BONNEVILLE POWER ADMINISTRATION

Conceptual Spawning Habitat Model to Aid in ESA Recovery Plans for Snake River Fall Chinook Salmon

Annual Report 2002 - 2003 | September 2005 | DOE/BP-00000652-21

Geist, David, "Conceptual Spawning Habitat Model to Aid in ESA Recovery Plans for Snake River Fall Chinook Salmon", 2002-2003 Annual Report, Project No. 199406900, 20 electronic pages, (BPA Report DOE/BP-00000652-21)

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2003 Progress Report to Bonneville Power Administration

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Project 1994-069-00

October 2003

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Summary

The goal of this project is to develop a spawning habitat model that can be used to determine the physical habitat factors that are necessary to define the production potential for fall chinook salmon that spawn in large mainstem rivers like the Columbia River's Hanford Reach and Snake River.

This project addresses RPA 155 in the NMFS 2000 Biological Opinion:

Action 155: BPA, working with BOR, the Corps, EPA, and USGS, shall develop a program to:

1) Identify mainstem habitat sampling reaches, survey conditions, describe cause-and-effect relationships, and identify research needs;

2) Develop improvement plans for all mainstem reaches; and

3) Initiate improvements in three mainstem reaches.

During FY 2003 we continued to collect and analyze information on fall chinook salmon spawning habitat characteristics in the Hanford Reach that will be used to address RPA 155, i.e., items 1-3 above. For example, in FY 2003:

- We continued to survey spawning habitat in the Hanford Reach and develop a 2-dimensional hydraulic and habitat model that will be capable of predicting suitability of fall chinook salmon habitat in the Hanford Reach;
- Monitor how hydro operations altered the physical and chemical characteristics of the river and the hyporheic zone within fall chinook salmon spawning areas in the Hanford Reach;
- Published a paper on the impacts of the Columbia River hydroelectric system on main-stem habitats of fall chinook salmon (Dauble et al. 2003). This paper was made possible with data collected on this project;
- Continued to analyze data collected in previous years that will ultimately be used to identify cause-and-effect relationships and identify research needs that will assist managers in the improvement of fall chinook habitat quality in main-stem reaches.

During FY 2004 we plan to:

- Complete preliminary reporting and submit papers based on the results of the project through FY 2004. Although we have proposed additional analysis of data be conducted in FY 2005 (see below), we anticipate a significant number of key papers being prepared and submitted in FY 2004 which will go toward identifying the data gaps this RPA is intended to address;
- Make available data from this project for use on Project 2003-038-00 ("Evaluate restoration potential of Snake River fall chinook salmon") which is a BPA-funded project that will start in FY 2004;
- Present results of our work at regional and national meetings in order to facilitate technology transfer and information sharing.

Background

Current mainstem production areas for salmonids are now largely restricted to habitats that remain non-inundated, i.e., the Hanford Reach of the Columbia River and the Hells Canyon Reach of the Snake River (Dauble and Watson 1997; Groves and Chandler 1999; Battelle and USGS 2000; Dauble and Geist 2000; Dauble et al. 2003). Although the Hanford Reach stock of fall chinook salmon (*Oncorhynchus tshawytscha*) is relatively healthy (Huntington et al. 1996; Dauble and Watson 1997), the Snake River fall chinook salmon were listed under the Endangered Species Act (ESA) in 1994. The Hanford Reach may be considered as having the only "core population" of fall chinook salmon within the Columbia River system (ISG 1996). Recovery planning is underway for stocks listed under ESA and will rely on a combination of spawning habitat protection and restoration (NPPC 1994; NMFS 1995; Dept. of Commerce 1997), among other actions. If habitat in other portions of the basin can be protected, then the core population of fall chinook salmon in the Hanford Reach may be able to seed depressed stocks (ISG 1996). With limited recovery funding, it is important to find the specific habitats that should be protected and enhanced (Rondorf and Miller 1993).

