# Innovative Use of Cr(VI) Plume Depictions and Pump-and-Treat Capture Analysis to Estimate Risks of Contaminant Discharge to Surface Water at Hanford Reactor Areas – 15315

Charles Miller *, Kris Ivarson *, Matthew Tonkin **, James Hanson ***
* CH2M HILL PRC
** S.S. Papadopulos & Associates, Inc.
*** US DOE

## ABSTRACT

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. Cooling water leakage, as well as intentional discharge of cooling water to ground during upset conditions, produced extensive groundwater recharge mounds consisting largely of contaminated cooling water and resulted in wide distribution of hexavalent chromium (Cr[VI]) contamination in the unconfined aquifer. The 2013 Cr(VI) groundwater plumes in the 100 Areas cover approximately 6 $km^2$ (1500 acres), primarily in the 100-HR-3 and 100-KR-4 groundwater operable units (OUs). The Columbia River is a groundwater discharge boundary; where the plumes are adjacent to the Columbia River there remains a potential to discharge Cr(VI) to the river at concentrations above water quality criteria.

The pump-and-treat systems along the River Corridor are operating with two main goals: 1) protection of the Columbia River, and 2) recovery of contaminant mass. An evaluation of the effectiveness of the pump-and-treat systems was needed to determine if the Columbia River was protected from contamination, and also to determine where additional system modifications may be needed. In response to this need, a technique for assessing the river protection was developed which takes into consideration seasonal migration of the plume and hydraulic performance of the operating well fields.

Groundwater contaminant plume maps are generated across the Hanford Site on an annual basis. The assessment technique overlays the annual plume and the capture efficiency maps for the various pump and treat systems. The river protection analysis technique was prepared for use at the Hanford site and is described in detail in M.J. Tonkin, 2013. Interpolated capture frequency maps, based on mapping dynamic water level observed in observation wells and derived water levels in the vicinity of extraction and injection wells, are developed initially. Second, simulated capture frequency maps are developed, based on transport modelling results. Both interpolated and simulated capture frequency maps are based on operation of the systems over a full year. These two capture maps are then overlaid on the plume distribution maps for inspection of the relative orientation of the contaminant plumes with the capture frequency. To quantify the relative degree of protection of the river from discharges of Cr(VI) (and conversely, the degree of threat) at any particular location, a systematic method of evaluating and mapping the plume/capture relationship was developed. By comparing the spatial relationship between contaminant plumes and hydraulic capture frequency, an index of relative protectiveness is developed and the results posted on the combined plume/capture plan view map. Areas exhibiting lesser degrees of river protection are identified for remedial process optimization actions to control plumes and prevent continuing discharge of Cr(VI) to the river.

## INTRODUCTION

The primary risk driver behind groundwater remediation at the Hanford reactor areas is protection of aquatic species in the Columbia River from discharges of hexavalent chromium-contaminated groundwater migrating from beneath the former reactor operation areas. The location of the Hanford Site is shown in Figure 1. A Record of Decision (ROD) under DOE’s authority as lead agency under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) mandated that an interim remedial action be implemented to control continuing release of the chromium-contaminated groundwater to the adjacent Columbia River. The groundwater remedial actions are presently focused on the Hanford 100-D, 100-H, and 100-K Reactor Areas.

The interim remediation action is pump-and-treat remedy that utilizes a series of extraction wells to remove contaminated groundwater, an ion-exchange treatment system to remove hexavalent chromium from the extracted groundwater, and a series of injection wells to replace the treated water into the aquifer. The remedial systems in the 100-D, H, and K Areas are presently very effective at removing the target contaminant from groundwater. Evaluating the degree of protection afforded the river by the current remedy, however, is a challenging undertaking. Historically, such assessments were defined in qualitative terms. This paper describes application of a quantitative assessment methodology to defining river protection at the Hanford Site. The methodology relies on a combination of three independent analyses, an inferred contaminant plume distribution depiction, and two separate estimates of hydraulic capture by the operating pump-and-treat systems. The results of the analysis are subsequently used to identify and map shoreline areas that fall into three categories: 1) “Protected”, 2) “Protected, but additional action may be required”, and 3) “Not Protected”. The resulting categorization is then used to identify optimization actions to be applied to the remedy to enhance river protection.

