Plume Values

The uranium plume interpretation used in the groundwater model was updated using an additional 7 years of uranium concentration data and the model was run to determine how the updated plume conceptualization would impact model predicted cleanup times [3].

For the 2005 modeling design and for operational purposes, the uranium plume was divided into three different areas: the South Plume (Plume South of Willey Road), the South Field (Plume North of Willey Road, and the former Waste Storage Area (WSA) (Plume in the northwest corner of the site) (Fig. 1). In the 2005 design, the South Field included both the southern South Field and the northern South Field. As shown in TABLE I, modeling results based on the updated uranium plume concentrations predicted longer clean up times in all three areas ranging from 6 to 9 years.

TABLE I Model predicted cleanup dates based on updated plume concentrations

Alternative	South Plume	South Field	WSA
2005 Plume Interpretation	2015	2022	2023
2012 Plume Interpretation	2021	2028	2032
Increase in Years	6	6	9

Remedy Progress and Operational Effectiveness

Remediation progress is reported each year in the Annual Site Environmental Report. When the site was turned over to LM in 2006, approximately 76.5 ha (189 acres) of the GMA were above the uranium FRL of 30 µg/L. At the end of 2013, approximately 51.5 ha (127.3 acres) of the GMA remained above the uranium FRL (a reduction in size of 25 ha [61.7 acres]) (Fig. 2). From August 1993 through December 2013, 5,345 kg (11,784 lb) of uranium have been removed from the GMA.

Following EPA guidance [4], the uranium concentration trend determined from uranium concentrations measured at the extraction wells is reported each year along with the 95 percent upper confidence limit (UCL) for the concentration data. Both trends are then compared to the model predicted uranium concentration trends for the extraction wells to determine how closely the remediation is following the modeling prediction for cleanup.