Our research in the Hanford Reach and elsewhere suggests that spawning habitat for anadromous salmonids is a combination of both standard habitat characteristics (depth, substrate, velocity, and slope) and geomorphic features of river systems (hyporheic zone characteristics, riverbed permeability, channel shape, and longitudinal bed slope). Through funding provided by the Fish and Wildlife Program since 1994, we have been investigating the relationship between hyporheic flow and fall chinook salmon spawning in the Hanford Reach (Geist 1998; Geist et al. 1997; Geist et al. 2000; Geist 2000). Our research suggests that in spawning areas with equal amounts of depth, substrate, and velocity (i.e., standard habitat characteristics), fall chinook salmon spawning is more prevalent in areas of hyporheic upwelling (Geist 2000). The hydrologic exchange that occurs within the hyporheic zone may be an important geomorphic process occurring within large river systems that affects where fall chinook salmon spawn (Geist and Dauble 1998; Geist 2000).

The underlying assumption of our research in the Hanford Reach is that the spatial extent of fall chinook salmon spawning area predicted using standard habitat characteristics exceeds the spatial area actually used. The discrepancy between the locations fall chinook salmon spawn and the habitat predicted to be useable or not useable are termed errors of omission and commission. We propose that errors of commission and omission can be reduced by examining how the geomorphic features of spawning and non-spawning areas differ. In the process, a better understanding of the important characteristics of fall chinook salmon spawning areas can be obtained. This information can be used to address recovery actions for salmon listed under the ESA.

Project Objectives and Current Status

The objective of this project is to define the production potential of fall chinook salmon that spawn in the Hanford Reach. We will provide fisheries and resource managers with the information they need to determine if the Hanford Reach fall chinook salmon population is indeed healthy, and whether this population will be capable of seeding other satellite populations in the future. We will accomplish this purpose by continuing our on-going research at determining the carrying capacity of the Hanford Reach for producing fall chinook salmon under current operational scenarios, and then begin an assessment of whether the Reach is functioning as a model of a normative river as is widely believed. The product of our research will be a better understanding of the key habitat features for mainstem populations of anadromous salmonids, as well as a better understanding of the measures that must be taken to ensure long-term protection of the Hanford Reach fall chinook population.

Although the project was originally funded in FY 1994, it was significantly re-defined in FY 2000. At that time five tasks were proposed to accomplish the project objective. The purpose of this progress report is to briefly describe the activities that have been completed on each of the five tasks from FY 2000 through FY 2003.

Task a. Conduct limits analysis

The purpose of this task is to identify areas within the Hanford Reach that would not be spawning habitat-limited due to constraints imposed by depth, substrate, lateral slope, and/or velocity (i.e., standard spawning habitat characteristics). The product of this task will be an analysis of the amount of fall chinook salmon spawning habitat that is available in the Hanford Reach versus what is used.

Study sites were selected in the fall of 1999. In order to ensure study sites were representative of the full range of potential spawning habitat, the Reach was stratified based on geomorphic features of the river channel. Transects of river cross-sections collected by the US Army Corps of Engineers in the early 1980s were used to calculate two ratios: F = channel width/mean channel depth and d* = maximum depth/mean depth. These two ratios were combined to create four potential geomorphic classes. Once classified, the transect was designated as a spawning area or non spawning area. This designation was done based on aerial redd surveys conducted in the Reach since the early 1940s (Dauble and Watson 1997). Although the Reach is 51 miles long, only 17 miles (rivermile 359 to 376) has been surveyed for shoreline bathymetry. The shoreline bathymetric survey was done as part of the Hanford Reach stranding project and involved the Department of the Army conducting a SHOALS/LIDAR survey along both sides of the river to define potential stranding habitat. Detailed bathymetric data are needed to run the hydraulic models that we used to evaluate spawning habitat. Thus, we restricted the study to this 17 mile section, hereinafter referred to as the study area. If additional bathymetric data become available, we would propose to extend our hydraulic model and habitat analysis to these areas[1].

Within the 17 miles, there were only 4 (8%) transects representing the geomorphic class Fd*3. Therefore, this class was removed from further consideration. Of the remaining three classes, most (43%) of the spawning occurred near transects classified as Fd*1 which represented river cross sections that were typically asymmetrical and wide, with part of the transect containing a shallow bar that deepened into a v-shaped deep thalweg. Transects classified as Fd*4 (symmetrical cross section and relatively uniformly deep) were mostly representative of non-spawning areas while transects classified as Fd*2 (symmetrical cross section that is wide and with relatively uniform shallow depths) were split evenly between spawning and non-spawning areas. Nine study sites were randomly selected from the pool of 44 transects, with three sites each located in the upper, middle, and lower sections of the study area.

