CDA • ACB
CDA 2009 Annual Conference
Congrès annuel 2009 de l'ACB

CANADIAN DAM ASSOCIATION
ASSOCIATION CANADIENNE DES BARRAGES

Whistler, BC, Canada
2009 Oct 3-8

HIGH RESOLUTION 3D HYDRAULIC NUMERICAL MODELING FOR WEP ENVIRONMENTAL APPROVAL AND ENGINEERING

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ABSTRACT:

The Waneta Expansion Project, a partnership of Columbia Power Corp. and Columbia Basin Trust, involves the construction of a second powerhouse at the Waneta Dam on the Pend d'Oreille River just upstream of its confluence with the Columbia River. During the WEP environmental review process, a key issue was the sub-population of white sturgeon in the confluence waters. Extensive biophysical analyses were carried out to examine potential effects, using a hydraulic 3-D numerical model developed specifically for this reach of the two rivers. The model had a very high resolution of 3 m by 3 m in the horizontal and 10 vertical layers for a total of 92,000 grid elements. It was calibrated and validated using data obtained from field surveys of river velocities, water levels and temperatures for a variety of flow conditions. Using the model, the pre- and post-project river velocities and temperatures were computed and compared, specifically regarding effects in the deepwater habitat of the Waneta Eddy, in the near-bottom velocities in the egg deposition areas and in the late summer water temperatures. These analyses, along with fisheries biological interpretations, were used in the comprehensive review by the BC Environmental Assessment Office and Federal Government Departments, particularly the Dept. of Fisheries and Oceans. The Project received its Environmental Approval Certificate in November 2007. The 3-D numerical model was also used for input to engineering issues on the water levels immediately downstream of the Waneta expansion plant and water velocities in the headpond with the plant in operation.

RÉSUMÉ:

Le Projet d'Expansion de la Waneta, un partenariat entre la Columbia Power Corp. et le Columbia Basin Trust, vise la construction d'une deuxième centrale électrique au barrage de Waneta sur la rivière Pend d' Oreille juste en amont *du confluent* avec la rivière Columbia. Le processus d'études environnementales (WEP) touche principalement la population d'esturgeon blanc dans les eaux du confluent. Des analyses biophysiques approfondis ont été effectuées pour examiner les effets possibles sur la dite population en utilisant un modèle hydraulique numérique à trios dimensions développé spécifiquement pour la région des deux rivières. Le modèle a une résolution fine de 3 m par 3 m en vue de plan et 10 couches horizontales en profondeur pour un total de 92 000 éléments pour l'ensemble de la grille. Le modèle a été calibré et validé en utilisant des données obtenues lors de mesures des champs de vitesse de l'eau, des niveaux d'eau et des températures pour une série de conditions de débit. En utilisant le modèle, les vitesses et les températures prise avant et après le projet ont été calculées et compares; particulièrement, les effets sur l'habitat en eau profonde des eaux tournantes de cette région (Waneta Eddy), sur les vitesses du fond dans les secteurs de dépôt d'œufs et sur les températures de l'eau vers la fin de l'été ont été comparées. En incluant des interprétations biologiques de pêche, ces analyses ont été employées dans la revue complète par le bureau d'évaluation environnementale du C.B. et les services gouvernementaux fédéraux, en particulier Pêches et Océans Canada. Le projet a reçu son certificat d'approbation environnementale en novembre 2007. Le modèle numérique à trois dimensions a également été employé lors de l'évaluation des contraintes hydrauliques immédiatement en avale du Projet et en qui concerne le champ de vitesse en amont de la prise d'eau de la nouvelle centrale durant son opération.

1. INTRODUCTION

The Waneta Expansion Project (WEP), a partnership of Columbia Power Corporation and Columbia Basin Trust, involves the construction of a second powerhouse at the Waneta Dam on the right bank of the Pend d'Oreille River just upstream of its confluence with the Columbia River (Figure 1). The expansion project may have potential effects on the flow and circulation patterns in the area of the confluence of the Columbia and Pend d'Oreille rivers. During the WEP environmental review process, a key issue was the sub-population of white sturgeon in the confluence waters. Previous studies revealed that this confluence area has some significant morphological and circulation features, which are important for white sturgeon such as the deepwater low-speed Waneta Eddy for sturgeon rearing and feeding and the jet-like, high-speed Pend d'Oreille River outflow for sturgeon spawning and egg deposition (Hildebrand and Fissel, 1997; Hildebrand, 2001).

