EVALUATE THE RESTORATION POTENTIAL OF SNAKE RIVER
FALL CHINOOK SALMON SPAWNING HABITAT

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Status Report 2006

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Introduction

The Bonneville Power Administration (BPA) Project 2003-038-00, *Evaluate the restoration potential of Snake River fall Chinook salmon spawning habitat*, began in FY04 (15 December 2003) and continues into FY06. This status report is intended to summarize accomplishments during FY04 and FY05. Accomplishments are summarized by Work Elements, as detailed in the Statement of Work (see BPA's project management database PISCES).

This project evaluates the restoration potential of mainstem habitats for fall Chinook salmon. The studies address two research questions: "Are there sections not currently used by spawning fall Chinook salmon within the impounded lower Snake River that possess the physical characteristics for potentially suitable fall Chinook spawning habitat?" and "Can hydrosystem operations affecting these sections be adjusted such that the sections closely resemble the physical characteristics of current fall Chinook salmon spawning areas in similar physical settings?" Efforts are focused at two study sites: 1) the Ice Harbor Dam tailrace downstream to the Columbia River confluence, and 2) the Lower Granite Dam tailrace. Our previous studies indicated that these two areas have the highest potential for restoring Snake River fall Chinook salmon spawning habitat.

The study sites will be evaluated under existing structural configurations at the dams (i.e., without partial removal of a dam structure), and alternative operational scenarios (e.g., varying forebay/tailwater elevations). The areas studied represent tailwater habitat (i.e., riverine segments extending from a dam downstream to the backwater influence from the next dam downstream). We are using a reference site, indicative of current fall Chinook salmon spawning areas in tailwater habitat, against which to compare the physical characteristics of each study site. The reference site for tailwater habitats is the section extending downstream from the Wanapum Dam tailrace on the Columbia River. Escapement estimates for fall of 2000 indicate more than 9000 adult fall Chinook salmon returned to this area, accounting for more than 2100 redds within a 5 km section of river.

Progress by Work Element

Work Element A: Compile data at Columbia River Tailrace Site

Milestones: map spawning areas, collect physical data, model hydraulics

This Work Element is intended to quantify the physical characteristics that define suitable fall Chinook salmon spawning habitat at Wanapum Dam tailwater reference site. The studies make use of existing data at spawning areas and redd locations, as well as newly acquired data.

Spawning habitat will be evaluated from Wanapum Dam downstream to Crab Creek, which is the downstream extent of fall Chinook salmon spawning. The study area shoreline is characterized by arid shrub steppe ecotypes with low vegetative cover. Near-shore habitat throughout the study area consists of basalt bedrock formations, unconsolidated basalt, and unconsolidated cobble/gravel.

Spawning habitat suitability will be ranked within the project area using suitability indices. Predictions of spawning habitat suitability for the entire project area will be made by comparing characteristics of channel morphology and hydraulics to suitability criteria from redds in the Wanapum tailrace. Characterization of channel morphology and hydraulic modeling required that a three-dimensional surface of channel bed elevations (bathymetry) be created. Suitability criteria were based on empirical and modeled measurements of depth, substrate, velocity, and

channel bed slope of fall Chinook salmon redds from the Wanapum tailrace. A hydraulic model was used to predict how habitat suitability changed with discharge. For the modeling, the suitability indices of individual characteristics were combined into one composite index to assess relative habitat quality for the entire project area.

Bathymetry

The development of a bathymetry data set for the Wanapum tailrace (Priest Rapids pool) involved the compilation of new and existing data. The following datasets were acquired and processed into the final bathymetric data set.

Data was acquired from a Light Detection And Ranging (LiDAR) data collection effort that was performed in 2002 and encompassed the full pool length of Priest Rapids, extending from RM 397.0 – 415.8. Data was provided by the LiDAR contractor (3Di, Inc.) in an ASCII text file format and was extracted and processed into a vector GIS format using a specially developed UNIX Bourne shell script. The data has a ground spacing (resolution) of approximately 4-meters. LiDAR data was used to build out-shore terrestrial areas (including in-stream islands) in the bathymetric dataset.

USGS Digital Elevation Models (DEM) were processed into vector spot elevations at a 10-meter resolution. DEM was assembled and additional processing was performed to seam mosaic gaps and filter out data anomalies. This dataset was primarily minimally used to fill outer boundary areas not covered with the LiDAR dataset.

Bathymetry data originally collected by Sverdrup for other forebay/tailrace studies was acquired and incorporated into the data processing. The data was provided in the form of spot elevations and contour data. Data is primarily concentrated at the Priest Rapids Dam tailrace and Wanapum Dam's forebay and tailrace. Approximate resolution of the dataset is 1-2 meters.

PNNL collected bathymetry data in the form of vector spot elevations to fill in areas with little or no existing data in the Priest Rapids pool. Data was collected using an Innerspace 455 single-beam, survey-grade, echo sounder with an 8-degree transducer, operating at 208 KHz, and a manufacturer's stated vertical accuracy of 3.05 cm. The echo-sounder was coupled and synced with a real-time differentially corrected sub-meter GPS (Trimble ProXR) providing horizontal positioning and depth values. Vertical positioning was established using piezometers positioned throughout the Priest Rapids pool. The piezometers were surveyed in to allow for the measurement of an accurate water surface elevation and logger results were extrapolated by time and space to establish a true pool bottom elevation.

