Use of the Advanced Trident Probe to Investigate Upwelling Groundwater in the Columbia River Hanford Reach – 10558

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ABSRACT

A new technology is being successfully used to identify and sample areas where contaminated groundwater is upwelling in the river bottom in the Hanford Reach areas to support a remedial investigation of Hanford Site Releases to the Columbia River. The advanced Trident Probe[1] is a field research tool that has been adapted for use in the currents and depths of the free-flowing Columbia River in south-central Washington State. The probe's ability to detect the differences between two freshwater systems (groundwater and surface water) enables users to identify where groundwater is seeping into the Columbia River and to better understand groundwater patterns from shore to shore. The Trident Probe is also being used to collect samples of pore water and surface water at selected locations. Because it has been historically difficult to sample in a fast moving riverine system, there has been an absence of clear understanding the physical and chemical connection between groundwater and Columbia River water.

The groundwater upwelling part of the remedial investigation is being implemented in three phases. Phase I consisted of a technology demonstration of the Trident Probe in the Columbia River environment that was successfully completed in September 2008. Phase IIa consisted of "in situ" conductivity and temperature mapping at 675 locations in the Hanford Reach. The mapping locations consisted of a combination of transect points selected where known contaminated groundwater plumes are intersecting the Hanford Site shoreline and scientifically derived locations. The Phase IIa work was completed in August 2009.

Phase IIb activities consisted of collecting pore water samples at a subset of the locations mapped in Phase IIa to screen for indicator contaminants from the known groundwater plumes in the area. Between August and December 2009, more than 240 pore water samples were collected and analyzed to complete the Phase IIb work.

The groundwater upwelling investigations will conclude with Phase III characterization activities. This phase will include collection of pore water, sediment, and surface samples for characterization of a broad list of contaminants. Phase III locations will be selected from a subset of the Phase II locations, focusing on those with the greatest pore water concentrations for indicator contaminants. The Phase III activities are anticipated to be complete in early 2010.

Beginning in early 2010, information and sample results from the field investigation will be used to characterize current conditions within the Columbia River and will be combined with existing data to conduct a baseline ecological risk assessment and baseline human health risk assessment.

[1] Patent Pending - Costal Monitoring & Associates

INTRODUCTION

The Columbia River flows through the U.S. Department of Energy (DOE) Hanford Site, in south-central Washington State. A primary objective of the Hanford Site cleanup mission is protection of the Columbia River through remediation of contaminated soil and groundwater that resulted from its weapons production mission. These remedial actions were initiated under the *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA) [1] in 1994 and continue today, with an emphasis on activities in the "River Corridor" because of its proximity to the river and presence of the former production reactors in the 100 Area and fuel fabrication and development facilities in the 300 Area (Fig. 1).