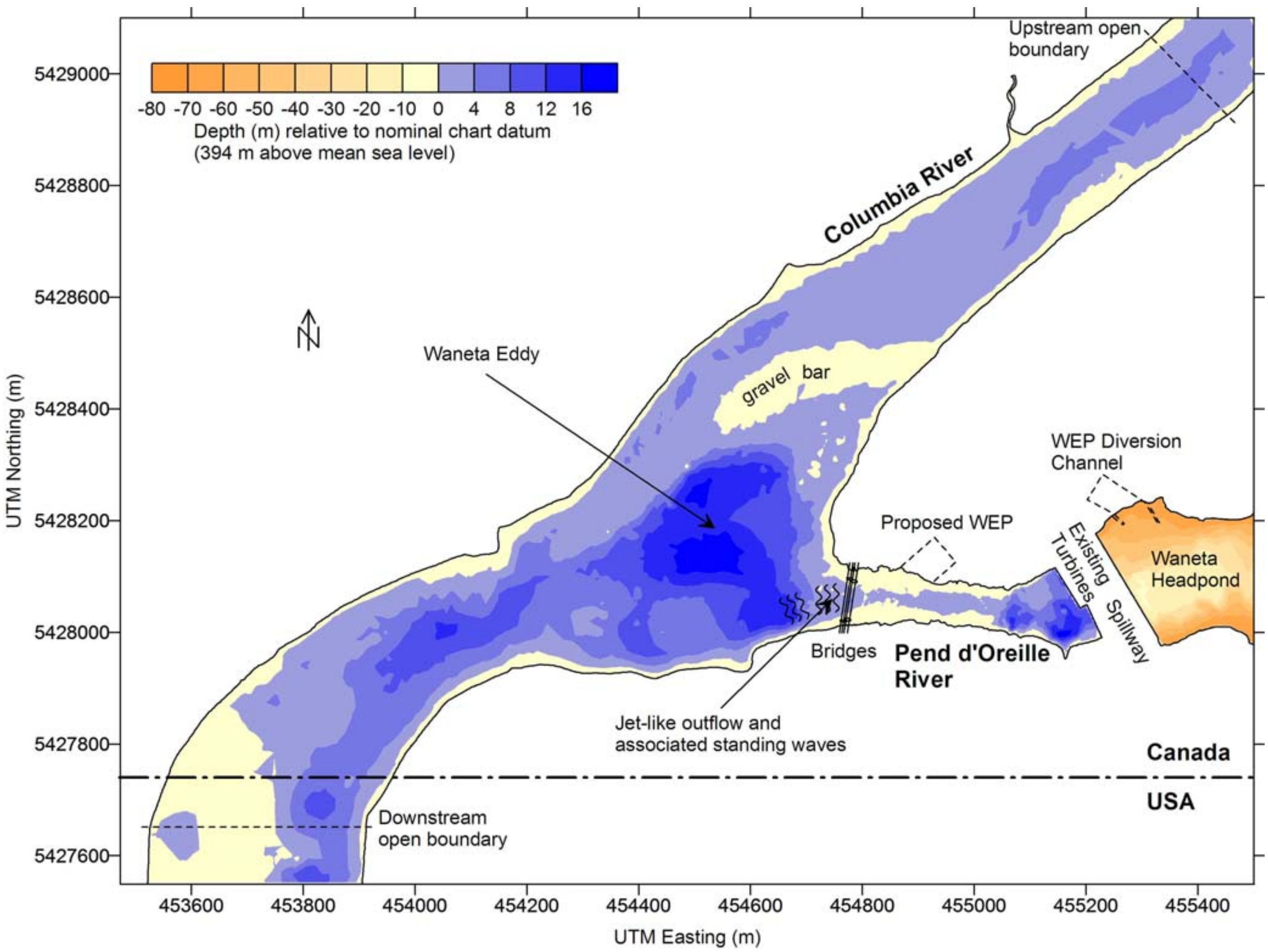

Figure 1: Study area showing geometry, model domain and boundaries.

The confluence of the Columbia and Pend d'Oreille rivers is located about 500 m north of the Canada and USA border (Figure 1), where flows from the upstream Columbia River and the Pend d'Oreille River join together before passing into the United States. The center of the confluence is a region of a large embayment with a water depth up to 18 m or more, much deeper than the surrounding areas. The flows in this area appear comparatively weak, typically less than 0.5 m/s, and usually rotate in counter-clockwise direction, known as the Waneta Eddy. On the northern side of the Waneta Eddy, the main channel of the Columbia River features large flows through typical water depths of 2 to 6 m relative to chart datum at 394 m above mean sea level (MSL). Just upstream of the confluence of the two rivers, a large gravel bar extends out from the eastern shore which confines the main flows of the Columbia River to a comparatively narrow channel along the western shore. Immediately to the south of the Eddy is the strong jet-like outflow from the Pend d'Oreille River into the Columbia River. The flows under the road and rail bridges, where the Pend d'Oreille waters enter the Columbia River, are normally turbulent due to the shallow and narrow Pend d'Oreille passageway. This discharge zone is characterized by large standing waves indicative of a supercritical flow regime. The highly turbulent, standing wave area extends downstream as far as the southeast corner of the deep portion of the Waneta Eddy.

Extensive biophysical analyses were carried out to examine potential effects, using a hydraulic 3-D numerical model COCIRM developed specifically for this reach of the two rivers. The model had a very high resolution of 3 m by 3 m in the horizontal and 10 vertical layers for a total of 92,000 grid elements. It was calibrated and validated using data obtained from field surveys of river velocities, water levels and temperatures for a variety of flow conditions. Using the model, the pre- and post-project river velocities and temperatures were computed and compared, specifically regarding effects in the deepwater habitat of the Waneta Eddy, in the near-bottom velocities in the egg deposition areas and in the late summer water temperatures. These analyses, along with fisheries biological interpretations, were used in the comprehensive review by the BC Environmental Assessment Office and Federal Government Departments, particularly the Dept. of Fisheries and Oceans. The Project received its Environmental Approval Certificate in November 2007. The 3-D numerical model was also used for input to engineering issues on the water levels immediately downstream of the WEP plant and water velocities in the headpond with the plant in operation.

2. IMPLEMENT OF 3D COCIRM

2.1 Brief description of the 3D model

In this study, a high resolution 3D numerical model, COCIRM, is applied to simulate the flows in and around the confluence of the Columbia and Pend d'Oreille rivers as well as in the Waneta headpond. The "COCIRM" model, developed over the past several years, represents a computational fluid dynamics approach to the study of river, estuarine and coastal circulation regimes. The model explicitly simulates such natural forces as pressure heads, buoyancy or density differences, wind stress and drag arising from the shoreline and the river bottom. The model applies the fully three-dimensional basic equations of motion combined with a second order turbulence closure model, then solves for the time-dependent, three-dimensional velocities (u, v, w), turbulence kinetic energy (q), water surface elevation (ξ), water temperature (T) and salinity (s) (Jiang, 1999; Jiang et al, 2003; Fissel and Jiang, 2008). The model is capable of representing discharge outfalls and intakes in a realistic manner. A semi-implicit finite difference method was applied in the COCIRM model. This numerical solution method has the advantages of a minimal degree of implicitness, good stability and consistency, and high computational efficiency at a low computational cost. The horizontal grid element sizes are typically in the range of 5 to 100 m. The vertical sigma-grid or z-grid may be distributed unevenly, with typically 10 – 20 layers.

This COCIRM model operated on two separated domains, respectively the confluence model downstream of Waneta Dam and the headpond model upstream of Waneta Dam. The bathymetry data used in both model areas have the resolution of 3 m or better. The confluence model extends approximately 1260 m upstream from the Waneta Eddy and 1050 m downstream to an area just south of the Canada and US border. The model runs on a grid with 3 m by 3 m horizontal grid cell size and 10 equally-spaced sigma layers. The inflow discharges from the upstream boundaries at the upstream Columbia River, existing Waneta Dam and proposed WEP tailrace were given and represented in a realistic manner in the model (Jiang and Fissel, 2002). The boundary conditions for the downstream portion of the Columbia River were specified through a modified form of Sommerfeld radiation approach introduced in Orlanski (1976).