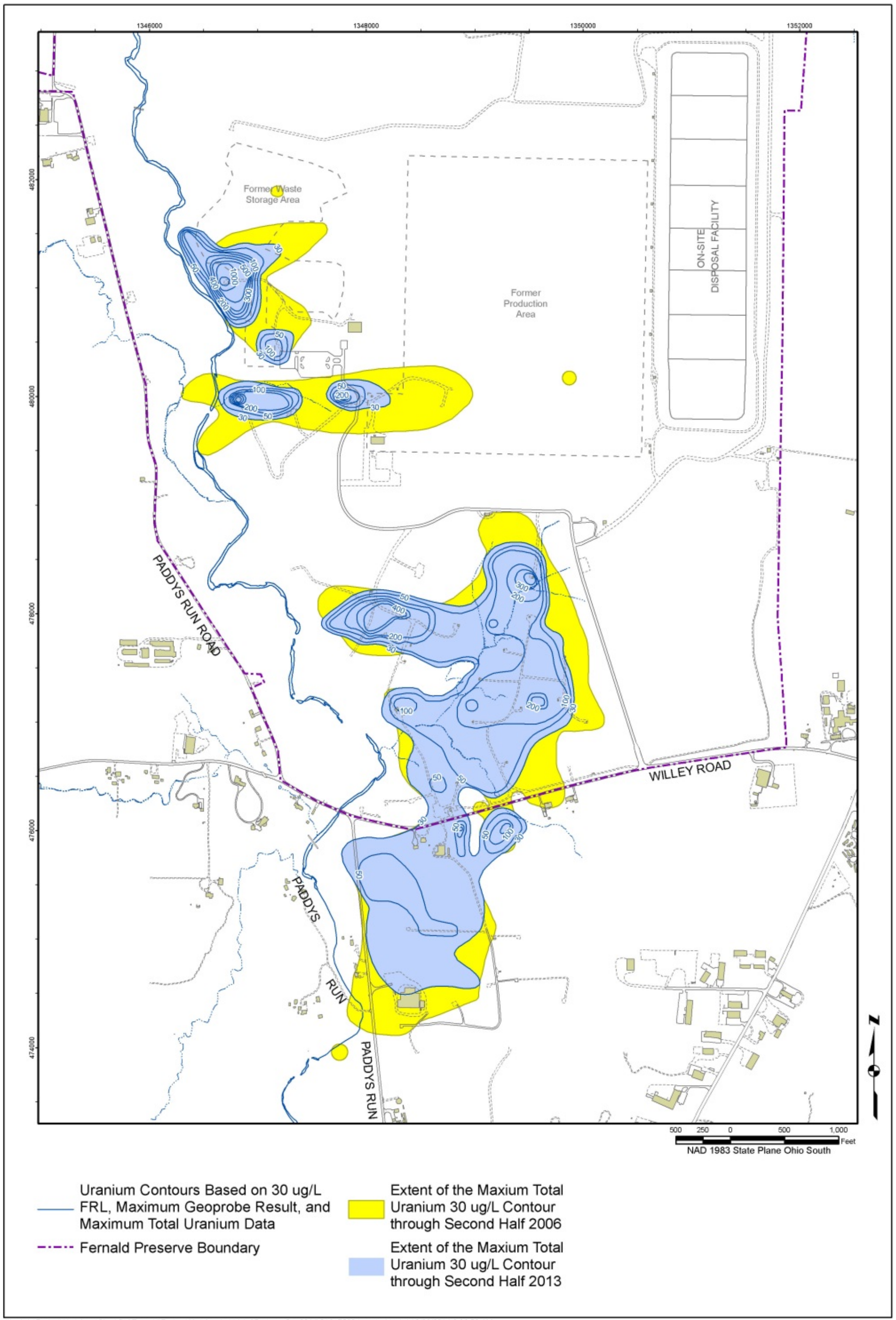

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Fig. 2. Location of the 51.5 ha (127.3 acres) of the GMA that remained above the FRL in 2013 compared to 2006.

A decline in the effectiveness of the pump and treat operation is indicated by the asymptotic trend of uranium concentration being tracked over time at the extraction wells. The asymptotic nature of the declining concentration curves is a common observation for pump-and-treat operations. The level of contamination measured at wells may be greatly reduced in a moderate period of time, but low levels of contamination may persist. The contaminant mass removed may decline over time and gradually approach a residual level. At that point large volumes of water are pumped to remove small amounts of contamination. This can be caused by the diffusion of contaminants in low-permeability sediments, and/or hydrodynamic isolation within the well field. Operational adjustments can be used to change hydrodynamic conditions within the aquifer in an attempt to increase operational effectiveness [4].

Modeling Operational Adjustments

Sixteen different operational alternatives were modeled using the site groundwater model that had been updated with the additional 7 years of uranium concentration data to determine if the model-predicted cleanup times could be shortened [3]. Only pumping rates were adjusted for the modeling exercises. All other modeling parameters approved for the 2005 model design remained unchanged. Additional extraction wells were also considered for some of the operational alternatives modeled.

The additional modeling took into account the following considerations:

- **Sorbed uranium contamination in the vadose zone of the aquifer –** Uranium contamination is bound to aquifer sediments in the unsaturated portion of the GMA beneath former contamination source areas. This contamination will remain bound unless water levels in the aquifer rise and saturate the contaminated sediments, allowing the bound contamination to dissolve into the groundwater. Therefore, excessive drawdown of water levels in these areas needs to be avoided.
- **Stagnation zones within the uranium plume –** Stagnation zones exist within the uranium plume. These stagnation zones are created by the competition of extraction wells for water within the aquifer. Reducing the impact of stagnation zones on cleanup time predictions was a modeling consideration.
- **Preferred flushing pathways within the uranium plume –** The GMA is both heterogeneous and anisotropic. Groundwater flowing through the aquifer matrix seeks the pathway of least resistance to the extraction wells. A result is that coarse-grained material is flushed of contamination more effectively than the finer-grained aquifer material because more water is moving through the coarser material. Geochemical factors also contribute to this effect. More surface area is available in the finer-grained material for contamination to sorb. This means that more uranium will sorb to the finer-grained materials that are less flushed than the coarser-grained materials that are often flushed better. Contamination sorbed to the finer-grained aquifer material slowly leaches out into the more active flow paths. Over time, this ineffective flushing of finer-grained material

results in reduced cleanup efficiency and prolonged cleanup times. Operational changes are often used to help alleviate this condition.
- **Impact to off-DOE property owners –** A main priority of the pump-and-treat operation has been, and remains, to minimize the impact that the pump-and-treat operations have on off-DOE property owners. Another main priority of the operations is to clean up the off-DOE property portion of the plume as quickly as possible.
- **Individual well pumping limitations recognized through operational experience –** Operational experiences indicate that it may be difficult to maintain a 1,514 – 1,892.5 Lpm (400-500 gpm) pumping rate in some areas of the plume. This is not due to the yield capability of the aquifer. It is due to the biological and chemical plugging that occurs in the extraction wells due to the high iron and magnesium concentrations found in the aquifer.
- **Net system extraction rate –** As identified in the Baseline Remedial Strategy Report for Operable Unit 5 (OU5) [5], the net groundwater extraction rate for the pumping system should not exceed the recharge rate of the regional aquifer, nor should it cause excessive water table drawdown.
- **Maintaining hydraulic containment of the maximum uranium plume –** Alternatives were also modeled to demonstrate that hydraulic control of the maximum uranium plume would be maintained.
- **Treatment considerations –** Re-allocation of budgeted pumping capacity from areas of the aquifer where uranium concentrations are low to areas of the aquifer where uranium concentrations are higher could result in the need of groundwater treatment prior to discharge in order to meet discharge limits at the Great Miami River (i.e., a monthly average no greater than 30 µg/L and no more than 272.4 kg (600 lb) per year).