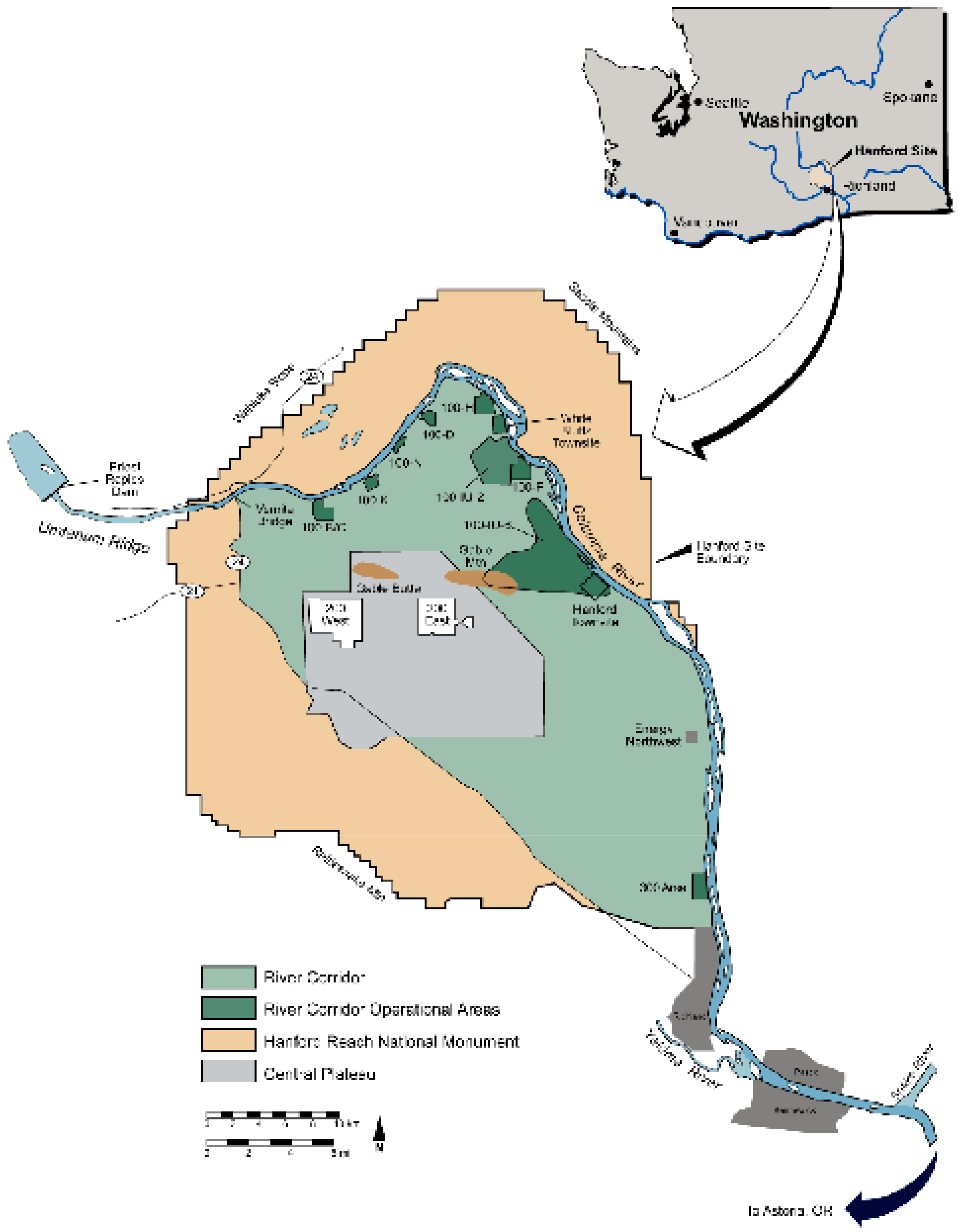

Fig. 1. Columbia River and Hanford Site River Corridor.

Hanford Site History

The Hanford Site became a federal facility in 1943 when the U.S. Government took possession of the land to produce weapons-grade plutonium during World War II. During the subsequent five decades of Hanford Site operations and nuclear material production, large quantities of chemical and radiological by-products were discharged to the environment. Liquid effluents from plutonium production reactors were discharged directly to the Columbia River and unplanned overland flows from retention ponds and basins occasionally occurred. In addition, plumes of contaminated groundwater developed in portions of the Hanford Site as a result of waste disposal practices and subsequent migration through the soil. Some of these contaminated groundwater plumes have reached the Columbia River, discharging as springs along the shoreline and upwelling through the river bottom.

Hanford Site production activities continued until the late 1980s, when the mission focus changed to cleaning up the radioactive and hazardous wastes that had been generated during the previous decades. In 1989, areas of the Hanford Site were placed on the National Priorities List under CERCLA authority, leading to the cleanup actions that are in progress today.

Remedial Investigation of Hanford Site Releases to the Columbia River

Within the Columbia River system, large amounts of surface water, sediment, and biota data potentially related to Hanford Site contaminant releases have been collected since the start of operations in 1945 through various sampling and monitoring programs. Areas upstream, within, and downstream of the Hanford Site boundary have also been investigated per U.S. Department of Energy orders. The impacts of Hanford Site releases to the Columbia River are now being formally assessed under CERCLA.