The headpond model includes the proposed WEP diversion channel and a portion of Waneta Dam headpond extending approximately 1.5 km upstream from the dam. The model runs on a horizontal grid of size 3 m by 3 m and 15 vertical sigma-layers with higher resolution near the bottom in order to appropriately represent near-bottom turbulence boundary layer and sediment processes. The outflow discharges from the spillway, existing

Waneta Dam turbines, and proposed WEP turbines are represented in a realistic manner in the model. The open boundary conditions at the upstream end were specified by water levels (Jiang and Fissel, 2008).

2.2 Model calibration and validation

In the confluence area, the flow patterns and the outflow standing waves, etc., appear to be dynamic and vary considerably with different flow combinations of the Columbia and Pend d'Oreille rivers. To evaluate the model performance and validate it as a reliable tool for the environmental assessment, the flow combinations of the two rivers in all model calibration and validation cases must span a substantial range of discharges to represent various flow features for which the in situ observed current data are available. Since 1994, extensive field measurements of currents in this region, mostly in the confluence area, have been carried out by ASL Environmental Sciences Inc. and R.L. & L. Environmental Services Ltd., using ship-borne ADCP (Birch, 1994; Birch, 1996; Hildebrand and Fissel, 1997; Birch and Boubnov, 2001; Birch and English, 2001). These data allow for the extensive model calibration and validation cases realized in this study. In total, two calibration cases (C1 and C2) and seven validation cases (V1 – V7) were selected and carried out. These cases are believed to be sufficient for the model validation requirements (Table 1).

In the headpond model, one calibration case and one validation case (Table 1) were conducted to optimize the major hydrodynamic parameters to give the best fit between the modeled and in-situ observed velocity vertical profiles and flow patterns measured in the field survey by ADCP in 2008 (Fissel et al., 2008)

Table 1: Summary of model calibration and validation cases.

Model area	Model case		Discharge (m^3/s)				Temperature (°)		Observation taken
			Upper Columbia River	Pend d'Oreille River			Upper Columbia River	Pend d'Oreille River	
				Exsiting Power house	Spillway	Total			
Confluence	Cali.	C1	1,812	229		229	18.8	22.4	Aug. 31, 94
		C2	2,300	725	209	934	2.5	1.5	Feb. 08, 96
	Validation	V1	1,982	510		510	18.8	22.2	Aug. 30, 94
		V2	951	147		147			Jul. 15, 01
		V3	1,104	227		227			Oct. 20, 01
		V4	1,104	510		510			Oct. 20, 01
		V5	951	283		283			Jul. 15, 01
		V6	2,550	34		34			Oct. 06, 96
		V7	2,039	720	359	1,079	10.0	13.0	May 18, 94
Headpond	Calibration			775		775			Apr. 9, 08
	Validation			402		402			Apr. 8 – 9, 08

The model was initially tested and operated in calibration runs. Various physical parameters, mainly bottom drag coefficient and horizontal and vertical eddy diffusivity coefficients, were repetitively adjusted to achieve optimal agreement with the observations. The vertical diffusivity for the model, as derived from the second order turbulence closure model (Mellor and Yamada, 1982), was found to be robust. Some adjustments of the horizontal diffusivity were made through the user-specified calibration parameter in Smagorinsky's formula (Smagorinsky, 1963). The bottom drag coefficients were the most important parameter for the purpose of model calibration. Once reasonable agreement is attained in the calibration runs (as seen in Figure 2 for the C1 model case), the model was next operated in validations runs using the previously optimized physical parameters and compared with different observation data sets. The agreement between the model outputs and the observations is used to assess the capabilities of the model. Following the methods of Murphy and Winkler (1987), the results of the validation model runs were compiled and analysed in detail. The resulting modelling validation report (Fissel and Jiang, 2002) was the basis for a favourable peer review of the model conducted anonymously a DFO numerical modelling scientist.