Of the 16 alternatives modeled, the selected alternative had the following operational changes. Well locations are provided on Fig. 1.

- Increase the pumping rate at two off DOE-property wells (RW-6 and RW-7) in the South Plume from 757 to 1,135.5 Lpm (200 to 300 gpm) each to shorten the predicted cleanup time of the South Plume by 1-2 years.
- Turn off three extraction wells in the South Field that no longer provide benefit to the continuing pump-and-treat operation (EW-28a, EW-31, and EW-32) because the uranium concentration of the pumped water at the wells was low (approximately 10 µg/L or less).
- Re-allocate the pumping budget by taking the freed up capacity from the three wells that were turned off and increasing the pumping rates at select wells in the southern portion of the South field to shorten the model predicted cleanup time of the southern South field by 8-9 years.
- Increase the overall system pumping rate by 1,135.5 Lpm (300 gpm), from 18,073.4 to 19,208.9 Lpm (4,775 to 5,075 gpm).

The selected approach is innovative over the 2005 design approach in that it is proactive in adjusting pumping rates to more efficiently address the remaining uranium plume in the aquifer over time, and provides a new approach for addressing the uranium plume in the South Field Area in that it divides the South Field into a northern and southern half. By dividing the South Field, predicted cleanup of the southern half of the South Field is achieved 8-9 years earlier than what was previously predicted using the 2005 target pumping rates. This is favorable in that it predicts an earlier cleanup of the on DOE-property portion of the uranium plume that has the greatest potential for migrating to off DOE-property.

The overall time length of the predicted cleanup for the entire remediation under the selected alternative is shown in TABLE II. The entire cleanup is increased by one year from 2032, but the predicted accelerated cleanup of the Southern South Field 8 to 9 years earlier makes the one year extension of the overall remedy an acceptable trade off.

TABLE II Overall time length of predicted cleanup

South Plume and Southern South Field	**Northern South Field**	**Waste Storage Area**
2020	2028	2033

Fig. 3 provides a summary of how the net system target pumping rate will be changed over time compared to the previous 2005 design. The 2005 modeled design called for a constant system target pumping rate of 18,073.4 Lpm (4,775 gpm) for the entire remedy (shown in red on Fig. 3). The new selected approach will adjust the net system target pumping rate as the remediation progresses to maximize operational effectiveness. As shown in Fig. 3, for the first 8 years, the net system pumping rate will be 19,208.9 Lpm (5,075 gpm). This is 1,135.5 Lpm (300 gpm) more than the previous design. In year 9, if cleanup predictions in the South Plume and southern South Field are realized, the new system pumping rate will be reduced by 6,434.5 Lpm (1,700 gpm) to a new net system pumping rate of 11,638.9 Lpm (3,075 gpm). In model year 17, if cleanup predictions in the northern South field are realized, the net system pumping rate will be reduced by an additional 7,475.4 Lpm (1,975 gpm) to a new system pumping rate of 4,163.5 Lpm (1,100 gpm).