Once the nine study sites were selected, we began to assess whether empirical and modeled measurements of standard habitat characteristics (i.e., substrate, depth, velocity, and slope) were limiting fall chinook salmon spawning. Substrate data were collected by underwater videography in 2000 and 2002. Because of the challenges inherent in sampling the bed of large rivers (i.e., deep and fast water), the substrate data were collected using a boat-deployed, video-based adaptation of the pebble count method (Wolman 1954). The video system consisted of a high-resolution monochrome camera with wide-angle lens connected to an 8-mm camera recorder located on the boat. The camera was placed inside a waterproof housing and mounted on a weighted platform containing two downward-pointing lasers, providing reference scale within each video image. Positional data were recorded with a real-time differential global positioning system. The pebble count method typically dictates sampling 100 stones selected without bias from specific geomorphic features (Wolman 1954; Church et al. 1987; Kondolf 2000). The study area was delineated into 13 distinct geomorphic units based on the location of the nine study sites, channel morphology, and hydraulic characteristics. A total of 100 substrate images were collected by underwater videography within each geomorphic unit. Within each unit, samples were collected in a spatially distributed manner so that fairly uniform coverage of each unit was attained. This sampling scheme was appropriate for obtaining overall sediment size characteristics of a distinct geomorphic unit, or even for an entire reach (Wolcott and Church 1991; Crowder and Diplas 1997).

The substrate images were treated as pebble counts, in that the processing software automatically selected the grain at the center of each image. The grain was then measured by the software, resulting in an estimate of the length of the apparent long (a) and intermediate (b) axes for each grain. In addition to the boat surveys using the video camera, shallow shoreline areas that could be waded were sampled by the traditional pebble count method (Wolman 1954). All pebble count sampling was performed by the

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[1] The USFWS has received funds to conduct a SHOALS/LIDAR survey on the remaining 34 miles of the Reach, however, this has yet to be completed.

same observer to eliminate multiple-observer sampling error (Wohl et al. 1996). To reduce measurement error and obtain samples directly comparable with sieve analysis, all grain size measurements were made with an aluminum template containing square openings in ½-phi size classes from 128 mm (-7 phi) to 2 mm (- 1 phi) (Hey and Thorne 1983). The grain size estimates derived from all substrate sampling were used to develop cumulative grain-size distributions for each geomorphic unit. Substrate grain-size maps were generated by first calculating variograms (Isaaks and Srivastava, 1989) of the empirical substrate measurements. Each geomorphic unit was separately mapped using standard geostatistical software (Deutsch and Journel, 1998) to create a spatial map, and ordinary kriging (Isaaks and Srivastava, 1989) was used to estimate the spatial distribution of the substrate data within the defined mapping areas. This substrate surface was subsequently converted to an ArcInfo grid coverage for use in assigning substrate values to habitat cells.

A bathymetric surface of the riverbed surface was computed using both depth and water surface elevation data. Depth data were collected using an Innerspace Technology Model 455 single-beam echosounder operated to collect a depth at 3- and 10-s intervals. The echosounder depth data were linked with global positioning system data using Trimble HydroPro on a laptop computer. The majority of the bathymetry data were collected in October, 2000. Seven Solinst level loggers were installed throughout the study area and surveyed for their elevation by a licensed surveyor. Once the elevations of the data loggers were determined, the logger data (i.e., depth data) were used to establish accurate river surface elevations during the bathymetry data collection period. Data processing was accomplished by combining the SHOALS data collected in the shallow, shoreline areas with the overlapping bathymetric surveys collected in the deeper parts of the channel. A triangulated irregular network (TIN) surface of the bathymetric data was created which contained a variable node spacing in both the x and y directions. Using ArcInfo, a bathymetric GIS coverage was created from the TIN which had a regular node spacing of 3 m x 3 m.