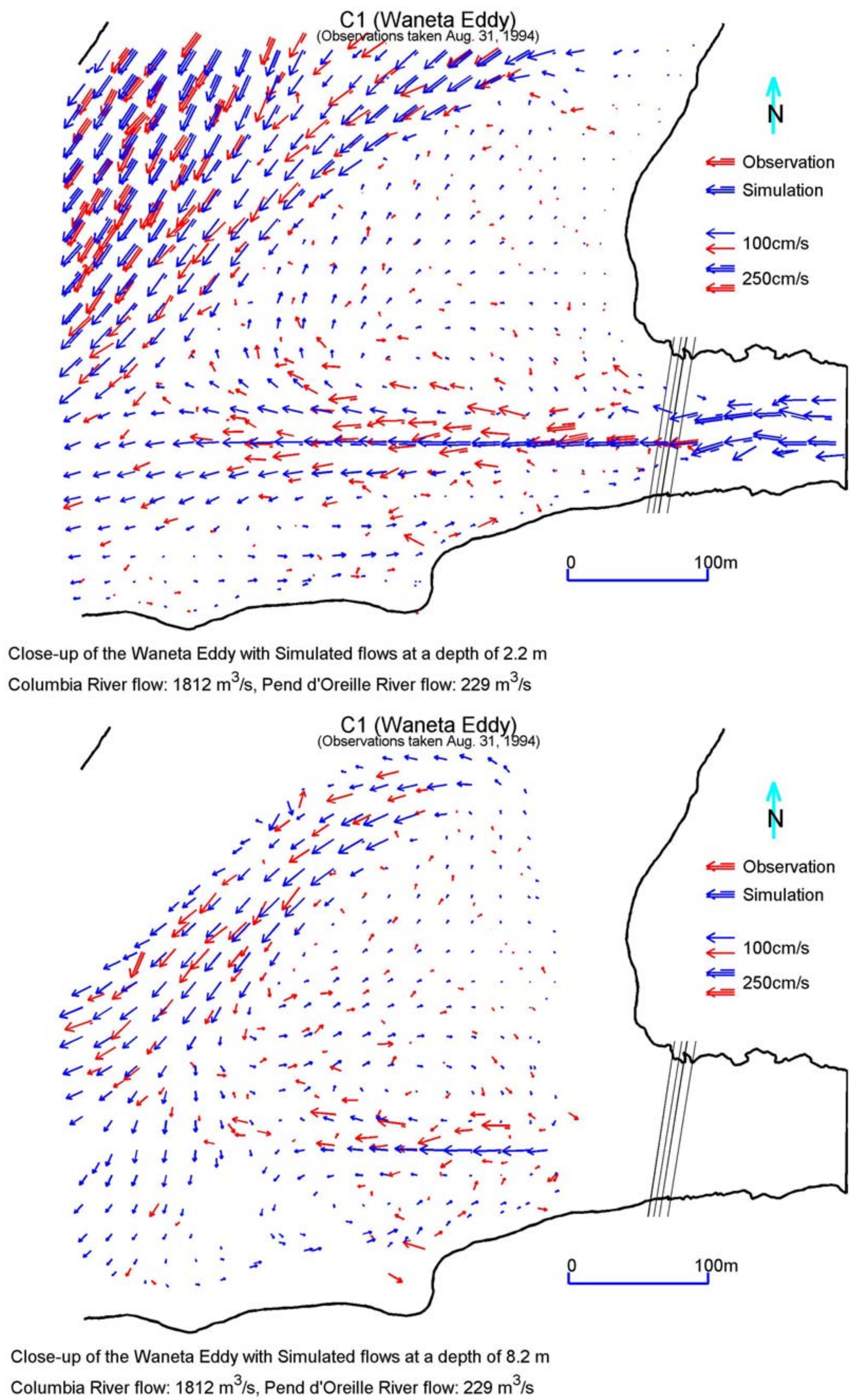

Figure 2: C1 model results for the Waneta Eddy area at 2.2 m (upper panel) and 8.2 m (lower panel) water depths, with comparisons to observations from Aug. 31, 1994.

2.3 Dynamic Confluence Circulation Patterns

The confluence circulation patterns vary dynamically with the variations of discharges from upper Columbia River and Pend d'Oreille River. At extremely low Pend d'Oreille River flow, such as the "speed-no-load flow" of 34 m^3/s in the validation case V6, the entire embayment area from the gravel bar to the southern shore is occupied by a large counter-clockwise eddy (labeled as C in Figure 3), driven by the shears of the main Columbia River flow. The weak Pend d'Oreille River flow joins the eddy along the eastern bank. As the Pend d'Oreille River discharge increases, the outflow gains more and more momentum to break through the big eddy. In these cases, the actual circulation patterns are dependent not only on the Pend d'Oreille River flow, Q_{pdr}, but also on the Columbia River discharge level, Q_{col}. For moderate to high levels of Q_{col} (≥ 1,300 m^3/s), the outflow gradually shifts southward towards to southern shore as the Q_{pdr} increases. At the same time, the clockwise eddy (labeled as P inFigure 3, which is driven by the shear of the Pend d'Oreille outflow, gradually shrinks and the counter-clockwise eddy C becomes dominant. During this process, a third eddy appears near the southern shore, namely south shore eddy (labeled as S in **Error! Reference source not found.**), driven by the shears from both Columbia main flow and the Pend d'Oreille outflow, and disappears at high level of Q_{pdr}. For the low flow level (Q_{col} < 1,300 m^3/s), the gravel bar acts as a weir or dam with little or no water passing over it. As a result, the deep water area is dominated by the clockwise eddy P if the Pend d'Oreille River discharges are at low to modereate levels (100 – 500 m^3/s). At the high flow level (Q_{pdr} > 500 m^3/s), the water elevation at the confluence increases and the gravel bar is submerged with a considerable amount of water passing over it. Consequently, the counter-clockwise eddy C becomes dominant again.

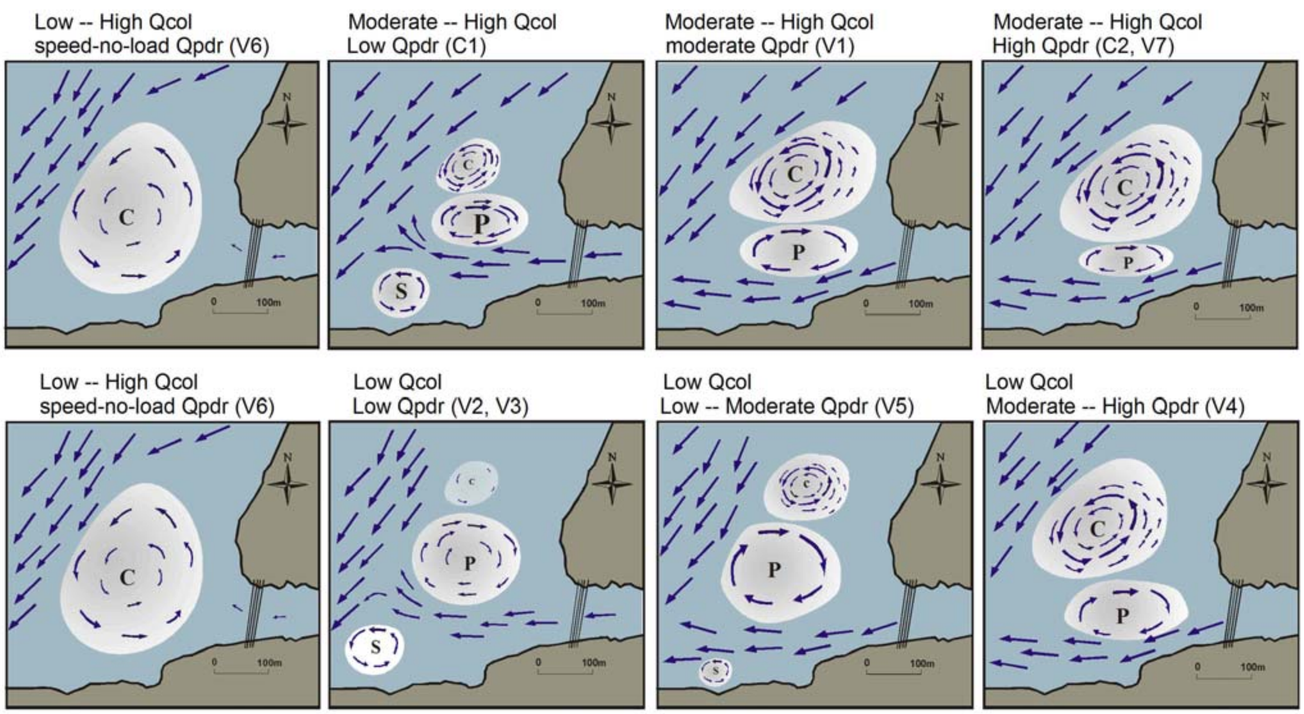

Figure 3: Schematic diagram of the circulation patterns in the confluence area.