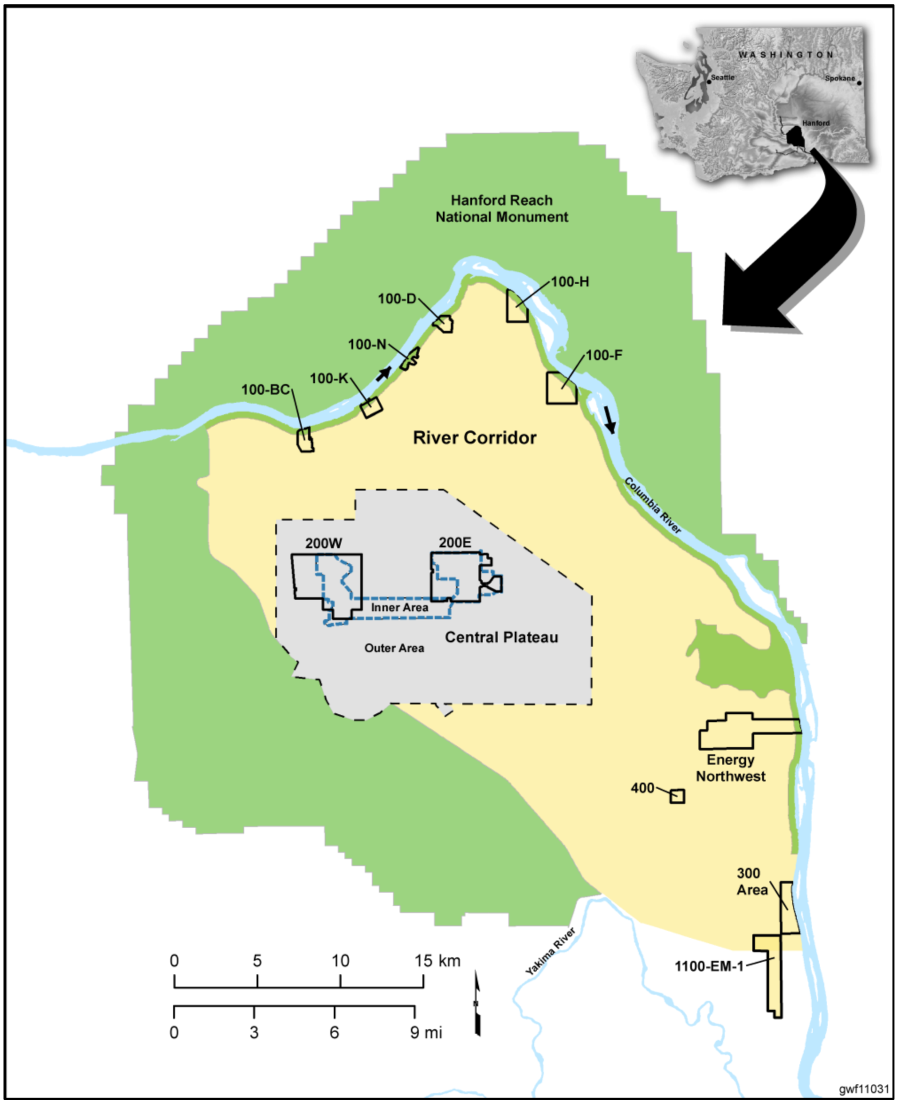


Figure 1. Location and Plan View of USDOE Hanford Site.

## METHODS

The river protection evaluation is a three step process: 1) prepare the inputs (i.e., inferred plumes, estimated capture areas), 2) overlay the plumes and capture areas, and 3) perform the quantitative protection analysis. These steps are described in the following subsections.

### Plume Mapping

Annual plume maps are prepared using groundwater monitoring data derived from sampling and analysis of groundwater from well locations throughout the operable unit. Well-specific samples are collected and analyzed from groundwater monitoring wells and from pump-and-treat system extraction wells. Treatment system effluent sample analyses are assigned to system injection wells as point values for use in preparing plume distribution maps. Groundwater measurement data are reduced and then Kriged to prepare the gridded values used in preparing concentration contour maps. Because of seasonal variability in aquifer behavior (both hydraulic and contaminant concentration), plume maps are prepared illustrating the inferred distribution of hexavalent chromium at seasonal periods describing high and low river stage. During the high river stage period, the aquifer re-equilibrates to a higher elevation; this has been observed to produce higher contaminant concentrations at some locations (e.g., near source areas). As the river stage declines after the freshet, the groundwater gradient is increased toward the river and the potential for exposure of aquatic receptors to groundwater contaminants is increased. Figures 2 and 3 illustrate the inferred hexavalent chromium distribution in 100-KR-4 OU during the low river stage and high river stage periods of 2013, respectively.

In addition to the plume mapping, individual well concentration time series are evaluated to identify specific locations where concentration trends are downward, upward, or unchanged. The type of wells from which the data were collected (e.g., extraction wells or monitoring wells) is also considered in the final analysis.

**Capture Analysis**

Two hydraulic capture analyses are performed, one using a traditional water table mapping approach, and the other based on results of simulation of groundwater flow using a wide-area numerical model developed for fate and transport analysis in the Hanford 100 Areas. Groundwater elevation in the 100 Areas is dynamic, exhibiting seasonal and diurnal variations in gradient resulting from operation of the extraction and injection wells as well as from the variations in river stage. The Columbia River exhibits seasonal variations in stage up to 4 meters or more, with diurnal fluctuations of 2 meters or more (Figure 4).

The water table mapping approach uses groundwater elevation measurements collected from monitoring wells, derived heads from operating extraction and injection wells, and the boundary condition water elevation of the adjacent Columbia River. Monitoring well elevations are collected by hand measurements during groundwater sampling events and by a system of pressure transducers and data loggers in selected wells. Dynamic head measurements in injection and extraction wells are collected from in situ pressure transducers that provide operational level control to the pump-and-treat systems. The river stage elevation, which defines the down gradient discharge boundary condition, is assembled from a combination of local pressure transducers and data loggers placed at selected locations, and from derived elevations based on measurements reported by the United States Geological Survey (USGS) at a nearby, upstream location. For the river protection analysis, interpolated water table contour maps are created on a monthly basis, using all available measurements and a combined capture analysis (the Interpolated Capture Frequency Map), based on conventional inferred gradient inspection, is prepared.

A second, independent, capture estimation is prepared using the 100 Area Groundwater Model, a MODFLOW-based numerical simulation developed to describe groundwater flow and contaminant fate and transport for the entire Hanford river corridor area. As with the groundwater elevation analysis, the modeled, or simulated, capture analysis is compiled for an entire year and a resultant capture frequency map (the Simulated Capture Frequency Map) is prepared. Both the interpolated and simulated results are presented in terms of capture frequency. Capture frequency describes the tendency for a particle at any particular grid location to move toward a groundwater extraction well. Combined monthly interpolated water level and simulated hydraulic containment maps of 100-KR-4 OU during 2013 are shown in Figures 5 and 6. The annual capture frequency summary maps for 2013 in 100-KR-4 are shown in Figures 7 and 8 for the Interpolated Capture Frequency Map and Simulated Capture Frequency Map, respectively.