The *Remedial Investigation Work Plan for Hanford Site Releases to the Columbia River* [2] was issued in October 2008 to initiate the remedial investigation. The work plan established a phased approach to characterize contaminants, assess current risks, and determine whether or not there is a need for any cleanup actions. The scope of remedial investigation focuses on the impacts of Hanford Site hazardous substance releases to the Columbia River and its users.

Field investigation activities supporting the remedial investigation were initiated in October 2008. The field investigation was designed to fill the data gaps and characterization needs that were identified as part of the scoping process. Media collected in the field investigation has included island soil, shoreline sediments, river bottom sediments, core sediments, surface water, and fish from a 120 mile stretch of the Columbia River extending upstream and downstream of the Hanford Site. Field investigation activities are anticipated to be complete in early 2010.

Following the field investigation, a baseline human health and ecological risk assessment will be conducted. The risk assessment activities that are initiated in 2010 will lead to a scientific/management decision point in 2011. It is at this scientific/management decision point that the Tri-Parties will identify the scope and begin the associated planning process for any further investigation activities that may be needed to continue the remedial investigation process.

One focus of the field investigation is further delineation of areas where contaminated groundwater is upwelling in the Columbia River bottom within the Hanford Reach area and determination sediment concentrations at those locations. A new field research tool, the advanced Trident Probe, is being used to identify where groundwater is seeping into the Columbia River and to collect samples of pore water and surface water samples. Previous techniques have been used for this type of characterization near the Hanford Reach shoreline. Because it has been difficult to sample in the offshore water depths and currents, there has been a data gap with understanding the connection between groundwater and the Columbia River water.

Conceptual Site Model Overview

Past waste management and waste disposal practices at the Hanford Site have resulted in the presence of several contaminated groundwater plumes. Groundwater beneath the Hanford Site discharges to the Columbia River via springs and subaqueous (below the riverbed) groundwater upwellings. The movement of groundwater provides a means for transporting Hanford Site-related contaminants to the Columbia River at these discharge locations.

Because direct discharges from the Hanford Site to the Columbia River no longer occur, groundwater upwellings are considered to be the current dominant pathway for Hanford Site-related contaminants (e.g., strontium, uranium, and chromium) to enter the Columbia River. Shoreline springs were documented along the Hanford Reach long before Hanford Site operations began during World War II. During the early 1980s, researchers identified 115 springs along a 66 km stretch of the Hanford Reach. The predominant areas of groundwater discharge at that time were in the vicinity of the 100-N Area, Hanford townsite, and 300 Area.

The presence of shoreline springs also varies with river stage (river-level elevation). The water table and the associated groundwater gradients near the Hanford Reach are strongly influenced by river stage fluctuations. At the 300 Area, the river stage is also influenced by the elevation of the McNary Dam pool. River water moves into the Hanford Site aquifer as the river stage rises (bank storage) and then discharges from the aquifer in the form of shoreline springs as the river stage falls. Following an extended period of low river flow, groundwater discharge zones located above the water level of the river may cease to exist when the level of the aquifer and level of the river come into equilibrium.

Bank storage of river water also affects the contaminant concentration of the springs. Spring water discharged immediately following a river stage decline generally consists of river water or a mixture of river water and groundwater. In general, the percentage of groundwater in the spring water discharge increases and then stabilizes over time following a drop in river stage.

Measuring the specific conductance of the spring water discharge provides an indicator of the extent of bank storage because Hanford Site groundwater has a higher specific conductance than Columbia River water. Surface water conductivity in this region of the Columbia River ranges from about 130 to 145 µS/cm, whereas groundwater typically ranges from about 400 to 600uS/cm or higher. Columbia River water temperatures in the region typically range from about 0.5ºC in the winter months up to 27ºC during the late summer months. Groundwater in the region has less seasonal variability in temperature, ranging between about 7º to15ºC.