3. MODEL RESULTS SUPPORTING WEP ENVIRONMENTAL APPROVAL

3.1 Productive Habitat Area

Following completion of WEP, the Canadian Pend d'Oreille hydroelectric system daily flows will be reshaped to maximize electricity generation values. This will result in post-project operations increasing daily variations in water levels below Waneta Dam, and consequently, potential loss of fish habitat in the confluence area downstream of Waneta. As a key parameter for the WEP environmental approval, the productive habitat area within the varial zone was estimated based on the 3-D model results. The varial zone is the area that lies between the upper and lower annual water levels that occurs in each reach. The productive capacity of the littoral zone associated with the confluence area was modelled over time with the assumption that wetted area had a benthic recovery time of 20 days. In the modelling effort, this was simulated by assuming no habitat value for the first 10 days after being re-wetted, followed by immediate full recovery after day 10. This value was selected based on literature reviews of periphyton and benthic macro-invertebrate recovery times of de-watered habitat.

To examine the changes in productive habitat below Waneta Dam between pre- and post-project conditions, an empirical model was developed to compute habitat availability of the littoral zone in the river reference area. Because of the complexity in flow patterns, the model was separated into four sub-regions in order to facilitate the derivation of appropriate relationships. These four sub-regions are respectively Columbia downstream of confluence, center of confluence, Columbia upstream of confluence, and Pend d'Oreille River. The river reference area in the first sub-regions is primarily dependent on the Columbia River discharge, and the river reference area in the last sub-regions is primarily dependent on the Pend d'Oreille River discharges. In the other two sub-regions, the river reference areas are dependent on both Columbia and Pend d'Oreille river discharges.

The empirical model is derived as a least square fit of the 3-D numerical model derived wetted area (A), applied separately to each of the four sub-regions, as a function of the Columbia and Pend d'Oreille river discharge values (Q_{col} and Q_{pdr})

$$A = \alpha Q_{pdr} + \beta Q_{col} + \chi \left(\frac{1}{Q_{pdr} + Q_{col}} \right)^{\delta} + \varepsilon \quad (1)$$

Where α, β, γ, δ and ε are the coefficients derived from the least square fit.

The empirical model wetted area values are in very good agreement with the wetted area reference data, as obtained from the 3-D numerical model for over 40 combinations of river flows. Correlation coefficients exceeding 0.995 were attained for all four sub-regions.

The changes in daily productive habitat area downstream of the Waneta Dam, resulting from the operation of WEP, was computed by individual years from 1991 to 1999, inclusive, and for the average values for the 1991 – 1999 period (as seen in Figure 4). The computations were with the present enhancement version (WSFAP-1998) and the Post-Project Enhancement version (WSFAP-PPE) of the White Sturgeon Flow Augmentation Program, which has been accepted by the appropriate regulatory agencies. In summary, the daily average reduction in productive habitat area relative to Pre-Project conditions as computed over the full year based on the nine year average values is 0.37 hectares for Post-Project with WSFAP-PPE as compared to 0.34 hectares for Post-Project with WSFAP-1998. The difference between 0.37 and 0.34 is very small being well within the normal daily variability of productive habitat area.

3.2 Low Velocity Habitat Area

The low velocity area affected by the Waneta Eddy relevant flows represents another important white sturgeon habitat in the Pend d'Oreille/Columbia confluence, as per the WEP environmental approval requirement. The 3-D model results provide detailed insight into the potential impact of the WEP regarding this habitat issue. A total of five representative flow discharge combinations were carefully selected for modelling, based on the simulation of the Pend d'Oreille discharges for the average 1991 to 1999 conditions at different times of the year, along with the average Columbia River discharges for the same dates. Well-established environmental habitat flow parameters specified by the project's fisheries consultant were computed and mapped for the selected cases.

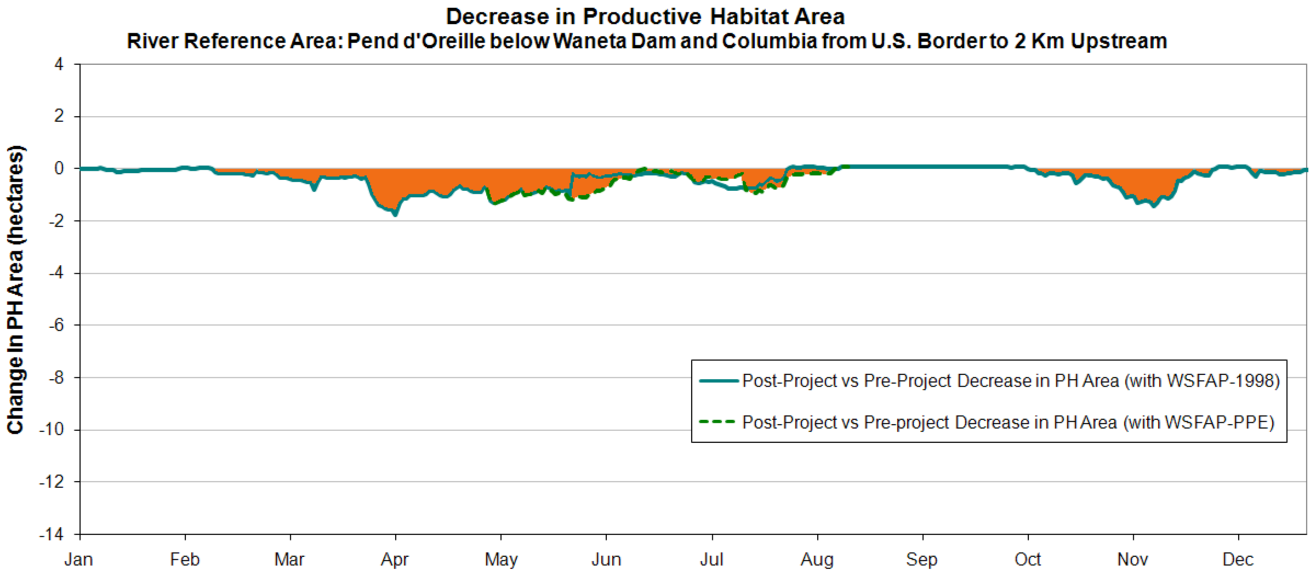

Figure 4: Average decreases in productive habitat area resulting from the operation of WEP for the 1991 – 1999 period.