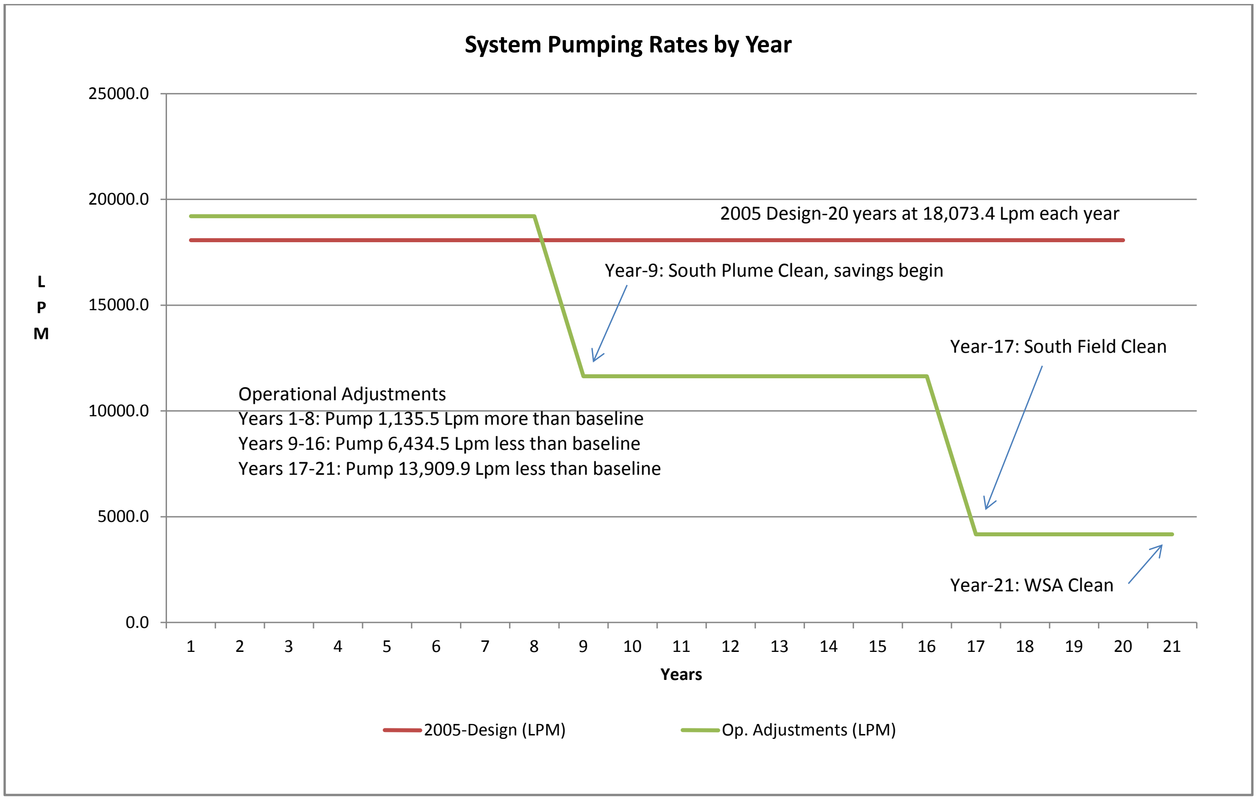

Fig. 3. This chart summarizes how the system target pumping rate will be changed over time in comparison to the 2005 design.

A cost benefit of this innovative approach of adjusting the target pumping rate as the remedy progresses is illustrated in Fig. 4. Fig. 4 compares predicted cumulative estimated costs for the 2005 modeled approach (based on target pumping rates) compared to the selected new operational approach. As shown in Fig. 4, for the first 8 years, because the net system pumping rate is higher with the operational changes 19,208.9 Lpm versus 18,073.4 Lpm (5,075 gpm versus 4,775 gpm) the operational costs are also slightly higher. In year 9 though, if cleanup predictions in the South Plume and southern South Field are realized, it is predicted that operational costs will decrease because the net system pumping rate will decrease. Comparing the two operational alternatives, implementation of the operational adjustments defined for the selected alternative has the potential to realize a predicted savings of $6,088,000 dollars over the life of the pump-and-treat operation.

Recognized Risks for the Selected Alternative

Pumping at higher rates from some of the wells in the well field comes with recognized risks. There is a risk that the higher individual well pumping rates specified in the first 8 years of operation with the operational changes may not be sustainable. The groundwater model does not account for operational challenges resulting from bio-fouling and plugging of the pumps and well screens.