CHALLENGES OF THE HANFORD REACH ENVIRONMENT

The Columbia River stretches 2,000 km from the Canadian province of British Columbia through the U.S. State of Washington, forming much of the border between Washington and Oregon, before emptying into the Pacific Ocean. Measured by the volume of its flow, the Columbia River is the largest river flowing into the Pacific from North America and is the fourth-largest river in the United States.

Most of the Columbia River within the United States is impounded by dams. The area known as the Hanford Reach is a 51-mile stretch of the Columbia River that flows unimpeded between the Priest Rapids Dam to the head of Lake Wallula upstream of McNary Dam. The Hanford Reach is the only free-flowing portion of the river above Bonneville Dam in the United States.

Locating and measuring contaminants in areas known as "upwellings," where groundwater emerges into the riverbed, is a key to assessing risk to the bottom-dwelling, or "benthic," community. But finding these areas and taking precise measurements in the space between rocks and sediment where the benthic organisms live and fish lay their eggs can be difficult. Conventional methods can be labor-intensive and often impractical in the fast moving waters, deep channels, and large boulders that exist in the offshore Columbia River system.

PREVIOUS SHORELINE INVESTIGATIONS

Historically, the tools and techniques used for delineating and sampling contaminated aquifers beneath the Hanford Site have been labor-intensive methods deployed along the shoreline. These methods, including vertical drive points, wells, and horizontal pore water devices, are not suited for off-shore, rapid, measurements (e.g., specific conductivity and temperature of pore water) of groundwater upwellings. A 1:1 mixing dilution model was then used to extrapolate the estimated concentrations that might be found in the off-shore riverbed areas. Tissue concentrations of sentinel organisms (e.g., Asiatic clam) have been used to map Hanford Site contamination out to water depths of about 2m, but fast and deep water conditions limited divers from collecting samples much deeper [3]. Other devices have been deployed in soft-bottom, slow-moving water bodies throughout the world to obtain small (less than 100 mL) samples of pore water. However, the Hanford Reach contains high velocity waters and coarse substrates (armored riverbed) that make deployment and installation of these devices nearly impossible.

TRIDENT PROBE TECHNOLOGY

The Trident probe[2] is a flexible, multi-sensor, water-sampling probe for screening and mapping groundwater upwelling plumes at the surface water interface. Traditional capabilities of the Trident probe included the following:

- In-situ measurement of bulk conductance (direct contact conductivity of sediment).

[2] Patent Pending - Coastal Monitoring Associates

- In-situ measurement of temperature: Detects groundwater by thermal contrast with surface water sensors.
- Pore-water and surface water sample collection: Simultaneous collection and monitoring of pore-water and surface water samples.

The traditional Trident probe has been used in other applications to detect major differences in direct contact conductivity (bulk conductance) of the sediment in soft-substrates and relatively slow moving water of fresh and saltwater systems. Insertion of the probe into sediment substrate has typically been accomplished manually using a push-pole system. The traditional Trident probe has also been used in other applications to detect differences in temperature as an indicator of groundwater versus surface water in relatively slow moving water ways.

However, the traditional version (bulk conductance) was not effective for detecting the type of low-level changes in conductivity of groundwater water (i.e., the liquid phase specific conductivity greater than approximately 160 μS/cm) versus surface waters (i.e., the liquid phase specific conductivity less than approximately 160 μS/cm) as seen in the Hanford Reach of the Columbia River. By not being able to precisely pinpoint these subtle conductivity changes, groundwater upwellings in the Hanford Reach go undetected. Further the temperature difference between groundwater and river water in the Columbia River can be zero, particularly during the late summer, fall, spring, and early summer periods. This makes it difficult to distinguish groundwater using temperature differences alone.

Adaptation for Use in Hanford Reach Conditions

One of the newly designed features of the (Liquid-Tip Trident probe), is an in-situ conductivity sensor that eliminates potential interferences from sediment in the riverbed (Fig. 2). This new technology afforded DOE an opportunity to more fully characterize and map areas of groundwater seepage in the Hanford portions of the Columbia River.

