Development of a Groundwater Transport Simulation Tool for Remedial Process Optimization – 15316

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ABSTRACT

The groundwater remedy for hexavalent chromium at the Hanford Site includes operation of five large pump-and-treat systems along the Columbia River. The systems at the 100-HR-3 and 100-KR-4 groundwater operable units treat a total of about 9,840 liters per minute (2,600 gallons per minute) of groundwater to remove hexavalent chromium, and cover an area of nearly 26 square kilometers (10 square miles).

The pump-and-treat systems result in large scale manipulation of groundwater flow direction, velocities, and most importantly, the contaminant plumes. Tracking of the plumes and predicting needed system modifications is part of the remedial process optimization, and is a continual process with the goal of reducing costs and shortening the timeframe to achieve the cleanup goals.

While most of the initial system evaluations are conducted by assessing performance (e.g., reduction in contaminant concentration in groundwater and changes in inferred plume size), changes to the well field are often recommended. To determine the placement for new wells, well realignments, and modifications to pumping rates, it is important to be able to predict resultant plume changes. In smaller systems, it may be effective to make small scale changes periodically and adjust modifications based on groundwater monitoring results. Due to the expansive nature of the remediation systems at Hanford, however, additional tools were needed to predict the plume reactions to system changes. A computer simulation tool (the Pumping Optimization Model, or POM) was developed to support pumping rate recommendations for optimization of large pump-and-treat groundwater remedy systems.

INTRODUCTION

The Hanford Site nuclear reactor operations required large quantities of high-quality cooling water, which was treated with chemicals, including sodium dichromate dihydrate for corrosion control. As part of routine reactor operations, contaminated cooling water was discharged to various structures (e.g., pipelines, retention basins), which often leaked. In addition, during upset conditions such as fuel element failures, the cooling water was diverted from the regularly used retention basins to other disposal areas such as ditches or other engineered structures and allowed to infiltrate directly into the soil column. These practices resulted in extensive groundwater recharge mounds consisting primarily of contaminated cooling water and resulted in the wide distribution of contamination by hexavalent chromium and other constituents in the unconfined aquifer (HW-77170, BNWL-CC-1352).

The majority of the groundwater contamination associated with contaminated cooling water, is located along the River Corridor, where the reactors were located (Figure 1). Along the River Corridor, which includes the 100-HR-3 and 100-KR-4 groundwater operable units (OUs), the primary contaminant of concern is hexavalent chromium (Cr[VI]). The Cr(VI) groundwater plumes (at concentrations above 20 μg/L) in these two OUs encompassed approximately 5 km^2 (1,235 acres) in 2013, extending across the Horn areas in 100-HR-3 (Figure 2), and represents the vast majority of contaminated groundwater areas along the river corridor.