All bathymetric source data used for the Priest Rapids pool is summarized in Table 1 and attributed with data source and time of publishing or data gathering, respectively. All surveys were collected and/or processed into the following the projections and datums:

- Projection: Washington Stateplane, South Zone 5626
- Horizontal Units: Feet
- Vertical Units: Feet
- Horizontal Datum: North American Datum of 1927 (NAD27)
- Vertical Datum: National Geodetic Vertical Datum of 1929 (NGVD29) Spheroid: Clarke 1866

Table 1. Bathymetry data sources for the Wanapum Dam tailrace

Name	Data Source	Year
LiDAR	3Di, Inc	2002
USGS Digital Elevation Models	USGS	2001
Sverdrup bathymetry data	Parametrix	N/A
PNNL Survey	PNNL	2001

Data were processed primarily using a Geographic Information System (GIS) software package, Arc/INFO v. 8.1.2, from Environmental Systems Research Institute, Inc. (ESRI). As indicated prior, LiDAR data was pre-processed using a customized data extraction script and then incorporated into the GIS. The various data sources were brought into a common projection and horizontal/vertical datum before surface generation was performed. Prior to surface processing, raw data set elevations were compared for a measure of quality control. Vector elevation data was then compiled into a three-dimensional surface using a Triangulated Irregular Network (TIN) methodology. Several iterations of this processing were performed to eliminate data anomalies. The final TIN was converted into a regularly-spaced raster using a nearest-neighbor type interpolation. The output resolution of the dataset is 10x10 feet. Color-shaded relief maps of the final bathymetry surfaces are presented in a series of plates in Figures 1 and 2. This surface was used to create the MASS2 computational mesh and bathymetric input data.

Hydrodynamic model

Depth-averaged water velocities downstream of the Wanapum, Ice Harbor, and Lower Granite Dams were simulated using the hydrodynamic and water quality model MASS2 (Modular Aquatic Simulation System 2-D). MASS2 is an unsteady, two-dimensional, model that simulates hydrodynamics and water quality in rivers and estuaries for subcritical and supercritical flow regimes (Perkins and Richmond, 2004b and 2004c). The model uses a structured multi-block, boundary-fitted, curvilinear computational mesh to represent the river geometry. The blocks may be of varying resolution that allows the simulation of complex river or estuary systems. Finite-volume methods (Patankar, 1980) are used to discretize and solve the conservation equations for mass, momentum, and water quality constituents. The model is computationally efficient; it has been used to simulate flow conditions over long reaches (10 to 75 miles) at high spatial resolution (cells sizes are typically 15 to 150 feet) and high temporal resolution (on the order of 30 seconds).

MASS2 has been used in several applications on the Columbia and Snake River systems. These studies include simulating dissolved gas transport and water temperature (Richmond, et al 1999 and 2000), time-varying salmon physical habitat and stranding caused by discharge fluctuations (Perkins, et al 2004), and radionuclide transport (Kincaid, et al 2000).

Gridgen was used to develop the computational mesh for each study reach. Bottom elevations for each mesh cell were determined from continuous, three-dimensional, raster-based bathymetric surfaces for each reach. The computational mesh extends from Wanapum Dam, the upstream inflow boundary, to Priest Rapids Dam, where the downstream stage boundary is specified (Figure 3). The mesh contains 18 blocks with a total of 96,512 cells. The computational mesh covered an area of 15,971 acres. The lateral resolution ranged from 10 to

715 ft and averaged 38 ft. The longitudinal resolution ranged from 13 to 564 ft and averaged 56 ft. Smaller mesh cells (average size of 26x26 ft) represent these regions of interest while areas downstream of Crab Creek are represented by larger grid cells (Figure 4). A detailed view of the mesh at the upstream Wanapum Dam boundary is shown in Figure 5. The variable mesh size increases computational efficiency by using increased resolution only in areas of interest.

The input boundary conditions required for MASS2 are river discharge at the upstream boundary and water surface elevation (stage) at the downstream boundary. Hourly discharges from Wanapum Dam and hourly forebay elevations from Priest Rapids Dam (North Pacific Water Management Division, Northwestern Division, U.S. Army Corps of Engineers, see www.nwd-wc.usace.army.mil) were obtained for October 2000. These data were used to calculate the 10, 50, and 90 percent exceedence values for discharge and forebay elevation during October 2000 (Table 2). These values were used to specify the upstream inflow and downstream water elevation for the MASS2 model of Wanapum tailrace.

Table 2. Columbia River spawning season scenarios used for upstream (inflow) and downstream (stage) boundary conditions for the MASS2 model of the Wanapum tailrace. Exceedence is the percent of time a particular discharge is equal to or greater than the specified value.

Boundary Condition	Exceedence		
	10%	50%	90%
Wanapum Inflow (cfs)	120,600	75,000	38,500
Priest Rapids forebay elevation (ft)	487	486	484.4

The Wanapum tailrace was a new application of MASS2 and model results were validated by comparing simulated depth-averaged velocity, both magnitude and direction, with observations. The locations of the acoustic Doppler current profiler (ADCP) measurements are shown in Figure 6. The velocity bins in the vertical were depth-averaged to compute a value that can be compared to the simulated depth-averaged velocity. Figure 7 shows the depth-averaged velocity simulated by MASS2 compared to the depth-averaged ADCP velocities. The simulated depth-averaged velocity magnitude and directions are in reasonable agreement with the measurements. Figure 8 shows a comparison of the simulated and measured velocity magnitudes. The mean absolute error is 0.62 ft/sec. The Manning's n values chosen from the model validation process are summarized in Table 3.

