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Technical Solutions Study – Hanford Operations

Optimization of Groundwater Pump and Treat Systems at Hanford

Prepared by

The Office of Cleanup and Acceleration
Core Technical Group (EM-23)

September 30, 2004

EXECUTIVE SUMMARY

At the request of the U.S. Department of Energy (DOE), Richland Operations Office (RL), DOE's Office of Environmental Management, Core Technical Group (EM-23) performed a Remediation System Evaluation (RSE) of selected ground water pump and treat systems at the DOE Hanford Site. The RSE process, developed by the U.S. Army Corps of Engineers (ACOE), is an independent and holistic evaluation of the system intended to meet the following primary objectives:

- Assess the performance and effectiveness of the system to achieve remediation objectives.
- Identify opportunities for reductions in operational costs.
- Verify that a clear and realistic exit strategy exists for the site.
- Confirm adequate maintenance of government-owned equipment.

In addition, the RSE was also intended to identify applicable numerical simulation optimization approaches to improve the extraction systems at Hanford.

The RSE process provides recommendations that are not prescriptive, but should be considered by the project team and stakeholders for possible implementation as deemed appropriate. The RSE process (and report format) has been used successfully at a large number of Department of Defense and US EPA sites and one NASA site and this approach is applied here.

The four remediation systems addressed in this study, 100-NR-2, 100-KR-4, 100-HR-3, 200-UP-1, are located on the DOE Hanford Site. The RSE site visit in April 2004 found the four ground water extraction and treatment systems at Hanford evaluated herein are generally well run and maintained. The operators are knowledgeable and have a strong dedication to maintaining and improving the system. The operating contractor and PNNL have considered ways to cost-effectively manage the ground water contaminant plumes, including alternative technologies such as apatite or dithionate injection, and modifications to the existing ground water extraction and treatment systems, such as changes in approach to changing ion-exchange resins.

The benefits of continuing the operations of two of the systems, 100-HR-3 (100-H area only) and 100-NR-2 have been debated. Though the 100-H system has been quite successful in reducing chromium concentrations, the extracted water now exhibits concentrations near the clean-up level for chromium and well below the discharge criterion. Through negotiations with the regulatory agencies and other stakeholders, extraction of ground water at the 100-H site may ultimately be terminated as extracted concentrations continue to decline. There have been a number of studies conducted by DOE that indicate little additional value for extraction and treatment at the 100-N area. The regulatory agencies have seen value in continued operation of the system to maintain containment of the plume and reduction of Sr-90 flux toward the river. As these issues are discussed, consideration should be given to the simple recirculation of untreated water at the two sites. This would continue to reduce contaminant loading on the

Columbia River, yet would avoid the substantial treatment costs currently incurred. Potential annual savings may be over $175,000 for the 100-H area and $110,000 for the 100-N.

The ability of the 100 Area extraction systems to contain the chromium and strontium plumes is evaluated through the use of simplified flow modeling. The evaluation is limited by the models' inability to specifically consider the potential vertical components of flow, site hydrogeologic heterogeneity, and the highly significant transient changes in the river stage and the effect of these changes on ground water flow. Rigorous verification of capture would require additional characterization including the installation of additional piezometers to verify the development of the necessary capture zones. Such effort may not be necessary since the regulatory community appears willing to accept some uncertainly in the capture zone.

The costs incurred for operating the 100 Area systems are very high, especially for ones with a high degree of automation. The need for the 11 operators to operate these systems must be re-examined. The staffing levels could be reduced by more than half. This recommendation is based on observations at numerous other Federal remediation sites with comparable complexity. Such a change could potentially save over $600,000 annually.

The replacement and disposal of ion-exchange resins represent a significant cost. The use of alternative regenerated resin for lead-vessel uranium removal could save $36,000 annually. The project team is considering the use of the MR3 adsorption system as a replacement for the current ion-exchange system. The RSE team is concerned that such a system is largely unproven at full-scale for chromium removal and will represent a substantial increase in the level of required operation and maintenance. As a result, the RSE team urges other alternatives be considered instead.

The use of ex-situ zero-valent iron treatment for chromium reduction and removal in lieu of ion exchange processes could save $1.5 million annually, and would cost perhaps $750,000. In-situ treatment could save significant sums for treatment over the life of the projects. The RSE team recommends the Hanford team consider in-situ bioremediation using soluble carbon sources such as lactate or emulsified vegetable oils, but such approaches would require pilot testing with clear decision criteria for full-scale implementation.

Some reductions in the monitoring program could be easily implemented without jeopardizing the ability to respond to changes in the migration and remediation of the contaminants. Additional characterization of the vertical extent of the plume at 200-UP-1 and the lateral extent of the chromium plumes at the 100-D area (southwest and northeast of the extraction system) and 100-H area (southeast of the extraction system) is recommended. The report includes a table (Exhibit 19) of recommended removal of select monitoring points, reductions in frequency of sampling, and reductions in the analytical program. The RSE team acknowledges another technical assistance team will be addressing this issue in more detail. The implementation of additional extraction wells in the 100-D area to address the migration of chromium through the gap between the existing extraction system and the ISRM is appropriate. The pump and treat technology is proven for containment of contaminant plumes and this represents only an expansion of an existing technology in place at the site.

The Hanford project team should clarify goals and exit strategies for each site. A negotiated approach for deciding when to cease (or restart) pumping from specific extraction wells or from the site as a whole would formalize the decision process. The exit strategy should consider:

- True protection of aquatic species in the Columbia River
- A clear program to address remaining sources; either to remove or render them inert
- Establishment of milestones for plume concentration reductions, with contingencies for additional or focused extraction to reduce hot spots (this has reportedly been accomplished for the systems at Hanford and documented in reports that were not made immediately available for this review)
- A negotiated framework for deciding when extraction from specific wells, and treatment processes, can be terminated
- Consideration of alternatives to ground water extraction

The exit strategy must consider source treatment. This will require additional characterization of the source areas to the extent necessary to cost-effectively implement a remedial alternative and to develop useful ground water models that can be used in decision-making and optimization. The RSE team suggests an evaluation and decision process be initiated when the extraction well concentrations fall below the cleanup goal. For example, in the 100 Area, the process would entail periodically simulating the concentrations of chromium that would reach the Columbia River in the absence of the pumping from that well. When the modeling results indicate, with some certainty, that contaminant concentrations reaching the River will be below the cleanup level, the extraction can be ceased. Monitoring would then continue once the extraction well is shut down to verify the model predictions, and subsequent monitoring results would be used to recalibrate the model. If subsequent modeling suggests the plume may cause an unacceptable impact to the river, the extraction well can be restarted.

Treatment of the chromium sources should not include soil flushing, but rather other low-cost, robust techniques, though additional chromium source characterization in the 100 Areas may be warranted depending on the cost of the remedial technology. Gaseous reduction may be a robust alternative to soil flushing for vadose zone chromium treatment. The RSE team understands additional studies are underway to better understand the sources of uranium and technicium in the vadose zone at the 200-UP-1 area. Observations of the concentration trends following the cessation of pumping at this site (since it has essentially met its interim remedial goals) may help provide additional information for the conceptual site model refinement and for numerical model development.

The need to update the ground water flow and transport models depends on the future uses of the models and the rigorousness of goals set for each extraction system. Rigorous evaluations of the capture of contaminants at the 100 Area systems would require improvements in the models to better reflect heterogeneities and the impact of the river stage fluctuations. The models would also need to be improved if numerical optimization techniques were to be applied. The systems at 100-D and 100-K areas, as well as any future full-scale ground water extraction design for the 200 Area would benefit from application of numerical optimization. Substantial savings or reductions in treatment time are possible. The use of the STOMP model code in a manner similar to its use at the 100-N area may be appropriate, or the installation-wide CFEST model could be used for site-specific studies provided the resolution of the model is increased in the areas of interest and the “zoomed” model is recalibrated based on the data from the specific site.

The Hanford team is interested in the application of simulation optimization techniques to improve system performance and cost-effectiveness. The RSE team's cost-benefit analysis indicates that flow and transport optimization can be expected to substantially reduce costs at the 100-KR-4, 100-H, and 100-D areas, but the significant investment required to improve flow and transport models in the 200-UP-1 and 100-NR-2 areas are not likely to yield sufficient savings to cover the costs of the analysis. If flow and transport optimization is undertaken, a number of existing field-tested tools are available that could be used in conjunction with site-specific flow and transport models.

Exhibit 22 summarizes recommendations for improvements in effectiveness, cost reduction, and which may also help DOE gain site closeout.

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1.0 INTRODUCTION

1.1 Purpose

At the request of the U.S. Department of Energy (DOE), Richland Operations Office (RL), DOE's Office of Environmental Management, Core Technical Group (EM-23) performed a Remediation System Evaluation (RSE) of selected ground water pump and treat systems at the DOE Hanford Site. The RSE process, developed by the U.S. Army Corps of Engineers (ACOE), is an independent and holistic evaluation of the system intended to meet the following primary objectives:

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1.2 RSE Team Composition

The team conducting the RSE consisted of the following individuals:

- Beth Moore, US DOE HQ; Hydrogeologist and Review Project Lead

- Dave Becker, USACOE; Geologist and Review Team Leader

- Rob Greenwald, GeoTrans, Inc.; Hydrogeologist

- Lindsey Lien, USACOE; Environmental Engineer

- Barbara Minsker, University of Illinois; Environmental Engineer

1.3 Persons Contacted

The following individuals were contacted during the RSE to obtain their observations and input on the conduct of groundwater pump and treat operations at the Hanford Site.

- D.D. Blankenship, Operator, Fluor Hanford

- Gregory Deroos, Operator, Fluor Hanford
- Dib Goswami, Washington Department of Ecology
- Jared Isaacs, Director of Pump and Treat Operations, Fluor Hanford
- Vern Johnson, Operations Manager, Fluor Hanford
- John Morse, U.S. Department of Energy
- Bill McMahon, CH2M Hill
- Shannon McPeek, Fluor Hanford
- Scott Petersen, Fluor Hanford
- Dan Harmon, Operator, Fluor Hanford
- Tony True, Operator, Fluor Hanford

1.4 Site Locations, History, and Characteristics (200-UP-1, 100-NR-2, 100-KR-1, 100-HR-3)

The four remediation systems addressed in this study, 100-NR-2, 100-KR-1, 100-HR-3, 200-UP-1, are located on the DOE Hanford Site. The Site is located in south-central Washington approximately 4.5 mi northwest of Richland, Washington and encompasses over 540 square mi. The Hanford Site is largely located southwest of the Columbia River and consists of scrub-covered desert. The Site topography includes the Central Plateau, the Rattlesnake Hills, Gable Mountain, and the Columbia valley and related terraces. The elevations on the Hanford Site range from over 2,952 ft above sea level along the top of the Rattlesnake Hills, to approximately 394 ft above sea level along the Columbia River.

The Hanford facility was used for uranium and plutonium production and refinement as part of the US nuclear weapons program starting in World War II. Production has essentially ceased and remediation of environmental contamination is in progress. The following sections detail the locations, operational history, and physical characteristics of the areas near the remedial systems evaluated as part of this study.

1.4.1 Site Location and Land Use

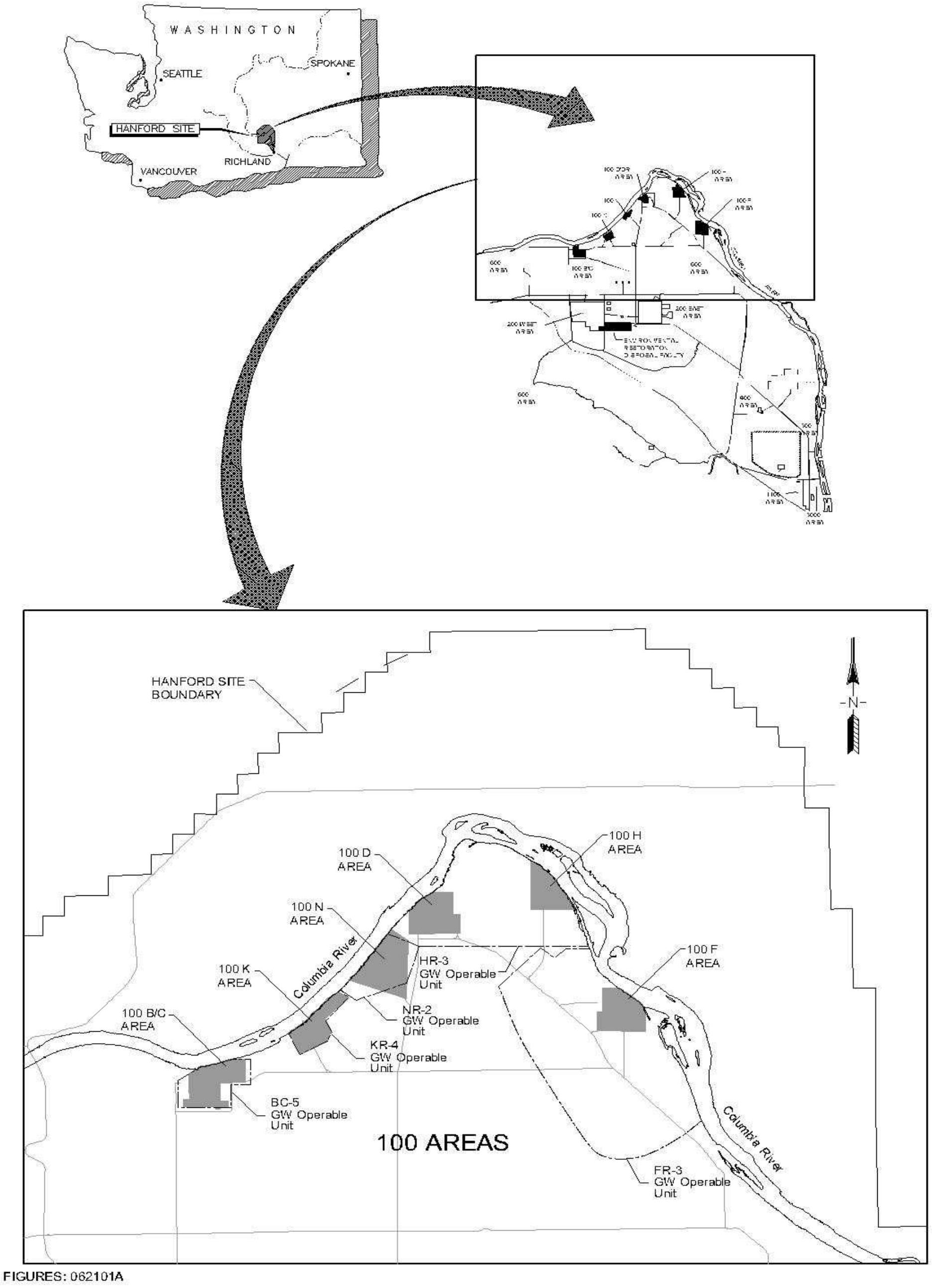
The 100-NR-2, 100-KR-1, and 100-HR-3 extraction and treatment systems are located along the Columbia River in the northern portion of the Site. The 200-UP-1 extraction system is located in the west-central portion of the site in the 200 West industrial area. Treatment of water produced at the 200-UP-1 site is piped to the Effluent Treatment Facility (ETF) located several miles away. The ETF was not evaluated as part of the study. Exhibit 1 shows the locations of the sites. Site land use is generally industrial with environmental restoration efforts as the only real activities. The land use across the Columbia River (at some distance from the 100 Area) is agricultural. The Columbia River is used for recreation, fishing, and as important habitat for salmon and other aquatic species.

1.4.2 Site History

The reactors in the 100 Area were used for plutonium production. During operation of the 100-D/DR, 100-HR-3, and 100-KR-4 Reactors, large volumes of water were pumped from the Columbia River to cool the reactors. Sodium dichromate was added to the cooling water to inhibit corrosion of the reactor piping. The cooling water containing hexavalent chromium was discharged into various structures on site and leaked into the soil, contaminating the groundwater. Water has continued to be discharged to or stored in one basin (182 basin) at the DR area, and leakage is suspected. Leaks and spills related to the process of mixing the dichromate into the water also potentially contributed to soil and ground water contamination, particularly at the 100-D facilities. Ground water extraction systems have been in place generally since the mid- to late-1990s at these sites (1997 for the KR and HR areas, 1998 for the DR area).

In 2000, an In Situ Redox Manipulation (ISRM) barrier was established southwest of the DR area ground water extraction system to address a different chromium plume. The injection of sodium dithionate occurred along a line of wells parallel to the Columbia River and is intended to establish long-lasting reducing conditions to treat the shallow chromium contamination found to exist in that area through the reduction of natural iron (ferric) oxides to the ferrous state. The reduced iron would continue to reduce hexavalent chromium to its less toxic and less mobile trivalent form. The ISRM barrier is being assessed for improved performance through additional aquifer characterization studies and evaluation of emerging amendments.

Exhibit 1: Location of Pump and Treat Sites



The operation of the 105-N Reactor required the use of pass-through cooling from the reactor's primary cooling loop, the spent fuel storage basins, and other reactor-related sources (ITRD, 2002). The system was not truly closed-loop, however, as some water was continually added and withdrawn from the flow. Decontamination solutions and small amounts of rinsate from these activities were diverted to the 1301-N or 1325-N Liquid Waste Disposal Facilities (LWDFs). Liquid discharges to this facility contained radioactive fission and activation products, including cobalt, cesium, strontium, and tritium. As discharged effluent percolated through the soil column, radioactive and hazardous constituents were retained in the soil. Other contaminants that sorb less readily to the soils, traveled directly to the groundwater and on to the Columbia River. The contaminant of concern at 100-N is strontium-90 (Sr-90). A pump and treat system has been operating at the NR area since 1995.

The facility at the 200-UP-1 site recovered uranium starting the 1950s into the 1990s. Waste water containing various contaminants, including uranium and technetium, were discharged to several “cribs” or wooden sumps.

1.4.3 Site Characteristics

1.4.3.1 Hydrostratigraphy

The Site is underlain by Pleistocene-age catastrophic flood deposits (primarily sands and gravels) of the Hanford formation, semi-consolidated sands, silts, and clays of the Ringold Formation, and Tertiary-age flood basalts that typify the surrounding Columbia Plateau. Faulting and folding have affected the basalts and older alluvial deposits at the facility. Gable Mountain represents an exposure of uplifted basalts.

Where saturated, the Hanford Formation has a high hydraulic conductivity and hosts productive extraction wells. It can display significant heterogeneity. The Ringold Formation at the sites includes heterogeneous units of water-bearing sands and gravels (the Unit E sand and gravel most notably), and less permeable silty sand to clay of the Lower Ringold Mud Unit. The base of Unit E is an erosional surface and at the D area, the Unit E has been deposited in a trough eroded through the Lower Ringold Mud Unit. Though the Hanford Formation typically rests on the Ringold Unit E, in places including the H area, the Hanford unit was deposited directly on the Ringold Mud Unit, following the erosion of the Unit E. The basalts have significant hydraulic conductivities associated with the rubble zone at the tops of individual flows, though the intact cores of the flows are generally considered aquitards.

1.4.3.2 Site Ground Water Conditions

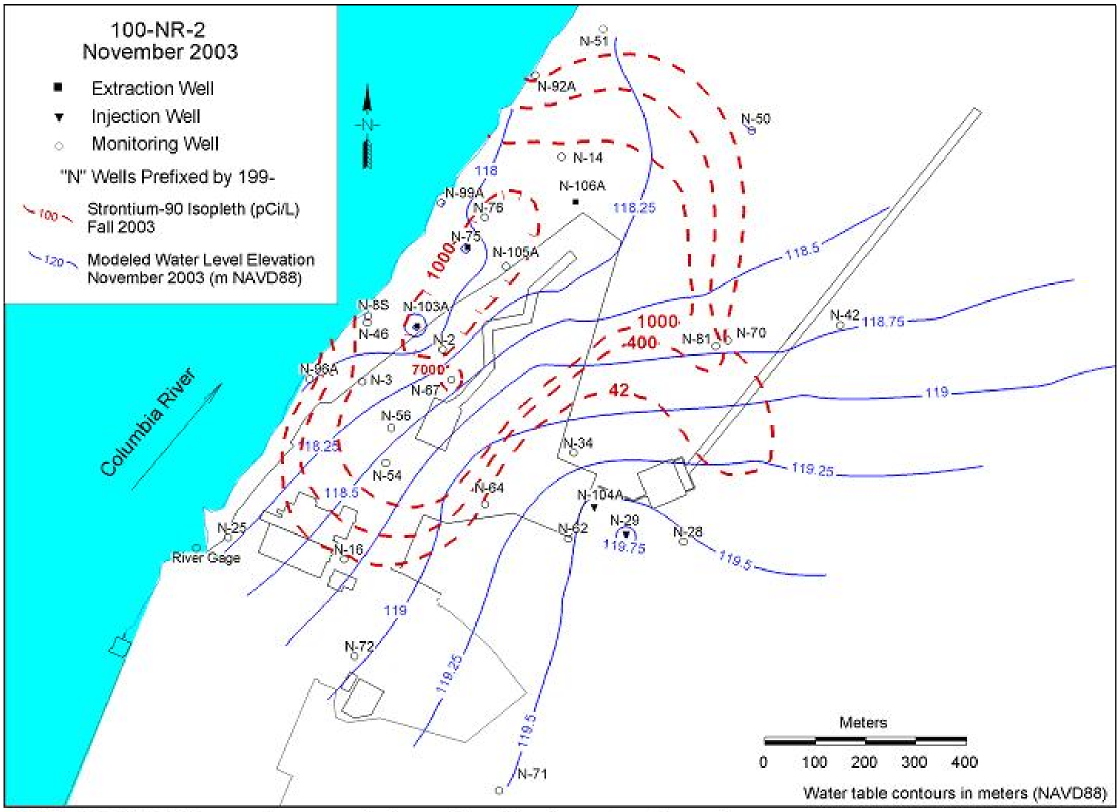
Ground water at the 200-UP-1 area is found in the Ringold Unit E at depths of greater than 164 ft below the surface. Ground water flow in that area is generally west to east. Water levels are slowly falling due to cessation of artificial groundwater recharge from historical discharges to ponds and wells associated with process operations and disposal.

At the DR/HR, KR, and NR areas, ground water is encountered in either the Hanford (e.g., the DR area), or Ringold Unit E (e.g., the HR area) at depths of approximately 82 ft. At the DR area, ground water flow is generally to the north in the vicinity of the ground water extraction system, and west near the ISRM barrier. The flow is strongly affected by use of the 182-D reservoir that creates a ground water mound that in the past had separated the plumes addressed by the ground water extraction system and ISRM barrier, respectively. Cessation of use of the basin has apparently resulted in the migration of chromium toward the gap between the extraction wells and the existing ISRM barrier. Consequently, the 100-HR-3 pump and treat system is being extended toward the barrier to intercept ground water flowing through the gap toward the River. At the KR and NR areas, ground water flow is generally northwest toward the Columbia River. The Columbia River has a significant effect on the ground water flow at the sites in the 100 Area. Under normal conditions, the river is a gaining stream in the vicinity of the 100 Area. Increases in river stage of 10-16 ft due to the operation of upstream dams can cause a reversal of ground water flow in the vicinity of the sites and the storage of water in the materials along the river. Modeling studies documented in a DOE ITRD report (2002) indicate that river fluctuations influence the unconfined aquifer flow gradient up to 4,000 ft in from the river edge.

1.4.3.3 Site Contaminants and Sources

At the 100-D, 100-HR, and 100-KR-4 areas, the contamination is primarily chromium with some radionuclides such as strontium-90 (Sr-90) and tritium. At the 100-NR-2 area, the primary contaminant is Sr-90. At the 200-UP-1 area, the primary contaminants are uranium and technetium-99 (Tc-99). Exhibits 2 through 6 show the configuration of the contaminant plumes at each site.

Exhibit 2: 100-NR-2 Plume



*Well 199-N-105A is used as a monitoring well and backup extraction well.