Instead of trying to physically push the probe directly into the armored riverbed of the Hanford Reach, a ruggedized driving frame[3] outfitted with in-situ sensors and sampling tubes, was developed to lower the unit to the river bottom and drive the probe to various depths. The driving frame was also equipped with a rudder system to help stabilize the unit while working in fast-moving waters of the Hanford Reach (Fig. 3). In addition, an Aqua-view™ underwater camera was installed on the driving frame to help the field crews locate areas of the riverbed that were relatively free from large-boulders and was also used to document the depth at which the probe was driven into the riverbed. The work vessels were equipped with heavy-duty davit systems, capstans, and a driving frame docking station to deploy and retrieve the system safely and efficiently. A safety boat (pilot boat) accompanied the work vessels at sites with deep and/or fast-moving river conditions to assure rapid emergency response and recovery if needed.

[3] Patent Pending - Coastal Monitoring Associates

Fig. 2. Advanced Trident Probe Measurement and Sampling Tool and Closeup of Ruggedized Probe Tip. The pore water probe and surface water probe are configured for measurements approximately 30 cm into the riverbed and 30 cm above the riverbed, respectively.

Fig. 3. Trident Probe Driving Frame and Rudder System for Deep and Fast-Moving Water.

UPWELLING STUDY OBJECIVES AND DESIGN

The primary objective of the remedial investigation upwelling study is to determine the impacts to river bottom sediments adjacent to locations where contaminated groundwater is upwelling. The results from the study will help to determine whether or not any cleanup actions are needed to address risks to humans or river biota from contaminated sediments at these locations. An underlying assumption of the study is that separate cleanup actions are underway or will be implemented in the future to address Hanford Site contaminated groundwater plumes such that ambient water quality standards are met.

Eight study areas were established for the upwelling activities - each of the reactor sites (100-B/C, 100-K, 100-N, 100-D, 100-H, and 100-F), the Hanford townsite, and the 300 Area. A multi-phased upwelling investigation design was established in the work plan [2], with the results from each phase progressively informing the plans for the subsequent phase.

- Verify technology application in Hanford Reach environment (Phase I)
- Identify locations where groundwater is upwelling (Phase IIa)
- Identify locations where contaminated groundwater is upwelling (Phase IIb)
- Characterize sediment, pore water, and surface water at locations where contaminated groundwater is upwelling (Phase III)

Configuration of the pore water and surface water probe was designed to collect measurements and samples from pore water at depths of 20-30 cm into the riverbed and surface water at 30 cm above the riverbed. Specific design elements and results for each of the study phases are summarized in the subsections that follow.

Phase I - Technology Demonstration

The technology demonstration design was to deploy the Trident Probe in a range of river conditions (e.g., water depths and velocities) and bottom formations (e.g., fine-grained sediments, gravels/cobbles, and cemented formations [e.g. Ringold Upper Mud]) within the Hanford Reach area. When deployed, the test objective was to verify the ability to draw pore water and measure in situ temperature and conductivity of both surface water and pore water.

Phase IIa – Conductivity and Temperature Mapping

Within each of the eight upwelling study areas, five transects were established based on known Hanford Site groundwater plume contours and input from Groundwater Project technical team members. Five additional transects were added between reactor areas and south of the 300 Area to provide information outside of known plume areas. All transects started at the Hanford Site near shore (e.g., reactors areas) and continued across the entire river channel to the far shore. As an example, the five transects established for the 100-B/C study area and a sixth transect between the B/C and K areas is shown in Fig. 4. Transects were established in a similar manner for each of the eight study areas.

The design called for in-situ conductivity and temperature measurements of pore water and surface water at 5 points on each transect. In addition, measurements at 5 to 10 field selected judgmental points adjacent to each transect were to be taken to help identify upwelling patterns influenced by preferential flow paths (e.g., river channeling, dredging). Elevated readings from other adjacent areas, bathymetry, presence of sediment accumulation areas, indications from sonar or underwater camera observations, observed changes in geologic formations, and the locations of structures (pipelines, outfalls, and intakes) that may present opportunities for preferential flow were factors that could be considered for the selection of judgmental measurements.