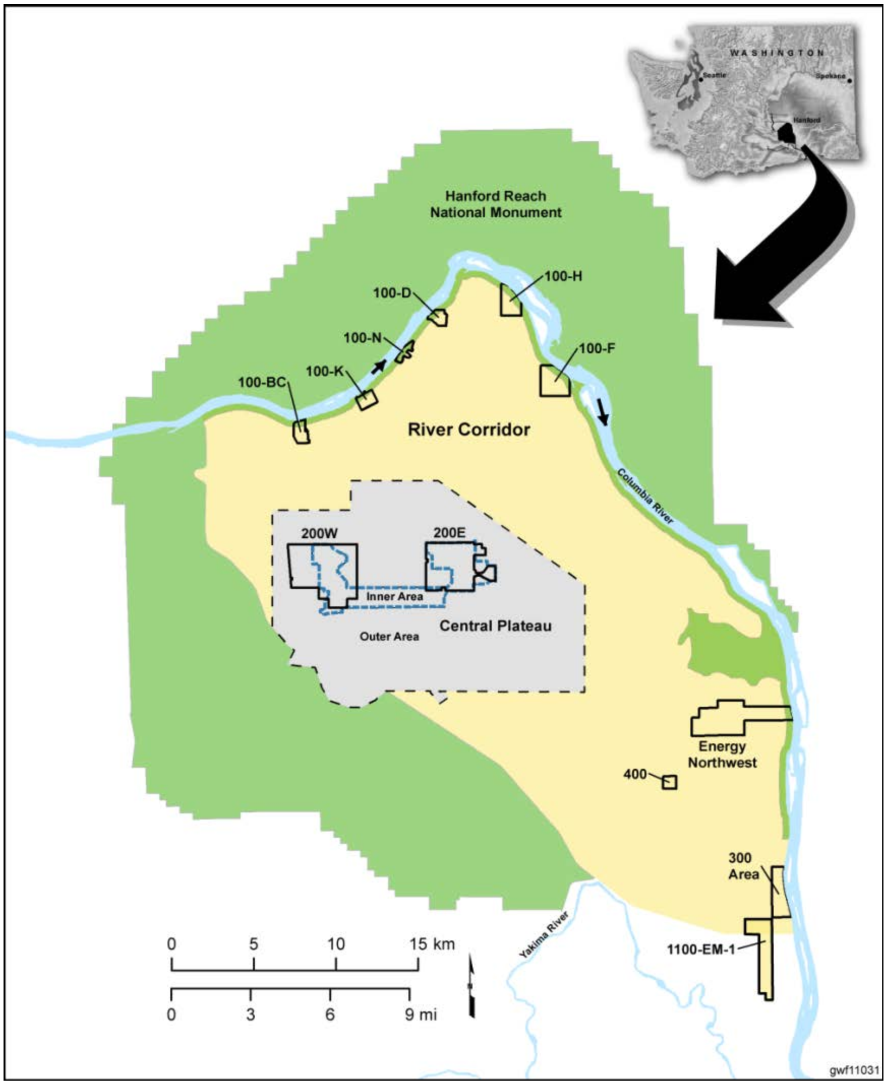

Figure 1. Location and plan view of USDOE Hanford Site.

Initial steps taken to remediate the groundwater contamination at the 100-HR-3 and 100-KR-4 groundwater OUs included pump-and-treat technology using ion exchange (IX) resins to remove Cr(VI). The first pump-and-treat systems were installed in these two areas in 1996, however the initial systems had relatively few groundwater extraction wells and a limited system capacity. Substantial expansions and upgrades to these systems were implemented from 2007 to 2014. For example, the expansion for 100-HR-3 included installation of over 70 wells and construction of new treatment facilities. The two treatment systems at 100-HR-3 now have the capacity to treat 5,300 liters per minute (1,400 gallons per minute), and the three systems at 100-KR-4 treat 4,540 liters per minute (1,200 gallons per minute), with average flows often exceeding the system design. Figure 2 shows the pump-and-treat system layout at 100-HR-3 at the end of 2013 (DOE/RL-2014-32, *Hanford Site Groundwater Monitoring Report for 2013*).