The model results (as seen in Figure 5 for Case 1) show that changes in the low velocity areas affected by the Eddy relevant flows at various times throughout the year can be either positive or negative. In all but one case (not shown), these area changes are very small. The low velocity habitat area change in the one exception (Case 5), which shows a reduction of 28% in low velocity area during light load hours on one average day in early November, is well within the range of low flow area reductions that occur at other times under pre-project conditions. In all five cases considered, the physical effect of the project on Eddy near-bottom temperature changes are found to be much smaller than 1.5 °C, generally considered by fisheries biologists as a threshold level for discernible biological effects.

3.3 Near-Bottom Velocities at Different Locations of Egg Mats

Extensive historical surveys have shown that the strong flow areas along the south shore of the Columbia/Pend d'Oreille confluence are important white sturgeon spawning and incubation habitat in the June to July spawning period. As one of the key issues for the WEP environmental approval, the 3-D model results were used to estimate the potential effect of WEP operations on the near-bottom velocities at a total of nine locations of egg mats, which were identified from recorded data of incubating eggs in the spawning area (Figure 6). An empirical model was developed to examine the changes in the near-bottom velocities at these locations between pre- and post-project conditions. The empirical model is derived as a least square fit of the 3-D numerical model derived near-bottom velocity (V_b), applied separately to each of the nine locations of egg mats, as a function of the Columbia and Pend d'Oreille river discharge values

$$V_b = \alpha' Q_{pdr}^{\ \beta'} + \chi' Q_{col}^{\ \delta'} + \varepsilon' \left(\frac{1}{Q_{pdr} + Q_{col}} \right)^{\phi'} + \varphi' \left(\frac{Q_{pdr}}{Q_{pdr} + Q_{col}} \right)^{\gamma'} + \eta' \left(\frac{Q_{col}}{Q_{pdr} + Q_{col}} \right)^{\lambda'} + \mu' \qquad (2)$$

Where $\alpha', \beta', \chi', \delta', \varepsilon', \phi', \varphi', \gamma', \eta', \lambda'$ and μ' are the coefficients derived from the least square fit.

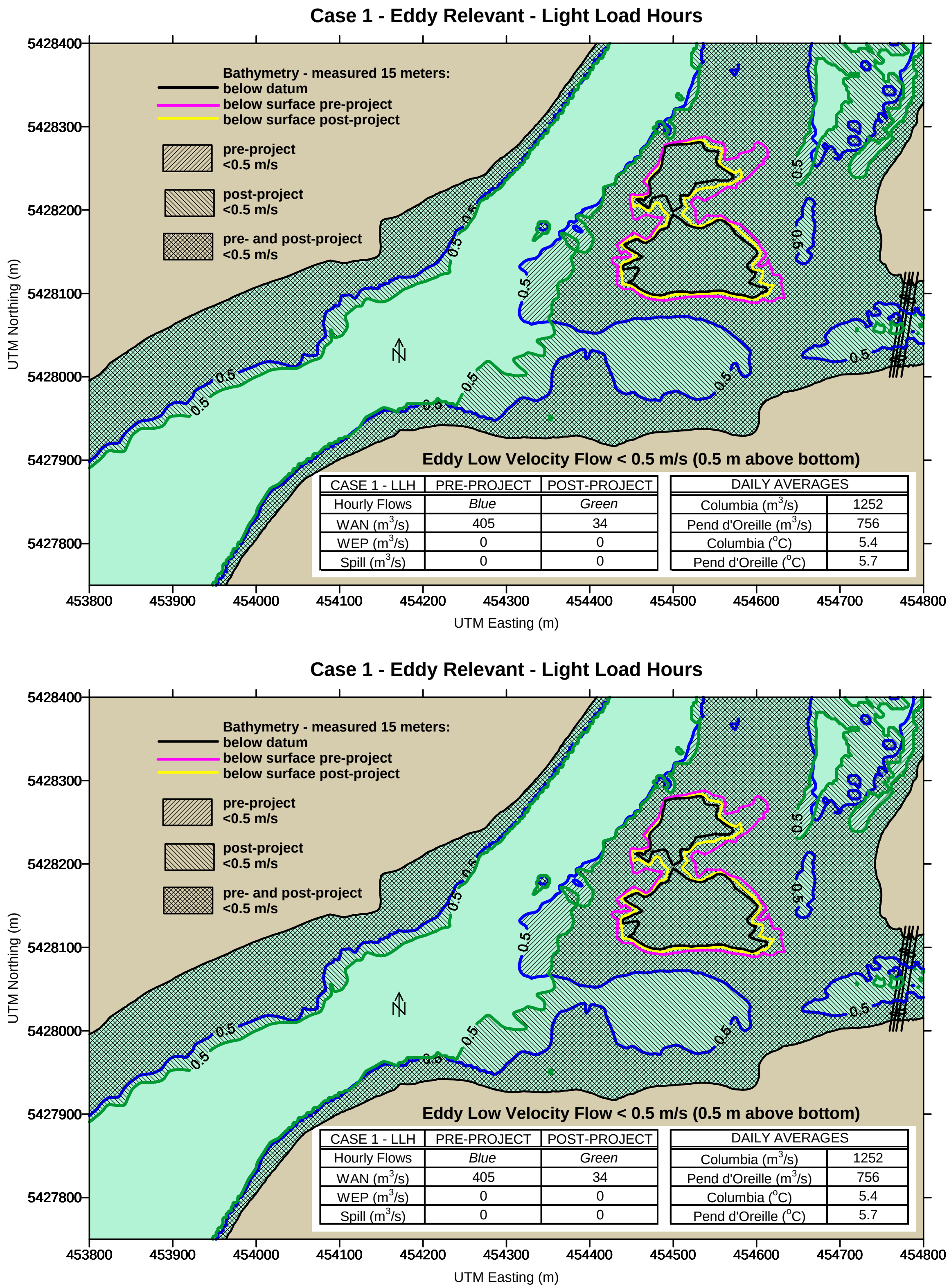

Figure 5: Case 1 model results of the low velocity habitat areas for light load hours (upper panel) and heavy load hours (lower panel).