A hydraulic model (MASS2) was used to predict how depth and velocity changed with discharge. MASS2 is a finite-volume, unsteady two-dimensional depth-averaged hydrodynamics and transport model (Scheibe and Richmond, 2002; Richmond et al., 1999). Input requirements for the model included channel bathymetry, channel bed roughness information, and stage/discharge relationships at the model boundaries. Channel bed elevations and roughness height were specified based on the GIS coverages of bathymetry and substrate. Stage/discharge relationships were based on discharge and velocity measurements collected in October, 2000, with an RD Instruments Broadband acoustic Doppler current profiler (ADCP model BB-DR-600). The ADCP recorded depth, water velocity, and direction data that provided velocity readings associated with both XY coordinates and depths (Z). In addition to the stage-discharge relationships, these data were also used to provide calibration data to the hydraulic model.

Once the input requirements were met for the hydraulic model, the model was used to generate velocities and depths over a range of discharges from 40,000 to 180,000 cubic feet per second (cfs) in 10,000 cfs increments. Hourly discharge values at Priest Rapids Dam were used as input to the model. Output from the model was taken for the period between 15 October and 15 November (fall chinook salmon spawning period).

The results from each model run were imported into a GIS database, providing hydraulic data (e.g., depth and velocity) for each node in the study area. A continuous surface for each hydraulic variable was created using an inverse distance weighting interpolation between nodes. The interpolated value within 3 m x 3 m cells was determined by a linearly weighted average of the cell's three nearest nodes. The weight was a function of inverse distance, such that nearby sampling points had more influence on the interpolated value. Riverbed slope was estimated using a similar approach in the GIS via an algorithm that fits a plane to the elevation values of a 3 cell by 3 cell neighborhood around the cell being processed. The slope for a given cell was calculated using the average maximum technique based on the surrounding 3x3 neighborhood.

Once the GIS coverages were created for each of the habitat variables, individual "habitat cells" (Payne and Lapointe 1997) were created which contained a value for substrate, slope, and depth and velocity at a given discharge level. Habitat values were assigned to habitat cells in the GIS by treating the center of each habitat cell as a sampling point at which the data were extracted.

Aerial photography was used in 2000 and 2001 to determine where fall chinook salmon locate their redds within the study area. In addition, aerial photography from 1994 and 1995 was available for this analysis. In 2000, a contractor was hired to take aerial photographs of salmon redds. The contractor was tasked with establishing 165 ground reference points along the river within the study area. Reference points were 2 m, right angle crosses of white Tyvek material 35 cm in width. Photographic scale was to be 600 m/image. Photographs were acquired on November 10-12, 2000. Image processing was initially completed by the contractor. Upon receipt of the final product, we discovered that the precision and accuracy was poor (up to 100 m off in some cases) and variable (water was worse than land). We attempted to remedy this with the contractor, but were eventually unsuccessful. Thus, the images from 2000 are useable only for purposes of generally locating spawning areas and not for individual redd locations.

In 2001, we contracted with Walker and Associates, Seattle, Washington, to take aerial photographs of salmon spawning locations. Stereo color aerial photography at a nominal negative scale of 1:7,200 was obtained November 8, 2001, using a Zeiss precision aerial camera equipped with a gyro-stabilized mount and an image-motion-compensation magazine. This camera was also equipped with an event-marking feature which permitted shutter-opening events to be recorded in a GPS data format collected during the flight mission. A GPS was used to navigate flight lines and fire the camera. Pre-marks were establish prior to the flight and were used in combination with a digital elevation model (DEM) to orthorectify the images during photograph processing. The resulting accuracy of the images was ~ +/- 8 cm. Once images were received from Walker, PNNL staff digitized individual salmon redds into an ArcInfo GIS coverage.

Logistic regression analysis is currently being used to determine whether there is a relationship between the standard characteristics of a habitat cell (i.e., substrate, depth, velocity, and slope) and the location of salmon spawning. Separate analyses are being conducted for 1994, 1995, and 2001 using the median discharge values for each of those years (October 15 through November 15) to model depths and velocities, and the aerial photographs specific to those years to establish whether a habitat cell is classified as a spawning area or a non-spawning area. In each year, assigning a cell's spawning designation was done by using a radius of 10 m around a cell that was known to contain a redd. Consequently, all habitat cells within 10 m of a cell where a redd was located were reclassified as spawning cells. This value was used because 10 m is the approximate mean distance between spawning cells in the raw data. For all three years, a portion of the habitat cells will be used to construct the logistic regression model and an independent portion from the same year will be used to test it. Separate models will be created for each of the nine study sites.