Another objective for the mapping phase was to refine the range of acceptable river conditions to collect field measurements. The work plan identified that favorable conditions would generally be present at sustained flows of 80 to 120 kcfs at Priest Rapids Dam. However, repeated field measurements of in situ conductivity could be used to verify and refine the range of suitable river stages for Phase II and Phase III activities.

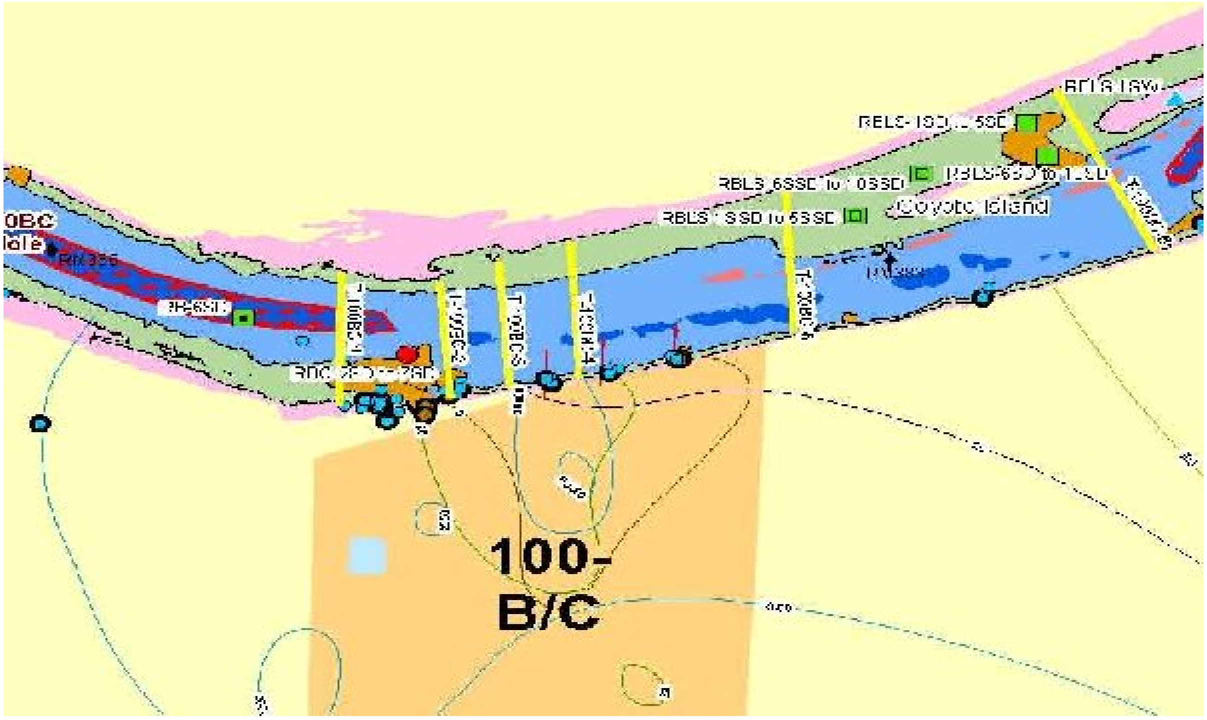

Fig. 4. Example of Transects Established for the 100-B/C Study Area (shown in yellow).

Phase IIb – Indicator Contaminant Screening

Conductivity and temperature measurements of pore water and surface water and collection of pore water samples at 20 to 30 locations within each of the eight upwelling study areas was planned for Phase IIb. Areas of high conductivity (>160 µS/cm) from the mapping surveys, spatial distribution of data, and factors such as known or suspected areas of contamination (e.g., close to aquifer tube locations) were criteria established to aid selection of sampling locations for indicator contaminant screening. Indicator contaminants were established for each of the eight study areas based on known information about existing Hanford Site groundwater plumes (Table I). Final indicator contaminant screening locations and quantities were subject to approval by the U. S. Department of Energy, U. S. Environmental Protection Agency, and Washington State Department of Ecology (the Tri-Parties).