Exhibit 3: 100-KR-4 Plume

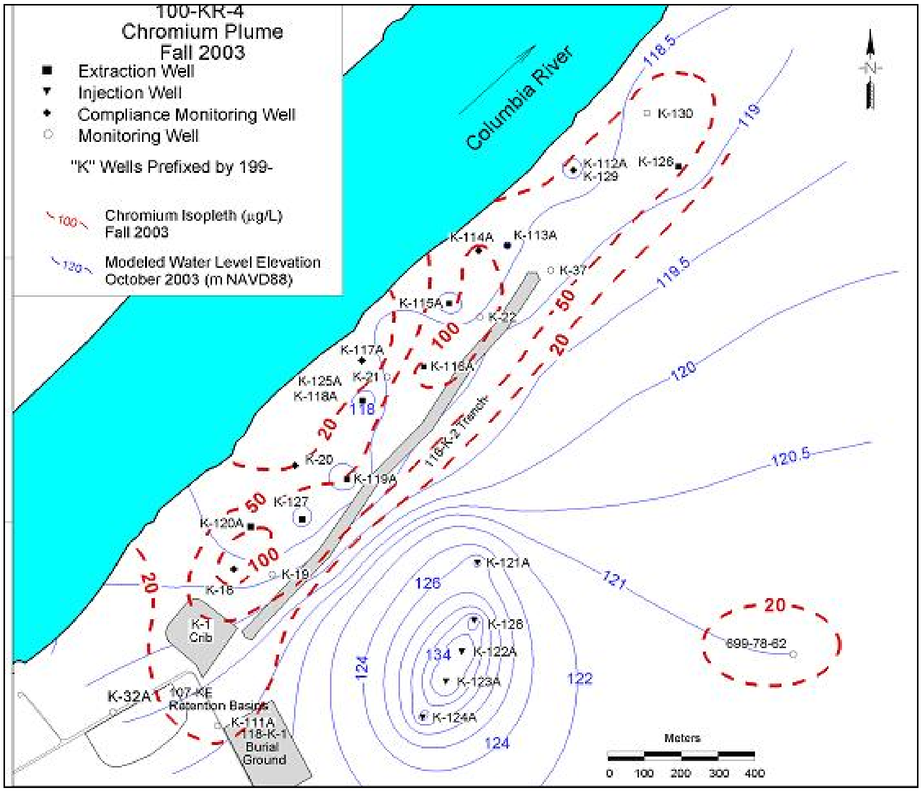


Exhibit 4: 100-HR-3 Plume, H Area

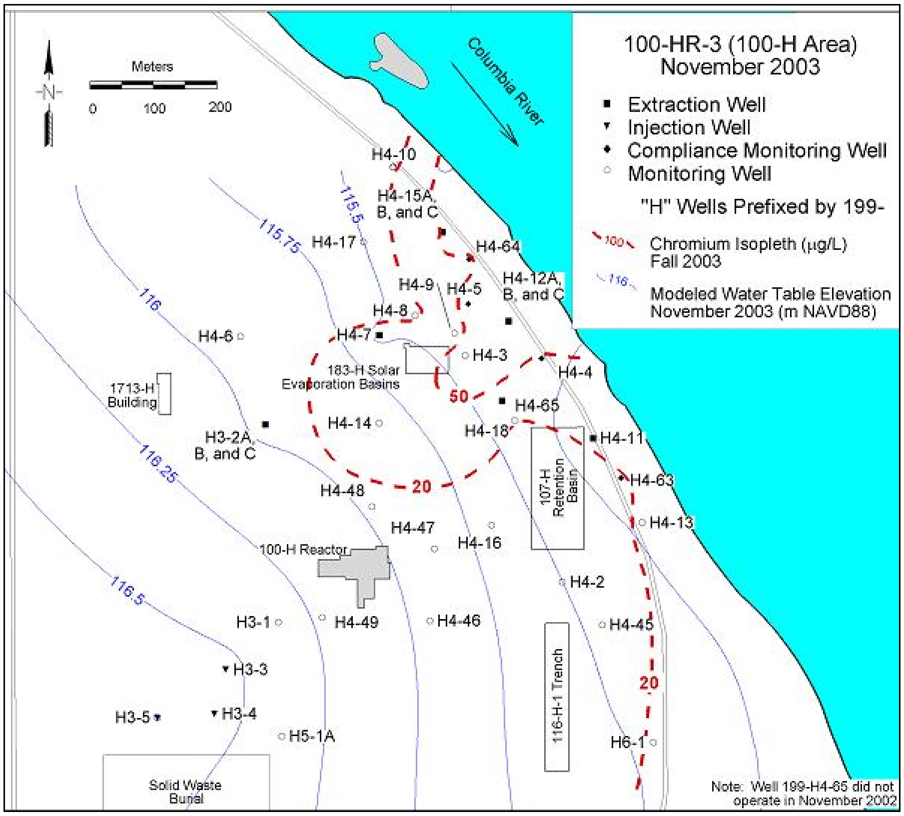


Exhibit 5: 100-HR-3, D Area

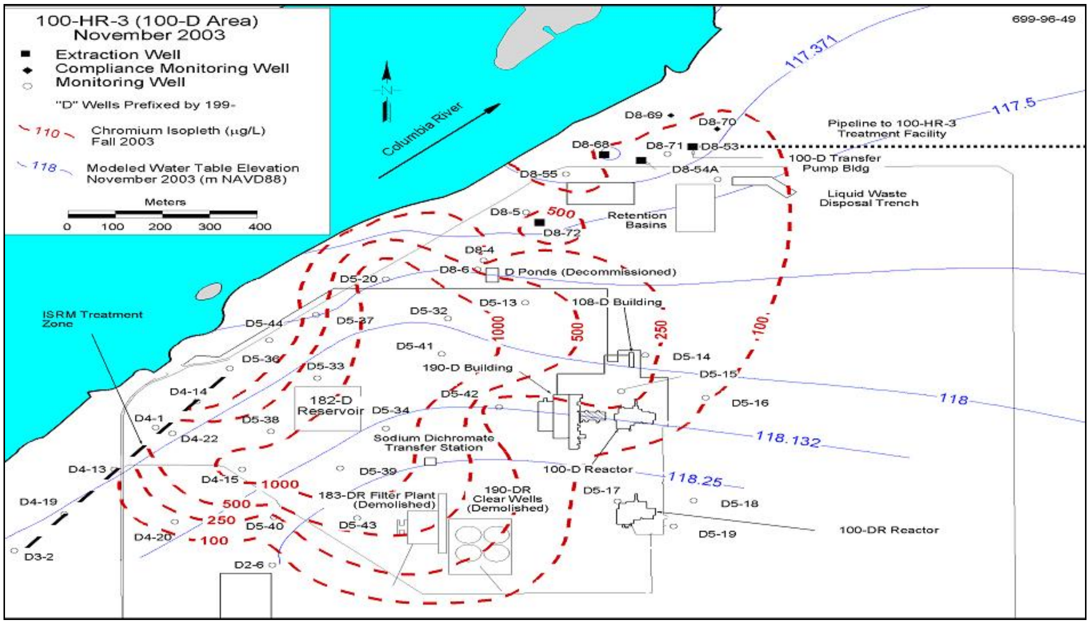
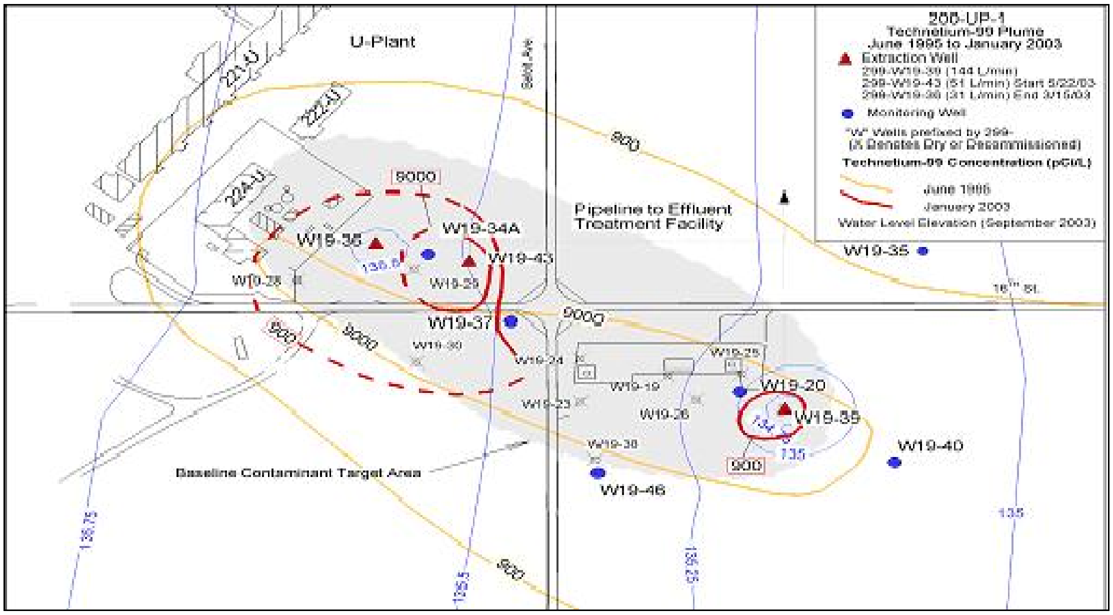


Exhibit 6: 200-UP-1 Plume



2.0 SYSTEMS DESCRIPTION

2.1 System Overview

2.1.1 Area 200-UP-1

The 200-UP-1 Groundwater Operable Unit (OU) pump and treat system is an interim remedy removing primary contaminants uranium and Tc-99, and secondary contaminants carbon tetrachloride and nitrate. The entire 200-UP-1 Groundwater OU addresses conditions and plumes beneath the southern third of the 200 West Area and adjacent portions of the surrounding 600 Area. (The adjacent 200-ZP-1 area is also located in the 200 West Area, but the pump and treat system at 200-ZP-1 was not evaluated as part of this effort). Carbon tetrachloride and nitrate plumes are extensive over the 200 West Area, but are considered secondary contaminants at 200-UP-1. Reductions to secondary contaminants' plume sizes and mass reductions from treatment at the 200-UP-1 OU are beneficial but of minor impact to the overall 200 West Area plumes. Water from the 200-UP-1 OU is transferred to the ETF, which is designed to treat water from a variety of sources including water from the vitrification facility currently under construction.

2.1.2 Area 100-NR-2

The 100-NR-2 pump and treat system is an interim remedy operated to reduce the migration of Sr-90 contaminated groundwater to the Columbia River. The ROD for the site requires the four extraction wells must maintain a minimum process flow rate of 60 gpm or greater. Extraction wells N-75, N-103A, and N-106A function as the primary extraction wells under normal conditions with extraction well N-105A used as a backup well. Piping is located above grade, which requires freeze protection during the colder months of the year.

The ion exchange (IX) treatment system uses clinoptilolite (clino) as an exchange media. The process must achieve and maintain an average Sr-90 removal rate of 90 percent for the volume of water treated over the entire operational cycle between ion exchange media change outs. Treated effluent is discharged into injection wells N-104A and N-29.

2.1.3 Area 100-KR-4

The 100-KR-4 groundwater remedy was initiated as an interim action to intercept and control hexavalent chromium contamination. The OU consists of a nine well extraction well network with a variable pumping capacity between 175-300 gpm, two water transfer facilities, a single combined treatment system located in the 100-K process building, and a five well groundwater injection system. The DowX 21-K resin based ion exchange system must meet a regulatory discharge limit of 50 ug/l, but is designed to maintain effluent chromium levels below 22 ug/l.

2.1.4 Area 100-HR-3

The 100-HR-3 groundwater OU remedy addresses contamination from both the 100-DR and 100-HR areas and was initiated as an interim action to intercept and control hexavalent chromium contamination. The 100-HR-3 groundwater OU consists of a ten well extraction well network with a variable pumping capacity between 205-320 gpm, two water transfer facilities, two IX treatment systems co-located in an existing process building (1713-H), and a three well groundwater injection system. The DowX 21-K resin based ion exchange system must meet a regulatory discharge limit of 50 ug/l, but is designed to maintain effluent chromium levels below 22 ug/l.

2.2 Ground Water Extraction and Injection Systems

Five different ground water extraction systems have been evaluated in this study including those at 100-D, 100-H, 100-KR-4, 100-NR-2 and at 200-UP-1. The systems include wells and (generally) above-ground piping to the respective treatment plants. The details for each system are provided below.

2.2.1 200-UP-1

Three extraction wells are currently pumping approximately 50 gpm, the stated goal for this system. The three extraction wells are 299-W19-36, 299-W19-39, and 299-W19–43. Well 299-W19-39 was designed as an extraction well, but 299-W19-36 was originally an injection well and 299-W19-43 was originally a monitoring well. Wells 299-W19-36 and –39 are 6-in-diameter steel wells with approximately 50 ft of screen and well 299-W19-43 is a 4-in-diameter well with approximately >30 ft of screen. The wells are over 210 ft deep and are screened in the Ringold Unit E. The wells are equipped with stainless steel submersible pumps that deliver water via a pre-existing pipeline to the Effluent Treatment Plant. The layout of the wells is shown in Exhibit 6.

2.2.2 100-D and 100-H Areas

Four extraction wells operate at the 100-D area and six extraction wells operate at the 100-H area, and all contribute water to the 100-HR-3 treatment plant (which is located in the 100-H area). Most wells are 6-in-diameter steel wells that extend to 75 – 90 ft below grade, though two of the wells in the 100-D area (199-D8-53 and 199-D8-54a) are 4-in-diameter wells. The wells in the northern portion of the 100-D area and the 100-H area are screened in the Hanford Formation and the wells in the southern portion of the 100-D area are screened in the Ringold Unit E. Three new extraction wells are currently being installed in the 100-D area southwest of the existing extraction wells and northeast of the ISRM barrier to capture the chromium plume migrating through that gap in containment. Extraction wells are equipped with submersible pumps with variable-frequency drive motors for flow control.

High-density polyethylene (HDPE) discharge piping is completed above ground from each well to transfer stations at the 100-D and 100-H areas and from the transfer stations to the treatment plant at the 100-H area. The piping is uninsulated and must be drained back to the wells to avoid freezing if extraction is stopped in the winter. The 100-D area wells (D8-53, D8-54A, D8-68, and D8-72) discharge to transfer storage tank T-D01. The 100-H area wells (H4-12A, H4-15A, H4-11, H4-17, and H4-65) discharge into transfer storage tank T-H03 which pumps the water to the treatment facility tank T-H01 where it is combined with the flow from well H3-2A. Transfer tank T-D01 is insulated and heat traced, has a capacity of 9,200 gals and is located adjacent to the 100-D area transfer facility. Transfer tank T-H03 is insulated and heat traced, has a capacity of 9,200 gals and is located adjacent to the 100-H area transfer facility.

Wells are controlled from an operator-interface controller (OIC), in the treatment facility 1713-H. The OIC starts and adjusts the flow rate from each well by varying the motor speed through the AFD located on each pump motor. The PLC makes adjustments to valve positions and downstream pumps based on the well output. The PLC will automatically adjust the plant flow rate to maintain a constant level in the transfer tanks. Well pumping is suspended when levels in the transfer tanks exceed a predetermined maximum level, if a flow rate below a predetermined level is not attained, or high pressure at the wellhead occurs. The wells are also provided with a solenoid valve drain back provision should the extraction well shut down for any reason other than a power failure. Well piping in contact with groundwater is stainless steel, piping above the water level is galvanized steel, and the wellhead manifold is constructed of PVC. The wellhead manifold includes the drain back solenoid, pressure switch and local pressure indicator, insulation and heat tracing. The PVC piping transitions to HDPE transmission piping downstream of the header.

Three, 6-in-diameter injection wells return the extracted water upgradient of the 100-H chromium plume. Well locations are shown on Exhibit 4 and Exhibit 5.

2.2.3 100-KR-4 Area

Nine, 6-in-diameter steel extraction wells operate at the 100-KR-4 area. The wells are 40 – 100 ft deep and are screened in the Ringold Unit E. The wells located around the 100-KR-4 treatment plant as shown on Exhibit 3. The nine wells in the groundwater extraction system are divided into three groups. The first group of wells (K-119A, K-120A, and K-127) discharge to transfer storage tank T-K01 at flow rates between 65-104 gpm, the second group of wells (K-126, K-112A, K-115A, and K-113A) discharge into transfer storage tank T-K02 at a rate between 60-105 gpm, while the last 2 wells (K-116A, and K-125A) discharge directly into tank T-K03 located in the treatment building at a rate between 50-88 gpm. The piping is uninsulated and must be drained back to the wells to avoid freezing if extraction is stopped in the winter. The wells are also provided with a solenoid valve drain back provision should the extraction well shut down for any reason other than a power failure. The wellhead manifold includes the flow back solenoid, pressure switch and local pressure indicator, insulation and heat tracing. A bypass pipe at the wellhead allows the water drained from the piping to re-enter the well without passing back through the pump. Piping in contact with groundwater is stainless steel, piping above the water level is galvanized steel, and the wellhead manifold is constructed of PVC. Five, 6-in-diameter injection wells return the extracted water south of the 100-KR-4 extraction wells and the 116-K-2 trench source area. Well locations are shown on Exhibit 3.

The wells are equipped with submersible pumps with 3 HP variable-frequency drive electric motors for flow control. Wells are controlled from an operator interface computer (OIC), in the process building. The OIC starts and adjusts the flow rate from each well by varying the motor speed through the adjustable frequency drive (AFD) located on each pump motor. The PLC makes adjustments to valve positions and downstream pumps based on the well output. Well pumping is suspended when levels in the transfer tanks exceed a predetermined maximum level, or if a flow rate below a predetermined level is not attained or high pressure at the wellhead occurs.

2.2.4 100-NR-2 Area

Four extraction wells operate at the 100-NR-2 area. All but one of these wells are 8-in-diameter; the other well is 4-in-diameter. The wells are 85 - 115 ft deep and screened in the Ringold Unit E. Each well is equipped with 1 to 5 HP electric submersible pumps, but the electric motors are not variable-frequency drive. Flows are controlled by valves located in the PVC manifold located at the influent tank. Combined flow rates are typically near 60 gpm as required by the system criteria. One of the two level transducers in each well will shut off the well based upon low water level in the well. Each well is equipped with a pressure relief valve set at 150 psi, a flow meter, and a siphon bypass to allow water to siphon back into the well should the pump be idle for greater than 15 minutes. All of the extraction wellhead instrumentation is installed in the heat-traced PVC manifold, with the exception of the water level transducers.

HDPE discharge piping is completed above ground to the treatment plant. The piping is uninsulated and must be drained back to the wells to avoid freezing if extraction is stopped in the winter. A bypass pipe at the wellhead allows the water drained from the piping to re-enter the well without passing back through the pump. Each conveyance pipeline is equipped with a 30-micron filter connected to the heat-traced PVC influent manifold located outside the treatment tent next to the influent process tank. Each filter assembly consists of stainless steel housing containing replaceable 30-micron filter cartridges, and is equipped with pressure gages on the influent side as well as the downstream of the filter to determine when the filter cartridges are spent.

Two, 8-in-diameter injection wells return the extracted water south of the 100-NR-2 treatment plant. Well locations are shown on Exhibit 2.

2.3 Treatment Systems

2.3.1 Area 200-UP-1

As discussed in Section 2.2, the extraction system consists of one continuously operating well (299-W19-39) paired with one of two other wells (299-W19-36, 299-W19-43) to produce an average flow rate of 50 gpm. Average flow rate during FY03 was 47.1 gpm, slightly less than the 50 gpm requirement. Water from the two operating wells is discharged through an existing 6.8 mi buried transfer pipeline that discharges to the ETF. The ETF effectively removes the Tc-99 and uranium, as well as the secondary contaminants nitrate and carbon tetrachloride. Following treatment, the water is discharged to the State-approved land disposal site north of the 200 West Area.

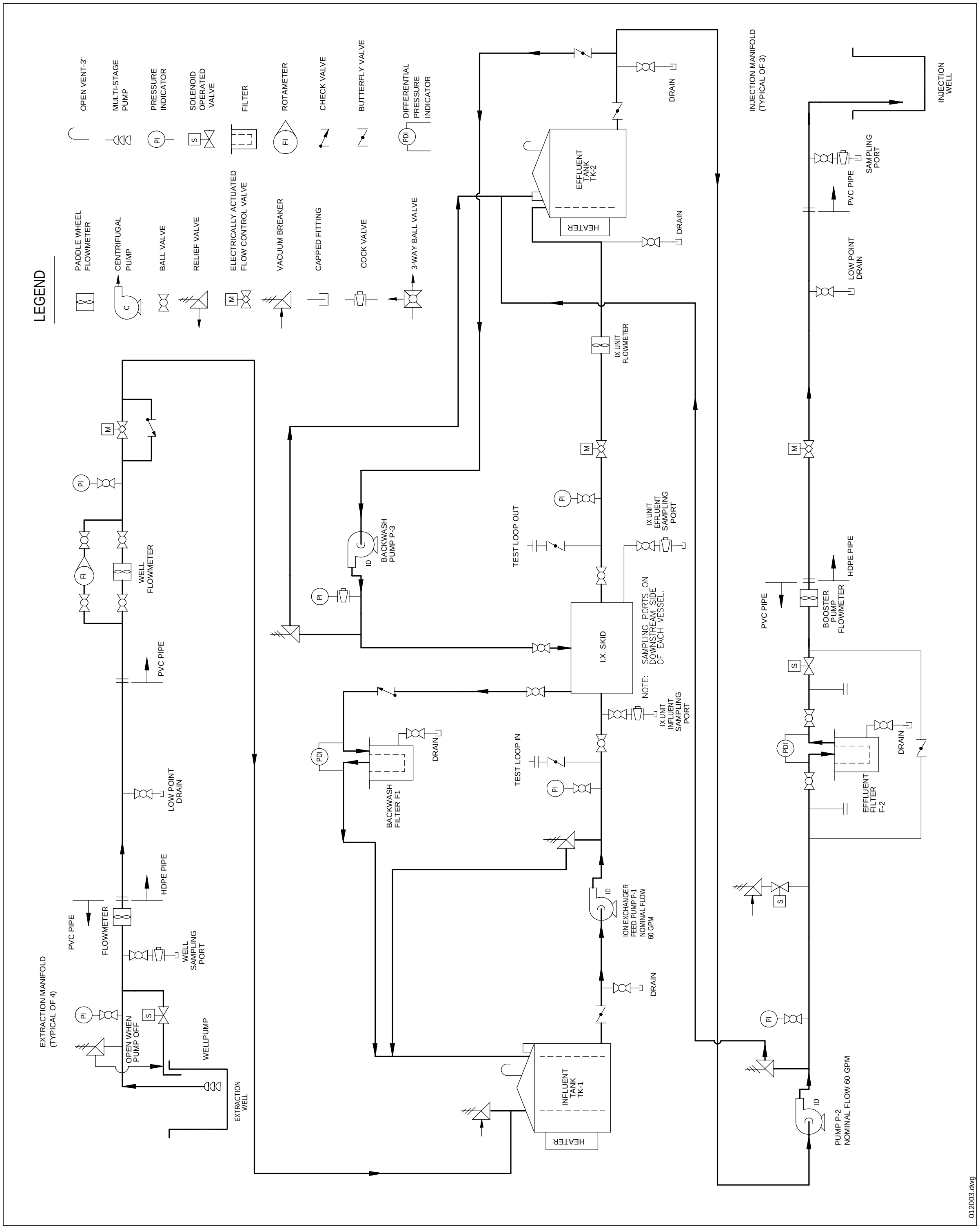
2.3.2 Area 100-NR-2

The l00-NR-2 pump and treat system includes four extraction wells, an ion-exchange (IX) treatment system housed in a process building (tent), two injection wells, and the necessary equipment and components to support these systems. Exhibit 7 is a simplified schematic of the 100-NR-2 System. The major system components are addressed below.

2.3.2.1 Influent Process Tank

The insulated and heat traced influent process tank has a capacity of 13,000 gals. Influent from each well is piped above the top of the tank and discharged to below the water level to prevent air entrainment. Water levels in the tank are monitored using an ultrasonic level transmitter that provides level data to a PLC. The PLC initiates a shutdown of the extraction well pumps if the water level is too high and a shutdown of the influent feed pump if the water level is too low. Water is conveyed to the IX feed pumps through a 4-in-diameter pipeline where it is reduced to 3 in upstream of the IX pumps operating in parallel.