We have completed preliminary analysis using logistic regression on the standard habitat variables. In general, the models did a reasonably good job of telling us the types of habitat fall chinook salmon would not spawn at. However, consistent with our previous studies, the errors of commission (predicted to be a spawning site but not used) were high at some sites (see Task c for comments on results). At these sites, we plan to conduct a more detailed analysis using ideas that are based in part on the reasoning developed in Leclerc et al. (1996). Specifically, we will test whether there are differences in the stability of habitat between cells that are predicted to be habitat and are used versus areas that are predicted to be habitat but are not used. This analysis will involve using hourly discharge data to calculate hydraulic variables such that we can examine how short-term changes in depths and velocities affect spawning site selection. In addition, we are investigating where complex hydraulic variables that express the turbulence of the flow are better predictors of spawning habitat use. Finally, we will use the results from Task b to refine suitability criteria.

Task b. Select and describe appropriate geomorphic features and hyporheic zone characteristics in areas where limits analysis suggest spawning should occur.

The purpose of this task is to determine which geomorphic features are correlated with spawning. The product of this task will be a conceptual model that can be used to predict spawning habitat suitability of fall chinook salmon in big rivers.

In 1999 we assessed water quality of the hyporheic zone using piezometers that were installed on transects within each of the nine study sites. We established piezometers on both sides of the river channel, and if present, on either side of islands or bars. These piezometers were referred to as transect piezometers and were designed to provide single sampling points that would be used to represent major riverbed characteristics at each of the nine study sites.

Piezometer screens were constructed of either slotted stainless steel Johnson Screen (0.038-cm slot size) or brass wire mesh Moss Midwest screen with an equivalent size opening. Both had a 31.0-cm screened interval and a 3.2 cm inside diameter. The screen was welded on one end to a 12-cm drive point and on the other end to a variable length section of galvanized steel pipe (3.2 cm inner diameter) threaded on top. Piezometers were installed by inserting a solid steel drive-rod into the piezometer and either pounding the piezometer with the rod or with a post-pounder (Geist et al., 1998). The average depth below the riverbed for these piezometers was 64.5 cm (range 37.5-72.5 cm).

A total of 24 transect piezometers were installed in 1999 and subsequently monitored in 1999 and 2000 during October and November of each year. Sampling consisted of taking measurements of the electrical conductivity (EC), head, temperature, and dissolved oxygen of the riverbed (via the piezometer) and in the river column immediately adjacent to the piezometer. Data collected from the piezometers in 1999 and 2000 were very similar. Riverbed temperatures averaged 12.7 C (95% CI = 12.4-13.0 C) in 1999 and 13.1 C (95% CI = 12.8-13.4 C) in 2000. During this same time period, the river temperatures in both years were slightly cooler than the riverbed at 12.3 C (12.0-12.5 C) in 1999 and 12.8 C (12.5-13.1 C) in 2000.

Differences in electrical conductivity between the riverbed and the river have been used to determine the relative amount of groundwater at a given site. The data from 1999 and 2000 were similar at all sites. Some of the sites had significantly higher EC values in the riverbed suggesting a higher proportion of groundwater at these sites. For example, the highest differences in EC occurred at T64 which is a spawning area located near the 100 H reactor. The riverbed EC values at this site in 1999 and 2000 were up to 150 uS cm^{-1} higher than the river. In contrast, another significant spawning area near T81 showed results that were consistent with previous investigations where the EC values of the riverbed were within 5 uS cm^{-1} of the river, suggesting a higher infiltration rate of river water into the sediments. As in the study sites where spawning occurred, there was no obvious pattern in the EC values within non-spawning areas. Some of the non-spawning sites had high EC values in the riverbed while others had low values.

Overall (all piezometers combined), riverbed dissolved oxygen levels averaged around 6 mg L^{-1} in both years but variability was high. As with temperature, there did not appear to be a clear pattern in riverbed oxygen values that was based on the spawning designation of a site. For example, in 2000, riverbed dissolved oxygen levels at two of the major spawning areas were significantly less than 5 mg L^{-1}, which is considered a minimum level to support developing embryos. It isn’t apparent if these values are real or a result of the difficulties in acquiring good measurements of dissolved oxygen within riverbed sediments; this is an important topic that needs further research.