Table I. Summary of Indicator Contaminants by Study Area.

Study Area	Indicator Contaminants
100-B/C, 100-K, 100-D, 100-H, 100-F	Cr+6
100-N	Strontium-90, tph
Hanford townsite	Tritium
300 Area	Uranium, VOC

Phase III - Characterization

Phase III locations will be selected from a subset of the Phase II locations, focusing on those with the greatest pore water concentrations for indicator contaminants. A minimum of one location for each transect in an area will be included in the Phase III characterization activities. Sample collection for Phase III will be expanded to include pore water, sediment, and surface water. In addition, analysis for all media will be expanded from indicator contaminants to broad suite of contaminants. Final sample locations and quantities for plume upwelling characterization are subject to approval by the Tri-Parties.

SUMMARY OF RESULTS AND FUTURE ACTIVITIES

Groundwater upwelling investigation activities have been completed up through Phase IIb, indicator contaminant screening. The following text presents a summary of results and findings from the completed work and identifies plans for future activities.

Phase I - Technology Demonstration Results

Phase I was successfully conducted in September 2008. Locations at 100-B/C, 100-N, 100-D, and the 300 Area were investigated during the test. The Trident probe was successful in identifying groundwater upwelling in a variety of substrate types, river velocities, and river depths. Additional tools that increased efficiencies of groundwater delineations included sonar and underwater video camera surveys. During this demonstration, a number of surface water measurements obtained 30 cm above the riverbed at groundwater upwelling locations indicated little to no influence of groundwater in the surface water based on measured conductivity and temperature differences.

Phase IIa - Conductivity and Temperature Mapping Results

In-situ temperature and conductivity measurements were mapped at more than 675 locations in the Hanford Reach between December 2008 and August 2009. The mapping locations consisted of a combination of transect points selected where known contaminated groundwater plumes are intersecting the Hanford Site shoreline and judgmental points. Judgmental points were selected using field observations and high-resolution bathymetry of the area, looking for suspected preferential pathways for groundwater to enter the river. Findings from Phase IIa results are summarized by the following:

- Differences between conductivity and temperature measurement effectively identified offshore riverbed locations within each of the eight study areas where groundwater emerges into the Columbia River.
- Groundwater discharge areas were encountered at locations along both the right and left banks and in the center of the river.

- Relatively high temperature differences (5° - 12°C) between pore water and surface water measured during the winter period were useful to identify locations that exhibited relatively higher groundwater discharge rates (i.e., at locations were temperature measurements indicated surface water at 30 cm above the riverbed was warmed by groundwater discharge).

- Reactor water intake structures (in water 15-30ft deep) were consistently found to exhibit relatively high conductivity and temperature differences, suggesting a preferential pathway for groundwater releases into the river there.

- Conductivity measurements recorded at a number of off-shore stations exceeded highest conductivity values reported from near shore wells or aquifer tubes (>700 µS/cm). These stations typically exhibited high temperature differences and typically contained a mixture of fine grained sediments and matrix of gravels/cobbles.

- Surface water conductivity was elevated above reference values (~140uS/cm) at a number of stations, particularly in areas where river flow was low and where high temperature differences suggested relatively high groundwater discharge rates.

Phase IIb – Indicator Contaminant Screening

River stages encountered during sampling events has been long-recognized as major factor affecting the concentration of contaminants at a site. As a precursor to the Phase IIb activities, an assessment was conducted to examine the differences in specific conductance of pore-water under varying river stage conditions. The objectives of this task were to: 1) identify water levels that likely suppress pore-water conductivity values above a set of baseline values, 2) evaluate possible time-lags associated with cycling river levels (particularly receding levels) and possible latent groundwater upwelling responses.