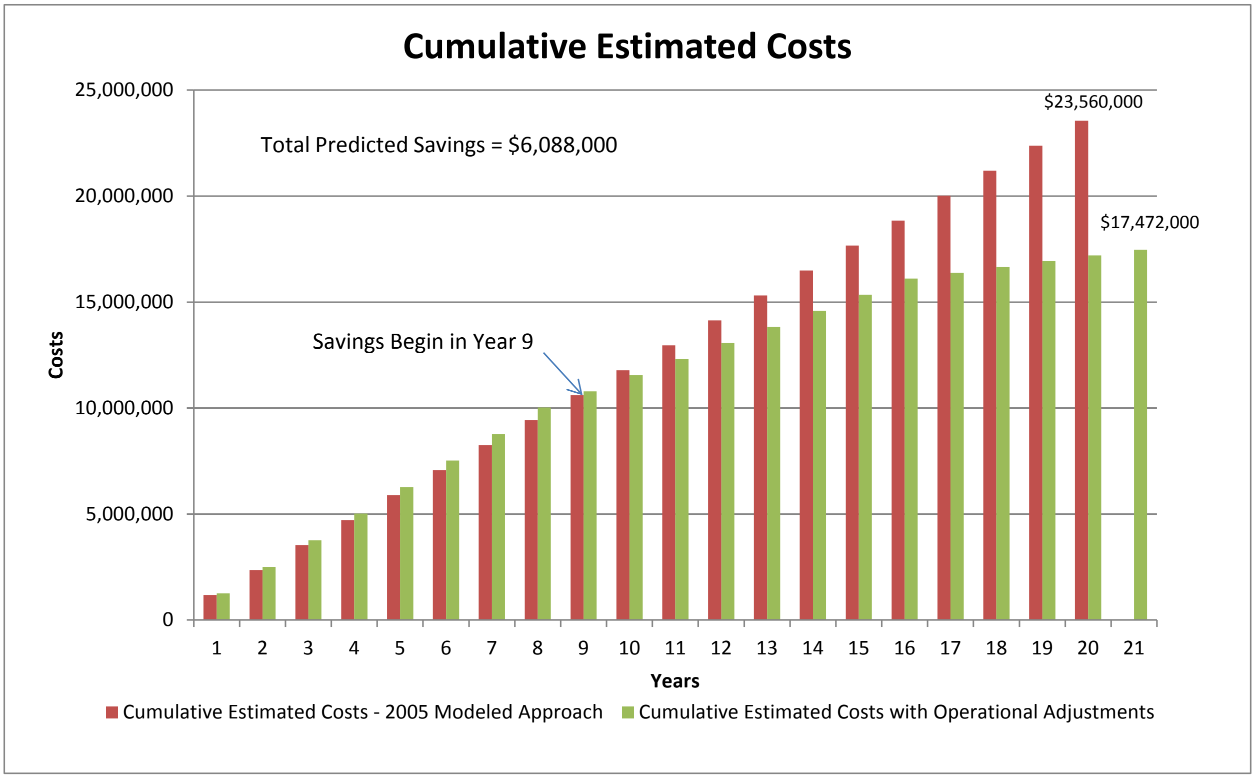

Fig. 4. Illustration of the predicted cost benefits of the target pumping rate adjustment in comparison to the 2005 design.

Increased individual well pumping rates will likely result in the need for increased maintenance to the pumps, motors, and well screens due to iron fouling and plugging. Newly installed (April 2013) epoxy coated pumps are being tested for use in mitigating maintenance problems related to iron fouling inside the pumps. However, only through long term operational experience will the feasibility of maintaining these higher pumping rates be proven. Should operational experience show that maintaining these higher pumping rates requires excessive maintenance and is not cost effective, individual well pumping rates may need to be reduced. Lower individual well pumping rates could result in increased cleanup times. If maintaining the higher pumping rates is not feasible, as indicated by excessive maintenance costs, reduction in pumping rates may be necessary.

The amount of groundwater that needs to be treated to maintain compliance with the monthly average uranium discharge concentration limit had decreased dramatically under the 2005 cleanup design. In 2013 routine treatment of groundwater to meet the established discharge limits (average monthly concentration of uranium not to exceed 30 µg/L and annual discharge of no more than 272.4 kg [600 lb] of uranium) was not needed. A flow weighted average uranium concentration was calculated for the new net system pumping rate of 19,208.9 Lpm (5,075 gpm) that is targeted for the first 8 years of operation. It was determined that the average monthly uranium concentration of the discharge water would be approximately 30.7 µg/L resulting in 309.8 kg (683 lb) of uranium each year being pulled from the aquifer. Some treatment will therefore be needed initially to meet discharge limits, but it is anticipated that the need for treatment will be short-lived.

Well Field Work Completed in the Spring of 2014

With the concurrence and support of EPA, Ohio EPA, and site stakeholders, preparations for implementing the operational changes began in 2014. In the spring of 2014 three extraction wells (EW-28A, EW-31, and EW-32) were turned off. Seven existing extraction wells were rehabilitated to address plugging caused by biofouling. Larger pumps were installed in seven extraction wells; and new motors were installed in three extraction wells. The pump-and-treat system began operating at a new target system design rate of 19,208.9 Lpm (5,075 gpm) on July 1, 2014.

CONCLUSION

Initial results based on the operational changes are promising. As the modeling predicted, the new higher pumping rates are removing more uranium from the aquifer, and groundwater treatment is once again required to meet agreed to discharge limits at the Great Miami River. Additional operational experience at the new system target pumping set point is needed to determine the impact that bio-fouling and plugging will have on the extraction wells at the higher pumping rates and whether or not continued operation at the higher pumping rates will be cost effective.

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