Exhibit 7: 100-NR-2 Pump-and-Treat System Schematic



2.3.2.2 Ion Exchange Treatment System

The IX treatment system consists of four down flow vessels operated in series. Treated water exits the fourth vessel in series under pressure from the influent feed pump, is then routed into the effluent holding tank. The 2-7.5 HP centrifugal pumps, one active and one standby, supply the IX treatment system. Each pump can be selected for operation via the hand-auto-off switch, power transfer switch, and the appropriate disconnect switch. If the head between the pumps and IX units exceeds150 psi, a pressure relief valve will divert flow back to the influent tank.

Each of the IX system vessels is constructed of steel with two viewing portals located in the sidewall of the vessel. The vessels contain a non-regenerate able ion exchange media called clino, a naturally occurring zeolite, formed by the devitrification of volcanic ash in lake and marine waters millions of years ago. The media is quite inexpensive and allows trouble free operation at the facility for approximately 30 days, when change out is necessary. Each tank has the capacity to hold 50 cu ft (approximately 3,000 lb) of clino for each operating cycle. Clino material is removed as slurry from the tank through a 5.1-cm (2-in) pipe in the base of the tank mounted next to the effluent. The clino slurry is deposited in a burial box where it is dewatered using well screen placed in the boxes to collect the water, and eventually placed in the on site disposal facility. Clino is loaded into the vessel through a 1-ft by 2-ft hatch near the top of the vessel using a portable bulk bag loading frame and associated screw conveyor assembly capable of handling 3,000-lb bags, which correspond to the capacity of each vessel.

The IX system is equipped with a manually operated backwash system that is used to remove fine-grained clino material following change out, and to backwash the media should the head loss through the vessel exceed 5 psi. Backwash water supply comes from the effluent storage tank, and spent backwash water can be directed to a decant tank, or after passing through 75-micron cartridge filters, back to the plant influent tank.

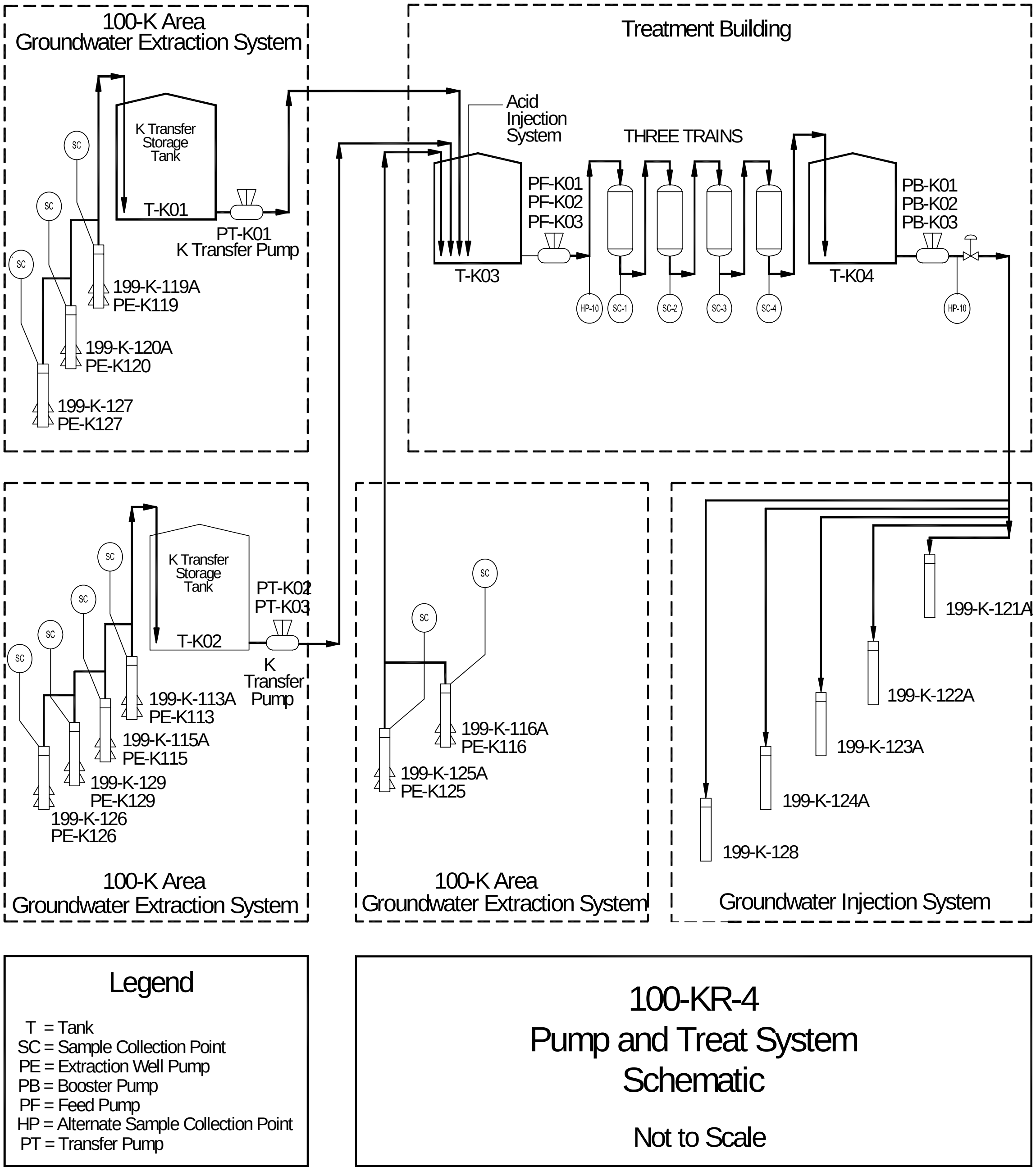
2.3.2.3 Effluent Process Tank

This tank is similar to the influent tank. The insulated and heat traced effluent process tank has a capacity of 13,000 gals. Effluent from the IX system, decant tank, and booster pump high pressure relief line is piped above the top of the tank and discharged to below the water level to prevent air entrainment. Water levels in the tank are monitored using an ultrasonic level transmitter that provides level data to a PLC. The PLC initiates a shutdown of the influent feed pump if the water level is too high and a shutdown of the effluent booster pump if the water level is too low. Water is conveyed to the 7.5 HP booster pumps through a 4-in-diameter pipeline, through a 30-micron cartridge filter on through an HDPE pipeline to the injection wells.

2.3.3 Area 100-KR-4

The l00-KR-4 P&T system includes nine extraction wells and associated above ground discharge piping with a combined flow rate of approximately 260 gpm, two water transfer facilities, an IX treatment system housed in the 100-K process building, five injection wells, and the necessary controls, equipment, and components to support these systems. Exhibit 8 is a simplified schematic of the 100-KR-4 System. The major system components are addressed below.

Exhibit 8: 100 KR-4 Operable Unit Pump and Treat System Schematic



2.3.3.1 Transfer Tank and Pumps

The individual well HDPE transmission piping terminates at the transfer building 1 or 2, and in the case of wells 199-K-116A and 119-K-125A in the treatment building. A 30-micron cartridge filter, with a differential pressure switch, flow meter, both remotely monitored are provided just prior to discharge into transfer tank K-T01, K-T02, or influent tank K-T03. Tanks K-T01, and K-T02 are located outside and require insulation and heat tracing to maintain the water temperature above freezing. Influent tank K-T03 is located in the treatment building, therefore, is not insulated or heated. The variable speed transfer pump operation is suspended when a predetermined low level set point is reached in the tank(s). The rate at which the transfer pump draws water from tanks K-T01 and K-T02 is controlled by the operators from the PLC in the treatment building. The operator attempts to maintain a constant level in the transfer tanks by adjusting the pump motor speed through the AFD. If the water level falls below a predetermined level in the transfer tanks, the pump will shut down and not restart until the water level reaches a predetermined water elevation. The transfer pump will also be de-energized when the water levels in the influent tank K-T03 or effluent tank K-T04 reach their high-high level set points. Transfer building 1 is equipped with 1 - 7.5 HP pump rated at 100 gpm, and transfer building 2 is equipped with 2 - 10 HP pumps each rated at 100 gpm.

Piping from the transfer facilities is 3-in-diameter HDPE located above grade. Transfer building 1 is located at a lower elevation nearly half a mile from the treatment plant. Transfer building 2 is located at a higher elevation approximately 0.4 mi from the treatment plant.

2.3.3.2 Influent Process Tank

The 3,000 gals influent process tank is constructed of cross linked HDPE. The tank has a level indicator and transmitter for level monitoring and pump control. Influent from the transfer facilities and wells are piped above the top of the tank and discharged to below the water level to prevent air entrainment. Water levels in the tank are monitored using an ultrasonic level transmitter that provides level data to a PLC. The PLC initiates a shutdown of the transfer/applicable extraction well pumps if the water level is too high and a shutdown of the IX feed pumps if the water level is too low.

2.3.3.3 Ion Exchange Treatment System

The IX treatment system consists of three parallel trains of four down-flow vessels operated in series. Treated water exits the fourth vessel in series under pressure from the influent feed pump, and is then routed into the effluent holding tank. Three AFD equipped 15 HP centrifugal pumps, rated at 200 gpm each, supply the IX treatment system. Variable speed pumps are controlled from the OIC workstation. The total flow rate through the IX system is based on influent tank K-03 elevation as well as a flow regulator, which monitors the total flow to all three parallel trains. In manual mode, the operator sets the flow per pump. Temperature sensors are installed upstream of the IX units to assure the water temperature does not exceed the 120-degree-F limits recommended for the resin. Flow meters and pressure sensors are also installed to monitor parameters upstream of the IX train.

Precipitation of $CaCO_3$ in the vessels and piping, especially during warm weather, necessitates the use of an automated sulfuric acid injection pump to keep scale formation to a minimum. The pH is monitored at the outlet of the influent tank K-03 as well as the outlet of the effluent tank K-04. Acid can be metered based on control from the OIC screen, locally from the metering pump controller, or using a ratio controller.

Each of the IX system vessels is constructed of steel with two viewing portals located in the sidewall of the vessel. The vessels contain a regeneratable organic ion-exchange media in the chloride form. The resin used is Dowex 21K, with a mesh size of 16 x 20. The media was specifically designed for uranium removal and in the absence of uranium and sulfates, or low levels of each, can be used effectively for removal of the primary contaminant at the OU, hexavalent chromium although its capacity is only about 10 percent that of uranium. The media is quite expensive ($200/cf new, $70/cf if regenerated) and typically requires each train be changed out over a period of 8 weeks. Each tank has the capacity to hold 80 cu ft. Tanks can be fed in any order, but the lead tank, contactor number 1, is generally the only tank that is fed out of sequence. A single vessel change out takes two operators about 2.5 hours to complete. The operators change out the media in one contactor per train on a two-week cycle. The IX media is removed as slurry from the tank through the base of the tank mounted next to the effluent line. The slurry is deposited in a tank where it is dewatered, and tested to ensure the activity in the resin does not exceed the 2 pCi/gr regeneration limit. If the activity limit is exceeded, the resin must be placed in the on-site landfill. If the activity is below that level, the resin is shipped off site to a vendor for regeneration. According to the staff the regeneration process can be repeated up to three times with little impact to the resin’s exchange capacity.

Each IX vessel is equipped with a differential pressure sensor that identifies an alarm condition when the vessel loss reaches a predetermined value. Backwashing can be initiated from the OIC should the head loss identify the need, or if a new IX bed is brought on line, and backwashing is used to remove fine grained material following change out. Backwash water supply comes from the effluent storage tank, and spent backwash water can be directed to a decant tank.

2.3.3.4 Effluent Process Tank

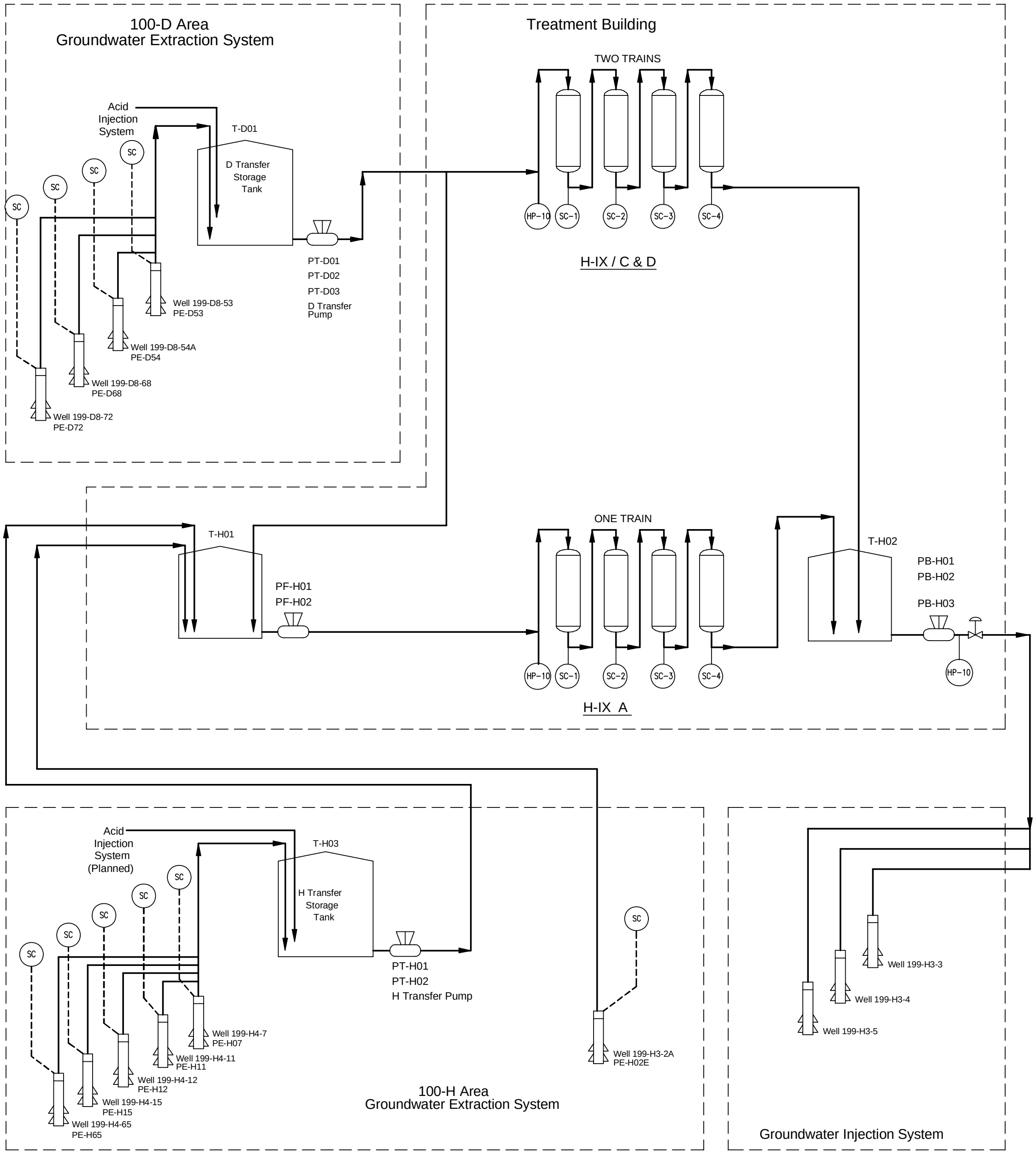
This tank is similar to the influent tank. The treated effluent process tank has a capacity of 3,000 gals. Effluent from the IX system is discharged to below the water level to prevent air entrainment. Water levels in the tank are monitored using an ultrasonic level transmitter that provides level data to a PLC. The tank also has floats located at the low water level and the high-high elevation. The high-high float will send a signal to the OIC stopping the transfer pumps feeding the IX trains while the low level switch will turn off the booster pumps which discharge to the injection wells. Water is conveyed to the 3 - 15 HP effluent booster pumps rated at 200 gpm, after passing through a 30-micron cartridge filter with differential pressure switches to monitor the head loss through the filter, and then through an HDPE pipeline to the injection wells. The AFD equipped effluent booster pumps are provided with pressure switches set to turn off the pumps if pressure exceeds a maximum set point. Flow meters are located downstream of the filters to monitor flow to each injection well, and is used by the OIC to adjust the flow to each well as the level in the effluent tank K-T104 varies. The injection flow rate is variable between 50 and 400 gpm.

2.3.4 Area 100-HR-3

The 100-HR-3 pump and treat system is actually comprised of two separate sites, approximately 2.5 mi apart that share a common treatment facility (building 1713-H). Areas 100-H and 100-D are intended to extract groundwater impacted by the former reactors located in their respective areas. The Area D pump and treat system includes four extraction wells with a combined flow rate of approximately 123 gpm, associated above ground discharge piping from each well to a groundwater transfer facility, and pumping and transfer piping to building 1713-H housing an IX treatment system. The Area H pump and treat system includes six extraction wells with a combined flow rate of approximately 96 gpm, associated above ground discharge piping from each well to a groundwater transfer facility, pumping and transfer piping to the building 1713-H where flow from the sixth well is joined with the remaining flow, an IX treatment system, and three injection wells. Leak detection sensors are provided throughout the facilities to monitor for the presence of liquids. Should an optical sensor detect a spill or liquid, an alarm will sound and the PLC will initiate a shut down sequence of the impacted systems.

Exhibit 9 is a simplified schematic of the 100-HR-3 System. The major system components are addressed below.

Exhibit 9. 100 HR-3 Operable Unit Pump and Treat System Schematic



Legend

T = Tank
SC = Sample Collection Point
PE = Extraction Well Pump
PB = Booster Pump
PF = Feed Pump
HP = Alternate Sample Collection Point
PT = Transfer Pump

100-HR-3
Pump and Treat System
Schematic

Not to Scale

H Schematic CY03.dwg

2.3.4.1 Transfer Tanks and Pumps

The individual well HDPE transmission piping terminates at transfer building D or H, and in the case of well H3-2A in the treatment building. A 30-micron cartridge filter, with a differential pressure switch, and flow meter, both remotely monitored, are provided just prior to discharge into transfer tank T-D01, T-H03, or influent tank T-H01 for well H3-2A. Transfer tanks are constructed of cross linked high density polyethylene. The tanks, located outside adjacent to the transfer buildings, are insulated and heat traced to maintain the water temperature above freezing. Influent tank T-H03 is not insulated or heated since it is located in building 1713-H. The variable speed AFD transfer pump operation is suspended when a predetermined low level set point is reached in the tank. The rate which the transfer pump(s) draws water from transfer tank is controlled by the operators from the PLC in the respective transfer building. The AFD can be controlled manually, locally at the panel, or remotely by the PLC. If the water level falls below a predetermined level in the transfer tank, the pump(s) will shut down and not restart until the water level reaches a predetermined water elevation. The transfer pump will also be de-energized when the water levels in the influent tank T-H01 or effluent tank T-H02 reach their high-high level set points. Transfer building D is equipped with 2 - 15 HP pumps each rated at 100 gpm, and transfer building H is equipped with 3 - 15 HP pumps each rated at 100 gpm.

The 2.5 mi of piping between transfer building D and 1713-H consists of 2-4-inch diameter HDPE lines located above grade as is the 0.5 mi of dual 3-in HDPE above-ground pipelines between transfer building H and 1713-H. Transfer building H is located at a lower elevation than the treatment plant. Transfer building D is located at a higher elevation than the treatment plant.

2.3.4.2 Influent Process Tank

The 3,000-gal influent process tank like the transfer tanks is constructed of cross linked HDPE. The tank has a level indicator and transmitter for level monitoring, temperature sensor, and pump control. Influent from the transfer facility D can be fed into T-H01 but generally is fed directly into IX trains C and D. Water levels in tank T-H01 are monitored using an ultrasonic level transmitter that provides level data to a PLC. Water from T-H01 is pumped through IX train A. The PLC initiates a shutdown of the transfer/applicable extraction well pumps if the water level is too high and a shutdown of the IX feed pumps if the water level is too low.

Acid injection facilities are provided at each transfer tank. Sulfuric acid is added to eliminate precipitation of $CaCO_3$ on the IX resin. The pH of the outlet from transfer tank T-D01 and T-H03 is monitored and sulfuric acid injected via metering pump until the set point pH is attained in the tanks. Acid addition can be controlled from the PLC via the OIC screen, the pH controller, by a ratio controller, or by pH and ratio control.

2.3.4.3 Ion Exchange Treatment System

Building 1713-H contains two separate IX treatment systems. The Area D IX treatment system consists of two parallel trains of four down flow vessels operated in series. Treated water exits the fourth vessel in series and is then routed into the effluent holding tank T-H02. The Area H IX treatment system consists of a single train of four down flow vessels operated in series. Water is pumped from tank T-H01 at a rate intended to maintain a constant level in the influent tank. The two AFD equipped 20 HP centrifugal pumps rated at 200 gpm each, supply the single train A IX treatment system. Variable speed pumps are PLC controlled from the OIC workstation. In manual mode, the operator sets the flow per pump. The total flow rate through the H Area IX system is based on influent tank H-01 elevation as well as a flow regulator, which monitors the total flow through the trains. The three AFD equipped 15 HP Area D transfer pumps operate in much the same fashion as the Area H process pumps. Temperature sensors are installed upstream of the IX units to assure the water temperature does not exceed the 120-degree-F limits recommended for the resin. Flow meters and pressure sensors are also installed to monitor parameters upstream of the IX train.

Each of the IX system vessels is constructed of steel with two viewing portals located in the sidewall of the vessel. The vessels contain a regeneratable organic ion exchange media in the chloride form. The resin used is Dowex 21K, with a mesh size of 16 x 20. The media was specifically designed for uranium removal and in the absence of uranium and sulfates, or low levels of each, can be used effectively for removal of the primary contaminant at the OU, hexavalent chromium although its capacity is only about 10 percent that of uranium. The media is quite expensive ($200/cf new, $70/cf if regenerated) and typically requires one train change out every six weeks. The first tank in the H train is dedicated to removing uranium present in the influent. The remaining vessels are dedicated to chromium removal and one vessel is changed out every two weeks. Each tank has the capacity to hold 80 cu ft. Tanks can be fed in any order, but the lead tank, contactor number 1, is generally the only tank that is not fed out of sequence. A single vessel change out takes two operators about 2.5 hours to complete. The IX media is removed as slurry from the tank through the base of the tank mounted next to the effluent line. The slurry is deposited in a tank where it is dewatered, and tested to ensure the activity in the resin does not exceed the 2 pCi/gr regeneration limit. If the activity limit is exceeded, the resin must be placed in the on site landfill. If the activity is below that level, the resin is shipped off site to a vendor for regeneration. According to the staff the regeneration process can be repeated up to three times with little impact to the resin’s exchange capacity.

Each IX vessel is equipped with a differential pressure sensor that identifies an alarm condition when the vessel head loss reaches a predetermined value. Backwashing can be initiated from the OIC should the head loss identify the need, or if a new IX bed is brought on line, and backwashing is used to remove fine-grained material following change out. Backwash water supply comes from the effluent storage tank, and spent backwash water can be directed to a decant tank.

2.3.4.4 Effluent Process Tank

This tank T-H02, is similar to the Train H Influent Tank T-H01. The treated effluent process tank has a capacity of 3,000 gals. Effluent from all three IX trains is discharged to a common tank prior to injection. Water levels in the tank are monitored using an ultrasonic level transmitter that provides level data to a PLC. The tank also has floats located at the low water level and the high-high elevation. The high-high float will send a signal to the OIC stopping the transfer pumps feeding the IX trains while the low level switch will turn off the booster pumps which discharge to the injection wells. Water is conveyed to the 3 - 25 HP effluent booster pumps rated at 200 gpm, after passing through a 50-micron cartridge filter with differential pressure switches to monitor the head loss through the filter, and then through an HDPE pipeline to the injection wells. The AFD equipped effluent booster pumps are provided with pressure switches set to turn off the pumps if pressure exceeds a maximum set point. Flow meters are located downstream of the filters to monitor flow to each of the three injection wells, and is used by the PLC via the OIC to adjust the flow to each well as the level in the effluent tank T-H02 varies. The flow rate to each injection well is variable between 50 and 110 gpm.