Conductivity of pore water and surface water was measured at a number of selected locations in the Hanford Reach. A one-dimensional unsteady river flow model, the Modular Aquatic Simulation System-1D (MASS1) [4], was used to characterize river flows and water surface elevations encountered when pore-water conductivity measurements were taken at these locations. MASS1 simulates unsteady flows and water surface elevations by solving the one dimensional equations of mass and momentum conservation (also known as the St. Venant equations). MASS1 is based on U.S. Army Corps of Engineers bathymetric data at 145 cross-sectional transects regularly spaced between Priest Rapids Dam and Richland, Washington. These results were then used to develop the following guidelines to increase representativeness for Phase IIb and III pore-water sampling events.

- Avoid sampling when river levels greater than 1 m above low water mark for at least 1-2 hrs prior to sampling

- Intermittently perform pore-water conductivity checks at selected QC stations near work site, particularly if water levels are near 1 m above low water mark

- Measure river level at 0.1 m increments from 0 to 3 m from low water mark before and after each sampling event using staff gauge installed near study areas (100-B/C, 100-N, 100-F, 100-H, HTS, and 300 Area)

- Post-process river stages encountered near work site using MASS1 model and time-specified discharge rates reported from nearby hydroelectric facilities to flag results where non-stable conditions were encountered.

- Look for pore-water conductivity values similar to Phase IIa

- Re-measure field QC stations intermittently to document current baseline high stable conductivity readings

Between August and December 2009, 240 pore water samples were collected to complete the Phase IIb work. Pump rates depended on recharge conditions determined by continuous in situ monitoring of pore-water conductivity to assure minimal short-circuiting with surface water. Findings from the Phase IIb activities are summarized by the following:

- Field sampling guidelines helped minimize the influence of river fluctuations and bank recharge so that results could be compared with one another.

- Indicator contaminants were detected in pore-water samples collected from a number of off-shore stations.

- High pore-water conductivity values indicated the presence of groundwater, but not necessarily the presence of indicator contaminants.

- Indicator contaminant concentrations were not normally distributed spatially, suggesting preferential pathways of groundwater movement to off-shore locations and non-uniform sources of the contamination.

Phase III - Characterization

Phase III characterization activities are anticipated to begin in early 2010.

ROLE IN THE INTEGRATED CLEANUP STRATEGY FOR THE RIVER CORRIDOR

The results of the groundwater upwelling activities and the broader remedial investigation of Hanford Site releases to the Columbia River are important to other Hanford Site cleanup activities in areas that border the Columbia River, also known as the "River Corridor." In 1991, the Tri-Parties agreed to a "bias-for-action" approach to the CERCLA process for the Hanford Site. The agreement, known as the *Hanford Past-Practice Strategy* [5], streamlined the RI/FS process to begin remediation of contaminated waste sites earlier than typically performed under the traditional CERCLA process in place at that time. Source and groundwater cleanup actions at the 100 Area and 300 Area National Priorities List sites, a geographical area broadly referred to as the "River Corridor" began in 1994 and continue today. These cleanup actions were authorized via interim action Records of Decision (RODs) that were supported by qualitative risk assessments to establish a need for action.

The Tri-Parties are now implementing a plan to transition from interim remedial actions to final remedial actions for the River Corridor source and groundwater operable units. The RODs that are produced from this effort will establish the final remedial goals and objectives and any associated actions required to complete CERCLA cleanup for the River Corridor. The process to pursue final cleanup decisions has been organized into smaller pieces of work that are more manageable and aligned with Hanford Site operational functions. Six final remedy RODs will be developed for areas associated with the following:

- 100-B/C reactors
- 100-K reactors
- 100-N reactor
- 100-D and 100-H reactors
- 100-F reactor and Hanford townsite
- 300 Area fuel fabrication and development facilities.

Each of the six final remedy RODs will be integrated to address both source and groundwater remedial actions for the decision area. The impacts of the Hanford Site releases to the Columbia River are an integral piece of these final decisions. If any cleanup actions are needed to address Hanford Site contamination in the river, they may be included with the final decisions for one or more of the six areas. It is also possible that a separate cleanup decision could be made that is specific to the Columbia River. The objective for all of these decisions would be to protect human health and the environment.

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