Table 3. Values of Manning's n used in each modeled reach.

River Reach	Manning's n value
Wanapum	0.026
Ice Harbor	0.027
Lower Granite	0.027

After the model was validated, steady-state simulations were run for the conditions specified in the "Boundary Conditions" section. Simulations provided water velocities and depths at a resolution corresponding to the computational mesh. MASS2 simulation results for the

Wanapum, Lower Granite, and Ice Harbor reaches were exported as Arc/Info grids of the following computed variables:

- depth (feet)
- water surface elevation (wsel, feet)
- velocity magnitude (vmag, feet/second)
- froude number
- bottom shear stress (shear, lbf/ft²)

One of the flow scenarios for the Wanapum tailrace corresponded to the conditions of a set of orthophotos. The MASS2 solution and the photo are shown side by side in Figure 9. Note that the simulated shorelines are very similar to those of the photo, especially for the island areas.

Substrate

Grainsize distribution was determined using Wolman pebble counts in areas that were shallow enough to wade in, and using an underwater video camera in areas that were too deep to wade in. Pebble counts were distributed evenly and points selected at random from within the selected polygon. A distance of approximately 30 meters between points was used. Points were collected below the high water mark, and marked with a Trimble ProXR GPS. Pebble count sample locations were determined randomly using a consistent selection method. The exact location of each grain was always the same relative to the observer, for example the first grain encountered in front of the observer's left boot. If the observer reached down to that point and contacted 2 grains, the grain on the left would be used each time, and so forth. After a grain was selected, the size class was determined using a metal template with holes representing ½ phi size classes. We recorded the largest size class for which the grain would not pass through the template.

The underwater video system consists of a high-sensitivity remote camera (Sony, model HVM-352) attached to a weighted platform. Recordings were made using a digital 8-mm recorder (Sony model GV-D800) located on the survey vessel. Two high-resolution monitors were used during the surveys for better viewing of the video obtained by the remote camera. An integrated video/tow cable attached to a manual winch with slip ring mechanism was used to raise and lower the camera sled to the desired depth. The camera was mounted on a diving sled platform containing two downward-pointing lasers, providing reference scale within each video image. Positional data were recorded using a Trimble ProXRS DGPS (real-time differentially corrected) receiver controlled with Trimble Aspen or TerraSync. From each location where video images were recorded to determine the riverbed grainsize, underwater video tapes were reviewed and one grain randomly selected for analysis. The random selection process followed arbitrary rules similar to the process of selecting a grain for a pebble count (i.e., if the reference laser falls between two grains always select the one from the same side, etc.). The intermediate (B) axis of each grain was measured using Optimus software to determine its length.

Ten equal area polygons were established to define the reference study site in the Wanapum Dam tailrace area (Figure 10). Within the polygon coverage an evenly distributed, 10m spacing point coverage was created to assist with data collection. The point coverage was loaded into Aspen and used as a navigational reference to collect each data point.

Several indices of substrate composition provide means of evaluating the quality of spawning gravels. The geometric mean (d_g) provides a measure of central tendency, while emphasizing

the extremes of the distribution rather than the median (Kondolf 2000). The geometric mean (d_g) is determined by:

$$d_g = (d_{84} \times d_{16})^{0.5}$$

The symbols d_{84} and d_{16} represent the grain size (mm) at which 84 and 16% of the sampled grains were finer than. The geometric sorting coefficient (s_g) is an indication of the sorting (or grouping) of similarly sized particles (Kondolf 2000). When particles of all sizes are well mixed together (also known as dispersion), s_g values increase. Conversely, when particles of the same size are grouped together (i.e., a deposit is well-sorted by particle size classes), s_g values decrease. The geometric sorting coefficient is determined by:

$$s_g = (d_{84} / d_{16})^{0.5}$$

The Fredle index (F_i) combines central tendency (d_g) with a different sorting coefficient (s_t). The Fredle sorting coefficient (s_t) is similar to s_g , except uses d_{25} and d_{75} instead of d_{16} and d_{84} . The Fredle index is a concise measure of d_g and s_g , is common in the literature (Kondolf 2000), and is thus a useful tool for comparing results to the literature. The Fredle index is determined by:

$$F_i = d_g / s_t = [(d_{84} \times d_{16})^{0.5}] / [(d_{75}/d_{25})^{0.5}]$$

A total of 4,974 underwater video substrate images were processed for the Wanapum Dam tailrace study area. For each point where an image was processed, a grainsize was determined and entered into a GIS (Figure 11). Grainsize sorting indices (e.g., d_g , S_g , and F_i), typically used to summarize grainsize distribution results, have not yet been computed for the reference location.

Channel morphology

The MASS2 model output was imported into a GIS database for analysis of hydraulic geometry at closely spaced cross-sections. Model results were extracted from 85 cross-sections spaced 50 – 100 m apart throughout the study area. At each cross-section the model results were used to calculate the top width, mean depth, and depth at individual stations spaced 3 m apart along a cross-section. These data were used to calculate the width to mean depth ratio F (an index of channel shape) and the maximum depth to mean depth ratio d^* (an index of cross-section asymmetry) for each cross-section. When considered simultaneously, these two indices summarize a continuum of cross-sectional channel form that ranges from narrow and deep triangular channels to wide and shallow rectangular channels (Figure 12). In order to categorize each cross-section within this continuum, we assigned each cross-section into one of four categories based on the combined F and d^* values (Table 4).