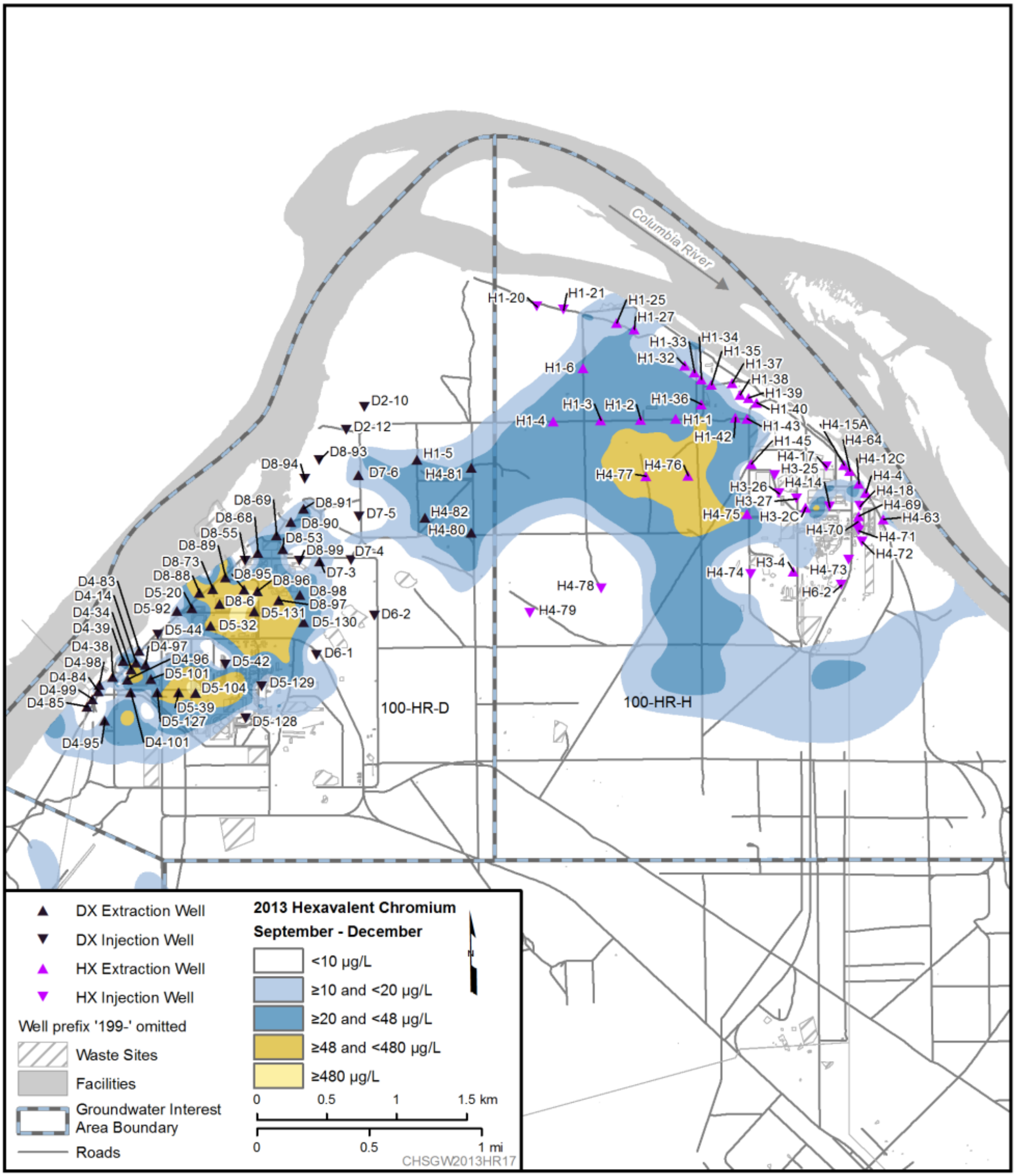

Figure 2. 100-HR-3 hexavalent chromium plume in 2013 with pump-and-treat system configuration

Maintaining an efficient pump-and-treat system incorporates continual evaluation of the system configuration through an optimization process. For these large pump-and-treat systems, optimization includes, among other things, a nearly continual evaluation of: the well field, river stage fluctuations (especially within the River Corridor area), well efficiency, pumping rates, conveyance line size and configuration, pump size, capture efficiency, and remedy performance during system operation. Initially, the results of system evaluations are used to guide timing of maintenance for existing wells, and changes to pumping rate.

Remedial system operations at the 100-HR-3 OU are used to describe application of the POM for evaluating system performance and preparing recommendations for system optimization.

PREDICTIVE MODELING

The pump-and-treat systems result in large scale manipulation of groundwater flow direction, velocities, and most importantly, the contaminant plumes. Tracking of the plumes and predicting needed system modifications is part of the remedial process optimization, and is a continual process with the goal of reducing costs and shortening the timeframe to achieve the cleanup goals.

In an effort to track the Cr(VI) across the site and determine the effects of the injection and extraction wells, scenarios were developed after predictive modeling. Initially, modeling of the plume migration relied on a 3D groundwater flow fate and transport model, specifically MODFLOW and MT3D. In this model, groundwater flow is simulated as three-dimensional (3D) using four layers. These layers represent the varying stratigraphy present across the 100 Areas of the Hanford Site.

Simulation of various pump-and-treat system modifications using the robust 3D model proved cumbersome. This was primarily due to the amount of time needed for each model run. In addition, any changes to the scenario required an additional model run, compounding the time needed to evaluate results. The transient nature of the river also increases the need for additional model runs due to the added level of complexity in evaluating plume changes.

To expedite the modeling process for planning purposes, a computer simulation tool was developed. This tool, called the Pumping Optimization Model, or POM, was designed to support development of pumping rate recommendations for optimization of large pump-and-treat groundwater remedy systems. The POM is based on a 1-layer derivation of a multi-layer contaminant transport model using MODFLOW. The POM allows for quick visualization of outputs and simulates the fate and transport inputs from the 3D model.

The POM provides for the following advantageous features:

- Short simulation run times (3 hours or less, depending on the number of Stress Periods calculated) using a Windows-based notebook PC
- Integral simulation output data post-processing for immediate visualization of results
- Direct interactive support for changing selected input parameters (e.g., well locations, well extraction/injection rates, start date and duration of pumping regimes) allows rapid scenario optimization
- Ability to present multiple simulations simultaneously
- Presentation of resultant simulated groundwater elevation contours and apparent capture zones.

DISCUSSION

The main advantage to the POM is being able to have a comparison of different scenarios and see the results in a short time period. A scenario using the existing plume configuration and pump-and-treat system is used as a base case for scenario comparisons.

Evaluation of the current configuration, which is the current (2013) pump-and-treat system configuration, indicated the need for additional extraction (Figure 3). Additional wells are required within 100-HR-3 to support ongoing groundwater remediation actions, support effective groundwater contaminant plume monitoring, and confirm remedial system performance. Areas were targeted based on the goals of remediation: 1) River protection 2) mass removal, and 3) plume delineation.