The difference in head (i.e., the height of the water in the riverbed minus the height of the river) is a good indicator of the potential for riverbed water to upwell into the river channel (i.e., positive heads) or for river water to downwell into the riverbed (i.e., negative heads). The potential energy gradient associated with the differences in heads is expressed as a vertical hydraulic gradient (VHG) which is the head difference divided by the distance below the bed where the measurement is being made (referred to as ΔL). In general, the riverbed water was, on average, about 4 cm higher than the river in both 1999 and 2000. There was quite a lot of variability with some non-spawning sites showing head differences of >5 cm and VHGs > 0.1. The only site that showed significant downwelling (i.e., negative head values) was at T94 which is a non-spawning study site. In general, the non-spawning sites had larger head differences and VHGs than the spawning sites. Interpretation of these data is on-going. Higher values would indicate that the amount of upwelling (or downwelling) may be higher. However, we have observed that in areas of low permeability, the head differences and VHGs can be large because of the energy gradient necessary to move water through the tighter pore spaces. Therefore, it is instructive to look at the permeability values at these sites.

Permeability was measured in November, 2000, using a slug test method that was developed on this project (Arntzen 2001). Slug tests were performed on the same piezometers where water quality was collected. To perform the test, an airtight pressure-regulating wellhead assembly was threaded to the top of the piezometer. The assembly consisted of a 5-cm ball valve coupled to a 20-cm section of schedule-40 polyvinyl chloride pipe containing a small valve stem for pressurizing. A pressure transducer (Instruments NW model 9800) was lowered into the piezometer to measure changes in hydraulic head during the test. A modified rubber stopper was used to seal the transducer cable's entry into the well assembly. The system was pressurized with a portable battery-powered air compressor (Black and Decker VersaPak cordless inflator), causing the water level in the piezometer to be depressed downward. When the water level in the well was sufficiently depressed, the air compressor was shut off, and the ball valve simultaneously opened, marking the beginning of the slug test. The change in water level was measured by the transducer and recorded by an electronic data logger (Campbell cr10x). When the pressure was released, the data logger recorded the pressure response (rising water level) with respect to time. When possible, the slug tests were repeated three to five times in each piezometer to ensure precision (Butler et al. 1996). A total of 62 slug tests were conducted in 21 piezometers; 3 piezometers were not sampled because the piezometer was damaged during installation. Methods for estimating hydraulic conductivity (a measurement of riverbed permeability) from slug test data have been summarized (Butler 1998). For the case of a partially penetrating well in an unconfined aquifer (e.g., riverbed conditions), reasonable data analysis techniques include the Hvorslev method (Hvorslev 1951) and the Bouwer and Rice method (Bouwer and Rice 1976; Bouwer 1989). Both methods involve plotting the natural logarithm of the head response against time. The slope of these data, together with data regarding piezometer geometry, were used to solve for hydraulic conductivity. We analyzed the data using both methods and found that results using Hvorslev were consistently 1.5 times the Bouwer and Rice results. In addition, our results are consistent with other studies comparing the two methods (Palmer and Paul 1987). Therefore, only results determined using the Bouwer and Rice method have been presented. Additional details will be provided in the final report on the computations necessary to estimate hydraulic conductivity values.

Hydraulic conductivity values ranged from 0.29 x 10^{-3} cm s^{-1} to 0.3 x 10^{-1} cm s^{-1}. These are typical of riverbed gravels and are comparable to hydraulic conductivity values from other alluvial rivers. For example, hydraulic conductivity values ranged from 10^{-1} to 10^{-4} cm s^{-1} in riverbed sediments of the Columbia River below Wanapum Dam (Geist et al. 2003) and from 10^{-1} to 10^{-3} cm s^{-1} in the Hells Canyon Reach (Arntzen et al. 2001). There was considerable variation between sites, with the highest conductivity values coming from the T94LB site and the lowest coming from the T101RB site. Hydraulic conductivity values appeared to be lower in the study sites located in the downstream end of the study area, as compared to slightly higher values at study sites toward the upstream end of the study area. Fine-grained silts and sands enter the Hanford Reach from various locations but most notably on the northeast side of the river in the areas where the bluffs have slumped and sloughed into the river channel. Many of the study sites exhibiting lower permeabilities are downstream of these slump areas. Therefore, low permeability values may be due to a larger amount of sediment within the riverbed sediments.