Table 4. Criteria for categorizing cross-sections based on F and d^* .

Fd^* Category	Definition	Description
1	$F \geq 100$ and $d^* \geq 2.0$	Cross section is typically asymmetrical, wide, with part shallow bar deepening into a v-shaped deep thalweg
2	$F \geq 100$ and $d^* < 2.0$	Cross section is symmetrical, wide,

3	$F < 100$ and $d^* \geq 2.0$	and with relatively uniform shallow depths Cross section is asymmetrical, narrow, with part shallow bar deepening into a v-shaped thalweg
4	$F < 100$ and $d^* < 2.0$	Cross section is symmetrical, narrow, and relatively uniformly deep

A quantitative analysis of the longitudinal bed form profile was completed using sequential bed elevation data from the thalweg of the river. Thalweg points (x-coordinate, y-coordinate, z-elevation) spaced no more than 50 m apart were imported into the GIS database from the bathymetry. The thalweg points were used in a bed form differencing technique to identify pools and riffles. The technique involves differencing successive bed elevations in a downstream direction, and then calculating the standard deviation of the resulting difference values. The standard deviation of bed elevation differences is used to set a threshold value that filters out small-scale bed undulations from large-scale pool-riffle bed forms. In this study, the threshold value was set at 2.5 times the standard deviation of bed elevation differences. Application of the technique resulted in thalweg points identified as riffle crests and pool bottoms. All other thalweg points were determined to be in riffles or pools based on their riffle proximity index (RPI)

$$RPI = 1 - \frac{rcelev - tpelev}{rcelev - pbelev}$$

where $rcelev$ = riffle crest elevation, $tpelev$ = thalweg point elevation, and $pbelev$ = pool bottom elevation. The RPI ranges from 0.0 to 1.0, where thalweg points with a RPI > 0.50 categorized as being in riffles, while the remaining points categorized as being in pools. Following this identification, all other thalweg points were categorized as being located in one of four areas along the longitudinal profile: on the upstream (1) or downstream (2) side of riffle crests and the upstream (3) or downstream (4) side of pool bottoms.

Fall Chinook salmon spawning locations were incorporated into the GIS database for an analysis of their spatial relationship with bed form types. GIS overlay techniques were used to code all cross-sections and thalweg points as spawning or non-spawning depending on their proximity to the observed spawning locations. Cross-tabulation tables and Pearson's Chi-square (χ^2) test statistic were used to test the null hypothesis that spawning habitat use was independent of bed form category ($\alpha=0.05$). Welch's t-test for unbalanced sample sizes and separate variances was used to test the null hypothesis that thalweg points in spawning and non-spawning areas had the same mean RPI ($\alpha=0.05$). The analyses of these data are ongoing, and not yet finalized.

Fall Chinook Salmon Spawning Habitat

The results from each MASS2 model run were imported into the 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 of individual "habitat cells" (Payne and Lapointe 1997) 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. The resulting surfaces for depth and velocity had cell sizes of 9 m² (3 m by 3 m) and were used to estimate potential spawning habitat. A habitat cell size of 3 m was chosen to estimate hydraulic conditions at a fine scale relative to channel size (mean widths ~300 to

800 m), particularly near the shorelines. Each habitat cell (i.e., 9 m²) was assumed to represent depth and velocity conditions of a hydraulically uniform area of river.

Once the physical channel characteristics were assessed and the hydraulic modeling was completed, spawning habitat suitability was assessed by comparing suitability criteria developed from characteristics of habitat cells in spawning areas to the entire population of habitat cells that were available for spawning. Habitat suitability criteria were formulated using a combination of empirical measurements of habitat use based on substrate, slope, depth and velocity at the location of individual redds and modeled data (Table 5). As previously described, depth and velocity values were modeled for each habitat cell for all nine model scenarios and pooled for analyses. Channel bed slopes were calculated for all habitat cells as described above. Available substrate was determined using empirical measurements made at geomorphic units within the entire study area. Substrate summary statistics based on the distribution within each geomorphic unit were used to categorize individual geomorphic units as “suitable” or “not suitable.” A unit (and consequently a habitat cell within that unit) was categorized as suitable for substrate if

1. The dg, d84, and d75 values (i.e., grain size in millimeters) were within the criteria defining the size range of suitable fall chinook spawning substrate (Table 5)
2. The unit lacked an appreciable amount of fine sediment as indicated by strongly negatively skewed grain-size distributions (Kondolf and Wolman 1993; Kondolf 2000).

Once depth, velocity, substrate, and slope were assigned to each habitat cell, the cell was classified as either suitable or not suitable for fall chinook spawning habitat (i.e., a binary classification). To be suitable, all of the characteristics of habitat cells had to fall within the criteria range (Table 5).

Table 5. Criteria defining suitable fall Chinook salmon spawning habitat. Criteria were based on empirical data measured at individual redds, as well as modeled hydraulic data within habitat cells that contained at least one fall Chinook redd.