The empirical model near-bottom velocity values are in very good agreement with the near-bottom velocity data, as obtained from the 3-D numerical model for over 40 combinations of river flows. Correlation coefficients exceeding 0.95 were attained for all nine locations.

The changes in the near-bottom velocities at the selected nine sites, resulting from the operation of WEP, were computed for a total of eight years, respectively 1996, 1998 and 2000 – 2005, when the white sturgeon incubations were monitored. Reduced flow velocities can result in increased egg predation reducing recruitment of white sturgeon. The flow histograms (not shown) indicate that the near-bottom velocities are generally 1.0 to > 2.4 m/s at most of the egg mat sites (sites C4, D1, E1 E1.5 and M1; locations shown in Figure 6) for seven of the eight years. In 2001, a year having the lowest discharges in past 40 years, the velocities are generally less than 1.0 m/s. The near-bottom velocities at site C1, and to a lesser degree at site C3, are noticeably reduced by comparison to the mat locations in the mainstem of the Columbia River flows. At site C1, the velocities are generally about 0.6 – 1.0 m/s in June and 0.2 – 0.6 m/s in July. The egg mat velocities were also modelled using hourly flows for the Pend d'Oreille River which would occur under post project conditions indicating only small differences from pre-project conditions. These modelling data supports the conclusion of no significant negative effects of past Pend d'Oreille flows or future project related flow changes on white sturgeon egg spawning/incubation.

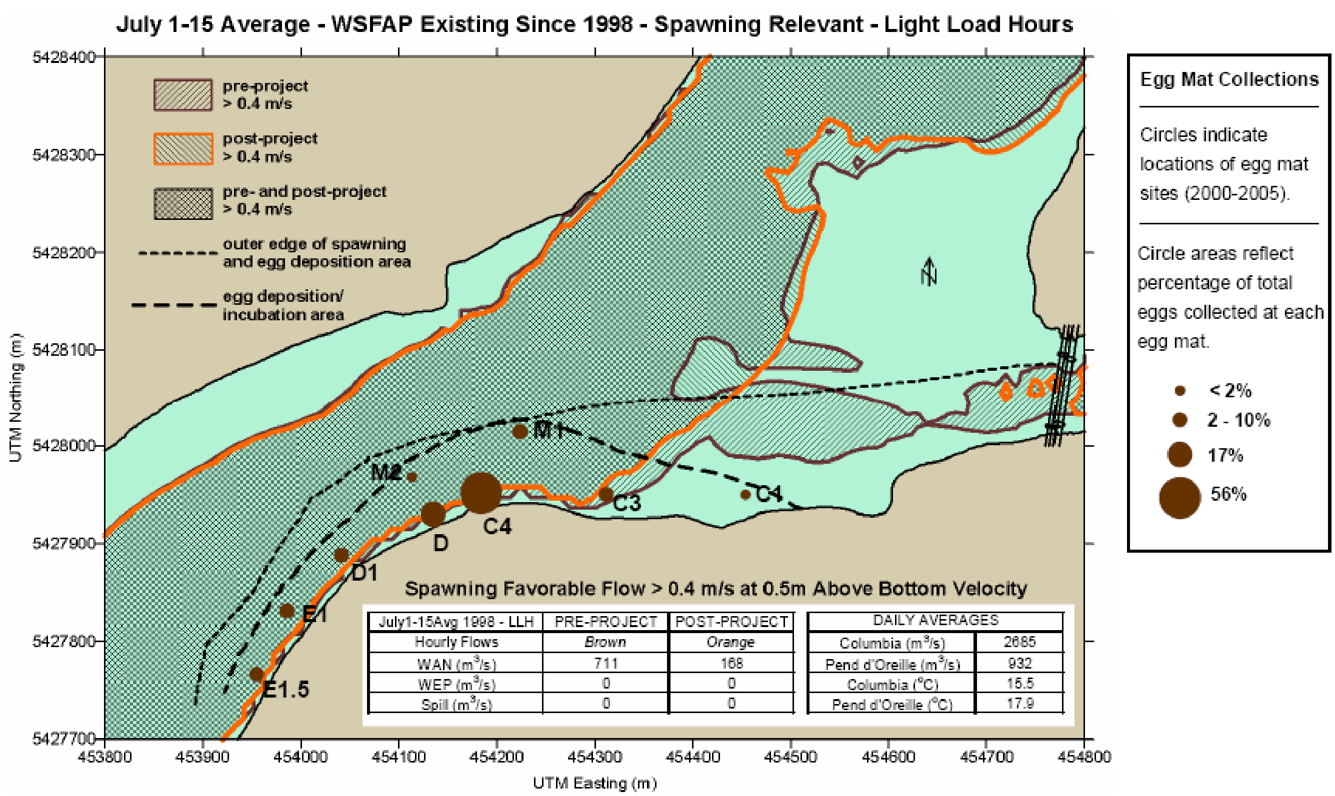

Figure 6: Map showing white sturgeon egg mat locations.

4. MODEL RESULTS SUPPORTING WEP ENGINEERING

4.1 Water Levels Downstream of Waneta Dam

After successful WEP Environmental Certificate application, the developed 3-D model was used to support the WEP engineering. One of the WEP engineering issues is the water elevations in Pend d'Oreille River. The model was applied to derive water elevations in Pend d'Oreille River downstream of Waneta Dam for various combinations of the flow rates from the Columbia river, existing Waneta Dam and WEP turbines as well as for several flow conditions under the effect of WEP rock fill workpad. These model results (not shown) provided detailed information of the water elevations at the WEP and existing Waneta Dam tailraces and the water level profiles along the Pend d'Oreille River outflow for WEP engineering design.

Before the applications, the model water elevations were calibrated and validated using the measured water elevations along left and right river banks at the Pend d'Oreille outflow region in 2007. Figure 7 shows the comparisons between modeled and observed water elevations for three flow conditions. It is seen that the model results are in good agreement with the observations in terms of the shapes of the water surface profiles and the big water drop under the bridges. Some discrepancies between the model results and data exist. The model water elevations are lower than the observations by around 0.15 m downstream of the bridges and by around 0.3 m upstream of the bridges. It is believed that these discrepancies are mainly caused by insufficient/inaccurate bathymetry input. It is also suggested that further refinement of the model parameters, especially bottom drag coefficient, is necessary to further improve the model performance.