As previously mentioned, the transect piezometers provided general information about each of the nine study sites. However, based on the variability within a study site, it was necessary that more data were needed at each site. Therefore, in November of

2000 and 2001, we established nine "focus areas" where we installed additional piezometers and conducted freeze-coring. These focus areas were nested within each of the nine study sites. At each focus area, 9 to 12 piezometers were installed approximately 30 cm below the bed where water quality measurements were made (as previously described) and slug tests were conducted. In addition, freeze core samples were taken at each of the focus areas. The freeze cores were used to characterize the particle size distribution within the riverbed, and to provide information on sediment properties that could be compared to the water quality and slug tests results.

Based on elevated electrical conductivity, groundwater was present at two of the sites: T101 and T90. Both of these study sites are located on the left bank of the river, near the lower end of the study area. Neither site is a location that fall chinook salmon have previously spawned. The upstream-most site (T54) expressed slightly elevated electrical conductivity values, suggesting pore water chemistries were somewhat affected by groundwater inflow. This site is located on the right bank of the river, and is also not a fall chinook salmon spawning area. At all other sites the electrical conductivity of the sediment was very similar to the electrical conductivity of the river and suggested the sediment pore waters were primarily composed of river water.

The average riverbed temperatures at all nine focus areas were always within 1 C of the average river temperature. There was very little variability within temperatures between the individual piezometers within a focus area. The exception to this occurred at focus areas T81 and T96 where riverbed temperatures varied by up to 1.5 C between individual piezometers. Dissolved oxygen measurements were taken inconsistently, and are suspiciously low. As in the previous measurements of dissolved oxygen, additional research on this topic is needed in the Hanford Reach.

At most locations, the vertical hydraulic gradient showed that the highest potential was for water to flow out of the bed into the river, rather than from the river into the bed. Head differences at most sites averaged < 2 cm and VHG < 0.08. The exception was at T96 where average head differences were ~7 cm, and the average VHG value was 0.2. This happened to be a site where we saw the greatest range of hydraulic conductivity values (range 0.0002 to 0.27 cm/s) and the highest average value (0.07 cm/s). For comparison, average hydraulic conductivity values at other sites ranged from 0.003 to 0.012 cm/s. The wide range in values suggests either very heterogeneous substrate conditions or variations in conditions at the time of the monitoring. For example, river levels dropped considerably during the time we tested T96 such that by the time we finished the piezometers were essentially out of the water. These factors will be considered in the final analysis.

We used a modified tri-tube freeze core technique to collect grain-size data from the riverbed (Everest et al. 1980; Rood and Church 1994). A total of 43 freeze cores were collected at the nine study sites in 2000 and 2001. We attempted to collect at least 4 freeze cores from each site; additional cores were collected at the T61 site to ensure we had representation of sediment within a non-spawning area. We attempted to collect at least 100 kg of sediment from each site to ensure representative data (Shirazi et al. 1981; Church et al. 1987). A series of hollow stainless steel tubes were driven into the river bed to a depth of approximately 50 cm below the bed surface. Liquid nitrogen was poured into the tubes and the frozen mass was extracted from the bed using a 2-ton tripod and chain hoist. The frozen sample was then photographed, placed in a vinyl bag, and transported to the laboratory for drying. The dried samples were then sieved into ½-phi size classes from 128 mm (-7 phi) to 0.0625 mm (4 phi). For each sample, the weight of the substrate in each size class was determined, yielding a percent-by-weight value for each size class. The percent finer for each size class from 0.032 mm (5 phi) to 0.001 mm (10 phi) were determined using a Sedigraph model 5001 (Weaver and Grobler 1981; Singer et al. 1988). For laboratory sample handling and quality assurance/quality control, researchers followed the guidelines of Guy (1969).