The resulting POM simulation indicated enhanced groundwater cleanup with the proposed well alignment. This scenario was named the “base case” for future modifications (Figure 4). It was noted by that the plume in the areas north of 100-H and along the Horn continued to show a slow response to the pump-and-treat operations. To address the slow response to the pump-and-treat operations, the use of injection wells was explored. A scenario was developed to illustrate the use of injection water to increase groundwater flow rates in nearby and downgradient extraction wells. Wells 199-H1-5 and 199-H4-81 were evaluated for use as injection wells, along with two additional extraction wells (Well A and Well B). The results are presented in Figure 5, with the base case also presented for comparison.

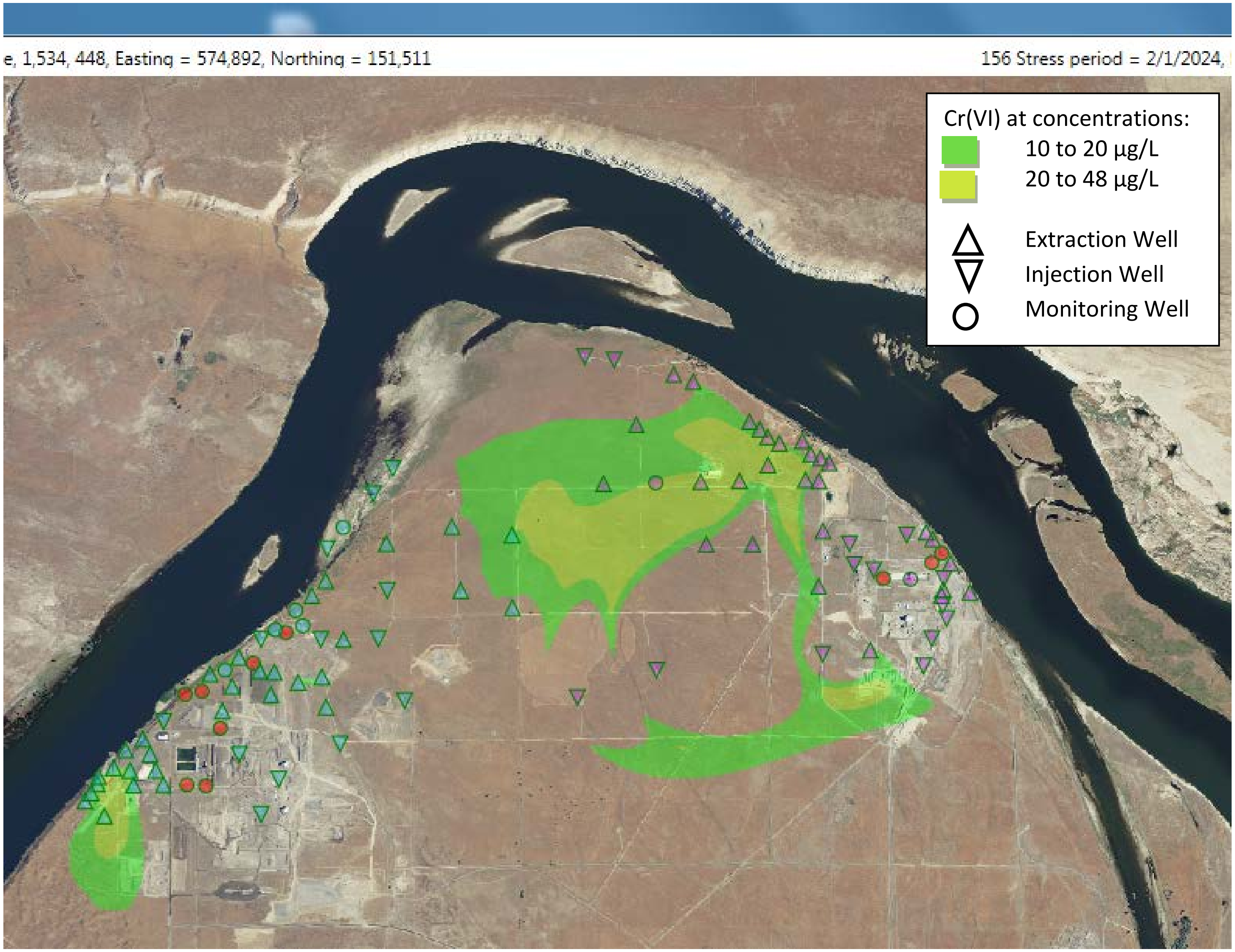

Figure 3. Predicted plume based on 2013 pump-and-treat system alignment

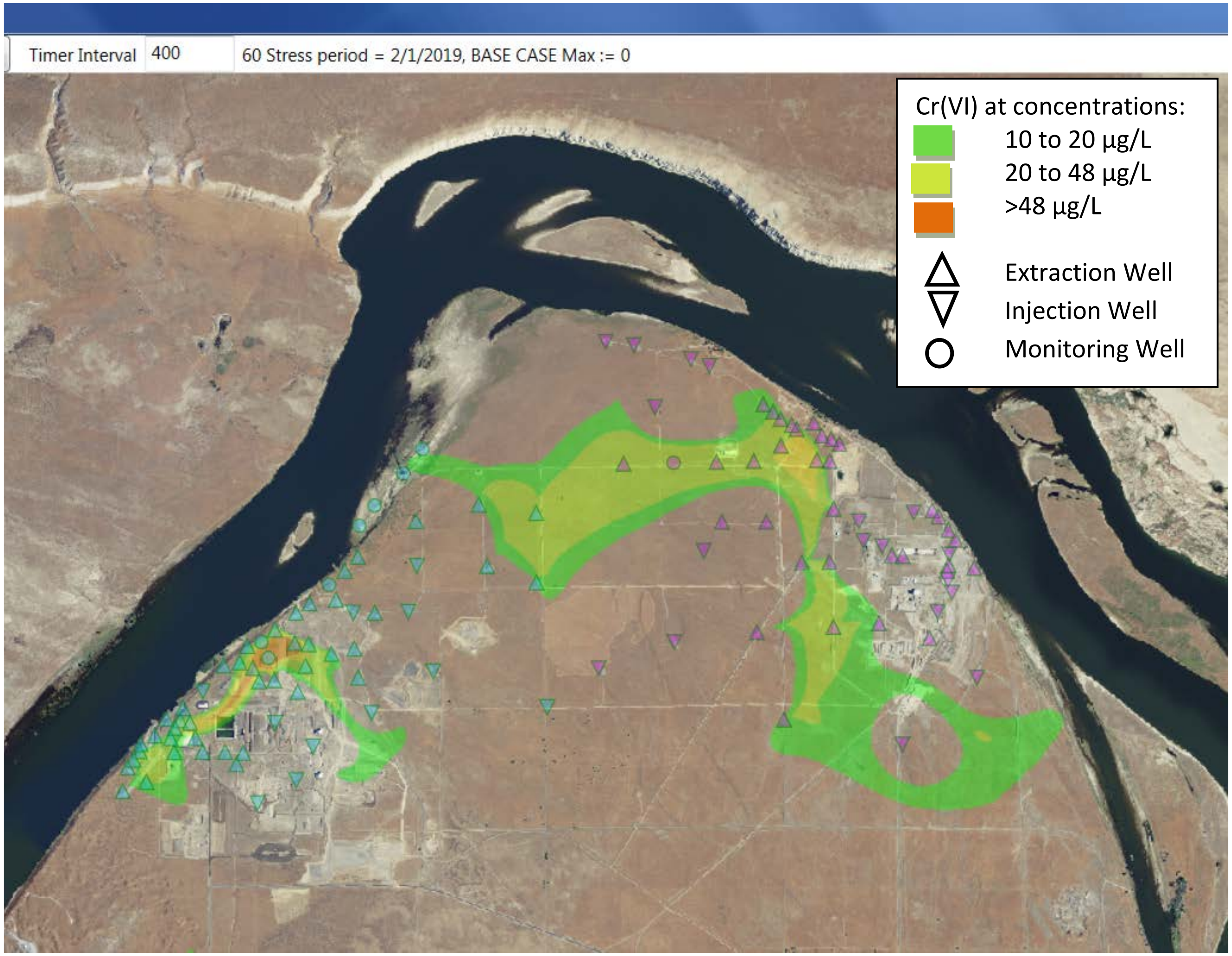

Figure 4. Proposed Well Alignment without additional modification (pumping starts in mid-2015); "Base Case"