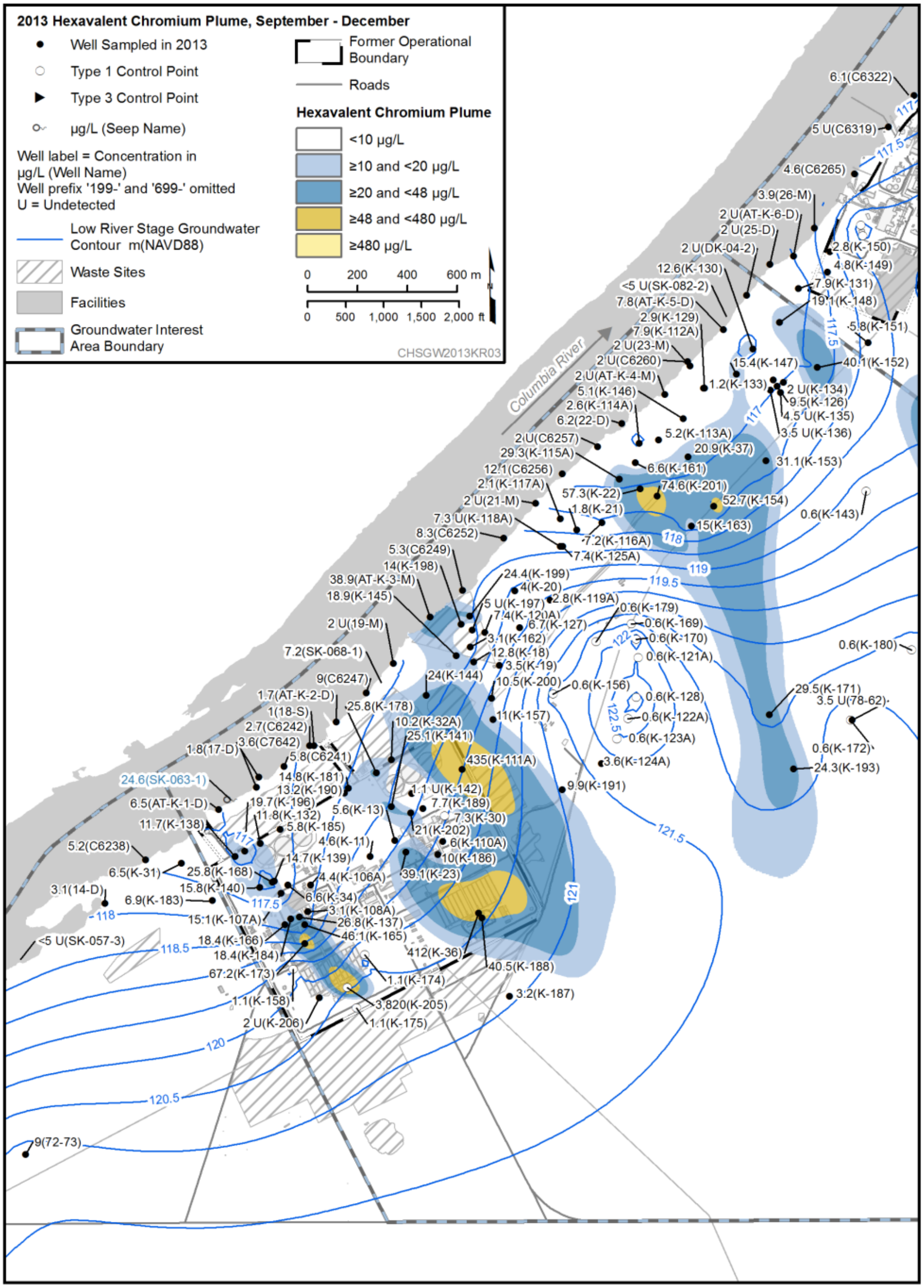


**Figure 2. 100-K Area Hexavalent Chromium Plume Distribution at Low River Stage 2013.**

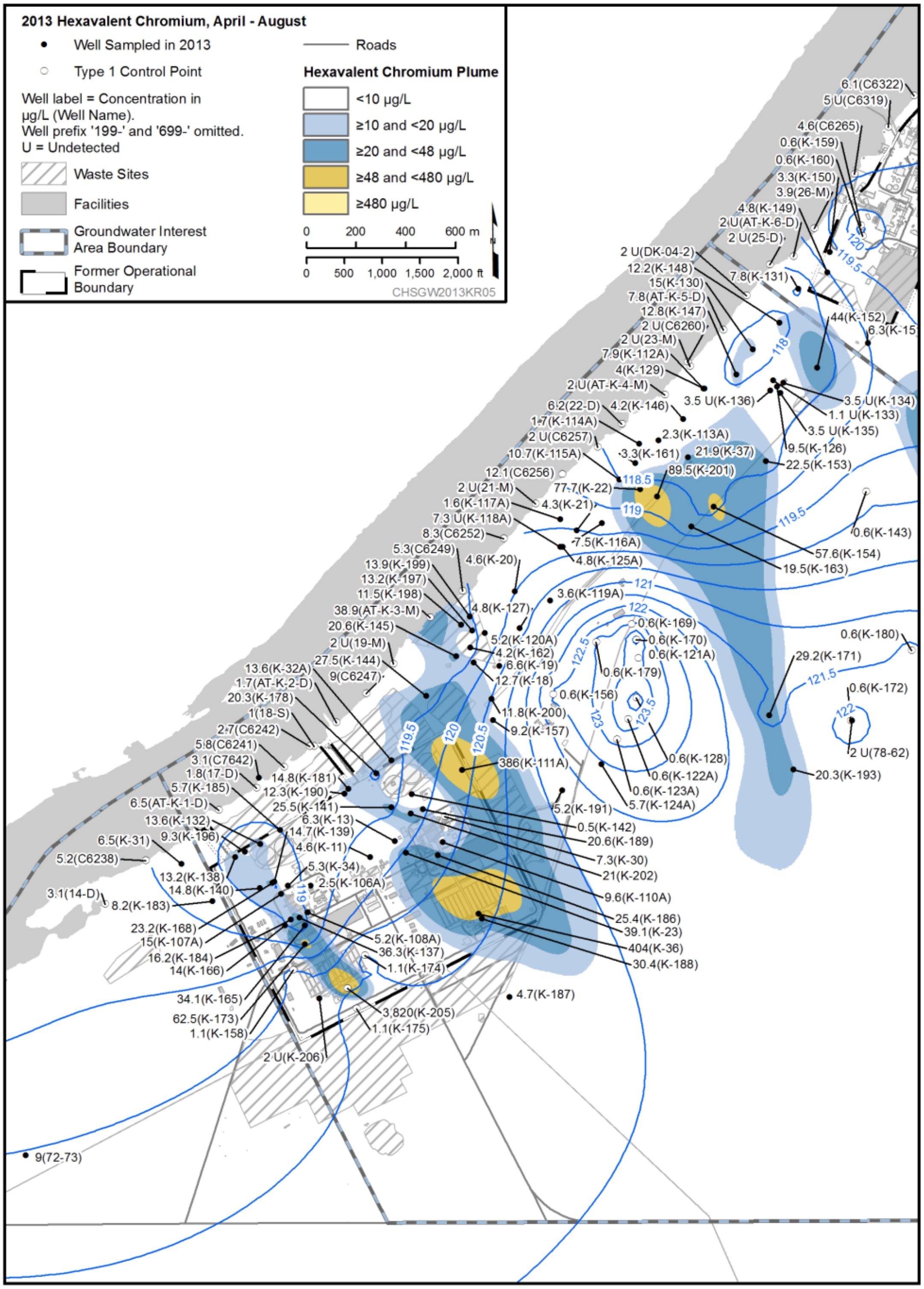


**Figure 3. 100-K Area Hexavalent Chromium Plume Distribution at High River Stage 2013.**

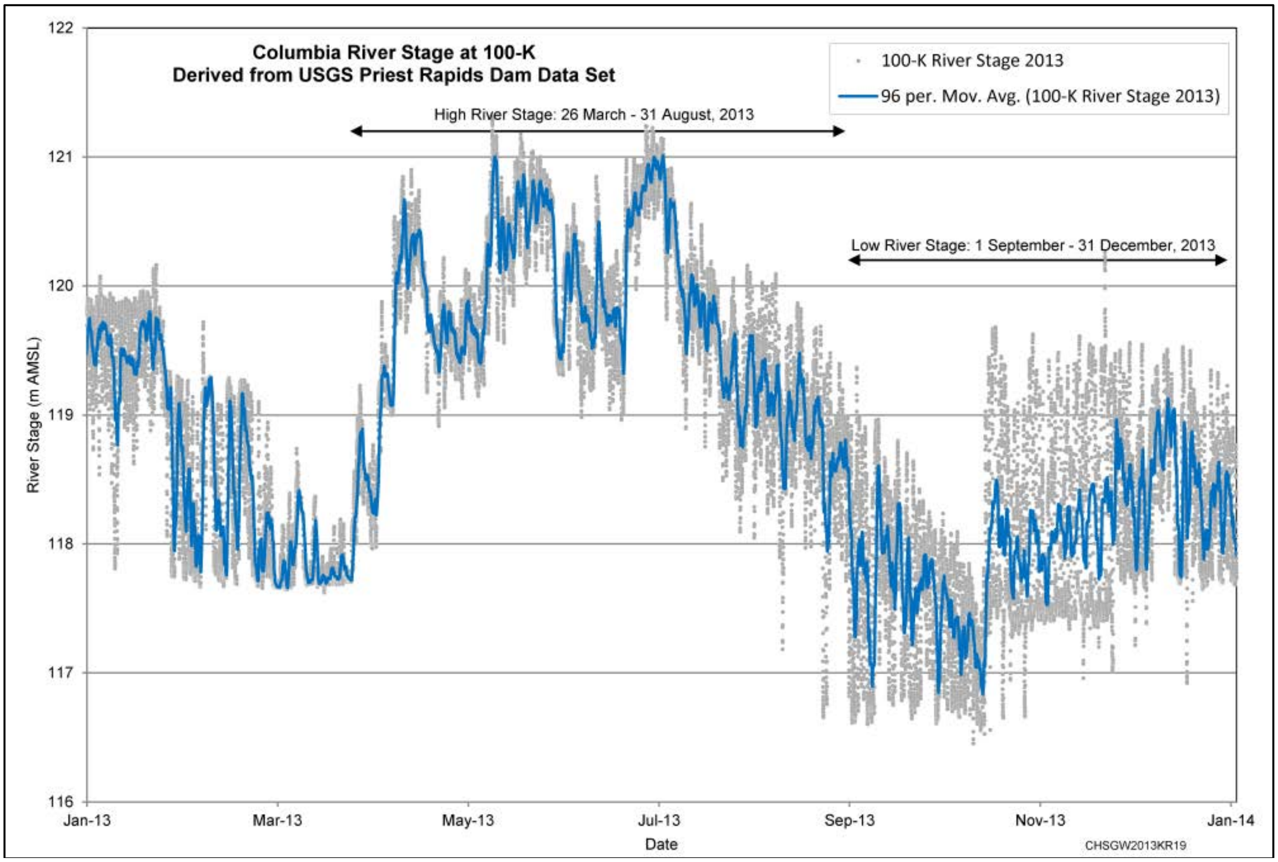

**Figure 4. Columbia River Stage Elevation at Hanford 100-K Area, 2013.**

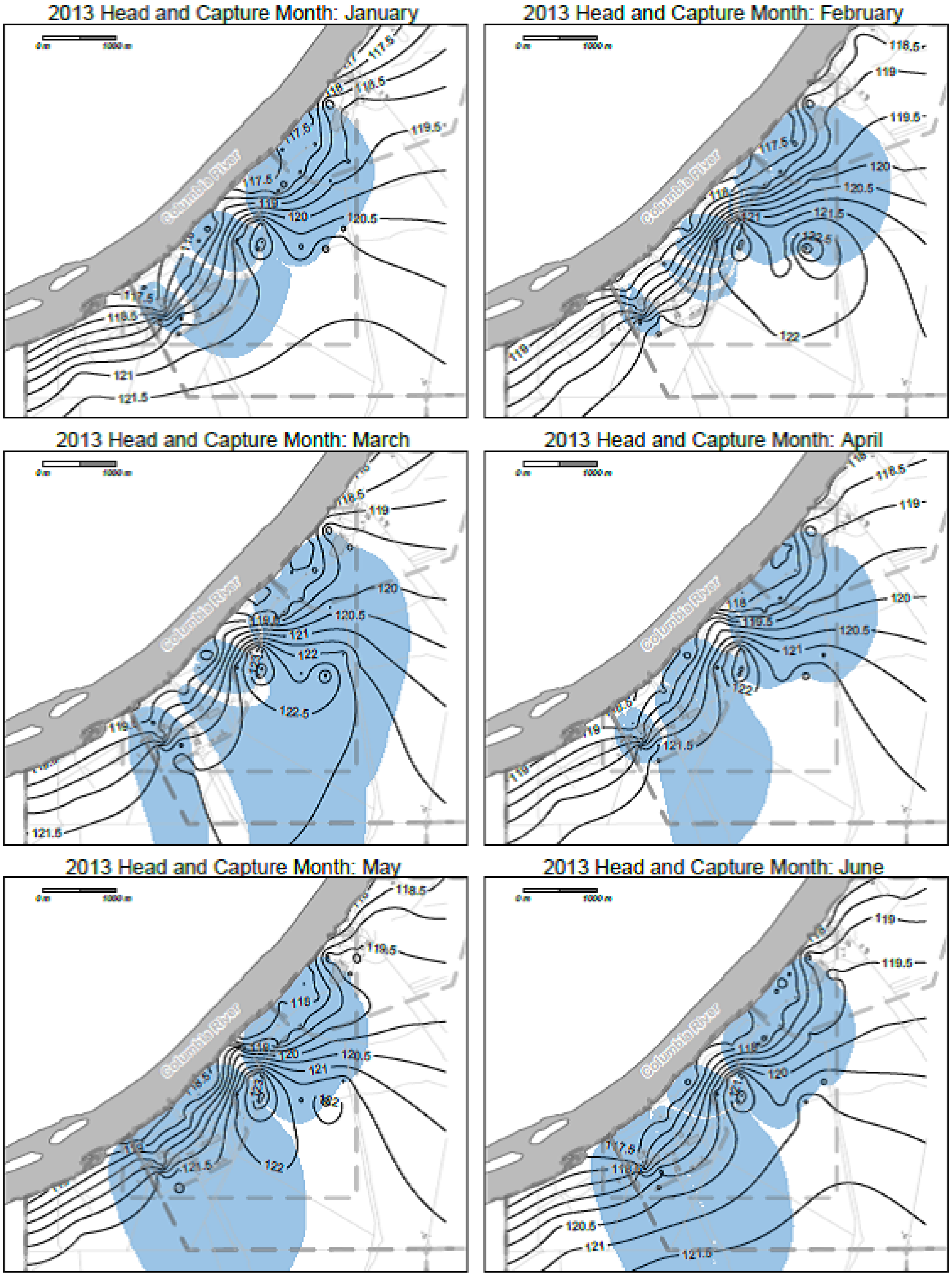


**Figure 5. 100-K Monthly Water Table and Simulated Capture for January through June 2013.**

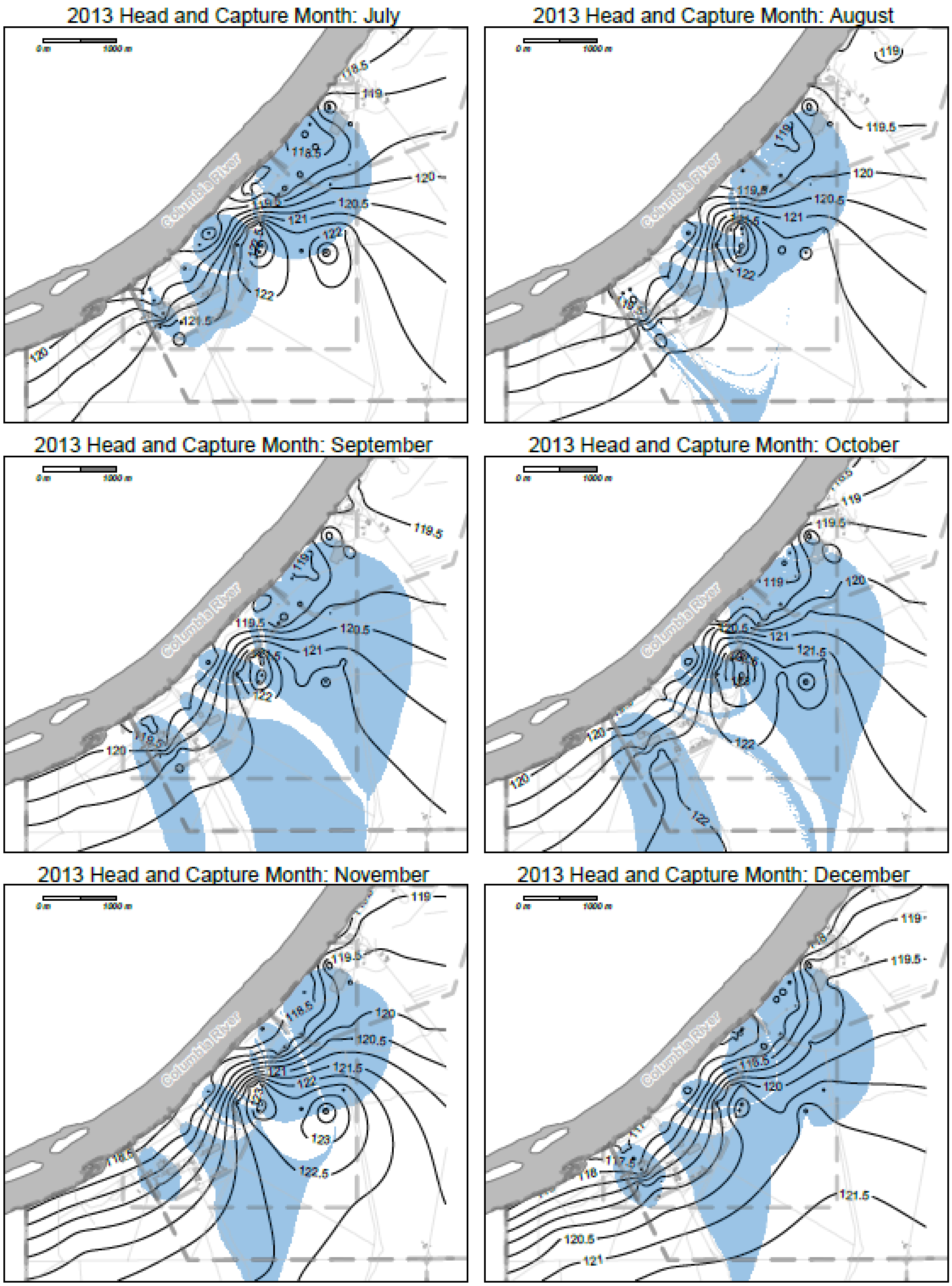


**Figure 6. 100-K Monthly Water Table and Simulated Capture for July through December 2013.**

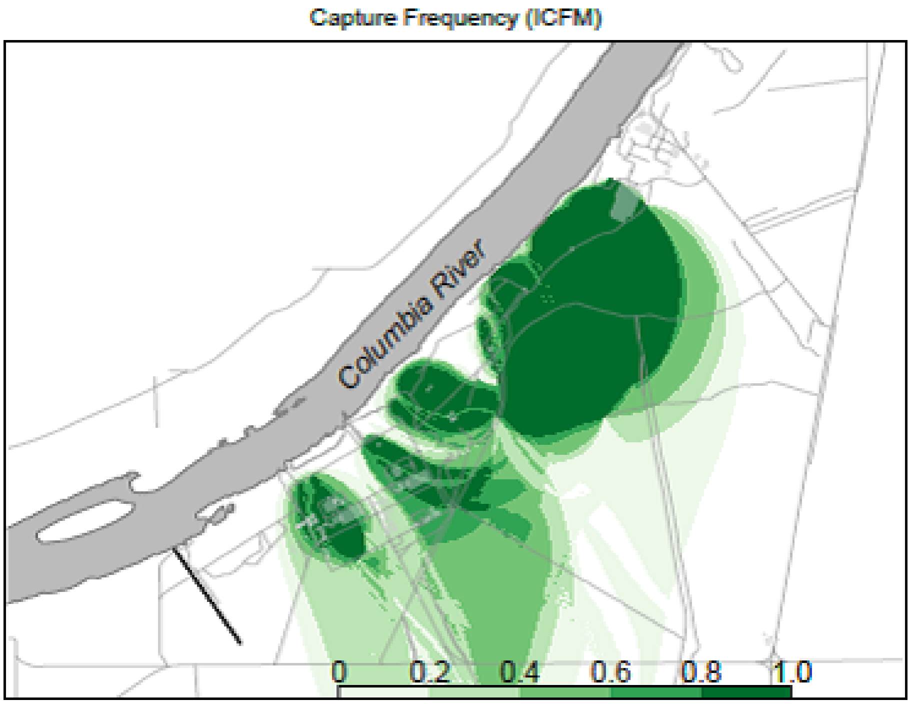