2.4 Monitoring Systems

The performance of each of the five ground water extraction systems is assessed based on piezometric and concentration data collected from a set of monitoring wells. These data are used to evaluate capture of the plume and the progress toward remediation goals. The monitoring systems for each site are described below. Note that discrepancies were noted in the numbers of wells sampled for the primary contaminants as reported in various documents, particularly for the 100 Area sites. Trend plots included in various reports through 2003 were the primary source of information regarding numbers of wells sampled and the frequency of sampling.

2.4.1 200-UP-1 Area

In addition to the three extraction wells, samples and water levels have been obtained from five monitoring wells at the 200-UP-1 site. A number of other monitoring wells have existed in the vicinity of the extraction system, but long-term declines in the water table have rendered a number of monitoring wells dry. Nine monitoring wells were abandoned in 2003. The monitoring wells used to assess the performance of the 200-UP-1 system include: 299-W19-20, 299-W19-35, 299-W19-37, 299-W19-40, and the recently installed 299-W19-46. All of these wells are monitored annually for uranium and Tc-99, except 299-W19-37, which is monitored semi-annually, and 299-W19-46, which is monitored quarterly. Samples have been obtained from multiple depths in 299-W19-46 for vertical profiling. The piezometric levels are monitored in numerous additional wells in the 200-UP area. Ground water flow direction and water table elevations in the 200-UP area are evaluated on a more regional basis.

2.4.2 100-D and 100-H Areas

Thirty-three monitoring wells have been typically sampled quarterly for chromium in the 100-D area. Monitoring wells D4-15, D5-38, D5-39, and D5-43, and compliance wells D8-69 and D8-70 are sampled on an approximately monthly basis. Monitoring wells D5-17, D8-4, and D8-5 are sampled annually; monitoring wells D8-54B and D8-71 are sampled approximately semi-annually. Sampling is also done on a generally less frequent basis for other contaminants of interest including Sr-90, tritium, nitrate, and sulfate. There are also sample tubes placed at the river banks for sampling ground water near the sediment-water interface.

Twenty-one monitoring wells and four compliance wells have been sampled for chromium in the 100-H area. Most wells are sampled semi-annually, but the compliance wells are sampled quarterly. A few monitoring wells are sampled annually, including H3-2C, H4-45, H4-47, and H6-1. Sampling is also done on a generally less frequent basis for other contaminants of interest including uranium, Tc-99, Sr-90, tritium, and nitrate. Water levels are measured at the wells; and some wells are equipped with data collection systems and transducers. These piezometric data are transmitted to a central location.

2.4.3 100-KR-4 Area

Twenty monitoring wells have been typically sampled semi-annually or annually for chromium in the 100-KR-4 area. Four compliance wells are sampled monthly for chromium. Monitoring wells 107A, 108A, and 36 are sampled approximately quarterly. Sampling is also done on an equal, or less frequent basis, for other contaminants of interest including carbon 14, Sr-90, tritium, and nitrate. Piezometric data are also collected.

2.4.4 100-NR-2 Area

Twenty-one monitoring wells have been typically sampled semi-annually to annually for Sr-90. These wells are also sampled for other contaminants of concern including tritium, chromium, manganese, sulfate, and petroleum hydrocarbons on a similar frequency. Water levels are also measured at the wells.

3.0 SYSTEM OBJECTIVES, PERFORMANCE AND CLOSURE CRITERIA

3.1 Current System Objectives and Closure Criteria

Exhibit 10: Remedial Action Objectives

Area	Document Cited	Remedial Action Objectives
100-HR-3 and 100-KR-4	*ROD for the 100-HR-3 and 100-KR-4, Interim Remedial Actions* (1996)	– Protect aquatic receptors in the river bottom substrate from contaminants in groundwater entering the Columbia River. – Protect human health by preventing exposure to contaminants in the groundwater. – Provide information that will lead to a final remedy.
100-NR-2	*Interim RA ROD, 100-NR-1 and 100-NR-2 (*1999)	– Protect the Columbia River from adverse impacts from the l00-NR-2 groundwater so that beneficial uses of the Columbia River are maintained. Protect associated potential human and ecological receptors using the river from exposure to radioactive and nonradioactive contaminants present in the unconfined aquifer. Protection will be achieved by limiting exposure pathways, reducing or removing contaminant sources, controlling groundwater movement, or reducing concentrations of contaminants in the unconfined aquifer. – Protect the unconfined aquifer by implementing remedial actions that reduce concentrations of radioactive and nonradioactive contaminants present in the unconfined aquifer. – Obtain information to evaluate technologies for Sr-90 removal and evaluate ecological receptor impacts from contaminated groundwater (by October 2004). – Prevent destruction of sensitive wildlife habitat. Minimize the disruption of cultural resources and wildlife habitat in general and prevent adverse impacts to cultural resources and threatened or endangered species.
200-UP-1	*ROD for the 200-UP-1 Interim Remedial Measure* (1997), as reported in *Fiscal Year 2003 Annual Summary Report for 200-UP-1 and 200-ZP-1 Pump-and-Treat Operations (draft, 2004)*	– Reduce contamination in the area of highest concentrations of uranium and Tc-99 to below 10 times the cleanup level under the Model Toxics Control Act (MTCA) (Washington Administrative Code [WAC] 173-340), and 10 times the maximum contaminant level (MCL) for Tc-99, as of the issuance of the ROD. – Reduce potential adverse human health risks through reduction of contaminant mass. – Prevent further movement of these contaminants from the highest concentration area. – Provide information that will lead to development and implementation of a final remedy that will be protective of human health and the environment

There was a Remedial Action ROD Amendment for 100-HR-3 in 1999 to revise the selected remedy to include an ISRM barrier wall for a portion of the D Area not within the capture zone of the existing pump and treat system. This Amendment did not alter the Remedial Action Objectives. The groundwater cleanup criteria for each area, for the primary contaminant(s) and for the identified co-contaminants, are identified below in Exhibit 11.

Exhibit 11: Groundwater Cleanup Criteria

Area	Groundwater Criteria: Primary Contaminant(s)		Groundwater Criteria: Co-Contaminant(s)	
100-HR-3 (D Area)	Chromium	22 ug/l	Sr-90 Tritium Nitrate Sulfate	8 pCi/l 20,000 pCi/l 45 mg/l 250 mg/l
100-HR-3 (H Area)	Chromium	22 ug/l	Sr-90 Tc-99 Uranium Tritium Nitrate	8 pCi/l 900 pCi/l 48 ug/l* 20,000 pCi/l 45 mg/l
100-KR-4	Chromium	22 ug/l	Sr-90 Tritium Carbon-14 Nitrate	8 pCi/l 20,000 pCi/l 2,000 pCi/l 45 mg/l
100-NR-2	Sr-90	8 pCi/l	Diesel Tritium Chromium Manganese Nitrate Sulfate	Criteria not identified 20,000 pCi/l 22 ug/l 50 ug/l 45 mg/l 250 mg/l
200-UP-1	Tc-99 Uranium	9000 pCi/l** 480 ug/l **	Carbon Tetrachloride Nitrate	5 ug/l 45 mg/l

* MCL for Uranium has subsequently been lowered to 30 ug/l, per Dib Goswami of Ecology.

** These values apply to the interim remedy, and are 10x the MCL values that existed at the time of the ROD for the interim remedy.

The 22 ug/l criterion for chromium is based on the 11 ug/l ambient water quality criterion in place at the time of the signing of the RODs and a 1:1 dilution ratio. Further criteria for discontinuing the pump and treat operations were identified for the 100-HR-3 and 100-KR-4 systems, as shown in Exhibit 12.

Exhibit 12: Criteria for Closing 100-HR-3 and 100-KR-4

Area	Document Cited	Criteria for Closing System
100-HR-3 and 100-KR-4	*100-HR-3 Pump and Treat System Design Description, April 2003* *and* *100-KR-4 Pump and Treat System Design Description*	– Pump and treat will continue until selected final action is implemented; or – Demonstrated to satisfaction of EPA and Ecology that: – Chromium sample results are below compliance

		value and expected to remain so – Effectiveness of treatment technology does not justify further operations – An alternate treatment technique is evaluated and proves to be more effective, less costly, and is consistent with the RAOs

No further criteria for closing the 100-NR-2 or the 200-UP-1 systems were identified. It should be noted that all of the systems evaluated are interim remedies. In each case, a final remedy will have to be established, and in each case the final remedy may have different objectives or closure criteria. For instance, for 200-UP-1, the interim remedy specified groundwater criteria for Tc-99 and Uranium that were 10 times the MCL at the time of the interim ROD, and an objective was to prevent further spreading of the highest concentration areas. A final remedy in the 200-UP-1 area may (or may not) specify more stringent groundwater criteria to obtain.

3.2 Treatment Plant Operation Goals

The treatment plant criteria identified for each of the systems is presented in Exhibit 13.

Exhibit 13: Treatment Plant Criteria

Area	Document Cited	Treatment Criteria	
100-HR-3	*100-HR-3 Pump and Treat System Design Description, April 2003*	Chromium	50 ug/l (actual limit) 22 ug/l (design criteria)
		co-contaminants	no criteria identified
100-KR-4	*100-KR-43 Pump and Treat System Design Description, April 2003*	Chromium	50 ug/l (actual limit) 22 ug/l (design criteria)
		co-contaminants	no criteria identified
100-NR-2	*Interim RA ROD, 100-NR-1 and 100-NR-2 (*1999)	Sr-90	> 90% reduction in Sr-90 concentration in the extracted groundwater
		co-contaminants	no criteria identified
200-UP-1	*200-UP-1 Groundwater Remedial Design/Remedial Action Work Plan* (1997)	Tc-99	MCL - 900 pCi/l
		Uranium	Estimated MCL - 20 ug/l
		Carbon Tetrachloride	MCL - 5 ug/l
		Nitrate	MCL - 45 mg/l

Note that since March 1997, the 200-UP-1 treatment is not treated at a system-specific treatment plant, and is instead performed at the Effluent Treatment Facility (ETF) in the 200 East Area, which treats water from other sources as well. Water is conveyed in a 7 mi pipeline from the extraction wells in the 200-UP-1 area to the ETF.

3.3 Action Levels

No action levels above and beyond the closure criteria presented in Section 3.1 were identified.

4.0 FINDINGS AND OBSERVATIONS FROM THE RSE SITE VISIT

4.1 Assessment of Source Characterization

Based on discussions with the DOE Richland Office project team, the probable source areas have been identified, though confirmation of residual soil contamination at some of the 100 Area sites has proven difficult.

4.1.1 200-UP-1 Area

The sources for the 200-UP-1 plume are reasonably well known. According to the project team, there is substantial mass of uranium and Tc-99 in the vadose zone that will act as a long-term source. Though it appears the interim ground water removal action at the site has been successful, there is a potential for recontamination of ground water above the interim standards in the long-term. Furthermore, there appears to be a likelihood that the contaminant concentrations will remain above the final cleanup standards even with continued ground water extraction. Additional characterization of the distribution, fate, and behavior of uranium in the subsurface is continuing according to the project team. This appears prudent.

4.1.2 100-HR-3 (H and D) and 100-KR-4 Areas

The chromium sources are generally well known, though residual mass in the vadose zone has not been easily identified. The modest concentrations in the cooling water, and the fact that the contaminant was dissolved in the water prior to discharge, suggests there is little residual mass in the vadose zone related to the cooling water discharge areas. The areas where the off-loading, storage, and mixing of dichromate occurred represent a more significant potential source. According to the project team, recent efforts to locate residual hexavalent chromium in several of these areas have failed. Actions to address potential chromium source areas must consider the uncertainty in the location, concentration, and presence of the source(s).

4.1.3 100-NR-2 Area

Strontium mass concentration in the 100-N Area vadose and saturated zones is the focus of the ITRD 2002 report. The source term distribution and mass flux estimates to the Columbia River are summarized as follows:

> From 1963 to 1985, operation of the LWDFs caused ground water levels to rise about 30 ft. Due to sorption of radionuclides on the aquifer material, the area where the water table was higher than present day contains significant quantities of Sr-90. In excess of 1700 Ci of Sr-90 is contained in the LWDFs and in the unsaturated zones below. This represents a large, but decaying, future source of contaminants to ground water. The current flux of Sr-90 to the Columbia River is several orders of magnitude smaller than historical releases during reactor operation. Strontium-90 sorbed to the soil since the LWDFs ceased operation 15 and 7 years ago, is considered to be in equilibrium. In 2002, it was estimated that 88.8 Ci of Sr-90 is contained in the saturated zone; the highest concentrations between the 1301-N LWDF and the Columbia River. The source term in the near-river environment (between the ground water extraction system and the Columbia River) represents the largest potential risk to human health and the environment. Recent modeling studies, described in Section 4.2, more accurately

estimate that the total, near-river environment source term is 91 Ci. It is estimated that this source term will reduce by decay in place after 300 years; only 5-6 Ci are expected to be released to the River.

4.2 Ground Water Models Used for System Design and Performance Assessment

Based on discussions during the RSE visit, groundwater modeling pertinent to system design and performance assessment has included the following:

- MicroFEM simulations of groundwater flow and particle traces (area specific) have been peformed by CH2MHILL (and more recently by Fluor) for steady-state scenarios to design pump and treat systems and/or illustrate capture zones for existing systems.

- CFEST simulations (Hanford site wide, with potential to "telescope" to local-scale models) have been performed by PNNL and have included both steady-state and transient simulations of groundwater flow, plus simulations of contaminant transport.

Each is briefly discussed below. In addition, the STOMP model was applied by Hydrogeologic to the 100-NR-2 area as part of an ITRD study. This is also briefly discussed.

4.2.1 MicroFEM Modeling

A brief summary of the MicroFEM modeling by area is provided in Exhibit 14.

Exhibit 14: Summary of the MicroFEM Modeling by Area

Area	# Model Layers	Steady or Transient	Boundary Conditions
100-HR-3 (D Area)	1	Steady	– Specified heads around model, including at the river – Boundary heads updated each year based on field measurements in fall, which is a time of year when hydraulic gradients are steep – Base is assumed to be top of Ringold mud, assumed to be no flow – No net recharge
100-HR-3 (H Area)	1	Steady	
100-KR-4	1	Steady	
100-NR-2	1	Steady	
200-UP-1	3	Steady	Same as above, except: – 3 layers to account for partial penetration of wells (aquifer is thicker than in 100-areas)

Values of transmissivity have been updated at least once since the models were first used to design the systems, and in the case of the 100-D model and the 200-UP-1 model, it has been stated that an attempt has been made to make the transmissivity values somewhat consistent with the corresponding values in the sitewide CFEST model. It was stated during the RSE site visit that comparisons are made between simulated and observed heads, but that detailed comparisons of simulated versus observed drawdown in response to pumping have not been performed in an attempt to update the model parameters. It was also noted that the comparison of observed to simulated head did not present the data in a manner that excludes data at extraction wells and then normalizes the difference between simulated and observed values ("model residuals") based on the range of measured values. In particular, the range of measured water levels in some of the areas is quite small, so that what appear to be small model residuals can actually cause significant differences in the modeled versus actual hydraulic gradient, which in turn can significantly impact the evaluation of capture.

These MicroFEM models are relatively simple models that represent many simplifications, particularly with respect to the transient nature of flow near the river. The modeling does not include the transient effects of the changing river stage on the water table, and therefore does not address the changing degree of capture during different parts of the day or different parts of the year. However, by using boundary water levels associated with the fall, when hydraulic gradients towards the river are reportedly steep, it is believed that some conservatism is provided regarding evaluation of capture.

The MicroFEM models were used to design the system pumping strategies and the design process used a trial-and-error approach, and not a more formal optimization approach. Recently, the 100-D area model has been used to simulate the expected capture zone of three new pumping wells and one new injection well planned to be installed between the existing pump and treat system and the ISRM barrier. The well locations were provided to the modeler, who was asked to develop pumping rates (trial and error) and then to illustrate particle traces given those pumping rates.

4.2.2 CFEST Modeling

The CFEST modeling includes a site-wide model that consists of seven layers:

- Hanford sand and gravels (one layer)
- Ringold muds and gravel/sands (3 layers of muds, 3 layers of gravel/sands)

Boundary conditions include lateral recharge, surface recharge (natural and artificial), discharge areas (such as the Columbia and Yakima rivers), and no flow boundaries (such as basalt). This was originally a transient model calibrated under steady state conditions to 1979 water levels, but recently a transient flow calibration has been performed for conditions dating back to 1943, using the UCODE parameter estimation code modified for use with CFEST. The calibration of transient conditions is particularly important because so much water was recharged back to the ground during operations, relative to current conditions, that cessation of the recharge has caused a gradual decline in water levels and changes in regional flow directions.

The site-wide model has large grid spacing, which makes it inappropriate for evaluating area-specific capture zones. It is possible to make local-area CFEST models using a "telescoping" approach, but that would still require some conditioning of boundary conditions and perhaps parameter values at the local scale, and to date the Micro-FEM models continue to be used for the area-specific evaluations.

Simulation of contaminant transport may be particularly important for the 200-UP-1 area. This is because the final remedy may incorporate conditions on concentrations that must be met in the 200-UP-1 area (with or without groundwater extraction) to protect potential downgradient receptors, and simulations of constituent transport over time may be a primary component of that analysis.

Transport modeling performed with CFEST requires specification of source terms. This is subject to great uncertainty because the location and strength of sources in both the saturated zone and the vadose zone are not well characterized. For instance, it was stated during the RSE visit that the remaining sources of Tc-99 and Uranium are not well characterized in the 200-UP-1 area (and similarly the remaining sources of hexavalent chromium in the 100-D area are not well characterized). The vadose zone is of particular interest due to the declining water levels over time (discussed earlier) that may have caused contaminant sources to be left in the vadose zone. This suggests that some type of modeling approach that combines the vadose zone and the ground water system may have merits. It was stated during the RSE site visit that an approach that combines the STOMP model for the vadose zone with the CFEST model for the unsaturated zone is being implemented for local 200-area simulation. Additionally, documents provided to the RSE team indicate that a geochemical model for uranium at 200-UP-1 is to be completed in FY04 to attempt to explain the behavior of uranium in both the unsaturated soil column and in groundwater, from the start of waste discharge in 1952 to the present.

4.2.3 STOMP Modeling at 100-NR-2 (ITRD, 2002)

Three modeling studies have been conducted in phases to assess Sr-90 release to the Columbia River under different scenarios of river stage relative to the aquifer, and transience, using Pacific Northwest National Laboratory's (PNNL) Subsurface Transport Over Multiple Phases (STOMP) code. STOMP is a finite-difference, numerical model designed to be a general-purpose tool for simulating subsurface flow and transport.

In 1997, Connelly used STOMP to estimate how bank storage may affect the Sr-90 release to the Columbia River and to estimate residence time within an in situ treatment zone. The results of Connelly's study demonstrated that steady-state modeling assumptions were inappropriate for the near-river environment; groundwater velocities were seriously underestimated. This first modeling study was therefore extended using STOMP to simulate transient interactions between the rising and falling Columbia River and the adjacent unconfined aquifer (Hydrogeologic, 1999). The results of this Sr-90 transport simulation showed little movement of the strontium over the time of simulation, six months, due to strong sorption of the Sr-90 to the sediments. Longer simulation times were required to understand the impact of groundwater–river interactions on the strontium transport, predicating the last phase of the modeling.

The primary objective of the additional groundwater modeling was to estimate contaminant flux to the Columbia River over a longer period of time, necessitated by strong sorption of the strontium onto the sediments, coupled with radioactive decay (half-life of 28.6 years). The results of the simulations indicate that very little movement of the Sr-90 plume is expected; the plume does not move downgradient, as originally hypothesized, by constant flushing of the contaminated sediments by the river water into the Columbia River. Sampling and monitoring data confirm that the Sr-90 impacts the upper portion of the saturated zone of the aquifer with fairly uniform concentrations, or slightly reduced, through time. The Sr-90 is bound to the soil, and the volume of clean water entering the aquifer yearly is insufficient to remove the contaminant from the sediments. The model predicts a total release to the Columbia River of 5 to 6 Ci in two half-lives, or about 60 years. The total source term was estimated to be 91 Ci, but will be reduced to cleanup levels by decay in place after 300 years; only 5-6 Ci are expected to be released to the River.

4.2.4 Uncertainty

All simulations of groundwater flow and contaminant transport are subject to many types of uncertainty, such as the uncertainties in the locations and strengths of remaining contaminant sources discussed above. Other uncertainties include hydraulic parameters (e.g., values, variations over space and depth, etc.), the disposition of boundaries (e.g., whether or not the base of the Ringold formation really no-flow as conceptualized in the MicroFEM models, etc.), and the variation of transport related parameters such as dispersivity and distribution coefficient. During the RSE visit, a series of presentations was made by PNNL staff regarding research they are performing to address the impacts of uncertainties on simulations at Hanford. Attempts are being made to identify and measure sources of uncertainty, but the ongoing tasks are a work in progress, and are not yet integrated into the pump and treat system designs based on the MicroFEM model simulations.

4.3 Assessment of Groundwater Capture

Annual reports for each area illustrate capture as represented in the MicroFEM model. These illustrations are generally produced by performing particle tracking in two ways:

- Backward-tracking from each extraction well to illustrate the region captured by each well
- Forward-tracking from a line of particles, to illustrate potential gaps between capture zones (i.e., particles that are not captured by the extraction wells)

As discussed above, MicroFEM produces steady-state simulations that do not account for transient flow conditions. Of particular concern are the transient effects of river stage fluctuations of the adjacent Columbia River on the pump and treat capture zones. Such interaction between the aquifer and the river is quite complex; rigorously evaluating the river-aquifer interaction would require additional effort and expenditure. These models also do not account for the likely significant heterogeneity of aquifer characteristics, and therefore may present an over-simplified view of capture. Additional characterization of aquifer heterogeneity would also require effort and expenditure. Finally, as discussed earlier, the ability of these models to predict aquifer responses to pumping has not been convincingly demonstrated in the documents reviewed by the RSE team.

It should be noted that recent transient modeling performed in the 100-N area to address SR-90 source term release in the near-river environment using STOMP (refer to Section 4.2.3) is adequate to assess the value of continued pump and treat, versus phase-in of other remediation technologies to reduce contaminant migration to the River (ITRD, 2002). The ITRD report summary and recommendations provide DOE Richland with a variety of alternative barrier designs, combined with monitored natural attenuation and phytoremediation approaches, to consider in long-term management of the Sr-90 contamination area and plume.

Ideally, additional lines of evidence to substantiate the delineation of actual capture would be available to support the illustrations provided by the simplified MicroFEM models. A brief summary of other potential lines of evidence, and the current site-specific limitations associated with each, is provided below:

- Potentiometric Surface Evaluation. Capture zone width can be evaluated from contours of potentiometric surface that are interpreted from measured water levels. Most of the potentiometric surface maps provided to the RSE team are assumed to be simulated from the MicroFEM model, rather than interpreted from field measurements. The RSE team noted there are relatively few locations where water levels are available; the density of water level measurements does not appear to be adequate to interpret the potentiometric surface. For the maps provided to the RSE team, that were based on actual water level measurements, it appears that the water levels at the extraction wells are included in developing the contours. This can lead to an overestimate of the aquifer response to pumping (due to well losses at the extraction wells), ideally, piezometers very close to the extraction wells would be available to more accurately represent aquifer conditions near the extraction wells. Few, if any, such piezometers in the immediate vicinity of the extraction wells appear to be present.

- Gradient Control Pairs. One potential line of evidence would be evaluation of water levels at “gradient control pairs” located downgradient of the extraction wells. Water levels from the extraction wells are not accurate for this determination, due to well losses associated with pumping, that have a tendency to overestimate the aquifer response. Water level measurements at strategically located gradient control pairs, perhaps measured continuously, could provide evidence that flow is inward toward the extraction wells, during different times of the day or different seasons of the year. However, few, if any, such “gradient pair” locations exist at the present time, so this line of evidence cannot be developed.