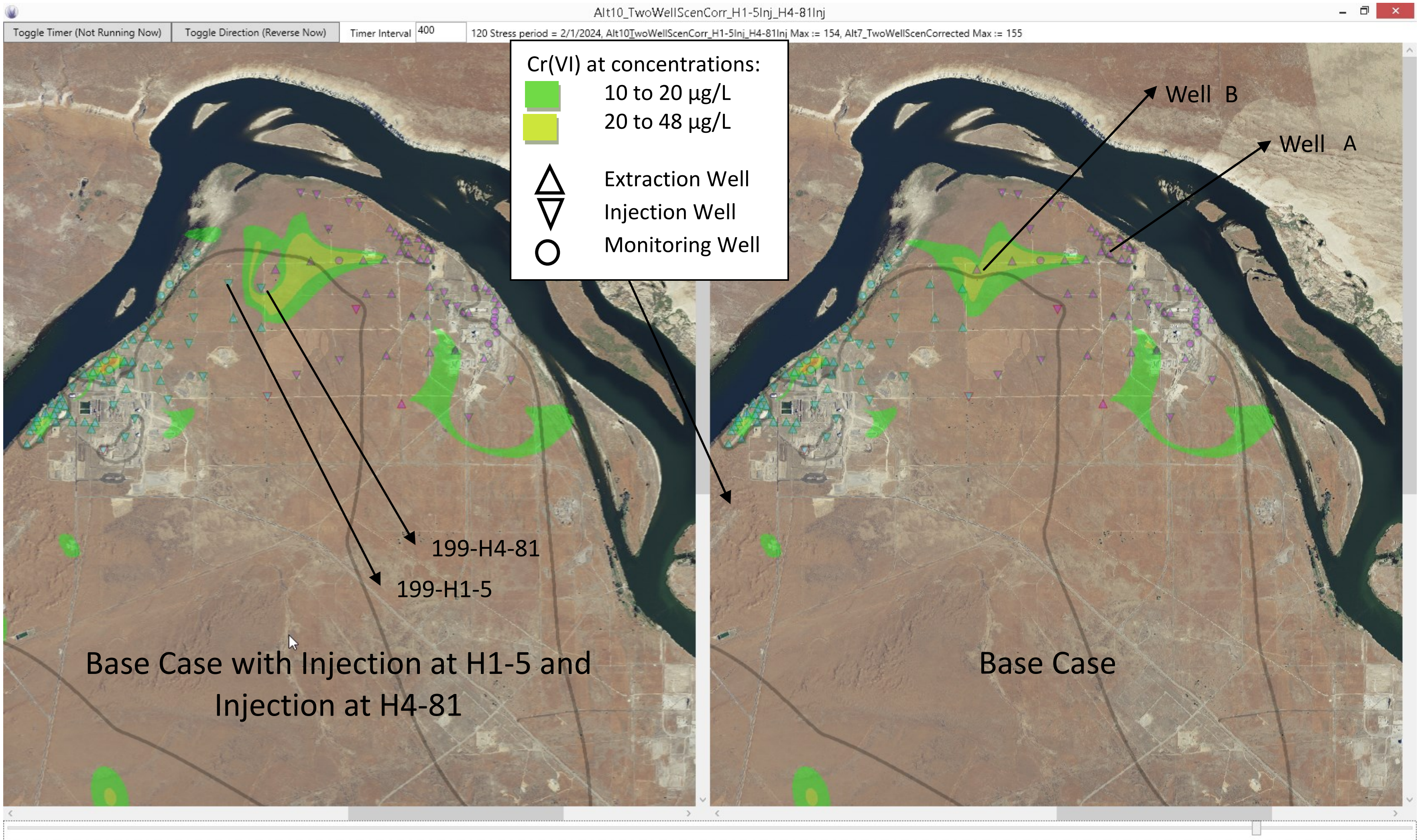

Figure 5. Predicted 2024 plume configuration scenario with injection and additional extraction

CONCLUSIONS

After analyzing the results from the various scenarios, the scenario using injection at Well 199-H1-5, with injection at Well 199-H4-81, and two additional extraction wells was chosen for implementation at the site. To confirm that the POM simulations matched the more robust 3D model results, the proposed well configuration and pumping rates was run.

The scenario was simulated with the equivalent 3D model with the following expectations:

- Simulated groundwater budgets should be similar to the POM
- Simulated Chromium plumes should be similar to the POM

The comparison shows that despite the presence of local differences, there is good agreement in the plume extents and directions of migration (Figure 6 and Figure 7). The local differences are to be expected because of geological heterogeneities. In addition, there is good agreement in comparison of the water budgets and head boundaries (Figure 8) providing verification of the 1-D POM model result against the more complex 3-D model. The POM model can be modified to compare the pump-and-treat optimization scenarios, therefore minimizing the cost of the 3-D modelling effort, saving the government valuable analyst resources. In addition, the POM can be adapted for use at other modeling applications at Hanford and other DOE sites that are currently using MODFLOW and MT3D for the fate and transport modelling. Use of this tool can greatly enhance the predictive modeling capabilities across the DOE complex.