**Figure 7. 100-K Area Combined Interpolated Capture Frequency Map for 2013.**

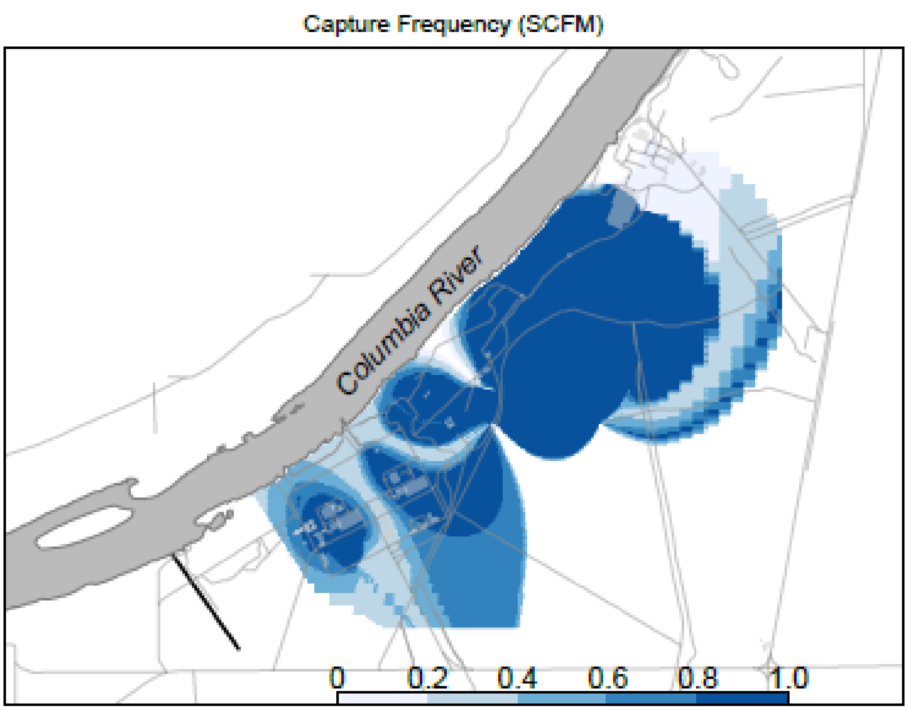


**Figure 8. 100-K Area Combined Simulated Capture Frequency map for 2013.**

## River Protection Analysis

The river protection analysis is performed by assembling the plume map with the capture frequency maps.

The plume distribution map based on the low river stage is selected for the analysis because it represents the highest potential exposure conditions at the river shore. A graphical depiction is then prepared that illustrates the conditions of groundwater hexavalent chromium concentration distribution, interpolated capture frequency, and simulated capture frequency on a single set of axes. An axis plot is prepared for a series of transects, each extending perpendicular inland from the river shore a distance of 1000 meters (1 kilometer). Transects are positioned on 100-meter centers starting upstream of the affected aquifer area and extending beyond the downstream extent of the affected area. The plots of conditions along each transect are then inspected to identify the point along each transect where the groundwater concentration exceeding the target hexavalent chromium concentration (i.e., 10 micrograms/liter) intersects the inferred capture frequency. Where the transect intersects a capture frequency of 90% or greater for both the Interpolated Capture Frequency and the Simulated Capture Frequency before it intersects a plume concentration exceeding the target, then that transect is assumed to be "protected". An example of a single transect examined for the 100-KR-4 in 2013 is shown in Figure 9; a total of 132 transects were used for the 2013 analysis at 100-K Area. Analysis of alternative conditions may result in classification of a transect as "protected, additional action may be required", or "not protected". The logic diagram for performance of the river protection analysis is shown in Figure 10. The assembled result of the river protection analysis for the 100-KR-4 for 2013 is shown in Figure 11. Each of the colored (i.e., green, yellow, red) circles along the river shore represents the evaluated condition along the inspection transect extending inland from the center of the circle.