- Concentration Trends Downgradient of the Capture Zone. Care must be taken when using concentration trends at monitoring wells to evaluate capture. Within the capture zone of the extraction wells (i.e., upgradient and some distance downgradient of the extraction wells) concentrations may not decrease. In this case, the monitoring point is within the capture zone, and contaminated water continues to flow past the monitoring point. Therefore, the ideal location to evaluate concentration trends is downgradient of the capture zone, where concentrations of impacted wells should decrease, and concentrations of un-impacted locations should not increase. However, this is a difficult line of evidence to develop at the 100-area locations because there is not much distance between the extraction wells and the River. Therefore, any conclusions might be ambiguous. For example, if concentrations do not decline at a monitoring well between the extraction wells and the River, it may be because the monitoring point is within the capture zone of the well, or because the capture zone is

> not sufficient. If concentrations go down at the monitoring well, it could be because river water is being mixed with aquifer water at that specific location. To evaluate this scenario, many monitoring points would be needed to demonstrate that there are no gaps in the capture zone.

It is very important to note that none of the interim remedies appear to have specific quantitative goals associated with demonstrating capture. It was noted by the RSE team that some gaps in capture have been identified in the modeling illustrations of capture provided in the annual reports for some areas, but such gaps are necessarily presented as a problem that needs to be corrected. It appears that some gaps in capture may not be inconsistent with meeting the overall objectives of the interim remedies. For instance, at the 100-N area the contaminant mass flux of the primary contaminant, Sr-90, to the river through any potential gaps in capture is quite small due to sorption of the strontium onto the native sediments.

It was also noted during the RSE visit that at the time of year when hydraulic gradients are most steep, it is most difficult to achieve high production rates at the extraction wells due to low water levels relative to the well screens. Higher pumping rates at the extraction wells would be optimal to achieve better capture when the gradient increases, but the wells do not accommodate increased pumping capacity due to well screen limitations. This has become exacerbated to some extent by the consistent decline in background water levels over time that has resulted from the cessation of recharge to the aquifer that historically was associated with plant operations.

The issue of vertical capture is not rigorously addressed in the reports provided to the RSE team. For the 100-area locations, the model used for the capture zone illustrations assumes that the base of the Ringold is a no-flow boundary. Monitoring data may exist to substantiate this assumption, but such information is not presented along with the capture zone evaluations. Similarly, the capture zone evaluation for 200-UP-1 is presented as a two-dimensional analysis, and not a three-dimensional analysis, thereby avoiding analysis of the vertical flow component of the capture design.

4.4 Ground Water Extraction and Injection System

The RSE team observed extraction wells at the 100-H, 100-N, and 200-UP-1 areas. No injection wells were visited during the brief tour. The wells appear to be well maintained. Some of the extraction wells were originally installed as monitoring wells and have been converted to extraction. It is not clear if the well efficiencies for these converted wells are comparable to those wells designed specifically as extraction wells. A subset of wells at the various sites is periodically selected for performance evaluation and these are pump tested. In general, there is little evidence of well fouling at the pump-and-treat sites. If there were any reduction in performance, the operators would first suspect inorganic scaling; there is no evidence of biofouling. Injection wells reportedly function very well.

The operators report that the solenoid valves are prone to failure and they are replacing them on average two per year. During some periods, some variable-frequency drive submersible pumps are running near the lower limit of flow (about 10 percent of the pump’s rated capacity). Other aspects of the well equipment appear to perform adequately.

The piping from the wells to the transfer stations or the treatment plants is generally above ground and this poses some problem. Though easily inspected, the piping can be damaged. In one case, a range fire damaged a pipeline. Damage due to vehicles also occurs. At the 100-N area, the operators have placed railroad ties adjacent to the piping to prevent vehicles from driving over the piping and this has been successful.

4.5 Treatment Equipment

A summary of the treatment equipment is included in Section 2.3. This section discusses equipment performance. The remaining three areas employ ion exchange units to remove unwanted contaminants. Area 100-NR-2 employs clino as the exchange media for removal of Sr-90, while the other systems use DowX 21-K resin to remove hexavalent chromium.

4.5.1 Area 100-NR-2

The four contactor ion exchange system is housed in a tent structure built in 1995. The tent contains all the major pumps, contactors, filters and other miscellaneous equipment to support the system. The tent was constructed because the interim removal action (IRA) was expected to have a life of approximately 10 years. The tent does not contain the control system that is housed in a small facility approximately 8 ft x 16 ft adjacent to the tent. The influent and effluent tanks, and the associated meters and headers from the extraction well field to the injection wells, are located outside the structure. The ion exchange system contains a total 200 cu ft of resin, or 50 cu ft per unit. All four of the contactors are presently operated in series, a system operation modification made several years ago when only 3 units were used and one was kept as a standby. The detention time at the regulatory prescribed 60-gpm flow rate is approximately 25 minutes or slightly over six minutes per vessel. The reduction attained in the train must average 90 percent over the life of the media. Due to cold weather limitations during CY2003, the removal efficiency decreased to slightly less than 90 percent for the year. This had little impact on the overall system efficiency. The influent concentration of Sr-90 is approximately 1900 pCi/l, and the average discharge/injection water concentration is approximately 190 pCi/l, well above (nearly 25 times) the groundwater MCL of 8 pCi/l. In order for the system to successfully remove Sr-90 the removal efficiency would need to exceed 99.5 percent through the system. It was not evident if the system is capable of meeting this criterion at any time during its current 30-day operating cycle. The cycle is based on an optimization study done with the clino several years ago. Water samples are taken at the treatment train influent and effluent at the midpoint during any treatment cycle, and just prior to media change out. Research into optional media for Sr-90 removal shows that resin selectivity for Sr-90 is very low, generally below that of other metals and even calcium, making the removal efficiency very low. New innovative processes such as the MR3 process being tested for the 100-D gap area hexavalent chromium plume shows some potential, as does appetite, another natural adsorption media. The natural zeolite clino is not regenerated, but instead is dewatered, containerized and disposed of in the Hanford on site disposal facility. Clino’s low cost of approximately $0.08 per lb, and the low onsite disposal costs, are its primary advantages. . A single change out requires 4 man-days of labor and this is the primary disadvantage of the use of the IX system.

The facility (tent) is approaching the end of its useful operating life. The lack of climate control equipment makes working conditions uncomfortable in the facility during temperature extremes even after interior insulation was added and efforts to plug holes in the facility were completed. The equipment within the facility, as well as the control system, continues to operate with minimal problems.

The need for this facility, or a replacement facility, is in question. This is discussed in more detail in Section 6.3.1, which presents recommendations regarding exit strategies.

4.5.2 Area 100-KR-4

Treatment facilities were not toured. The equipment is similar to that contained in the 100-HR-3 treatment facility (located in Area 100-H). A discussion of the equipment, orientation and basic operation is included in Section 2.3. Items that are applicable to the equipment and facilities discussed in Section 4.5.3 will be referenced in that section.

4.5.3 Area 100-HR-3

The H and D subunits, approximately 2.5 mi apart, make up the 100-HR-3 OU. Ground water from each subunit is extracted, discharged to a transfer station, and pumped to its respective treatment system housed in a common facility, 1713-H. The flow rate and influent concentration of hexavalent chromium varies between the two systems as identified below in Exhibit 15.

Exhibit 15: Comparison of 100-D and 100-H Areas

Area	Approx Flow Rate	Influent Chromium Concentration	Comments
100-D	120 gpm	~160 ug/l	Discharge criteria is 50 ug/l Cleanup criteria is 22 ug/l
100-H	90 gpm	~ 26 ug/l	

Discussions with staff at the site indicate the units are operating smoothly with few problems. The primary problem is with the high calcium carbonate ($CaCO_3$) content that leads to potential scaling on the resin. Sulfuric acid in low concentrations has been successful in reducing the scaling problems on the resin. The A ion-exchange train which serves the H area wells requires diffuser cleaning periodically due to brine (scale) build up on the diffusers. The H area has low levels of uranium, and intermittently Tc-99 present in the influent stream. The resins selected to remove the chromium removal have a higher selectivity for these two radionuclides over hexavalent chromium. Sampling is needed to determine activity level present on the resins (see Exhibit 16). If activity present on the resin exceeds 2 pCi/gr, the resin must be disposed in the on-site disposal facility (ERDF) as a high level waste. US Filter does the regeneration for Hanford provided it does not exceed the activity limit. IX regeneration facilities typically do not have the capability or the legal status to handle resins containing radioactivity.

Exhibit 16: Sampling Frequency

Location	100-HR-3	Test
Wellheads	Monthly	Cr
Tank Transfer Facilities Influent	Weekly	Cr
Tank Transfer Effluent	Weekly	Cr
Resin Beds	Weekly	Cr, U

4.6 Monitoring System and Program

The monitoring programs at the five plumes were qualitatively evaluated to assess the adequacy of the results for making site decisions. The evaluation considered the appropriateness of the monitoring network, sampling frequency, and analytical suite in light of the system objectives. Another technical assistance team will reportedly be visiting Hanford soon to assess the overall monitoring program. The data management program and the monitoring for treatment process decision-making were also evaluated.

4.6.1 200-UP-1 Area

The monitoring well network in the 200-UP-1 area has been significantly impacted by falling ground water levels. As described in Section 2.4, a number of wells have been lost, as the water table has dropped significantly. Additional monitoring wells have been added. In 2003, one new monitoring well was added, and nine ground water monitoring wells were abandoned. Although the plume (that portion with concentrations above interim standards) is defined by only six wells in the draft 2003 annual report, there are other wells in the vicinity that presumably further define the extent of contamination. The extent of the Tc-99 plume to the west (upgradient) of extraction well W19-36 is not fully defined. However, the extent of the 9000 pCi/l Tc-99 was not far upgradient from well W19-36 when characterized, and the extent should only have been reduced since then due to the operation of the extraction system.

The depths of the wells are relatively shallow, and reportedly, do not extend far below the water table. Though downgradient wells appear to confirm the uranium and Tc-99 are concentrated within the upper 32 ft of the water column, this is not confirmed within the extraction area. Interestingly, one now-dry monitoring well, 299-W19-29 (located near extraction well 299-W19-43), had increasing concentrations of Tc-99 prior to going dry in 1999, with a maximum concentration of over 25,000 pCi/l in its last year of sampling. This supports the concept that the contaminants have been most concentrated near the water table. Monitoring frequency for most wells at the site is appropriate for the site.

4.6.2 100-D and 100-H Areas

The monitoring network in the 100-H area appears to be more than adequate to define the remaining chromium plume at the site, at least within the area of the extraction system. There are 22 monitoring wells in the vicinity of the ground water extraction system and others in the 100-H area that area monitored. Many of the monitoring wells are now upgradient of the remaining chromium plume, and sampling of these wells do not appear to contribute to decision-making at the site. Note that the extent of the plume to the southeast of the extraction wells is not defined by the wells in the vicinity of the extraction system. Presumably, other monitoring points to the southeast further define the limit of the plume relative to the cleanup goal. The monitoring frequency is generally semi-annual. The need for semi-annual sampling is not clear for monitoring wells upgradient of the plume, nor is there a distinct benefit for semi-annual monitoring in the heart of the plume. Less frequent measurements would suffice. Note that some upgradient wells are sampled annually, including H4-3C, H4-45, H4-47, and H6-1. The analytical suite appears to focus on the contaminants of concern. Given that samples are analyzed for total chromium, sampling methods should be chosen to minimize suspended particulates.

The monitoring network at the 100-D area appears to also be more than adequate to delineate the chromium plume as defined by the 100-ug/l contour, but the 22-ug/l contour is not well defined, except in an upgradient direction. Presumably, there are other monitoring points outside the network near the extraction system that more fully define the extent to the northeast of the extraction system. It is not clear if there is a need for three upgradient wells near the 100-DR reactor if these wells are intended to monitor the chromium plume. Furthermore, two wells, D5-14 and D5-40, do not appear to contribute much useful information to define the chromium plume (i.e., the plume could be drawn in essentially the same shape without these wells). The majority of the wells are sampled quarterly, and some wells are sampled monthly. This frequency seems excessive in light of the rate of movement of the plume, and the extensive history of sampling in most of the wells. Quarterly sampling would seem appropriate for wells in the area between the ISRM barrier and the existing ground water extraction wells, given the changes that have been occurring there. Such sampling should continue for some period following start-up of the new extraction wells. The analytical suite seems reasonable, though the need for sulfate analysis is not clear. Again, the appropriate sampling methods include those that reduce suspended particulates in the samples.

4.6.3 100-KR-4 Area

The monitoring network for the 100-KR-4 area appears adequate to monitor the status of the chromium plume. A large number of monitoring wells near the reactor buildings are currently monitored for chromium but have concentrations consistently (over the past few years) below the cleanup goal. These wells are listed below. It is not clear if sampling these wells is required for monitoring other constituents of interest, but the value of the sampling and analysis for chromium is not clear. It appears that some of these wells have elevated nitrate relative to the MCL of 10 mg/l, but nitrate is not the primary contaminant of interest requiring extraction. One of the wells shown below, 199-K-109A, contains elevated strontium. The extent of the chromium plume is not defined at the 22-ug/l contour northeast of well 199-K-130. Monitoring wells sampled and analyzed for chromium near the K area reactors include: 199-K-106A, 199-K-27, 199-K-109A, 199-K-32A&B, 199-K-107A, 199-K-34, 199-K-108A, 199-K-34, 199-K-110A, 199-K-35, and 199-K-23. Of these, 199-K-109A has elevated Sr-90 levels.

The monitoring frequency appears optimized for some wells, but other wells are sampled too frequently given the history of concentrations, and the use of the concentration data. The compliance wells are sampled monthly despite having an extensive history of sampling. Well 199-K-114A does have significant variability, but wells 199-K-117A and 199-K-18 do not have significant variability. Less frequent sampling of these latter two wells would seem appropriate, especially considering the low concentrations in well 199-K-117A. The trend plots in the 2003 Draft Annual Summary Report (Appendix K) for several monitoring wells (199-K-107A, 199-K-23, 199-K-32A and -32B) present two chromium values for the same sampling event. One is typically very low (below the cleanup goal), and the other is relatively elevated. It is not clear if the two results represent a filtered and unfiltered sample result. If that is the case, then it would suggest the chromium, in some cases, may be related to suspended particulates and may not be related to hexavalent chromium.

4.6.4 100-NR-2 Area

The monitoring network at the 100-NR-2 area appears reasonable for its purpose. The northeastern boundary of the Sr-90 plume is only defined by wells 199-N-50 and 199-N-51, that are not regularly sampled, but are historically very low in Sr-90. The only potential duplication of information may be monitoring wells 199-N-3 and 199-N-18. It is not clear for what reason well 199-N-46 (near the Columbia River) is not sampled. The concentrations of Sr-90 are elevated, but apparently stable in well 199-N-99A, yet upgradient concentrations are significantly lower. Well 199-N-99A should be flushed regularly by bank storage effects related to changes in river stage. This may suggest little mobilization of Sr-90. Sampling frequency appears reasonable. A number of wells are sampled for chromium, yet none except 199-N-80, are elevated relative to the cleanup standard set at sites 100-D and 100-KR-4 areas. The sampling and analysis for chromium, as well as other metals such as manganese, could be terminated without loss of necessary information for decision-making.

4.6.5 Reporting

The annual reports provide good analysis of the sampling results and water level monitoring, as well as an update to the conceptual model for each site. This is an excellent practice. The analyses of the data trends are also valuable. Note that the figures in the annual reports do not include posted values for concentration or piezometric levels on the maps, so it is not easy to evaluate the adequacy of contouring. For the 100-NR-2 area, the maps of the strontium plume shown in the draft 2003 annual report did not display all monitoring wells that were sampled. (Note also the units in the trend plots in the appendix are incorrect – they show mg/l for nitrate and sulfate when the values plotted are ug/l).

4.6.6 Process Monitoring

The influent and effluent of the 100-HR-3 and 100-KR-4 systems are measured weekly. The influent and effluent of the 100-NR-2 system are measured every two weeks. Given the low variability of both influent and effluent for both the 100-HR-3 and 100-KR-4 systems (typically less that 25 percent in inter-week variability), the long history of monitoring these concentrations, and, more importantly, little impact of the week-to-week results on operational decisions, it would seem that sampling influent and effluent on a weekly basis is unnecessary. Twice per month or monthly sampling may be more appropriate. Field test kits (i.e., Hach) are used to sample between all IX vessels at the 100-KR-4 and 100-HR-3 systems on a weekly basis. The use of the Hach kits is appropriate. However, sampling between each vessel seems excessive, if the lead vessel has not broken through, and given the amount of history on resin use and the number of beds in series, the weekly sampling may not be necessary to make operational decisions.

4.7 System Strengths

The following is a list of observations made by the RSE team during the site visit that highlight some system strengths and/or previous optimization efforts:

- The treatment systems have a high degree of automation.

- There is substantial "pride of ownership" by the operators, and the systems are clean and well-maintained.
- The operators are knowledgeable and well trained.
- A preventative maintenance system has been implemented to minimize down time.
- The performance of the extraction wells is periodically evaluated and a plan exists to perform preventative maintenance rehabilitation if performance declines.
- The project team has, and will continue, to look for ways to more cost-effectively manage the ground water plumes, including improvement of redox manipulation, as well as emerging phytoremediation and apatite injection technologies.
- Optimization evaluations have been performed to attempt to find a least-cost solution for resin regeneration and disposal, based on tradeoffs between changeout frequency and the potential for creating low level radioactive waste.
- Optimization was performed to develop a more efficient approach for changing the clino in the 100-NR-2 treatment system.
- The project team facilitated a DOE HQ-lead ITRD remediation options evaluation of the 100-N area in 2002, and is proactively implementing the recommendations of the report by improving the pump and treat system, as well as negotiating modifications to the interim ROD.
- Annual reports provide a good overview of the analytical results and provide updates to the site conceptual models.

This is not intended to be an exhaustive list -- there are other strengths of the systems that could be highlighted.

4.8 Components or Processes that Account for the Majority of Annual Costs

The four systems evaluated for this RSE cost a total of approximately $4.3 M annually for the following categories: labor, materials, utilities, analytical, and waste disposal. Exhibit 17 provides a breakdown of costs for the four systems.

Exhibit 17: Cost Breakdown for Systems

Cost Category	100-HR-3 Cost in $1000s	200-UP-1 Cost in $1000s	100-KR-4 Cost in $1000s	100-NR-2 Cost in $1000s
Labor				
Operators/Craft	289	32	287	195
Engineering	177	44	221	114
Scientist	28	12	26	29
Overhead	280	40	249	119
Total Labor	774	128	783	457
Materials				
Resin/Parts	585	17	392	102
Taxes/Licenses	56	1	40	7
Total Materials	641	18	432	109
Analytical[1]	59	?	52	1
Utilities (BPA)	19	4	17	15
Disposal				
ERDF	15	6	15	56
Off-Site	132	0	130	14?
Sample Mngmt[2]	86	0	90	22
Total Disposal	233	6	235	78
Management and Support				
Admin Support	16	1	12	14
Reproduction	8	1	1	0
Vehicles	3	0	3	3
Total Support	27	2	16	17
Total Cost ('03)	1775	252	1563	702

[1] Does not appear to include well sampling and analysis

[2] Hanford Sample Management Office Prepares Materials for Off-site Shipping/Disposal

Approximately 75-80 percent of the costs are associated with labor and materials, with much of the remainder spent on waste disposal. A significant labor cost is incurred for the engineering support, approaching the cost of the operators in most cases. These costs include studies of resin use and alternatives, and the preparation of repair or maintenance orders. The costs for operator labor at all sites except 200-UP-1 are comparable to having two full-time (40+ hours/week) operators at each site. This is surprising, given the high degree of automation of the systems.

Resin costs, both the purchase of new resins and the disposal of spent resins, are a substantial portion of the costs at the 100-HR-3 and 100-KR-4 systems. Consequently, there is a high-cost sensitivity to mass loading at the systems. Anything that would reduce the flow and/or concentration in the influent, or would significantly reduce costs for the resins, would significantly reduce overall project costs. There are significant costs for packaging and shipping of spent resins and other wastes for off-site disposal. A specific office at Hanford charges these costs. These costs are not typically incurred at other sites with materials sent for off-site disposal. Apparently, the analytical costs provided to the RSE team are only for testing of spent resin.

4.9 Recurring Problems or Issues

4.9.1 Above-Ground Transfer Pipe Damage

Piping is located above ground due to tribal concerns over the potential for trenching to disturb artifacts. Piping has been damaged at various locations due to brush fires, cold weather freezing, mechanical damage caused by vehicles in the area.

4.9.2 Performance of the In Situ Redox Munipulation (ISRM) Barrier

The ISRM barrier is reportedly not performing as expected and may be allowing incompletely treated ground water to flow past to the Columbia River. Specifically, it has been unable to meet the performance requirements in areas of high flux. The prerequisite dithionate reaction is inhibited if inadequate ferrous oxide is present in the aquifer. The presence of highly permeable gravel lenses within the aquifer may contain inadequate concentrations of ferrous oxide to complete the treatment reaction to reduce chromium to the less toxic state.

A separate, DOE HQ Technical Assistance Team (TAT) assessed the ISRM barrier performance; findings of the TAT are summarized as follows:

> “The TAT determined that the actual cause of premature breakdown in reductive capacity of the aquifer in the 100-D Area is unknown; but that the primary causes are likely related to both physical and chemical heterogeneity and the presence of other oxidants such as nitrates within the aquifer. The TAT recommended an aquifer characterization study to improve the site-specific understanding of the physical and chemical heterogeneity of the aquifer along the location of the existing barrier, and, in order to understand the magnitude of the problem, the development and refinement of a conceptual model of the aquifer. The TAT recognized that the results of the aquifer characterization study must be utilized to further evaluate and select barrier-mending options. Mending options, which include chemical and biological reductants utilizing the existing barrier wells, must be further evaluated to determine viability based upon performance and cost criteria. It is highly likely that the recommended approach will consist of a combination of options applied as a treatment system. The overall approach for extending the barrier should utilize all the lessons learned from the mending of the barrier, including detailed aquifer characterization and testing of mending alternatives.”

4.9.3 Ion Exchange Contactors, Resin, and Component Scaling

The water in the 100-HR-3 area contains high levels of $CaCO_3$, in particular the 100 H area. Calcium carbonate tends to precipitate out during the summer months due to the elevated temperatures. The operators drip a low volume of sulfuric acid into the system upstream of the ion exchange units to limit scale buildup in the flow distributors and resin. Scale on the distributor results in non-uniform flow across the bed, and potentially cause channeling in the bed. Scale build-up on the resin could render it unusable, and impact regeneration effectiveness.

4.9.4 Activity on Dow X Resin

The presence of radioactive constituents in the 100-HR-3 area results in activity accumulation on the resin, especially uranium. The Dow X resin has a higher affinity for uranium than chromium which necessitates careful monitoring of the lead vessels. If the activity within the resin exceeds 2 pCi/gr, the resin is considered a high-level radioactive waste, and disposal at an off site facility is needed. The operators attempt to maximize the activity present on the lead vessel to limit costs for replacement of the resins in the downstream vessels. The operations staff is currently optimizing the use of the first vessel in each series to remove the radioactive constituents (i.e., sacrificial) and use down stream vessels primarily as the chromium removal vessels.

4.10 Regulatory Compliance

- At present, there are no known air issues related to the RSE sites.
- Prescribed flows at the 200-UP-1 site and 100-NR-2 site of 50-60 gpm, respectively, have not been continuously maintained.
- Monthly average effluent concentrations, not meeting the 90-percent removal efficiency from the 100-NR-2 plant, have occurred.

For the latter two conditions listed above, regulators have elected not to issue notices of violations.

4.11 Safety Record

The operators and engineering staff have indicated there have been no lost time accidents at the four OUs evaluated in this report.

5.0 EFFECTIVENESS OF THE SYSTEM TO PROTECT HUMAN HEALTH AND THE ENVIRONMENT

The assessment of system performance also includes a preliminary and qualitative evaluation of the effectiveness of the systems to prevent unacceptable exposures. The evaluation is necessarily limited, given that there are many aspects of the potential ecological risks in the Columbia River that the RSE team was not tasked to evaluate. Some risk assessments are ongoing (i.e., 100-N area for Sr-90 exposure) to establish appropriate, or any, new exposure levels needed to protect public and environmental receptors.