Variable	Values
Depth	0.30 – 11.50 m
Velocity	0.10 – 2.25 m·s ⁻¹
Substrate	20 – 270 mm
Channel bed slope	0.0 – 7.0 %

Suitable habitat was further classified for quality by assigning habitat suitability index (SI) values (weights) to each cell of suitable spawning habitat, thereby partitioning the suitable habitat into categories ranging from low to high quality. Habitat modeling with suitability curves typically requires the use of suitability criteria originating within the river of interest (Bovee 1995). We developed our depth, velocity, and channel bed slope SI curves based on data from the Wanapum tailrace using the modeled data and measured data from redds. We completed a frequency analysis with the depth, velocity, and slope data, resulting in probability-of-use values (SI curves) for a range of hydraulic conditions (Bovee and Cochnauer 1977; Bovee 1995). The SI curves represented weighted criteria, where a value of 1.0 indicated the optimum condition for a given hydraulic variable (Figure 13). Because the measured data from redds were biased towards the extremes of the depth and velocity distributions, the SI curves were adjusted at the

lower and upper ends to eliminate any artificial bi-modal distributions. The SI curves were adjusted through range and optimum analysis (Bovee and Cochnauer 1977); however, the depth and velocity values were always assigned an SI value $\leq$ the nearest value from the original SI curve.

The habitat suitability modeling proceeded by assigning SI values to the habitat cells based on depth, velocity, and channel bed slope for each discharge scenario; the substrate values were assigned SI values of either 1.0 or 0.0 based on the values in Table 5, and included in the calculation of the composite SI (CI) for the study area. The CI was calculated as the geometric mean of the input variables:

$$CI = (SI_1 \times SI_2 \times \dots \times SI_n)^{1/n}$$

where SI_n is the suitability index value for variable n , and n is the number of input variables. Calculating the CI based on geometric mean allows for compensatory relationships among variables but not as much as the arithmetic mean (USFWS 1981). For example, if one variable's SI value is 0.0, the geometric mean will calculate the CI as 0, meaning that if one variable is outside the range of suitable criteria the other variables cannot compensate for it. The resulting CI for each discharge scenario represents the weighted suitability of the study area, where a value of 1.0 indicates optimum potential fall chinook spawning habitat.

Work Element B: Compile data at Snake River Tailrace Sites

Milestones: compile spawning area data, collect physical data, model hydraulics

This Work Element is intended to quantify the physical characteristics that define suitable fall Chinook salmon spawning habitat at Ice Harbor Dam and Lower Granite Dam tailwater sites. The studies make use of existing data, as well as newly acquired data.

Bathymetry

A continuous three-dimensional, raster-based bathymetric data set was required to develop the computational mesh used by the MASS2 hydrodynamic model and to describe the physical habitat characteristics for each reach in the study. A new hydrographic survey was conducted at the tailraces of Ice Harbor and Lower Granite dams to supplement existing bathymetric data that were used in previous hydrodynamic models (Richmond, et al 1999) of these reaches.

Bathymetric data was collected using an Innerspace 455 single-beam, survey-grade, echo sounder with an 8-degree transducer, operating at 208 KHz, and a manufacturer's stated vertical accuracy of 3.05 cm. Positioning and depth data was collected and saved on a rate of one measurement per second. Horizontal and vertical position of the echo sounder was derived using a Trimble 5800 Real-Time Kinematic Global Positioning System (RTK-GPS) providing the most efficient and accurate data possible for the survey. The horizontal and vertical accuracy of the RTK-GPS was calculated to be less than 4 cm and was verified using other known and published benchmarks from the Washington Department of Transportation, U.S. Army Corps of Engineers, and the National Geodetic Survey. The RTK-GPS antenna and integrated receiver was mounted on a fixed-length survey pole above the echo sounder transducer. In order to calculate a true bottom elevation, the echo-sounder reported depth and survey pole length were

subtracted on-the-fly from the synced RTK-GPS elevations. Figure 14 illustrates the general hardware setup utilized for the hydrographic survey.

The hydrographic survey was conducted in the tailrace areas of Ice Harbor Dam on February 2-4, 2005 and extends from RM 2.4 (Highway 12 bridge) to RM 8.6. The surveys for the Lower Granite Dam tailrace were conducted on February 7-9, 2005 and extend from RM 99.8 – 106.3.

For the Ice Harbor Dam tailrace, the RTK-GPS base station was set at the National Geodetic Survey (NGS) benchmark “SA2465” which is located on the deck of the dam. This is a horizontal order “A” and vertical order “3” benchmark with a relative horizontal accuracy 5 mm and a relative vertical accuracy of 3 mm. The RTK-GPS base station was verified with Washington State Department of Transportation benchmark “Sacajawea 2 / Monument ID 30”, located at the northeast side of the Snake River Highway 12 Bridge.

For the Lower Granite Dam survey, NGS benchmark “RZ1892”, located on the deck of the dam (see Figure 15), was used as a base station for Lower Granite Dam tailrace hydrographic survey. This benchmark is a part of the High Accuracy Reference Network (HARN) and is published as a horizontal order “B” and vertical order “3” benchmark with a relative horizontal accuracy of 8 mm and a relative vertical accuracy of 3 mm. The base station was verified with the U.S. Army Corps of Engineers reference mark “39+52.98” also located on the dam platform. A new benchmark was established upstream of the Almota port and was verified back to the original reference benchmarks.