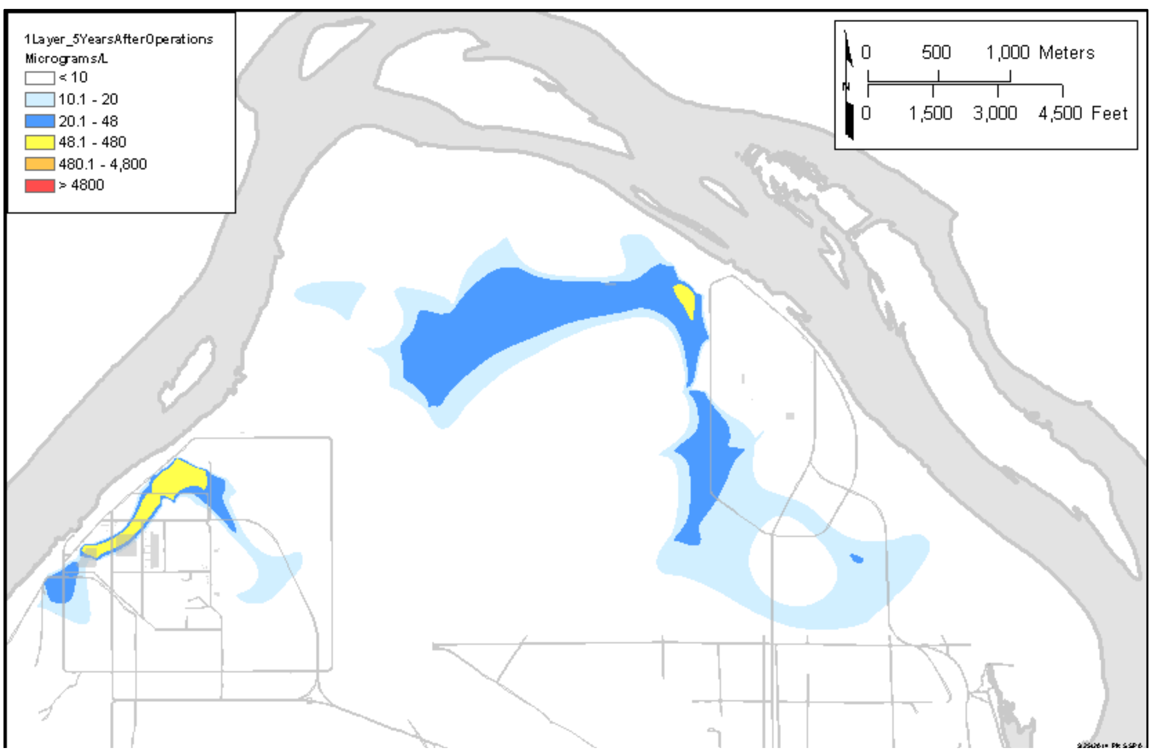

Figure 6. POM Simulation after 5 years of operations

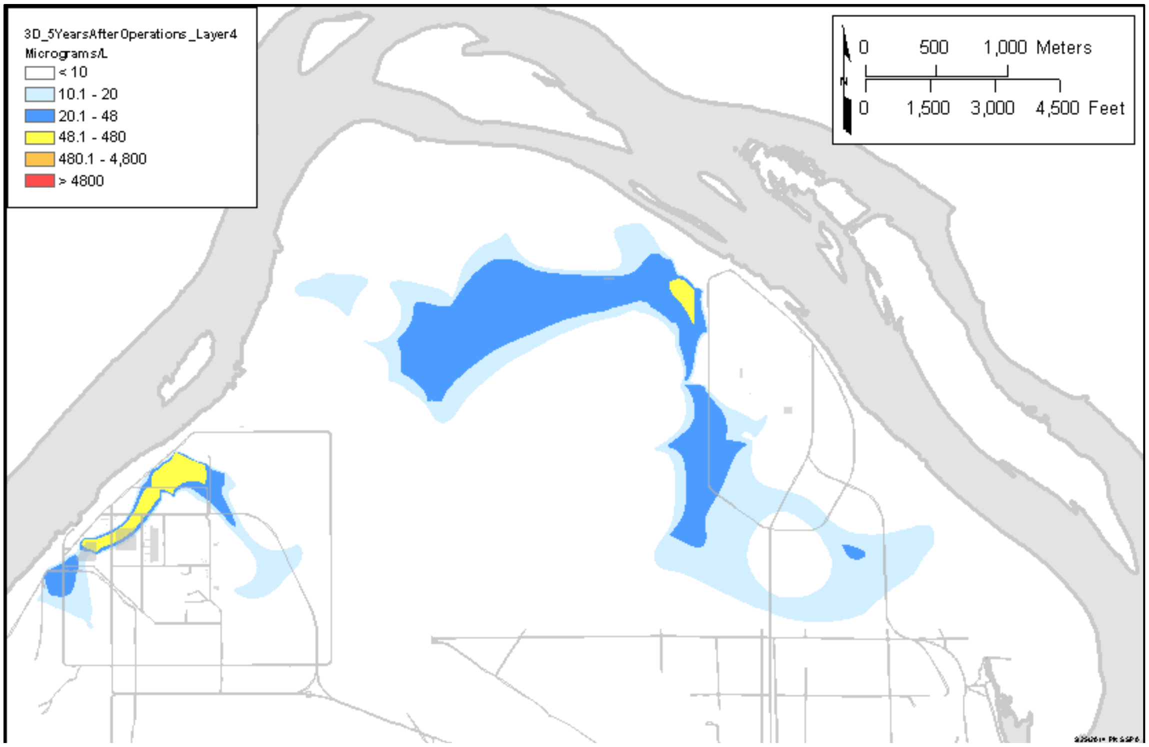

Figure 7. 3D Model (Layer 4) Simulation