Only initial concerns regarding risks associated with the operation of the ground water extraction and treatment systems are raised here; this review does not replace the “five-year” process. It is understood that a comprehensive evaluation of long-term risks related to the Hanford reservation is in preparation, and a five-year review is pending for 2005. The potential pathways assessed include ground water and surface water. No air impacts are anticipated; data related to sediment and soil exposures were not reviewed.

5.1 Ground Water

The 200-UP-1 system is an interim system meant to reduce peak concentrations. The hot spot addressed by the system is located within an extensive area of ground water contamination and there are no human or ecological impacts directly created by the current operations. The long-term loading on the ground water due to contaminant mass in the vadose zone is uncertain and the subject of current studies. It is possible that the contaminant hot-spot may be recreated if a portion of the mass of uranium and Tc-99 in the vadose zone is still mobile and there is a source of recharge at the source areas.

The 100-KR-4 and 100-HR-3 extraction systems appear to be functioning as intended, though there is apparently some contamination located between the extraction wells and the river that may occasionally be flushed back to the river. There are likely some gaps in capture in both space and time, but these do not appear to be a major concern based on interaction with the State regulator. The ground water extraction system and ISRM barrier at the 100-D Area do not appear to currently control the migration of chromium to the Columbia River between the ISRM barrier and existing extraction wells. Additional extraction wells are being added to capture contaminated water in the gap between the existing system and the ISRM barrier. In addition, a new chromium treatment plant is being installed. Finally, the project team has adopted recommendations of a recent review report to conduct additional subsurface characterization studies of the barrier to delineate areas of aquifer heterogeneity and channeling, as well as to evaluate new amendments for use, in combination with injected sodium dithionite.

The 100-NR-2 system has questionable effectiveness. In 2002, an ITRD report estimated a cost of $ 4,292,777/Ci of Sr-90 removal, and stated that the pump and treat system is not effective for reducing the Sr-90 concentrations in the aquifer (DOE/RL, 2001). The majority of the total contaminant mass inventory of Sr-90 is in the unsaturated zone below the LWDFs; the rate at which the Sr-90 moves through the unsaturated zone in an irrigation scenario is slow enough that it should decay before reaching the water table. Of the contaminant mass between the river and the extraction wells, which is not effectively prevented from slowly leaching into the Columbia River, only 5-6 Ci are expected to be released (see Section 4.2.3). The project team is evaluating the use of phytoremediation and an apatite barrier as alternatives to mitigate the migration of Sr-90 into the Columbia River.

5.2 Surface Water

No recent sampling data for the Columbia River were reviewed, but it is anticipated that the impact to river water quality from releases at the 100 Area sites is very minor due to the extremely large dilution factor. As indicated by both DOE staff and regulatory representatives, the primary concerns relate to the impact to ecological impacts in the river-bottom habitat, and these impacts are not directly addressed here.

6.0 RECOMMENDATIONS

The RSE team offers various recommendations regarding the extraction and treatment systems for the Hanford team to consider. DOE Richland, in consultation with the regulatory agencies, would presumably develop the process for building consensus and providing stakeholder review of documents relating to the implementation of the recommendations.

6.1 Recommendations to Ensure Effectiveness

6.1.1 Improve Source Characterization and the Conceptual Site Model

6.1.1.1 100 Area

Despite a number of attempts using soil sampling, residual hexavalent chromium has not been fully characterized in the 100 Area vadose zone, though the historical source locations are believed to be known (i.e., cribs and trenches). Uncertainties in the source characterization translate into large volumes of vadose zone soils potentially requiring treatment. Changes in the operation of the 182-D reservoir appear to have changed the flow paths of the chromium plume in the 100-D Area. The plume is currently uncontrolled between the ISRM barrier and the extraction wells. The current plans to expand the extraction system in the 100-D area appear warranted; the RSE team concurs with this decision. Ground water extraction represents a reliable approach to preventing migration of contaminants to the river in high to moderate permeability materials in the short term.

The capital and operational investment in the pump and treat systems, the ISRM barrier, and now, the expansion of the pump and treat system to capture affected ground water at the gap, will likely exceed $ 50 million dollars. Future investments are likely to include the following: (1) attempting improve performance of the ISRM barrier through additional subsurface characterization and amendment, (2) attempting to improve the treatment process, and (3) optimizing the performance of the pump and treat systems (i.e., determining better pumping rates and locations) in the out years. To obtain meaningful results from these future efforts, such that benefits from the investments are actually realized, improved contaminant source characterization and an update of the overall conceptual site model (CSM) is recommended.

Maintenance and optimization of long-term remediation systems (e.g., 100-D Area) is limited by uncertainties in the current understanding of the extent and mechanistic transport of chromium in the 100 Area (i.e., limitations to the current conceptual model), as well as the simplified nature of the MicroFEM flow models currently used (i.e., limitations to the current mathematical modeling). Updates to the mathematical modeling (discussed later in Section 6.4) will require an improved understanding of the effect of river stage fluctuations, aquifer heterogeneities, flow channeling, remaining contaminant sources, and so forth on the following: (1) multiple scenarios of chromium migration; (2) the performance of the barrier; and (3) pump and treat performance. These cannot be evaluated realistically with the limitations to the present CSM.

Additional source characterization should be performed to the extent that such efforts reduce or remove unacceptable uncertainties in the predictive results needed to operate and improve the remediation systems to achieve the RAO of chromium aquatic release limits to the Columbia River. The costs incurred to update the CSM and delineate the chromium source areas more accurately could potentially be offset by life-cycle cost savings that might result from improved system performance, reduced remedy duration, and phase-in of more passive and/or lower cost technologies.

6.1.1.2 200-UP-1 Area

The vertical extent of the contamination in the 200-UP-1 area is not well defined, especially since the water table has substantially dropped since characterization efforts have begun. The studies currently underway regarding the fate of uranium and other contaminants in the 200-UP-1 area would appear to be of significant value to predict the fate of the contaminants. These will also address the possibility of the recurrence of the ground water hot spots for Tc-99 and uranium near the sources.

6.1.2 Alternatives for the 100-D Area

The RSE team recommends that the Richland project team continue to evaluate robust, lower-cost alternatives to chromium source treatment. As discussed in Section 6.3.2, there are some vapor-phase reduction technologies that may provide relatively inexpensive treatment, and further characterization can be integrated into a phased implementation of the remediation.

In the long-term, alternatives that may passively treat the chromium face challenges. There may be difficulties in creating fracture-placed iron walls due to the relatively high permeability of parts of the aquifer. In-situ reduction through bioremediation using carbon amendments delivered in dissolved form may be rapidly flushed from the subsurface system and may require frequent replenishment. More persistent carbon sources, such as emulsions of vegetable oils, may be a more attractive alternative. The RSE team recommends further study of the potential of this technology to address the migration of chromium at the 100-D area. The evaluation should address the ability to adequately alter redox conditions, the production of objectionable levels of other toxic metals such as arsenic, the persistence of oil dissolution, and the long-term costs of the vegetable oil option relative to the cost of an optimized pump and treat system. Additional discussion on the technology and costs are provided in Section 6.2.4.3.

6.1.3 Increased Monitoring

A minor increase in the number of monitoring points is suggested. Additional monitoring of deeper saturated units in the vicinity of 200-UP-1 extraction wells is recommended at some point in the future. The extent of the chromium plume southeast of the 100-H area extraction system, and the lateral extent of the chromium plume northeast and southwest of the extraction system at the 100-D area, are poorly defined by the monitoring network shown in the annual report on the systems. The contours at the cleanup levels are open in those areas. If existing monitoring wells outside the monitoring networks shown in the reports do not effectively define the plumes, additional wells are required to assess the need for expanded capture. The annual reports for the extraction systems should be updated to post concentration values and water level elevations at each point, and each well included in the sampling program should be shown on the figures. Any additional monitoring should consider density effects on the vertical distribution of contaminants if high concentration releases (e.g., from chromate solution tanks or transfer facilities) were suspected or confirmed.

6.1.4 Changes to Verify and Improve Capture

Recommendations to change and improve capture must first be put into context of the remedy goals. As discussed in Section 4.3, none of the interim remedies appear to have specific quantitative goals associated with demonstrating capture. In addition, some gaps in capture may not be inconsistent with meeting the overall objectives of the interim remedies.

It is recommended that the goals with respect to plume capture be clarified, for each area, so it is clear which of the following two cases applies:

- Case 1: There is no strict requirement of hydraulic containment that can be quantified, such that the interim remedy could be considered successful even if there are gaps in capture over time and/or space, as long as receptors are not being harmed and progress is being made towards site cleanup.

- Case 2: There is a strict requirement of hydraulic containment, such that the interim remedy would be considered unsuccessful if there are gaps in capture over time and/or space

The RSE team discussed system goals with both representatives of DOE Richland and the State of Washington to determine the degree to which Case 1 or Case 2 described above apply at the various sites. Case 1 appears to be the current practice for the interim remedies for all the areas evaluated by the RSE team. DOE and the State of Washington appear to understand that the existing extraction systems may not provide full containment (notwithstanding the significant plume migration between the ISRM barrier and ground water extraction system at the 100-D). When Case 1 applies, performing rigorous capture zone analysis is not a primary need. Instead, it is recommended that a process be put in place to routinely determine that receptors are not being harmed, and progress is being made towards site cleanup, which is the primary emphasis. This process should specify measurements to gage performance toward the remedy goals, and should specify the types of results that would suggest the remedy is not successful.

For areas where Case 2 applies, as may be implemented in the final RODs, a three-dimensional “Target Capture Zone” should be delineated illustrating the specific three-dimensional zone of groundwater targeted for capture. Without defining the target capture zone, it is not possible to determine if actual capture is adequate. After defining the Target Capture Zone, actual capture should be interpreted with as many lines of evidence as is practical, and then be compared to the target capture zone for validation. Currently, only simplified steady-state flow modeling, with particle tracking, is used to illustrate capture extent. As discussed in Section 4.3, use of concentration trends may not be a useful line of evidence for evaluating capture in the 100-area systems due to the proximity of the Columbia River to the extraction wells. However, the installation of additional piezometers to provide “gradient control pairs” downgradient of the extraction wells could provide evidence of capture, if properly located. These piezometers could also provide useful information regarding changes in hydraulic gradients, and associated flow directions, over time that may be caused by external stresses (i.e., Columbia River stage level). In addition, such piezometers would provide useful data points for refining the calibration of future flow and transport models. Currently, flow model results are used to illustrate steady-state capture zones, particularly by comparing observed versus simulated drawdown responses to changes in pumping at the extraction wells.

Again, note that recommendations such as the addition of piezometer pairs, associated with Case 2, may not be justified in areas where Case 1 applies (i.e., where some gaps in capture may be acceptable). Since Case 1 appears to be the current practice for all of the interim remedies evaluated, no specific recommendations for locations of new piezometer locations are provided. The RSE team does not advocate one approach at the exclusion of the other provided there is no unacceptable impact to receptors and the team raises the issue to spur further discussion between DOE Richland and the stakeholders.

6.2 Recommendations to Reduce Costs

6.2.1 100-H Diversion to the Extent Pumping Continues

The water treated at the100-HR-3 system (located in the 100-H area) comes from both the 100-H area and the 100-D area. The chromium concentrations in the water from 100-D are much higher than chromium concentrations in the water from 100-H, as shown in Exhibit 18.

Exhibit 18: Chromium Influent Concentrations, 100-HR-3 System

Area	Approx Flow Rate	Influent Chromium Concentration	Comments
100-D	120 gpm	~160 ug/l	Discharge criteria is 50 ug/l Cleanup criteria is 22 ug/l
100-H	90 gpm	~ 26 ug/l	

The aquifer concentrations of chromium in 100-H are generally below 80 ug/l, not far from the cleanup criteria of 22 ug/l. It is possible that the interim cleanup levels will be achieved within several years in 100-H, or that a final remedy will be established that does not require continued pumping in 100-H. However, to the extent that pumping continues in 100-H to provide some degree of hydraulic containment, it is recommended that consideration be given to not treating the water pumped from 100-H, and instead re-injecting the untreated water. The concentrations of Cr in the combined influent from all 100-H extraction wells are very close to the cleanup criteria (due to extraction of water over a broad area). Since the 100-H influent is well below the treatment system discharge criteria, recirculation of this water should be acceptable. Assuming the 100-H influent (untreated) is mixed with treated water from 100-D prior to discharge (which generally is near the “non-detect” level for chromium), the recharged water would have concentrations far below the cleanup criteria. Please note that this is not an argument for simple dilution. Our recommendation would be to discharge the untreated 100-H influent, whether or not it is mixed with treated water from 100-D.

The mechanics of implementing this recommendation are extremely minor, requiring a simple bypass in the treatment system. Cost savings would result from lower resin usage, and less labor due to less frequent resin changes. In addition, less process monitoring would be required. Cost savings would be conservatively approximated at $175,000 annually [resin replacement 10 contactors x 80cf each x $135/cf (half regen/half new) + labor savings 5 percent reported in annual report $40,000 + 10 percent disposal costs $25,000].

6.2.2 Sr-90 Diversion to the Extent Pumping Continues

There was substantial discussion during the site visit about the benefits of continued pumping at 100-NR-2, because the amount of Sr-90 removed by the pumping systems is quite small. It is possible that a final remedy will be established that does not require continued pumping in 100-NR-2 based on alternate remediation technologies such as an in-situ apatite barrier or phytoremediation. However, while pumping continues in 100-NR-2 to provide some degree of hydraulic containment, it is recommended that consideration be given to not treating the water pumped from 100-NR-2, and instead re-injecting the untreated water. The treatment of Sr-90 is not efficient. There is no identified discharge criterion for Sr-90, although a requirement exists to reduce the influent concentrations by 90 percent. The current influent concentrations of approximately 1800 pCi/l are currently remediated to approximately 270 pCi/l, such that the recharged water is still more than 30 times above the cleanup criteria of 8 pCi/l. In the opinion of the RSE team, since water with concentrations substantially above the cleanup criteria is already being recharged into the aquifer, and Sr-90 is decaying over time due the radioactive half-life (28.8 yrs), the treatment of the water for Sr-90 prior to discharge appears to yield little or no environmental value. By reinjecting the water upgradient of the extraction system, the passage of the Sr-90 toward the Columbia River would be interrupted and delayed. This process would result in the temporary placement of Sr-90 in the soil and aquifer upgradient of the extraction system but would allow additional time for “treatment” by radioactive decay to occur. Such natural decay will have a far greater impact on the removal of Sr-90 than the engineered extraction and treatment system.

The mechanics of implementing this recommendation are extremely minor, requiring a simple bypass in the treatment system. Cost savings would result from lower media usage, and less labor due to less frequent media changes. In addition, less process monitoring would be required. Media savings would be approximately $11,500 annually (3,000 lbs per vessel x 4 vessels x 12 times annually x $0.08/lb). Labor savings would be approximately $20,000 (4 operators x 8 hours x $50/hr x 12 times per year). There would be no disposal fees for the ERDF, saving approximately $56,000 based on 2003 costs. Sample management costs of approximately $22,000 would largely be avoided. Assuming a slight reduction in operator activity due to reducing the number of processes, avoided disposal and analytical costs, reduced power and supplies required, the anticipated annual savings would be approximately $110,000.

6.2.3 Reduction in Operator Labor

It was noted during the site visit that there are 11 operators that run the systems for the entire site, on a rotating basis. It was stated that there are approximately three operators (8 hrs per day) operating the 100-area systems. At times when the treatment media are changed, additional operators are utilized. There is no treatment system specific to 200-UP-1 that requires operation.

The RSE team notes that the current treatment systems are highly automated, and should require little or no labor to operate on a routine basis. The benefits of highly automated systems should include reduced labor requirements, but those benefits do appear to be realized for these systems. In the opinion of the RSE team, one person could easily perform a visual inspection on all the systems at a frequency of several times per week (or even every day if that is thought to be necessary, although it is currently not done on weekends indicating that every several days should be adequate). This person could also easily handle the process monitoring sampling. All of the systems observed were highly computerized, and could be operated remotely. The systems are not attended by an operator on weekends, and it is evident that continuous operation is not critical, because alarms received on weekends are generally not addressed until Monday.

For the relatively infrequent times when more labor is required such as resin changes, maintenance, or sampling, additional labor can be accessed. Staffing at plants less automated, and of the same relative complexity, at military- and EPA-lead cleanup sites generally consist of two or three full time operators. These operators are generally responsible for doing most of the non-electrical/controls maintenance and equipment service, sampling, reporting, and data evaluation in the plant and well field. The current staff of 11 full-time operators and a supervisor is more than needed to safely and successfully operate these facilities. Assuming the staff was cut in half leaving 5 full-time operators and a supervisor, the savings afforded by this action alone would be over $600,000 annually (6 operators x $50/hr x 2080 hrs).

6.2.4 Treatment Alternatives

6.2.4.1 Resins

The Hanford project team should systematically review resin alternatives biannually to determine if new products have been developed that are more efficient than the present resins. The resin selected by the Fluor personnel to remove the hexavalent chromium is effective for removing chromium, but it is also extremely efficient at removing radionuclides, particularly uranium which is present at the 100 HR-3 pump and treat sites. Regeneration suppliers agree with the present operations protocol, which requires the lead unit be used to remove the uranium present in the waste stream since it cannot be regenerated. Potential cost savings from using the lead resin bed as a sacrificial bed to remove radionuclides based on the 2003 annual operating report would be about $36,000 [(80 cu ft/contactor x 3 contactors (2 @ 100 HR-3 and 1 @ 100 KR-4) x ($200-$50/cu ft)] assuming the area H system is kept on line.

The operations management staff is currently evaluating the use of a new system called the MR3 system that can be regenerated on-site. The system is to be installed at the 100-D gap area between the 100-D area extraction system and the ISRM, system where new extraction wells have been recently installed. Information on the process acquired via the Internet at http://www.mr3systems.com/ indicates this is the first installation by this company at a hexavalent chromium site. The system has the advantage of on-site regeneration of the resin with concentration of the brine in a solidified form for disposal. However, the process is extremely complex, and will necessitate much greater labor outlays than presently needed at the current chromium remediation facilities. The literature suggests this might have capabilities for removing Sr-90 as well, although it would likely remove nearly all the ions in the water first. The DOE may want to consider a lab-scale proposal, if Sr-90 treatment is to continue at the 100 NR-2 site. Cost savings is unknown at this point.

The Hanford operations staff should consider using previously regenerated resins with an affinity to the radionuclides of concern in lieu of the effective, yet expensive DowX resin in the lead vessel. There are many resins that are effective in removing uranium that could be employed for less than or equal to the cost of the regeneration. One regeneration vendor receives resin used for removing perchlorate from groundwater systems. The perchlorate is irreversibly bonded to the resin but occupies only a fraction of the resin capacity. This would otherwise reuse resins that were destined for landfill disposal elsewhere, and meet the needs of the Hanford project team at a reduced cost. A lab or bench scale test should be done to verify the appropriate loadings and impacts on the overall treatment process. Potential cost savings would be approximately $25,000 [2 vessel changes (100-H Area) x $125/cu ft (cost new resin $200 minus used $75) = $20,000 + reduced cost for lab analysis/characterization $5,000].

6.2.4.2 Zero-Valent Iron (ZVI) Contactor

In lieu of ion exchange, ZVI could be employed to reduce the hexavalent chromium in the HR-3 and KR-4 systems and uranium if necessary in the H system to meet discharge standards. Preliminary estimates indicate that a ZVI contact time of approximately 45 minutes would be needed. The volume of sand/iron required would be approximately 1,100 cu ft for the KR-4 and H areas and 1,500 cu ft for the D Area. Area H would require 2 rectangular tanks in series each approximately 12 x 12 x 6-ft-high containing 4 ft of mixed media, and Area D would require 2 rectangular tanks in series each approximately 12 x 16 x 6-ft-high containing 4 ft of mixed media. Cost for this option is approximately $120,000 each for the KR-4 and H areas, and $160,000 for the D area. In addition a pilot test run at the facility treating an actual side stream is recommended with clear and specific metrics for going forward with a full-scale implementation. Cost of this pilot test is dependant upon the size and duration of the pilot, amount of sampling and analysis, whether new equipment is purchased or existing equipment is adapted. Total estimated cost for installing all three systems would be in the vicinity of $750,000 ($500,000 for the three systems, removal of the old equipment, engineering and design, and other unforeseen costs). Monitoring costs would be similar to the current costs. Maintenance would be minimal and consist of a visual inspection of the media to ensure it does not plug. A conservative estimate of the annual savings would equal half of the costs associated with the HR-3 and KR-4 systems or $1,500,000 [(labor $774 + $783; Resin/Parts $641 + $432; disposal $233 + $235) 0.5] the cost applied to resin change outs annually. Note that the costs for the decommissioning of the ZVI contactor and disposal of the contents are not included and, though not estimated in detail, are assumed to be comparable to the capital costs for the ZVI contactors and contents. These costs will need to be accounted for in making economic decisions about the feasibility of implementing this treatment option.

6.2.4.3 Other Processes

There are a variety of processes that could be used for remediation of the hexavalent chromium plume. DOE Labs, including PNNL, has evaluated several technologies. Some of those technologies are as listed below:

- Permeable Reaction Wall -- The current use of pump and treat technology for the100 HR-3 and 100 KR-4 Areas could be replaced by the use of a permeable reaction (zero valent iron or nanoscale iron) wall. Such a wall would passively treat the plume by reducing the soluble hexavalent chromium to the insoluble trivalent chromium as it passes through the nanoscale iron or iron filings. Given the depth of the contamination, a trench/excavation method of wall placement will not work for this site. The iron and guar mixture would be placed using a system similar to the process used by GeoSierra in which uses azimuth-controlled vertical hydraulic fracturing technology to construct full-scale iron permeable reactive barriers (PRBs) to depths >120 ft bgs. This vertical hydrofracturing technology constructs the iron treatment wall from series of conventionally drilled boreholes along the prescribed wall alignment, with a specialized frac casing grouted into the boreholes. The iron treatment wall is constructed by injection of the iron filings into the frac casings with real time quality assurance monitoring of the injections to quantify the PRB geometry and iron loading densities to some height above the water table to account for fluctuations in piezometric levels caused by the Columbia River. Depth to the groundwater in the 100 area ranges from 70 - 80 ft bgs, and aquifer depth to approximately 130 ft bgs. The length of the wall would be approximately 0.6 mi in the 100-K area and 0.7 mi in the 100-D area. Based on ground water flow rates under natural conditions at the site, and the concentrations of the chlorinated organics, a required wall thickness was determined. The wall would potentially have a life span of 20 years or more. Cost of a wall of this magnitude would likely cost over $25 million to install over the distances identified. Note that there may be some concern for the successful installation given the coarse material at the site (see section 6.1.2.). Some demonstration may be needed with clear criteria established for going forward with a larger implementation.

- Biological Manipulation of Redox Conditions -- Accelerated anaerobic bioremediation could also be an alternative for reducing the hexavalent chromium to trivalent non-mobile chromium at the 100 area plumes. The biological redox barrier would be installed at the same location as described for the permeable reactive barrier described above, and installed at hotspots if appropriate. A “permeable injection point barrier” would facilitate the reduction. The approach uses direct-push technology (DPT) if possible, to deliver a slow-release organic substrate to the contaminated groundwater plume. Note that the use of DPTs may be very difficult in the gravelly, cobbly soils that are present in the subsurface. The presence of channels, as preferred contaminant pathways, would require a flexible field program and careful geologic observations to emphasize injection there.