All surveys were collected in the following the projection and datums:

- Projection: Stateplane Washington South, Zone 4602
- Horizontal Units: Meters
- Vertical Units: Meters
- Horizontal Datum: North American Datum of 1983 (NAD83)
- Vertical Datum: North American Vertical Datum of 1988 (NAVD88)
- Spheroid: Geodetic Reference System, 1980 (GRS80)

As a verification of the elevation data collected with the RTK-GPS / echo-sounder system, three pressure sensors were deployed and surveyed-in at the upstream, middle and downstream location of each survey area to track possible water level changes. These data were then used independently without the RTK-GPS vertical data to determine a bottom elevation. The pattern to collect the bathymetric data was performed in lateral transects (perpendicular to flow direction) which were pre-planned using ArcGIS software with digital orthophotography and existing bathymetry data. In the field, the pre-planned transects were loaded and viewed in real-time using Trimble’s HydroPro navigation and data collection software. The distance between transects was 51.8 m (170 ft) and 305 m (1000 ft) in alternating orders at the Ice Harbor Dam tailrace, and 51.8 m at the Lower Granite Dam tailrace. The varying transect widths were determined by using existing bathymetric data allowing for the collection of data where none currently existed. In order to test for the data quality of our hydrographic survey, all existing bathymetric data was overlapped with the current survey and was later tested for mean differences (determined to be no greater than 20 cm in both tailraces). There were a total of 187 transects collected at Lower Granite Dam tailrace and 149 transects at Ice Harbor Dam. Tables 6 and 7 reference source data and dates of collection for both Ice Harbor and Lower Granite tailraces. Figures 16 and 17 depict all surveys used for the development of the bathymetry, including the PNNL 2005 survey.

Table 6. Bathymetry data downstream from Ice Harbor Dam.

Name	Data Source	Year
Ice Harbor Tailrace Survey	USACE Walla Walla	1993
Port Survey	USACE Walla Walla	1995
Sediment Range Survey	USACE Walla Walla	1997
Navigation Channel Survey	USACE Walla Walla	2002
PNNL Survey	PNNL	2005

Table 7. Bathymetry data downstream from Lower Granite Dam.

Name	Data Source	Year
Sediment Range Survey	USACE Walla Walla	1987
Navigation Channel Survey	USACE Walla Walla	1992
Lower Granite Tailrace Survey	USACE Walla Walla	2003
PNNL Survey	PNNL	2005

The bathymetric data for the 2005 fieldwork was mainly processed using Golden Software's Surfer and ESRI's ArcGIS 9.x software. The 2005 data set was divided into sections with similar flow orientations and was processed using an anisotropic kriging technique, which generates a stream-wise surface grid from an irregular set of point data. This procedure ultimately provided a set of contour lines that would then be used generate a raster-based bathymetric surface. The use of anisotropic kriging has been found to minimize typical sinkhole and hillock effects that are commonly found when processing transect data, often leaving regions between data points with a higher elevations than actually observed (e.g. bullseye effect) or other miscellaneous data interpolation anomalies. Each stream section that was processed was verified for conformity with adjacent sections and if necessary, suspect data points were eliminated and data were reprocessed. The individual stream-sections were assembled into the two tailrace reaches, and a final surface with a resolution of 1.52 x 1.52 m (5 x 5 ft) was created using an Inverse Distance Weighting (IDW) technique which combined the anisotropic kriging-generated contour lines, survey point data, other available sources of bathymetry, and USGS 10-meter Digital Elevation Models (DEM) to represent the surrounding terrestrial topography of the two tailrace areas. IDW is an interpolation technique that estimates cell values in the raster that have been weighted so that the farther a point is from the cell being evaluated, the less important it is in calculating the cell's value. The final bathymetric surface grids were used for the hydrodynamic model MASS2. Figures 18 and 19 show the resulting bathymetric maps of Ice Harbor Dam and Lower Granite Dam tailrace surveys.

Hydrodynamic model

Depth-averaged water velocities downstream of Ice Harbor and Lower Granite Dams were simulated using the hydrodynamic and water quality model MASS2 (Modular Aquatic Simulation System 2-D) described above. The Ice Harbor and Lower Granite Dam tailrace reaches were

subsections of existing MASS2 models that originally encompassed larger river reaches that were configured and validated for the U.S. Army Corps of Engineers (USACE) Dissolved Gas Abatement Study (DGAS) study (Richmond et al, 1999). These existing model configurations were used as the starting point for this work.

Gridgen was used to develop the computational mesh for each study reach. Bottom elevations for each mesh cell were determined from continuous, three-dimensional, raster-based bathymetric surfaces for each reach. The Ice Harbor tailrace model extended from Ice Harbor Dam downstream to just upstream of the confluence with the Columbia River and consisted of 104,837 cells covering an area of 1516 acres. The lateral resolution ranged from 3 to 53 ft and averaged 29 ft. The longitudinal resolution ranged from 11 to 49 ft and averaged 25 ft. The Lower Granite tailrace model covered the area from Lower Granite Dam downstream to Snake River Mile 100 using a mesh with 74,955 cells covering an area of 2080 acres. The lateral resolution ranged from 10 to 79 ft and averaged 26 ft. The longitudinal resolution ranged from 16 to 65 ft and averaged 34 ft.

The input boundary conditions required for MASS2 are river discharge at the upstream boundary and water surface elevation (stage) at the downstream boundary.