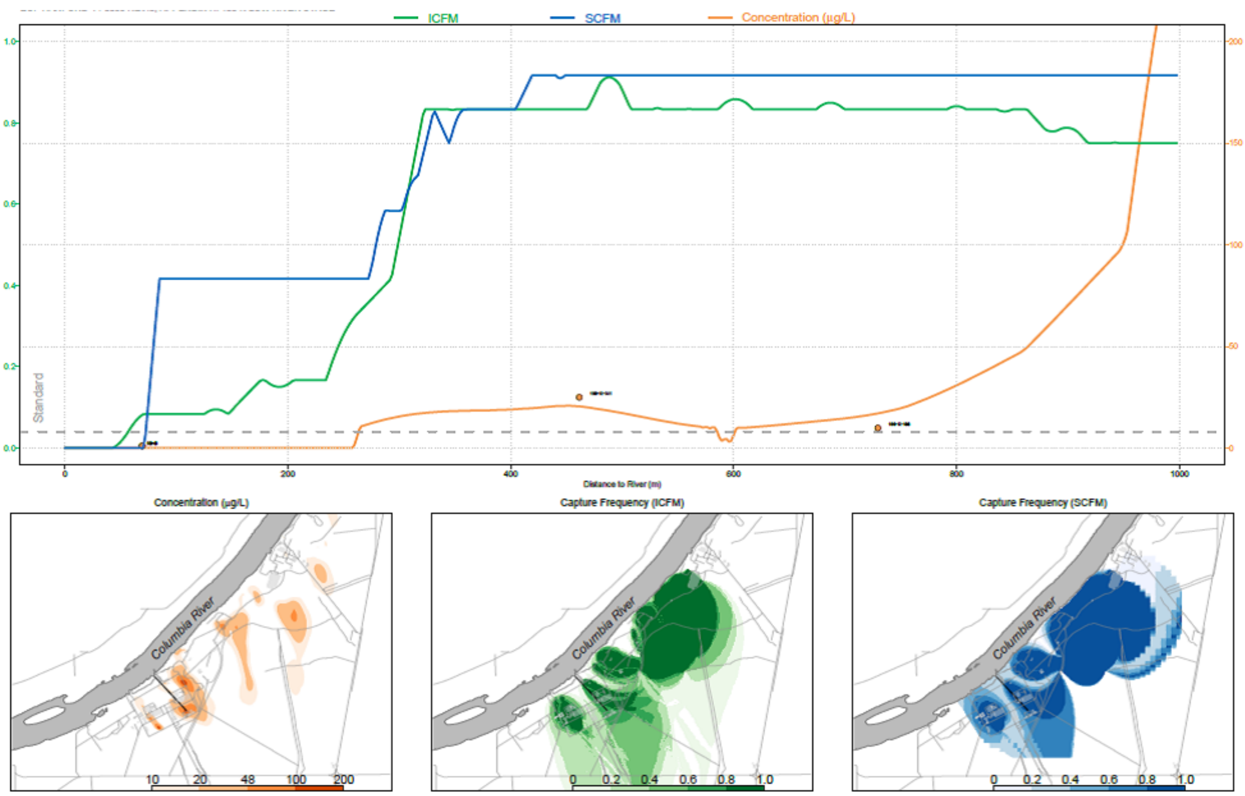


**Figure 9. Transect Conditions Indicating River Protection Status.**

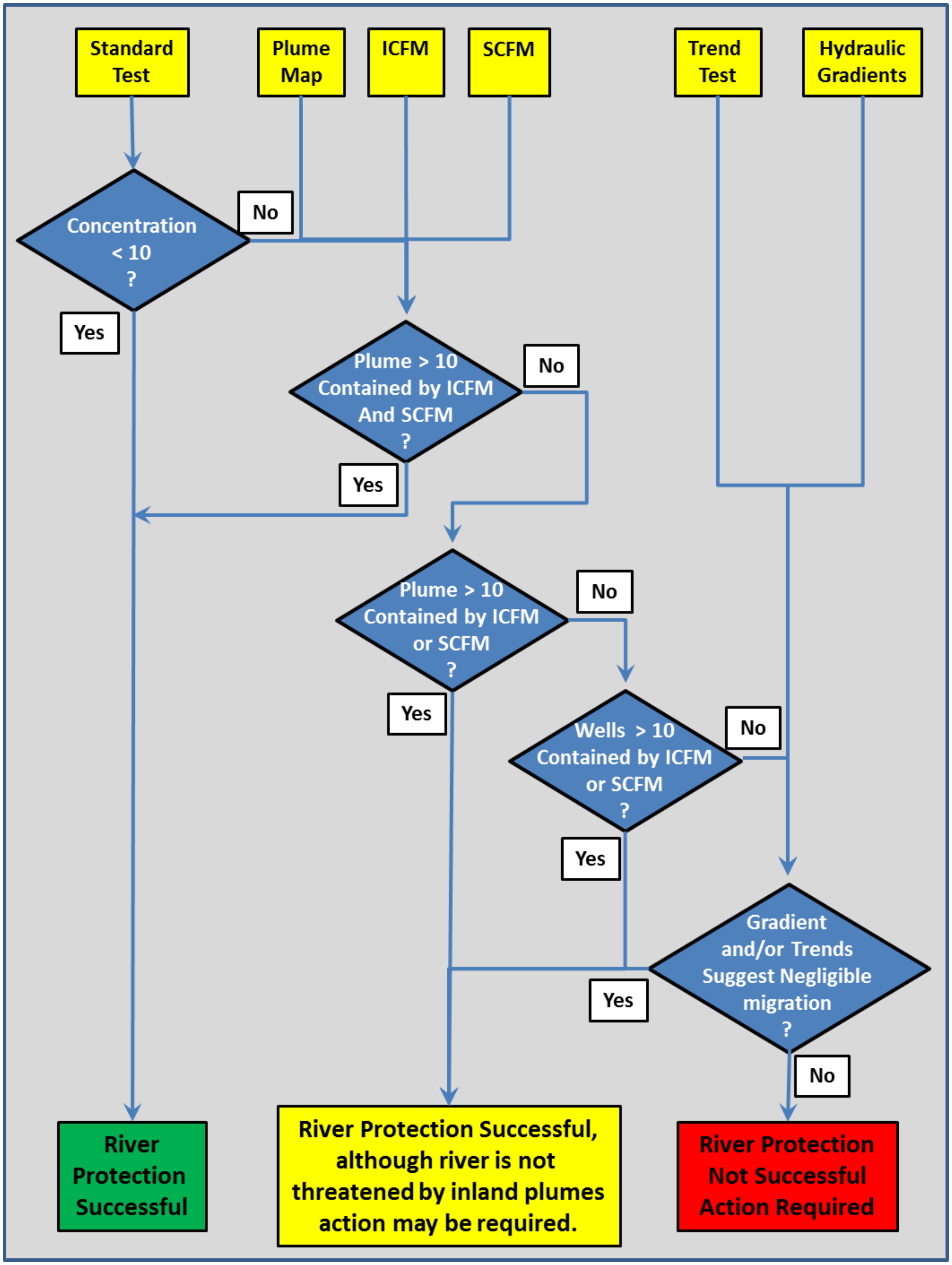


**Figure 10. River Protection Analysis Logic and Assignment of Categories.**

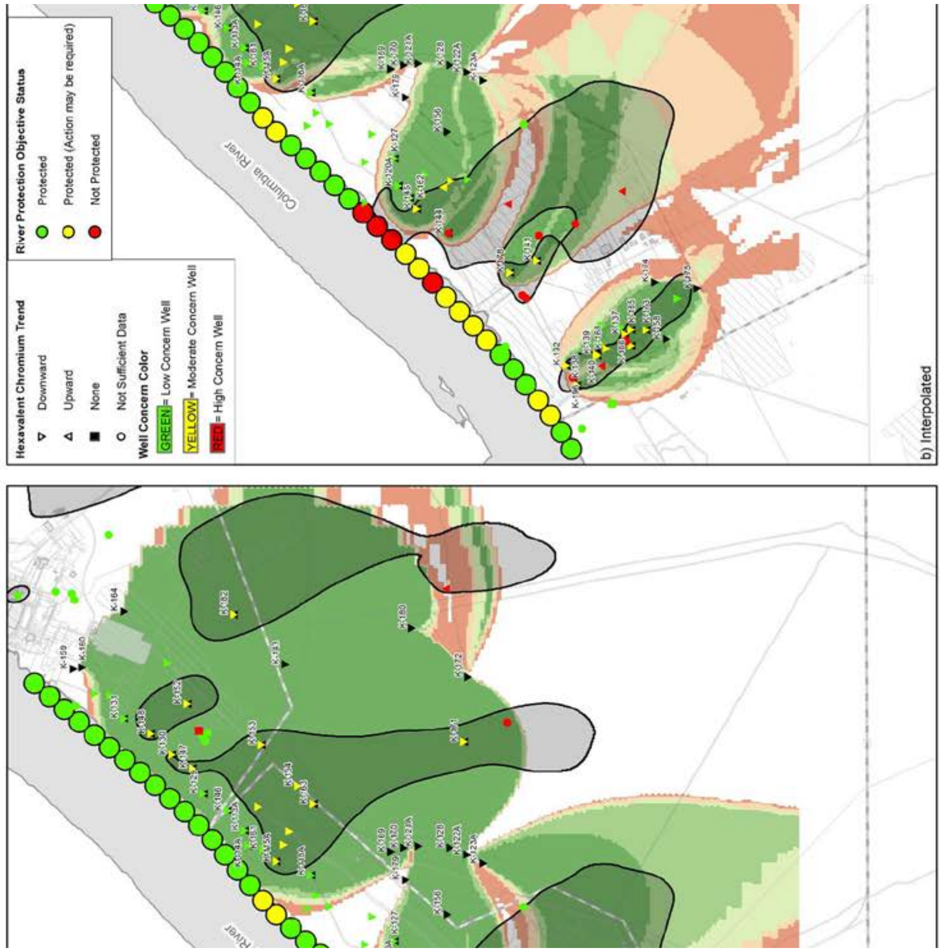


**Figure 11. Summary Graphic Indicating River Protection Status of Columbia River Shoreline at 100-K Area in 2013.**

## CONCLUSIONS

The river protection analysis has been implemented successfully in the Hanford 100 Areas to describe the efficacy of interim groundwater remedial actions. The results of the analysis present both a clear graphical depiction of the river protection status and clear information supporting ongoing remedial process evaluations. The shoreline areas categorized as red and yellow zones are subsequently scrutinized to identify changes in the pump-and-treat systems that will reduce, or eliminate continuing threats to aquatic receptors. In the case of 100-KR-4, remedial system optimization actions were implemented in 2013 and 2014 that are expected improve river protection at all locations with red and yellow protection classifications. These actions included installation of four new extraction wells at selected locations and conversion, or realignment, of four existing wells to extraction service. The river protection analysis will be performed for calendar year 2014 and compared to the previous year's performance.

## REFERENCES

1. U. S. DOE, *Hanford Site Groundwater Monitoring Report for 2013*, United States Department of Energy, August 2014, DOE/RL-2014-32, http://www.hanford.gov/c.cfm/sgrp/GWRep13/start.htm

2. U. S. DOE, Calendar Year 2013 Annual Summary Report for the 100-HR-3 and 100-KR-4 Pump and Treat Operations and 100-NR-2 Groundwater Remediation, September 2014, DOE/RL-2014-25, Rev. 0, http://www.hanford.gov/c.cfm/sgrp/GWRep13/start.htm

3. M.J. Tonkin, "Systematic Method for Evaluating the Length of the Hanford Reach of the Columbia River Shoreline that is Protected from Further Discharges of Chromium from the 100 Area Operable Units (OUs)", S. S. Papadopulos and Associates, Prepared for U.S. Department of Energy, February 2013.

## ACKNOWLEDGEMENTS

CH2MHILL Plateau Remediation Company, Inc., acknowledges the continuing technical support from the staff of S. S. Papadopulos and Associates in performing critical analysis of groundwater conditions at Hanford.