  Biological redox manipulation processes rely on either native or introduced microorganisms to reduce highly oxidized metals such as hexavalent chromium to its trivalent, non-mobile form. An organic substrate (electron donor) must be added to the groundwater to generate reducing conditions and provide the necessary carbon to support reduction of the hexavalent chromium. Organic substrates that have been used include soluble compounds such as lactate, molasses, or acetate. A second category of organic substrates includes relatively insoluble compounds such as the Hydrogen Release Compound (HRC) from Regenesis, and emulsified food grade oils. Soluble substrates must be added periodically at either high batch dosages or continuously at low dosages to maintain anaerobic/reducing conditions while slow-release substrates need to be added to groundwater less frequently than soluble substrates. If this barrier alternative was implemented, then the groundwater pump and treat systems in these areas would be shut down. The following assumptions were used to prepare the cost estimate: the barrier consists of 3 rows of injection points; 10 ft between rows; staggered positioning of injection points between rows; injection points spaced 10 ft apart within rows; an oil-water emulsion will be injected (5 percent oil); the design injection fluid radius for each point is 3 ft; aquifer porosity is 30 percent; and the contaminated aquifer thickness is 15 ft. Cost for the 100-K area would be approximately $5 million, and the 100 D area would be approximately $7 million.

6.2.5 Modifications to the Extraction Systems

Under current operations, there does not appear to be a need to pump well 199-H3-2, as it appears to be outside of the current plume. The continued pumping of well 199-H3-2 may lower influent concentrations from the 100-H area. If the recommendation to cease treatment of the extracted water from the 100-H area (section 6.2.1) is to be implemented, the continuation of operation of well 199-H3-2 may be beneficial to assure the influent concentrations from 100-H remain at or near the cleanup goal and below discharge limits. There do not appear to be other specific redundant wells at the other 100 area sites.

The three wells at the 200-UP-1 area are probably no longer all necessary to remediate the plume to interim remedy goals, but the three active wells will more quickly achieve reduction in concentrations, even though recent concentrations are at, or below, the interim goals. Once the concentrations in the vicinity of the 200-UP-1 system fall below the interim goals, the RSE team recommends pumping from the extraction wells be terminated, and monitoring for rebound should begin. The extraction wells at 200-UP-1 should not be abandoned until the final remedy is determined and/or there is no evidence of rebound. The shutdown of this system would save approximately $200,000 per year.

6.2.6 Monitoring Program Changes

As discussed in Section 4.6, there are a number of wells at the five sites that may not need to be sampled or that may be sampled too frequently (see Exhibit 19). Cost savings resulting from implementing these recommendations have not been evaluated, as specific costs for monitoring at each system were not provided. Note that recommended additions to the monitoring programs are discussed in Section 6.1.3.

A more detailed and comprehensive evaluation of the site wide monitoring program is planned for the summer of 2004. The scope of the evaluation is not completely certain; however, that evaluation should include the monitoring for these ground water extraction systems, if possible. Exhibit 19 lists some wells that could be candidates for removal based on our initial evaluation. Further analysis is needed to assess the importance of sampling these wells in light of the overall remediation objectives.

Exhibit 19: Recommended Monitoring Changes

Area	Well	Suggested Change	Rationale
200-UP-1	None	Additional wells may be needed	Declining water table caused dry wells
100-H Area	199-H4-6, H4-46, H4-47, H4-49, H5-1A	Remove wells from program for Cr	Upgradient. Plume boundary adequately defined without it.
	199-H4-9	Remove well from program for Cr	Plume adequately defined by nearby H4-3, H4-5
100-D Area	199-D5-18	Remove well from program for Cr	Upgradient. Plume boundary adequately defined without it.
	199-D5-14	Remove well from program for Cr	Plume adequately defined by nearby well D5-15
	199-D5-40	Remove well from program for Cr	Plume adequately defined in vicinity by nearby wells D4-15, D2-6
	Compliance Wells	Reduce frequency to quarterly	Velocity of ground water, long history of sampling, and decision-making process does not justify monthly sampling
	199-D5-20, D5-36, D5-37, D5-44, D8-4, D8-6	Retain quarterly sampling	N/A
	All other wells in DR Area program	Reduce to semi-annual sampling	Velocity of ground water, long history of sampling, and decision-making process does not justify quarterly sampling
	None	Additional wells may be necessary to define plume at cleanup level	If other existing wells do not define the plume at 22 ug/l, additional wells are needed
100-KR Area	199-K-106A, K-107A, K-108A, K-109A, K-110A, K-23, K-27, K-32A&B, K-34, K-35	Remove from program for Cr	Wells upgradient of plume, not needed to define Cr plume for remediation. Wells may be needed for other constituents, but only 199-K-109A appears to have high concentrations of Sr-90.
	Compliance Wells 199-K-117A and K-18	Reduce frequency to quarterly	Velocity of ground water, long history of sampling, low variability, and decision-making process does not justify monthly sampling
100-NR Area	199-N-18	Remove from program	Duplicates information from 199-N-3
	All wells	Remove Cr from analyte list	Cr levels below standards
Process Monitoring	Influent, Effluent at 100-H and 100-K Plants	Reduce frequency to twice per month or monthly	Little variability in concentrations, long history of results, decision-making process, Hach kit testing of inter-vessel effluent justifies less frequent sampling
	Intermediate Process Sampling	Reduce to sampling with Hach kits to locations downstream of lead vessel currently being significantly loaded	Until vessel begins to breakthrough, no need to sample effluent from downstream vessels.

6.2.7 Reduce Winter Temperatures in Transfer and Treatment Facilities.

The current procedure at all facilities in the 100-D Area and 100 KR Area is to heat them to operator comfort levels 61-64 degrees F, rather than to control freezing in the facilities which would require temperatures in the 41- to 45-degree-range. The temperature could be increased to be more comfortable for the personnel while maintenance is performed. Cost for this option was not assessed as part of this effort, but savings would be significant without impacting operations.

6.3 Modifications Intended to Gain Site Closeout

6.3.1 Development of Exit Strategies

The Richland Office has invested significant thought into the approach to overall site closeout. The environmental problems at the Hanford site are extensive and there are no easy answers. The RSE team has some suggested clarifications to the approach. The exit strategy for each plume should be documented in some way. This may be done within a final remedy proposed plan/record of decision or through some other document, as determined in consultation with the stakeholders. Please refer to the forthcoming Interstate Technology and Regulatory Council Technical Regulatory document on Remediation Process Optimization (see http://www.itrcweb.org) for more information on exit strategy contents.

6.3.1.1 100-D and 100-K Areas

If the chromium is truly in the mobile hexavalent form, and any continuing sources are addressed, the remediation of the chromium plumes should be rapid, given the high permeability of the geologic materials found at the 100-D and 100-KR areas. Pump and treat has been reasonably effective at preventing additional significant releases of chromium to the Columbia River, as discussed above. However, at the chromium-contaminated sites, clarification to the exit strategy is needed. This would entail verification of the remediation goals for the following:

- True protection of aquatic species
- A clear program to address remaining sources; either to remove or render them inert
- Establishment of interim milestones for plume concentration reductions, with contingencies for additional or focused extraction to reduce hot spots (this has reportedly been accomplished and documented in the Remedial Design Report Remedial Action Work Plan documents for the various operable units, though these reports were not made available for this review).
- A negotiated framework for deciding when extraction from specific wells, and treatment processes, can be terminated
- Consideration of alternatives to ground water extraction

Source treatment is integral to achieving goals in a reasonable period of time. Approaches and options for this are discussed in Sections 6.1.2 and 6.3.2. Performance metrics should include specific target concentration reductions (based on modeling) following the treatment of the source. If the milestones are not met, additional or modified extraction should be considered to maintain progress toward cleanup. The decision tree or logic diagram to cease extracting from an extraction well should be negotiated with the stakeholders and public. Such a decision can be based on the extracted concentrations, the observed monitoring well concentrations within that extraction well's capture zone, or the modeled impact of plume migration in the absence of extraction from that well. The RSE team suggests an evaluation and decision process be initiated when the extraction well concentrations fall below the cleanup goal. The process would entail periodically simulating the concentrations of chromium that would reach the Columbia River in the absence of the pumping from that well. When the modeling results indicate, with some certainty, that contaminant concentrations reaching the River will be below the cleanup level, the extraction can be ceased. Monitoring would then continue once the extraction well is shut down to verify the model predictions, and subsequent monitoring results would be used to recalibrate the model. If subsequent modeling suggests the plume may cause an unacceptable impact to the river, the extraction well can be restarted.

The basis for the 22 ug/l cleanup goal should be revisited. The factor-of-two dilution that is assumed to occur within the sediments at the riverbed interface seems overly conservative. The appropriate goal would ideally consider the degree of underflow that occurs, particularly in coarse sediments that may exist in the reaches adjacent to the 100 Area plumes.

6.3.1.2 100-NR Area

The exit strategy for the 100-NR area must consider the ability for the current extraction system to remove Sr-90 from the aquifer compared to natural decay and within the aquifer between the extraction system and the river. A recommended exit strategy for the 100-NR area is discussed in Section 6.2.2.

6.3.1.3 200-UP-1 Area

The current extraction system in the 200-UP-1 Area has almost achieved its interim goals. The future of treatment in the 200 Area is uncertain as the RI/FS is still ongoing, including investigations into the behavior of uranium in the Hanford environment. The ground water extraction system should be shut down when all wells achieve the interim goals, as the degree of rebound following cessation of pumping can be instructive (see Section 6.2.5). Rapid rebound would suggest either significant flux from the vadose zone or remobilization of contaminants following rewetting of previously dewatered materials. The timing of any rebound may elucidate the conceptual model. If unacceptable rebound occurs, the extraction system could be restarted.

Developing recommendations for a long-term exit strategy for the 200 Area is beyond the scope of this evaluation, as the RSE team was not asked to evaluate the 200-ZP-1 plumes, including the extensive carbon tetrachloride plume. However, there are three general alternative approaches:

1) To attempt to remediate the sources and remediate the entire dissolved-phase plume (i.e., cleanup) to some level that would protect receptors; presumably at the River, as land-use controls will likely be necessary at the Hanford site itself

2) To attempt to remediate the source and evaluate the potential for natural degradation, sorption, precipitation, decay, and dispersion to achieve levels protective at the exposure point

3) To contain the source and capture the dissolved-phase plume just upgradient of the exposure point

The costs for the first alternative are likely to be very high, even if one assumes that the time to closure is relatively short (i.e., several decades). The costs for the second alternative are more modest, but most would be incurred in the near-term, with long-term monitoring costs for an extensive period of time (i.e., decades to centuries, to be validated through predictive modeling). The third alternative minimizes near-term expenditures, but would likely entail modest operating costs over an indefinite period. Perhaps some cost-effective remediation technologies appropriate for the site would be developed in the interim. The selection of a general approach depends on the DOE policy, budgetary constraints, alternative land-use opportunities, regulatory review and approval, as well as stakeholder confidence. None of these can be evaluated by the RSE team.

As noted in Section 4.2, a final remedy for the 200-UP-1 area may incorporate conditions or concentrations that must be met in the 200-UP-1 area (with or without groundwater extraction) to protect potential downgradient receptors. This approach may have merit due to the large distance from the 200-UP-1 area to potential receptors. Attenuation processes including radioactive decay and dilution could potentially allow for effective natural remediation. Simulations of constituent transport over time may be a primary component of that analysis. The RSE team recommends that the project team focus on identifying the primary aspects of uncertainty related to such transport simulations. Much of this uncertainty will pertain to the source term in the transport model. A recommended approach may be to do a type of “end-member” transport modeling do simulate “best case”, “expected case”, and “worst case” scenarios. For instance, the “worst case” may have the strong source strength, the long source duration, and high transmissivities. Scenarios for source loading to groundwater can be developed using simplified 1-d models of the vadose zone to estimate source loading to the saturated zone over time, or may be estimated without detailed vadose zone modeling. Observations of uranium and Tc-99 rebound following cessation of pumping will provide calibration information for such models. If even under the “worst case” scenario it can be demonstrated with simulations that receptors will not be negatively impacted, then there may not be a need to do major additional characterization of sources and/or heterogeneities. However, if receptors are potentially impacted under some scenarios and not others, then this “end member” approach to analysis can be used to isolate the specific type(s) of uncertainty that are most important, and a plan to reduce those specific uncertainties with further characterization can then be developed.

6.3.2 Chromium Source Treatment

The treatment of the source areas may be necessary to allow remediation of the chromium plumes at the 100-KR area, and more importantly the 100-D area, in a timely fashion.

The project team mentioned it is considering flushing of the source area with clean water to mobilize the contaminant into the ground water where it can be captured by the extraction system. The RSE team urges the consideration of other alternatives that treat any residual hexavalent chromium in place instead. The costs for recovering the material in the dissolved-phase are high. The potential to use either in-situ chemical or biological processes to reduce the hexavalent chromium should be evaluated. Gaseous delivery of reducing gases such as hydrogen sulfide (DOE, 2000), sulfur dioxide, or ammonia or, carbon sources such as propane or methane that would result in biologically-driven reducing conditions, would represent potential alternatives. Oxygen displacement has been seen to be critical in applications of such treatment and may be achieved through the use of pure nitrogen as the carrier gas. These methods would require bench- and pilot-testing; the current extraction systems would remain in operation pending these tests. Gaseous delivery is inexpensive, and can treat large volumes with minimal surface disruption. Additional characterization can be integrated readily with the effort, but precise location of the source mass is not critical if the treatment, such as the gaseous delivery, can be robustly applied.

6.4 Recommendations for Ground Water Modeling

As detailed in Section 4.2, groundwater modeling pertinent to system design and performance assessment has included the following:

- MicroFEM simulations of groundwater flow and particle traces (area specific) for steady-state scenarios to design pump and treat systems and/or illustrate capture zones for existing systems

- CFEST simulations (site wide, with potential to “telescope” to local-scale models) that have included both steady-state and transient simulations of groundwater flow, and some limited simulations of contaminant transport

- STOMP simulations of ground water flow and transport for transient scenarios of river-stage effects in 100-N Area to assess Sr-90 mass contaminant decay and release to the Columbia River over 300 years

Recommendations for ground water modeling are presented in the following sections for (1) long term flow and transport modeling, and (2) MicroFEM modeling currently used to illustrate capture.

6.4.1 Long Term Flow and Transport Modeling

The RSE team recommends more complex flow and transport modeling than is currently performed in the 100 Area (i.e., transient, potentially three dimensional, incorporating fate and transport). This modeling should be commensurate with revisions to the CSM, discussed in Section 6.1.1.1. Just as the strontium mass contamination at 100-N area was further conceptualized and better managed through phased modeling using STOMP (see Section 4.2.3), so should the other 100 Area remediation systems (in particular, 100-D and 100-KR-4) be evaluated more rigorously in an attempt to improve remedy design and operation, evaluate alternate in-situ technologies, and reduce the time until cleanup.

The STOMP code implementation (i.e., inflow-outflow boundary conditions, contaminant flux estimates, etc.) and transient simulations that have been performed to assess river-stage effects on the strontium mass, decay, and transport in the 100-N Area serve as an effective demonstration for application to the 100-D area. Area-specific modifications to handle fate and transport processes associated with chromium contamination [i.e., no radioactive decay and considerably less sorptive on native sediments (lower K_d)] would be required. The RSE team recommends that the Richland project team evaluate the use of CFEST, against the attributes of STOMP, to address more complex modeling objectives. There is reason to believe that some cost-savings can be afforded using STOMP, since the application has already been successful in the 100-N Area. However, the longer-term objective of incorporating near-field simulations into the more regional CFEST model may outweigh the shorter term cost benefits of using STOMP.

This more complex modeling suggested above would also allow for substantially improved assessment of capture than is possible with the current MicroFEM modeling. The current MicroFEM modeling does not address the complex elements of the flow and transport dynamics, particularly in the vicinity of the river. However, the RSE team does not necessarily recommend more complex modeling for evaluation of capture zones at the 100-NR-2 or 200-UP-1 systems. In the case of 100-NR-2, the STOMP and MicroFEM simulations as well as the ITRD (2002) recommendations to evaluate remediation alternatives and manage the100-NR-2 pump and treat system, have been reviewed and in part implemented by the Richand project team, as well as the regulators. Although the RSE team did not conduct an independent review of the ITRD report conclusions and recommendations, the regulators, stakeholders, and public appear to accept the defensibility of the report findings.

In the case of 200-UP-1, the interim system will soon reach cleanup levels, and a long-term approach and exit strategy needs to still be developed (see Section 6.3.1.3). Therefore, capture zone modeling at 200-UP-1 based on more complex modeling is not an immediate priority. However, as discussed below, transport modeling at 200-UP-1 will be an important component of evaluating long-term remedial approaches and developing an exit strategy for the final remedy.

It was noted in Section 4.2 that transport simulations peformed with CFEST are subject to great uncertainty, in part because the location and strength of sources in both the saturated and zone and the vadose zone are not well characterized. For instance, it was stated during the site visit that the remaining sources of Tc-99 and uranium are not well characterized in the 200-UP-1 area (and similarly the remaining sources of Chromium +6 in the 100-D area are not well characterized). The vadose zone is of particular interest due to the declining water levels over time that may have caused contaminant sources to be left in the vadose zone. Obviously, improved characterization of the source loading to groundwater would help reduce such uncertainties. Similarly, uncertainties in hydraulic properties of the aquifer will impact results of the transport simulations. Therefore performing “end member” transport simulations first (as suggested in Section 6.3.1.3) is recommended to attempt to determine the types of uncertainty that are most critical with respect to remedy decisions. Then an approach to reducing the critical uncertainties can be developed (or a robust strategy can be developed for even the “worst-case” scenario, if that is determined to be more cost-effective than the characterization required to adequately reduce the uncertainties). Further discussion on uncertainty with respect to simulations is presented in Section 6.5.4.

6.4.2 Recommendations for MicroFEM Modeling Currently Used to Illustrate Capture

In the long term, the development of more complex models may eliminate the application of MicroFEM for illustrating capture. However, to the extent the MicroFEM modeling continues in the short term, several recommendations pertaining the MicroFEM modeling are offered.

When illustrations of capture based on the MicroFEM results are discussed in the main text of a report, they should be qualified in the main text of the report with language similar to the following:

> "These are illustrations of capture based on simulations from a numerical model of ground water flow that include many simplifications of the actual system. They are steady-state models that do not account for time-varying changes to the groundwater flow system, which may include significant daily and/or seasonal impacts due to changing levels of the Columbia River. Such transient impacts may cause actual capture to vary significantly over time. In addition, the numerical model likely does not fully represent aquifer heterogeneities, which may also impact the illustration of capture."

The RSE team notes that caveats similar to the language suggested above are mentioned in the Appendices of annual reports, but not in the main body of the report. Our recommendation is to include such language in the main body of the report.

With respect to presenting the validity of the MicroFEM predictions, the following recommendations are offered:

- When comparing simulated to observed water levels, statistics of model residuals (that exclude measurements at the extraction and injection wells) should be presented. These statistics should include mean residual, mean of absolute values of residuals, and a calculation of the mean of absolute values of residuals divided by the range in measured water levels at the specific points being utilized. This last calculation normalizes the residuals according to the range of measured values, and is important so that small absolute residuals are considered significant if they are large compared to the variation in water levels. A rule of thumb is calculated value should be less than 10 percent, and ideally should be less than 5 percent. If the calculated value is more than 5 to10 percent, further analysis should be performed to determine if the residuals are distributed spatially in a manner that biases the simulated hydraulic gradient, which would in turn cause significant error in the illustration of capture.

- Ideally, an evaluation should be performed to compare simulated versus observed drawdown in response to changes in pumping rates. These data can be obtained by shutting down pumping for a relatively short time period (several days), which generally occurs at some point during the year for maintenance in the treatment system. This analysis is best performed when piezometers are present near the pumping wells, which may not be the case for many of the extraction wells for the systems evaluated.

As currently applied, the issue of vertical capture is not rigorously addressed in the MicroFEM modeling. The models used for the capture zone illustrations simply assume that the base of the model is a no-flow boundary. If observed heads and drawdowns do not match well (see above recommendations), it is recommended that consideration be given to allowing water to pass through the bottom of the model, by modifying boundary conditions, or adding one or more additional model layers.

6.5 Recommendations for Simulation/Optimization

This section provides recommendations regarding the potential for mathematical optimization approaches to improve pump and treat operations at the Hanford Site. Mathematical optimization methods are numerical search algorithms that can be used to automatically search for optimal designs that satisfy specified objectives and constraints (called a "formulation"). For example, objectives could be to minimize cost of operating the pump and treat system, to maximize contaminant removal, or to minimize remediation time. Constraints could include a requirement that containment of the plume be achieved. The algorithm would then search for designs (typically pumping rates and well locations) that would best meet the specified formulation. To evaluate the extent to which any potential pump and treat design meets performance requirements, these approaches are typically coupled with flow and/or transport simulation models that predict the effects of each design on the system. Flow models can be used alone when the objectives only involve manipulating flows, such as achieving containment of the plume (i.e., "flow optimization"). When the objectives require consideration of contaminant levels, such as maximizing mass removal, then both flow and transport simulation models are required (i.e., "transport optimization"). Both flow and transport optimization have been demonstrated at several field sites and shown to provide substantial savings over trial-and-error optimization, where simulation models are run repeatedly to simulate different pumping scenarios that the analyst believes are promising (US EPA, 1999a,b; Minsker et al., 2003). Identified savings range from 5-50 percent over trial-and-error, with a typical gain of about 20 percent (Minsker et al., 2003).

Section 6.5.1 gives an overall assessment of the potential for these approaches to provide improved efficiencies at the Hanford Site. Subsequent sections highlight issues that will likely be encountered in implementing such approaches at the site, including selecting appropriate mathematical optimization approaches (Section 6.5.2), tradeoffs among multiple objectives (Section 6.5.3), approaches for addressing uncertainty (Section 6.5.4), and methods for addressing computational limitations (Section 6.5.5). Section 6.5.6 presents a summary of overall recommendations regarding simulation/optimization at the Hanford Site.

6.5.1 Overall Assessment of Simulation/Optimization Potential for the Hanford Pump and Treat Operations

The Hanford pump and treat systems evaluated by the RSE team appear to be operated using a strategy of maximizing pumping given the existing wells and equipment. In other words, each well is operated to pump out as much water as possible given the current water levels. This strategy is quite conservative, particularly for the sites that are near the River. For example, in the 100 Area, maximum water levels in the wells occur when the river stage is highest. At these times, the gradient towards the River would be lowest, and potentially even reversed, so high pumping rates may not be required to maintain capture. The continuous-flow telemetry and variable pumps installed in the 100 Area are ideally suited for providing real-time control of pumping in response to river levels, or at least seasonal adjustments. For the Sr-90 plume, only flow optimization would be needed to optimize containment, assuming long-term pumping operations continue in that area. For the areas where the goals are both containment and cleanup (this applies to the chromium plumes at 100-KR-4 and 100-D, and the plumes at 200-UP-1), transport optimization could potentially improve system efficiency and reduce costs by optimizing both flow control and contaminant removal. The chromium plume at 100-H is fairly close to cleanup levels, so the merits of investing in transport optimization may be questionable given that the area may clean up in a few years.

While the potential for improved efficiencies clearly exists, *no optimization should be considered without substantial investment to better characterize and model contaminant sources and, in the 100 Area, to better understand and model the transient river dynamics.* The accuracy of the optimization process relies entirely upon the flow and transport models to evaluate potential designs. PNNL has developed a site-wide transport model, CFEST, and STOMP has been applied to better understand Sr-90 mass contaminant transport in the 100-N Area to the saturated zone and the River. The CFEST model would need to be scaled down to an appropriate size to address each contaminant plume that is of greatest concern. The RSE team recommends that the value of STOMP simulations be considered in the 100 Area, as proved valuable in the 100-N Area to manage the source term, pump and treat system, as well as technology alternatives. Regardless of model selection, better characterization of contaminant sources, and incorporation of an improved CSM into a transport model, are prerequisites to optimization. Until such improvements can be made, the conservative pumping approaches currently in place should be continued.

Exhibit 20 shows current annual costs and potential cost savings that could be obtained with an optimization effort at each of the major sites. The cost savings are based on a number of assumptions:

1) Approximately 20 percent savings in operating costs are found through optimization, as was a typical result from previous optimization efforts (Minsker et al., 2003).

2) Operating costs affected by pump and treat optimization include only materials (resin), utilities, and resin disposal costs; labor costs are assumed unaffected by changes in pumping rates or well locations.

3) Optimized treatment systems run for an additional 20 years.

4) A discount rate of 3.5 percent is appropriate for discounting future costs.