Inflow discharges for the Snake River MASS2 simulations of the Ice Harbor and Lower Granite tailraces were determined using 1975 to 2004 operations records at Ice Harbor and Lower Granite (North Pacific Water Management Division, Northwestern Division, U.S. Army Corps of Engineers, see www.nwd-wc.usace.army.mil). Review of the data revealed that there were several years where the Lower Granite annual average discharge was higher than at Ice Harbor. Therefore, only the Ice Harbor discharge data were used in the subsequent analysis.

A wet or dry water year does not necessarily mean a corresponding wet or dry spawning season occurred in that year. To better represent the range of flow conditions, the annual records were ranked based on the average discharge during the spawning season. Ranking the data in this manner yielded the following classification: 2002 (dry), 1990 (normal), and 1984 (wet). For each of these types of spawning seasons a discharge that was exceeded 10, 50, and 90% of the time was computed (Table 8). These discharges were used as inflow conditions to both tailraces.

Table 8. Snake river spawning season discharges (cfs) used as upstream inflow conditions to the MASS2 models of the Lower Granite and Ice Harbor tailraces. Exceedence is the percent of time a particular discharge is equal to or greater than the specified value.

Type of Spawning Season	Exceedence		
	10%	50%	90%
Wet	52,000	44,000	34,500
Normal	34,500	21,700	19,100
Dry	18,200	15,300	12,600

The MASS2 models of the Lower Granite and Ice Harbor tailraces covered a reach that did not extend downstream to the forebay of the next Snake River dam. The required downstream stage was supplied by the one-dimensional MASS1 model previously applied to these sections of the river (Richmond, et al 2000). MASS1 simulations used the upstream discharges specified in Table 8 and the forebay elevations shown in Table 9. The computed stage at the appropriate

locations were extracted and used as downstream boundary conditions for the MASS2 simulations.

Table 9. Forebay elevations used in the MASS1 simulations to determine the downstream water surface elevation to be used in the MASS2 simulations.

Dam	Normal Forebay Elev. (ft)	Minimum Operating Elev. (ft)
Little Goose	638.0	633.0
McNary	340.0	335.0

In the Ice Harbor and Lower Granite tailraces, previous MASS2 validation simulations documented in Richmond, et al (1999) show that the model accurately represents the spatial and temporal distributions of the simulated quantities. Water surface elevations and velocities compared favorably with measured tailwater elevations at both dams and velocities measured using an acoustic Doppler current profiler (ADCP).

After the model was validated, steady-state simulations were run for the conditions specified. Simulations provided water velocities and depths at a resolution corresponding to the computational mesh. MASS2 simulation results for the Wanapum, Lower Granite, and Ice Harbor reaches were exported as Arc/Info grids of the following computed variables:

- depth (feet)
- water surface elevation (wsel, feet)
- velocity magnitude (vmag, feet/second)
- froude number
- bottom shear stress (shear, lbf/ft²)

Figures 20 and 21 show examples of the simulated distribution of velocity magnitude for the Ice Harbor and Lower Granite tailraces, respectively. The operating conditions correspond to a normal spawning year with a 50% discharge exceedance. The downstream stage elevation is for normal pool elevation at this particular discharge.

Substrate

Substrate sampling in the Ice Harbor and Lower Granite dam tailraces was completed using the same methods described above. In the Lower Granite and Ice Harbor tailrace areas, previous modeling results were used to select sampling locations that could not be ruled out as potentially suitable habitat based on depth or velocity. Riverbed bathymetry was then used to create polygons that represented distinct geomorphic features within the channel (i.e., a lateral bar). Nine polygons were established using a 35 m suggested point spacing (Figure 22).

A total of 2,178 underwater video images were processed to produce grainsize data collected from the Lower Granite and Ice Harbor Tailraces (Figure 23). In addition, 193 grains were measured using pebble counts in the Ice Harbor tailrace to augment underwater video data in shallow locations (Figure 23).

The geometric mean (dg), geometric sorting coefficient (Sg) and the Fredle index (Fi) were determined for Lower Granite and Ice Harbor tailrace grainsize samples and are summarized in Table 10.

Table 10. Indices of substrate composition have been computed to evaluate Lower Granite and Ice Harbor tailrace grainsize distributions.

	Polygon 1	Polygon 2	Polygon 3	Polygon 4	Polygon 5	Polygon 6	Polygon 7	Polygon 8	Polygon 9
d₁₀	2.0	2.0	2.0	2.2	2.0	2.0	2.0	2.0	2.0
d₁₆	2.0	2.0	2.0	2.9	2.0	2.0	2.5	2.0	2.0
d₂₅	3.0	2.2	2.0	4.0	2.0	2.0	3.8	2.9	2.7
d₅₀	6.8	5.4	4.8	8.7	4.8	2.0	7.2	5.6	5.3
d₇₅	12.6	8.0	7.6	10.7	7.5	2.0	19.0	9.6	9.0
d₈₄	18.2	9.5	9.0	11.5	9.0	2.0	33.1	15.6	12.1
d₉₀	23.6	10.5	10.1	13.2	10.3	2.0	62.0	43.4	20.3
d_g	6.03	4.36	4.24	5.77	4.24	2.00	9.10	5.59	4.92
s_g	3.02	2.18	2.12	1.99	2.12	1.00	3.64	2.79	2.46
f_i	2.94	2.29	2.18	3.53	2.19	2.00	4.07	3.07	2.69

Channel Morphology

The MASS2 model output will be imported into a GIS database for analysis of hydraulic geometry at closely spaced cross-sections. Model results will be extracted from 133 cross-sections spaced 50 – 100 m apart throughout the Ice Harbor Dam tailrace and 161 cross-sections spaced 50 – 100m apart throughout the Lower Granite Dam tailrace. The same methods described above will be used to quantify the channel morphology at the Snake River tailrace sites.