We are still analyzing the riverbed grain-size data. Preliminary results suggest that the percentage of fines (< 1mm diameter) is quite high, even in spawning areas. For example, average values for the spawning sites (T59, T64, and T81) were around 18%, however, the individual freeze cores suggested significant heterogeneity at the spawning sites. The highest percent fines from riverbed sediments came from T94 which is a point bar that standard spawning habitat characteristics suggests should be used for spawning. At this site, the percent fines in four freeze cores ranged from 14 to 46%, with an average of approximately 32%. Percent fines in sediment cores from other alluvial rives in the Pacific Northwest suggest that, in general, the percentage of fines in the Hanford Reach are higher than other locations. For example, in the Hells Canyon Reach of the Snake River, the percentage of fines was, in general, <12% (Arntzen et al., 2001). At two sites in the upper Snake River above Hells Canyon Dam, the percentage of fines in riverbed sediments near historic fall chinook salmon spawning areas was ~10% (Hanrahan et al. 2001). One must keep in mind, however, that because the Hanford Reach is contained within a wide, alluvial floodplain of low longitudinal gradient (<<1%), it is not surprising that the percentage of fines is high. Further, the percentage of fines is but one metric used to classify substrate quality. Additional metrics that characterize the matrix and the bed framework need to be used to describe potential spawning habitat. These metrics will be used to extensively evaluate the freeze core data from the Hanford Reach and will be presented in the final report.

A significant finding of our research thus far is that the fluctuating river stage creates a hysteresis effect whereby the water quality of the riverbed lags behind the change in surface water characteristics. This observation was made possible with the use of data loggers placed in the river and the riverbed at various locations throughout the Reach. For example, beginning in 1999 we placed temperature recorders at 10 piezometers that were installed within the nine study sites. In all cases the riverbed temperatures were warmer than the river (as much as 2 C warmer in some locations). Bed temperatures were generally lower in piezometers located at downstream study sites, e.g., riverbed temperatures at transects 96 and 101 (downstream end of the study area) were approximately 1 – 2 C warmer than transects located near the upstream end of the study area.

Data loggers capable of monitoring temperature and stage were placed in riverbed piezometers beginning in 2001. As of the end of FY 2003 all nine study sites have had continuous measurements of riverbed and river level and temperature for at least 6 months, and sometimes much more. Some of these data have been used to examine the hysteresis issue previously mentioned. We are ready to submit a manuscript that describes the relationship between hydraulic conductivity, vertical hydraulic gradient, and river stage. Our results suggest that in areas of low hydraulic conductivity (e.g., T96), the vertical gradient fluctuates over a wider range than in areas of high hydraulic conductivity (e.g., T64). The wider fluctuations and lower conductivities results in a more pronounced hysteresis. These hysteresis affects are significant when it comes to predicting the water quality conditions of the river bed at each of the study sites where the permeabilities are different.

The extensive amount of data logger data is being analyzed with the use of a custom database that is presently being constructed. Ultimately the database will allow us to query each site and examine these hysteric relationships in more detail. The database will also allow us to query other aspects of the data including how temperature of the riverbed changes in response to changes in river level.

Task c. Estimate potential redd densities at various seeding levels and compare to known values.

The purpose of this task is to compare the number of redds and redd densities from previous years' data sets to the percentage of available habitat used. In other words, we will compare the amount of habitat that is predicted to be used against the numbers of fish actually using this habitat. Preliminary analyses at the 9 study sites suggest that the simple variables of depth, velocity, substrate, and slope can predict most of the spawning habitat. However, just as in previous years, as much as 55 to 75% of the area that these data suggest should be used for spawning is not used, implying other features control where salmon spawn. This will be examined further in task d.

Task d. Extrapolate range of density values to other areas deemed suitable based on geomorphic features.

The purpose of this task is to estimate the potential production that could be possible if the densities observed in high escapement years were applied over areas where geomorphic features were suggestive of suitable salmon spawning habitat. The amount of useable habitat, based on limits analysis and geomorphic features, will be quantified. Redd densities (task c) will be used to calculate the total number of spawners that could utilize the Hanford Reach at various seeding densities.

Task e. Reporting.

This task will bring all of the previous tasks together into a final report. The report will likely consist of a series of chapters, with the different chapters forming manuscripts that will be submitted for publication.

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