Exhibit 20: Potential Cost Savings Associated with Mathematical Optimization

	100-H & 100-D	200-UP-1	100-KR-4	100-NR-2
	Cost in $1000s	Cost in $1000s	Cost in $1000s	Cost in $1000s
Total Materials Cost (/year)	641	18	432	109

Utilities (BPA) Cost (/year)	19	4	17	15
Total Disposal Cost (/year)	233	6	235	78
Total P&T Variable Costs (/year)	893	28	684	202
Expected 20% Savings/Year	179	6	137	40
Potential 20-Year Savings*	$2,538	$80	$1944	$574

Assumes discount rate of: 3.5 percent

The potential savings given in Exhibit 20 can be compared with the incremental cost of an optimization effort (i.e., does not include the cost of developing flow and transport models), which was estimated to range from $40,000 to $120,000 (Minsker et al., 2003). Any optimization at 100-NR-2 would involve only flow optimization, which would likely be worthwhile relative to the projected 20-year savings of $800,000. However, if the 100-NR-2 treatment system is converted to a containment system, eliminating material and disposal costs, then the potential 20-year savings from utility costs would only be $60,000 (present worth cost of $15,000/year over 20 years) and optimization would not be worthwhile, especially when extensive flow model enhancement is also needed to support the optimization. Obviously, optimization for 100-NR-2 would be moot, if pumping is discontinued in the future. Potential savings at 200-UP-1 do not appear sufficiently large to warrant the cost of transport model development and optimization, especially (1) given the lack of detailed monitoring data to support transport model development, and (2) given that the duration of continued pumping at this site is uncertain. Future design for a larger ground water system for the 200 Area that may be part of a final remedy may benefit from these methods, however, especially if reducing long-term cleanup time is a cost-effective approach to reducing life-cycle costs. The 100-H, 100-D, and 100-KR-4 sites have the greatest potential cost savings from optimization, with significant potential savings that would support investment in transport modeling and optimization. If 100-H is shut down substantially earlier, it is possible that optimization would not be worthwhile; a detailed analysis of this outcome is not possible given that the treatment costs for 100-H and 100-D cannot be separated.

The potential benefits of optimization are not all financial. The application of simulation optimization techniques may identify alternative configurations that may achieve cleanup in significantly less time than is currently projected. If optimizing cleanup time, a possible constraint may be to limit expenditures to those currently faced by DOE, or even some fraction of the current cost.

If mathematical optimization is undertaken, several issues will likely arise that will need to be addressed. These are summarized in the following sections.

6.5.2 Review of Mathematical Optimization Approaches

Numerous approaches are available that have been tested for groundwater remediation design, but the best approach(es) for this site will depend on the particular formulation that is developed. Mayer et al. (2002) provide a relatively recent survey of the major approaches and applications. In most real-world applications, objective functions for groundwater remediation design problems are nonlinear, nonconvex (i.e., the optimization algorithm’s search for the minimum would be analogous to trying to find the lowest valley in a mountain range), and nondifferentiable--usually occurs when binary well installation variables, those with 0-1 values, are used. Such characteristics are likely to apply at this site as well, since the river-aquifer dynamics are complex and transport models are by definition nonlinear. These complexities limit the types of approaches that can be selected.

Traditional derivative-based nonlinear optimization approaches, such as nonlinear programming implemented in the software package MINOS (Murtagh and Saunders, 1987), cannot be used without simplifying the formulation to remove integer variables. This process that can lead to solutions with numerous wells pumping at very low rates (McKinney and Lin, 1995), and risk identifying local minima (i.e., finding the bottom of the closest valley to the starting point, rather than the lowest valley). These limitations have led to a trend in recent years towards heuristic global optimization methods, including genetic algorithms, simulated annealing, and tabu search.

These optimization approaches have been the most widely used and tested at the field scale and were implemented in a recently-completed transport optimization demonstration (Minsker et al., 2003). They are also the only approaches available within off-the-shelf transport optimization packages such as SOMOS and MGO (see http://www.frtr.gov/estcp for details). The primary advantages of these approaches are that the codes already exist, they are easy to link with any existing simulation model, and they can handle any form of objective function and constraints. Moreover, for similarly posed problems, different groups using different approaches have found similar solutions, illustrating that near-global optimality was likely obtained. The disadvantages of these approaches are that they can require substantial computational effort to solve, an issue when the coupled simulation model requires more than a few minutes to solve, and they are not guaranteed to find the globally optimal solution. In practice, however, these methods have had good success in finding optimal, or near-optimal solutions, especially when used with appropriate parameter settings (see Reed et al. 2000, 2003 for guidance on parameter settings for genetic algorithms). Computational limitations have been addressed in a number of emerging techniques that are summarized in Section 6.5.4.

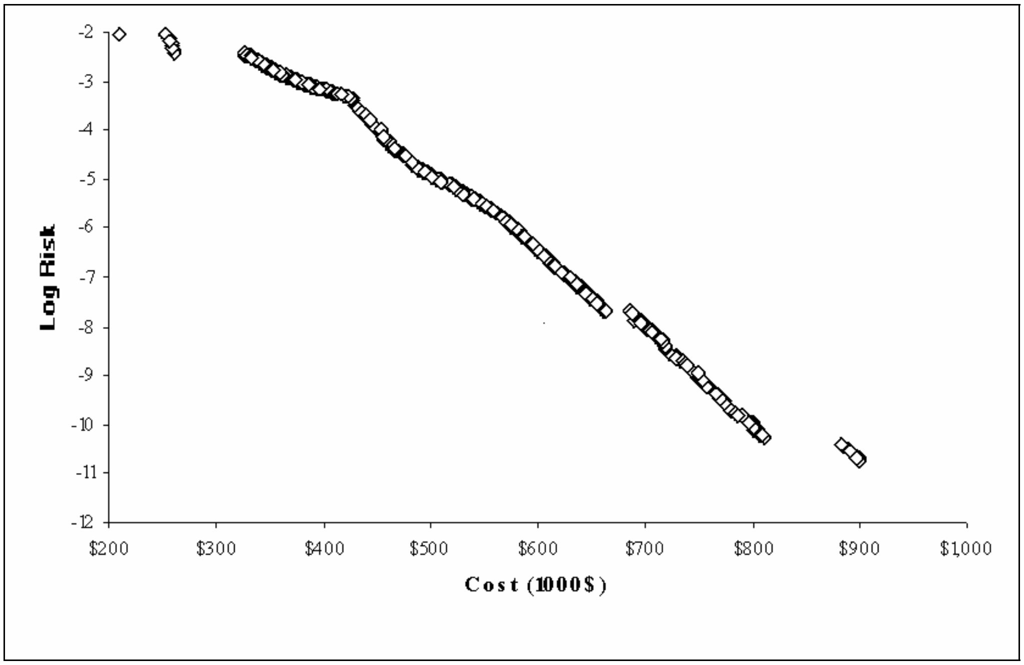
Several other global optimization approaches have been developed in recent years that have had limited field testing. These include outer approximation methods (e.g., Papadopoulou et al., 2002) and implicit filtering (Battermann et al., 2002). These types of approaches have the advantage of greatly reduced computational effort, but can only be applied with objective functions of particular limited forms. Applying these methods therefore often entails simplifying the objective function and/or constraints. Ren (2003) demonstrated that such simplifications can sometimes lead to solutions with 10-15 percent higher costs, which can be a substantial error at a site such as Hanford with high operating costs. If one of these approaches is selected for field testing at Hanford, the RSE team strongly recommends that a field-tested, heuristic approach with the full formulation be used as a comparison.

6.5.3 Tradeoffs Among Multiple Objectives

Remediation decisions often involve multiple, conflicting objectives, such as simultaneously minimizing cost and maximizing contaminant removal. The traditional approach to handling multiple objectives is to combine the conflicting objectives into a single objective. This can be done by weighting the objectives by their importance and then adding them, or by more sophisticated multi-attribute utility approaches that seek to quantify the decision maker’s preferences among the different objectives (see de Neufville, 1990). These types of approaches are difficult to apply to remediation design, where numerous stakeholders are involved in the decision-making that have may have quite different preferences. Instead, the approach that is usually taken is to identify optimal tradeoffs between the objectives, called the nondominated or Pareto front, and then allowing decision makers to negotiate after they see the tradeoffs.

Exhibit 21 gives an example of a Pareto front showing the tradeoffs between remediation cost and risk. Each dot on the figure represents the design with the lowest risk for a given level of expenditure or, conversely, the lowest cost solution for a given risk level. With most optimization approaches, the Pareto front must be generated by repeatedly solving the optimization problem for different, fixed levels of one objective (e.g., minimizing risk for different levels of expenditure). When the optimization is computationally intensive (e.g., when it is coupled with a complex simulation model, as will likely be the case at this site), or more than two objectives must be considered, this process can become unmanageable. In this case, multi-objective genetic algorithms have been shown to be more efficient than other optimization algorithms at identifying optimal tradeoffs (Deb, 2001), which they can accomplish with only a single optimization run. See Zitzler et al. (2000) for a comparison of different multi-objective genetic algorithm approaches.

Exhibit 21: Example of an Optimal Tradeoff Curve



6.5.4 Approaches for Addressing Uncertainty

Due to the uncertainties associated with characterizing the subsurface environment, predictions from fate and transport simulation models, and optimization models that rely upon them for making decisions, predictive results can have substantial inherent uncertainty. In most field applications of optimization to date, uncertainty has not been considered during the initial optimization process. Instead, post-optimization sensitivity analyses are used to identify how robust the optimal solutions are to potential errors in the models. The results are then used to adjust the recommended optimal solution to provide an ad hoc safety factor (e.g., by increasing the amount of pumping or by reducing water quality standards and re-optimizing). Such approaches are simple to implement, but may not provide substantial reliability in performance of the optimized system, or may overdesign the system.

Numerous, more rigorous stochastic optimization approaches have been developed that identify the most robust solutions given the expected model uncertainty (see Mayer et al., 2002, for a review of these approaches; more recent approaches include Battermann et al. 2002), but these have had limited if any field testing. Some of these approaches assume a certain form of the optimization problem. For example, Battermann et al. (2002) require a smooth objective function with small perturbations from uncertainty. As noted in Section 6.5.2, if one of these approaches is selected for this site, care must be taken to ensure that any modifications made to the optimization formulation to suit the algorithm are not introducing significant errors in the optimal solution. This can best be addressed through application of multiple methods.

Most stochastic optimization approaches involve generating multiple “realizations,” or potential scenarios of different model outcomes (e.g., multiple flow fields from different potential hydraulic conductivity values), and searching for designs that meet the objectives for all, or a significant fraction, of the realizations. The challenge in applying these methods at the field scale is that it is not possible to quantify all of the sources of uncertainty associated with groundwater flow and transport simulation. Most stochastic optimization methods have been tested only with hydraulic conductivity uncertainty, but numerous other sources of uncertainty exist (e.g., boundary conditions, source terms, small-scale heterogeneities, and preferential flow paths). Any investments made in characterizing uncertainty should be carefully balanced with the benefits of the information gained relative to the substantial uncertainty that will remain.

Sensitivity analyses using deterministic optimization models should first be undertaken to identify which aspects of the model most affect the performance of the optimal solutions found. Additional data collection efforts can then focus on those aspects of the conceptual model or specific parameters that are most critical to ensuring robust performance of the pumping design. It is likely that a broader effort using relatively simple approaches to quantify uncertainty in all of the key aspects will be more informative than making major investments in rigorous stochastic modeling approaches for handling uncertainty of only one parameter (e.g., hydraulic conductivity). Simpler uncertainty approaches can include soliciting expert opinions to identify a set of plausible modeling scenarios, using available data to fit simple probability distributions. For example, Singh et al (2004) used triangular distributions, which require only minimum, maximum, and most likely values, to characterize hydraulic conductivity values at Umatilla Army Depot; Guan and Aral (2004) utilize recently-developed fuzzy approaches.

Another challenge in addressing uncertainty at the field scale is that the computational requirements of testing potential designs on all realizations (which requires running the simulation model numerous times) can rapidly become unrealistic. Singh et al. (2004) showed that a new, noisy, multi-objective genetic algorithm can identify substantially more reliable solutions without increasing remediation costs at the Umatilla Army Depot. These findings build on previous studies that demonstrated the value of single-objective, noisy, genetic algorithms for identifying robust solutions with minimal testing of designs on multiple realizations (see, e.g., Gopalakrishnan and Minsker, 2001).

6.5.5 Methods for Addressing Computational Limitations

Another issue that will likely arise with a site of this complexity is computational effort required to solve the optimization problem when the simulation model is time-consuming to solve. This issue is a particular concern when transport simulation models are used for optimization, which are typically substantially more time-intensive than flow models, especially when uncertainty and/or multiple objectives are considered. In the transport optimization demonstration mentioned previously (Minsker et al., 2003), a number of heuristic approaches were used to overcome computational limitations in optimizing three complex field sites, including:

1) Limiting the number of potential well locations or pumping rates

2) Decomposing the optimization problem into sequential sub-problems that are easier to solve (e.g., by fixing pumping rates at capacity and optimizing well locations, then fixing well locations and optimizing pumping rates)

3) Creating surrogate or "response" functions that replace the simulation models during the optimization.

Such approaches may result in some loss of accuracy in finding the globally-optimal solution, but were still found to be more effective than traditional trial-and-error optimization (Minsker et al., 2003).

Of the approaches for addressing computational limitations, two that have been most widely applied and tested have been parallel implementations and response-function approaches. Parallel implementations, in which the optimization is done on multiple processors running in parallel, are most easily applied with optimization approaches that can be easily decomposed into independent processes, such as genetic algorithms. No existing off-the-shelf transport optimization software exists that uses parallel computing; this capability may develop in the next few years, as nationwide grid computing (automated parallelization of computer jobs to multiple computers distributed across the internet) becomes more accessible. Response-function approaches using neural networks have been widely applied, and tested (e.g., Aly and Peralta, 1999; Rogers et al., 1995; Minsker et al,. 2003). These approaches have also been implemented in off-the-shelf transport optimization software, such as SOMOS.

Emerging research in this area focuses on efficient response-function creation during the optimization process (an "online" approach), avoiding numerous upfront simulation runs to train the response function. SOMOS includes such an approach that has not yet been published (Peralta, personal communication). Yan and Minsker (2004) demonstrated that such an approach can reduce the number of simulation model runs required for optimization by more than 85 percent, using a field scale pump-and-treat optimization case study at Umatilla Army depot. Regis and Shoemaker (2004a, b) have developed an efficient online approach that uses radial basis functions to fit a local response function during the optimization. However, their approach is so far only applicable to continuous objective functions and constraints.

6.5.6 Summary of Recommendations Regarding Simulation/Optimization at the Hanford Site

In summary, the following recommendations are made regarding the potential for simulation/ optimization to be applied at the Hanford site:

- The potential clearly exists for flow and transport optimization to improve pump-and-treat operations and substantially reduce costs at the 100-KR-4, 100-H, and 100-D areas. However, the substantial investment required to improve flow and transport models in the 200-UP-1 and 100-NR-2 areas are not likely to yield sufficient savings to cover the costs of the analysis.

- Recommendations made in Sections 6.1.1 and 6.4 include better chromium source characterization, and updates to the conceptual site and mathematical models in the 100 Areas to simulate transient river interactions, and predict contaminant mass transport. Mathematical optimization should **only** be undertaken if substantial investment is made to improve existing flow and transport models, particularly for the chromium plumes at 100-KR-4 and 100-D/H.

- Mathematical optimization at a site of this complexity will require considerable expertise; one or several optimization experts may be required to assist with detailed optimization formulation and algorithm selection, including experts with field optimization experience. This process should be started simultaneously with any new simulation model development, to ensure that the simulation and optimization components are compatible.

- Although codes utilizing heuristic techniques cannot guarantee global optimality, they have been demonstrated to generate substantially improved solutions compared to trial-and-error. For similarly posed problems, different groups using different codes have found similar solutions, illustrating that near global optimality is likely obtained. The benefit of finding an exact global optimum relative to solutions found with the heuristic methods is likely to be small, and most likely not worth the additional cost of developing and applying new optimization codes. This is particular true when the new approaches will likely require simplifications to the optimization formulation that may result in sub-optimal solutions, so verification with tested heuristic approaches would still be necessary.

- If simulation/optimization is employed, an up-front cost/benefit analysis is recommended to evaluate the merits of incorporating uncertainty within the optimization process. This analysis should evaluate the additional effort of solving the optimization problems accounting for uncertainties, the types of uncertainties that could be reasonably addressed and appropriate methods for doing so, and the range of remaining uncertainties that would not be addressed. Sensitivity analyses with an initial deterministic optimization model is recommended to identify which potential uncertainties have the greatest impact on optimal solution performance.

- Numerous optimization approaches currently exist that would be applicable to this site, so extensive optimization code development should not be necessary. Some are available as off-the-shelf packages, but these would likely need modification to interface with existing (or potentially new) simulation models (such as CFEST). However, modifying existing optimization codes to utilize CFEST would require far less effort than developing new optimization codes. Others are research codes that would require more expertise to use than an off-the-shelf package, but may have capabilities that could be important for this site. Given the technical expertise available at PNNL to assist in implementing optimization code, the full range of available codes should be considered for this site. If an approach is selected that has not yet been field tested, we strongly recommend that a field-tested approach also be implemented for comparison.

6.6 Suggested Approach to Implementation of Recommendations

Some of the recommendations provided above can be pursued independently from others, while other recommendations must be considered in combination or sequence or are dependent on the achievement of certain conditions. This section attempts to recommend a course forward based on the consideration of interdependencies.

6.6.1 Recommendations Readily Implemented

The following recommendations should be considered for quick implementation that would not require significant regulatory involvement. These would offer significant savings to DOE:

- Re-evaluate operational labor costs.
- Evaluate other resins for lead IX vessels.
- Reduce temperature in facilities during the winter months.

6.6.2 Stand-Alone Recommendations Requiring Regulatory Coordination

These recommendations will require some coordination with the regulatory agencies but offer potential cost savings or increased effectiveness for the remedies in place. These recommendations would not require testing and future decision points:

- Increased monitoring at the 200-UP-1, 100-H, and 100-D areas
- Decreased monitoring at various pump-and-treat systems
- Recirculation of extracted water at the 100-H area if pumping continues, without treatment
- Recirculation of extracted water at the 100-NR-2 area if pumping continues, without treatment
- Evaluation of alternatives to IX for chromium treatment (e.g., zero-valent iron).

6.6.3 Recommendations with Inter-dependencies, Requiring Intermediate Decisions or Bench/Pilot Testing

A number of recommendations depend on the implementation of other recommendations or require the development of additional data or information before a decision for implementation can be made. Regulatory coordination will also be necessary. These recommendations include:

- Application of Mathematical Optimization Techniques. Applications of these techniques require improvements to the ground water fate and transport models to better reflect the site complexities. The improvements to these models are also dependent on the determination of the actual capture goals. The flow models should be substantially improved if a rigorous capture demonstration is required.

- Application of Chromium Source Treatment. The need for additional site characterization for the chromium source determination must be made in conjunction with the determination of the costs of the likely source treatment. The consideration of alternatives such as gaseous reduction will depend on a unified approach to characterization and treatment.

- Future of the 200-UP-1 System. The rebound test at the 200-UP-1 area can only occur when the interim concentration goals are met, and the rebound evaluation must be considered in light of the vertical characterization of the ground water plume, and the additional geochemical studies on the mobility of uranium in the vadose zone.

- Alternatives to Ground Water Extraction. The replacement of ground water extraction with in-situ treatment at 100-D, 100-K, and 100-N may require additional characterization, bench and pilot testing, and CERCLA documentation. The work should be coordinated with the work to characterize and treat source areas at the 100-D and 100-K areas.

7.0 SUMMARY

The observations and recommendations given above are not intended to imply a deficiency in the work of either the designers or operators, but are offered as constructive suggestions in the best interest of DOE and the public. These recommendations obviously have the benefit of the operational data unavailable to the original designers.

The RSE process is designed to help site operators and managers improve effectiveness, reduce operation costs, improve technical operation, and gain site closeout. In this report, several recommendations are made with respect to system effectiveness, cost reduction, and technical improvement. The report addresses potential ways to enhance remediation, improve reporting and data management.

The four ground water extraction and treatment systems at Hanford evaluated herein are generally well run and maintained. The benefits of continuing the operations of two of the systems, 100-HR-3 (100-H area only) and 100-NR-2 have been debated by the various agencies. The costs incurred for operating the four systems are very high, especially for ones with a high degree of automation. There are alternatives regarding use of regenerated resin, zero-valent iron, or in-situ treatment that could save significant sums for treatment over the life of the projects. Recirculation of untreated water at the 100-H and 100-N areas may represent a protective and cost-effective approach. The implementation of additional extraction wells in the 100-D area to address the migration of chromium through the gap between the existing extraction system and the ISRM is appropriate. Some reductions in the monitoring program could be easily implemented without jeopardizing the ability to respond to changes in the migration and remediation of the contaminants.

There are several data gaps and emerging issues. Additional characterization of the vertical extent of the plume at 200-UP-1 is recommended. The extent of the plumes at the 100-D and 100-H areas may also need to be further defined. The project team should clarify goals and exit strategies for each site. Treatment of the chromium sources should not include soil flushing, but rather other low-cost, robust techniques, though additional chromium source characterization in the 100 Areas may be warranted depending on the cost of the remedial technology. If more rigorous verification of plume capture is needed for the various 100 Area systems, additional piezometers would be needed.

The need to update the ground water flow and transport models depends on the future uses of the models and the rigorousness of goals set for each extraction system. Rigorous evaluations of the capture of contaminants at the 100 Area systems would require improvements in the models to better reflect heterogeneities and the impact of the river stage fluctuations. The models would also need to be improved if numerical optimization techniques were to be applied. The systems at 100-D and 100-K areas, as well as any future full-scale ground water extraction design for the 200 Area would benefit from application of numerical optimization. Substantial savings or reductions in treatment time are possible.

Exhibit 22 summarizes recommendations for improvements in effectiveness, cost reduction, and which may also help DOE gain site closeout.

Exhibit 22: Cost Summary Table for Individual Recommendations

Recommendation	Reason	Estimated Change in		
		Capital Costs	Annual Costs	Life-cycle Costs*
6.1.1 Improve Characterization and CSM	Effectiveness	Unknown		Unknown
6.1.2 Alternatives for the 100-D Area	Effectiveness	GW Extraction under construction Biobarrier >$7M	GW Extraction similar to present Biobarrier O&M $0 for some years (excl LTM)	
6.1.3 Increase Monitoring	Effectiveness	Unknown		Unknown
6.1.4 Changes to Verify and Improve Capture	Effectiveness	Unknown		Unknown
6.2.1 H Diversion	Cost Reduction	Minimal	Savings ($175,000)	($3.5M)
6.2.2. Sr-90 Diversion	Cost Reduction	Minimal	Savings ($110,000)	($2.2M)
6.2.3 Labor	Cost Reduction	$0	Savings ($600K)	($12M)
6.2.4.1 Resin Alternatives	Cost Reduction	$0t	Savings ($25K)	($500K)
6.2.4.2. ZVI Contactor	Cost Reduction	$750K	Savings ($1.5M)	($30M)
6.2.4.3. Permeable Reactive Barrier	Cost Reduction	>$25M	Savings ($2M) each Cr site	($15M)
6.2.5 Modifications to Extraction Systems	Cost Reduction	$0	($200K)	($200K) System planned for shutdown anyway
6.2.6. Monitoring Program Changes	Cost Reduction	Minimal	Not Quantified	
6.2.7. Reduce Building Temperatures in Winter	Cost Reduction	Not Determined, Need Study	Not Quantified	
6.3.1. Development of Exit Strategies	Site Closeout	Unknown		N/A
6.3.2. Chromium Source Treatment	Site Closeout	Not Determined, Need Study		N/A
6.4. Recommendations for Ground Water Modeling	All	Not Determined, Need Study		N/A
6.5. Recommendations for Simulation Optimization	All (100-D and 100-K areas)	>$100K, excludes model updates	($310K) estimated using rule of thumb	($5.2M)

Costs in parentheses imply cost reductions, refer to the section cited for cost development information.

* Assumes 20 years of operation at a discount rate of 0 percent (i.e., no discount).

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