Work Element C: Interpret data at Snake River Tailrace Sites

Milestones: modeled fall Chinook salmon spawning habitat suitability

Work has been initiated toward quantifying the physical characteristics describing fall Chinook salmon spawning habitat suitability at the Snake River tailrace sites. We are using the habitat suitability and channel morphology findings from the Wanapum Dam tailrace reference site (Work Element A) as a template describing fall Chinook salmon spawning habitat. We are quantifying the physical characteristics at the Ice Harbor and Lower Granite tailrace sites under a range of hydrosystem operational scenarios. The MASS2 model results for 9 operational scenarios from Work Element B are being used for this analysis.

Work Element D: Compare data at Columbia and Snake River Tailrace Sites

Milestones: analyze and compare reference and study site characteristics

Work has been initiated toward determining if changes in hydrosystem operations cause physical characteristics at the study sites to resemble those at reference sites. This involves comparing the physical processes measured and modeled at the reference site with physical processes modeled and measured at the study sites.

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Figures

Figure 1. Processed bathymetry for the Wanapum Dam tailrace.

Figure 2. Processed bathymetry for the Wanapum Dam tailrace.

Figure 3. The extent of the MASS2 computational mesh for the Wanapum Reach. The mesh extends from Wanapum Dam to Priest Rapids Dam. Computational block boundaries are shown by separate colors.

Figure 4. The specific area of interest for this study is downstream of Wanapum Dam and upstream of Crab Creek. In this area, the computational mesh has 125 cells distributed across the channel.

Figure 5. A detailed view of the MASS2 computational mesh near Wanapum Dam. Side-attaching computational blocks are used to input inflows from the Powerhouse.

Figure 6. Locations where ADCP measured velocities were sampled downstream of Wanapum Dam.

Figure 7. Comparison of simulated and depth-averaged measured velocities in the Wanapum tailrace. The color shades correspond to the bottom elevation of the channel.

Comparison of Simulated and Measured Velocity Magnitude

Figure 8. Simulated versus depth-averaged measured velocities in the Wanapum tailrace. The mean absolute error of the measured and simulated velocities is 0.62 ft/sec.

Figure 9. Comparison of an orthophoto of the Wanapum tailrace (left) to the simulated flow distribution at 75,000 cfs (right). Note the close correspondence between the actual and simulated shorelines. Wanapum Dam is located in the upper left corner of the orthophoto.

Figure 10. The reference study area in the Wanapum Dam tailrace is shown broken into ten polygons (bound by blue lines), with suggested sampling points within them (black tick marks). Known fall Chinook spawning locations are outlined in green.

Figure 11. Grainsize distribution results for the Wanapum Tailrace reference location. 4,974 points were recorded, analyzed, and color coded by their intermediate (B) axis length (cm).

Figure 12. The continuum of cross-sectional channel form based on the combination of width to mean depth ratio F and maximum depth to mean depth ratio d^* . These cross-section plots of bed elevation (solid line) and water surface elevation (dashed line) at a total discharge of $5094 \text{ m}^3 \text{ s}^{-1}$, represent the extremes of the F and d^* values for the sampled cross-sections. All cross-sections are plotted at the same scale. The vertical exaggeration is 40x.

Figure 13. Velocity and depth suitability curves for fall Chinook salmon spawning habitat in the Wanapum tailrace. Suitability curves were based on modeled (n = 47,227 cells) and empirical observations (n = 62 redds).

Bathymetry Collection

Figure 14. The bathymetry collection process utilizes an integrated group of components to enable real-time data collection and navigation.

Figure 15. GPS base station setup on the NGS benchmark “RZ1892” located at Lower Granite Dam.

Figure 16. Collective bathymetry survey data for the Ice Harbor Dam tailrace

Figure 17. Collective bathymetry survey data for the Lower Granite Dam tailrace

Figure 18. Processed bathymetry data for the Ice Harbor Dam tailrace

Figure 19. Processed bathymetry data for the Lower Granite Dam tailrace

Figure 20. Simulated depth-averaged velocity magnitude (ft/sec) in the Ice Harbor tailrace. Flow conditions are for the 50% discharge exceedance in a normal year and a normal downstream pool elevation. Ice Harbor Dam is located at the right side of the figure.

Figure 21. Simulated depth-averaged velocity magnitude (ft/sec) in the Lower Granite tailrace. Flow conditions are for the 50% discharge exceedance in a normal year and a normal downstream pool elevation. Lower Granite Dam is located at the right side of the figure.

Figure 22. Study areas in the Lower Granite tailrace (polygons 1-6) and Ice Harbor tailrace (7-9) were sampled using a suggested interval of 35 m. Sampling polygons are bound by blue lines, and suggested sampling points within them are black tick marks.

Figure 23. Grainsize distribution results for the Lower Granite and Ice Harbor Tailrace locations. 2,371 points were recorded, analyzed, and color coded by their intermediate (B) axis length (cm).