after 5 years of operations

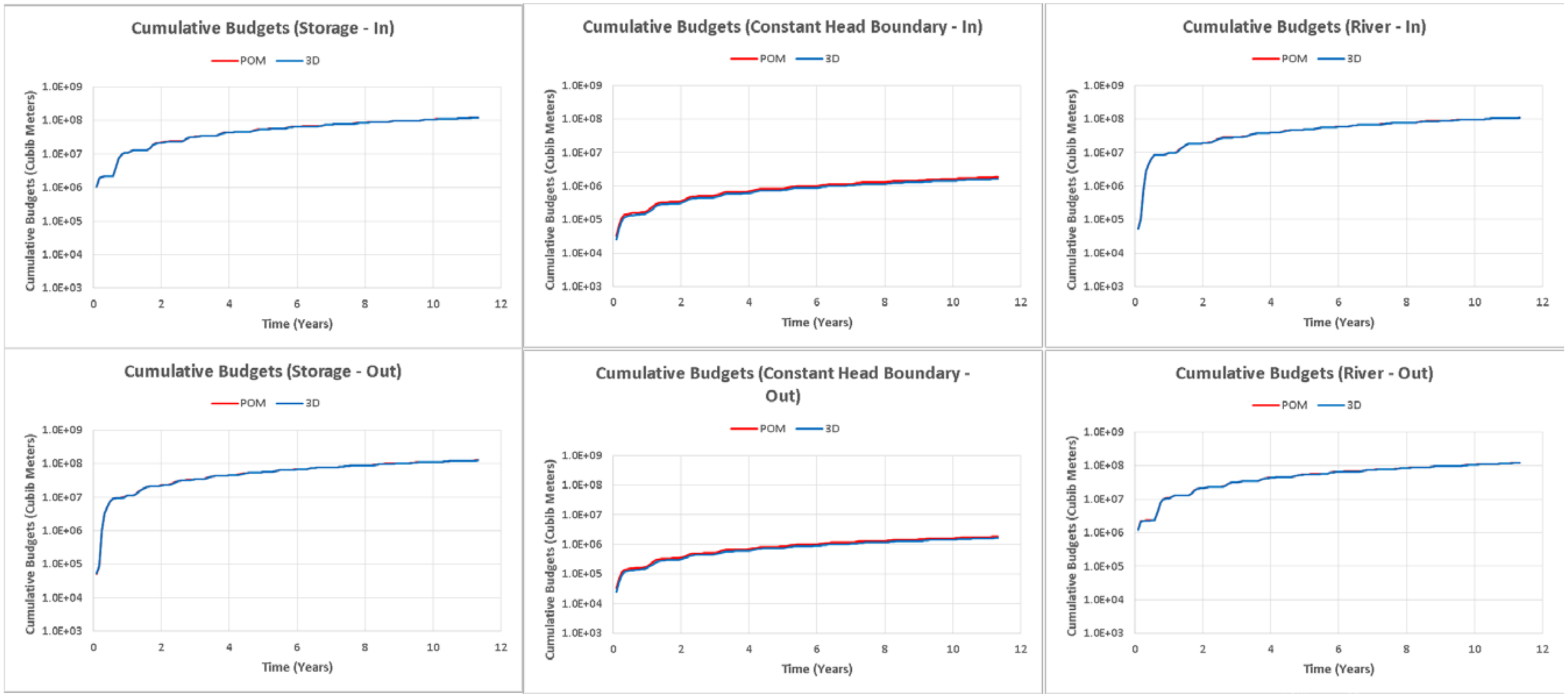

Figure 8. Head Boundary and Water Budget Comparisons

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