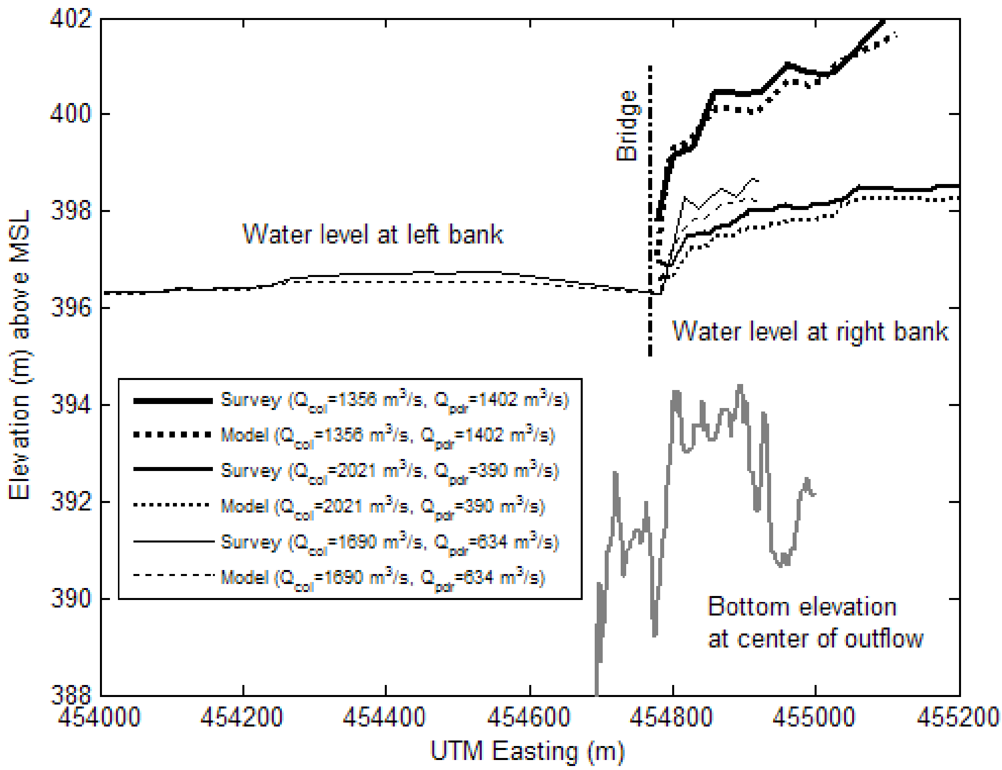

Figure 7: Modeled and observed water surface elevations in the outflow area.

4.2 Flows in Waneta Headpond

Another WEP engineering issue is the potential effect of WEP diversion channel (Figure 1) on the ambient near-bottom currents and consequently on the resuspension of the bottom sediments in the Waneta headpond area. These changes may lead to either positive or negative impact on contaminants releasing in the bottom sediments to downstream of Waneta Dam, which may have accumulated over many years in the past from deposition of Pend d'Oreille River sediments as they entered the comparatively large depths of the headpond where the velocities are reduced and sediments settle out of the water column onto the riverbed. To examine any possible changes to the near-bottom velocities, caused by the WEP operations, the 3-D model was applied to the headpond area with a horizontal resolution of 3 m by 3 m and 15 vertical sigma-layers having higher resolution near the bottom (Jiang and Fissel, 2008).

The model, at first, was calibrated and validated using the ADCP surveys of water velocities in the headpond area conducted in 2008 (Table 1). Figure 8 shows velocity vertical profile comparisons at three sites A – C (see Figure 9) for the calibration case. It is observed that the model velocity profiles at sites A and B are in good agreement with the observations. At site C, the model under-predicted the flow speed by about 3 cm/s compared to the observations.

The modeled headpond flow patterns were compared with observations at three vertical levels, respectively 2.5 m, 7.5 m and 12.5 m depths from the surface. Figure 9 shows the comparisons at 12.5 m depth respectively for the calibration and validation cases. Overall, the modeled headpond flow patterns are in good agreement with the observations. From these results, it is found that the flow patterns in the headpond are very analogous to those induced by basins with restricted outlets, such as sinks. In general, the flows appear to gradually converge and meanwhile become stronger towards the turbine intakes. At the southern corner upstream of the spillway, a well-developed, counter-clockwise eddy appears both in the model and observations with a size of around 100 m in diameter. In the proposed WEP diversion channel approach area, the velocities appear to follow shoreline and gradually turn from WNW to WSW before converging into the intakes. The typical flow speeds in this region range from 0.1 m/s to 0.3 m/s with weaker velocities near the shore.

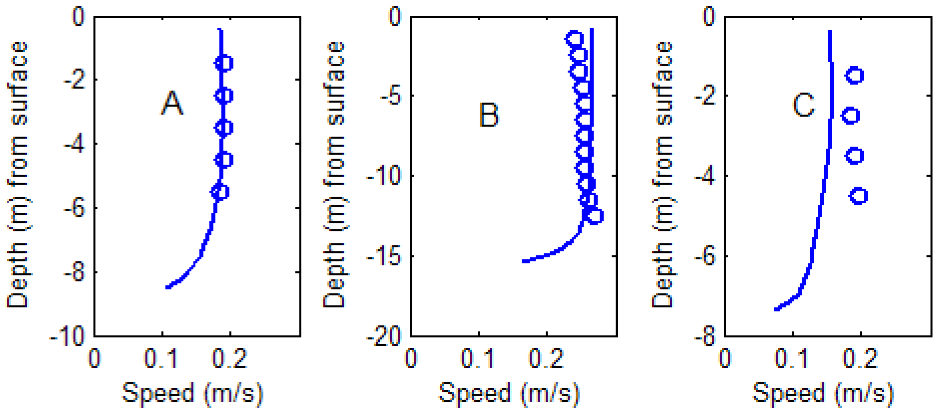

Figure 8: Calibration case modeled (solid lines) and in-situ observed (open circles) velocity vertical profiles at sites A – C.

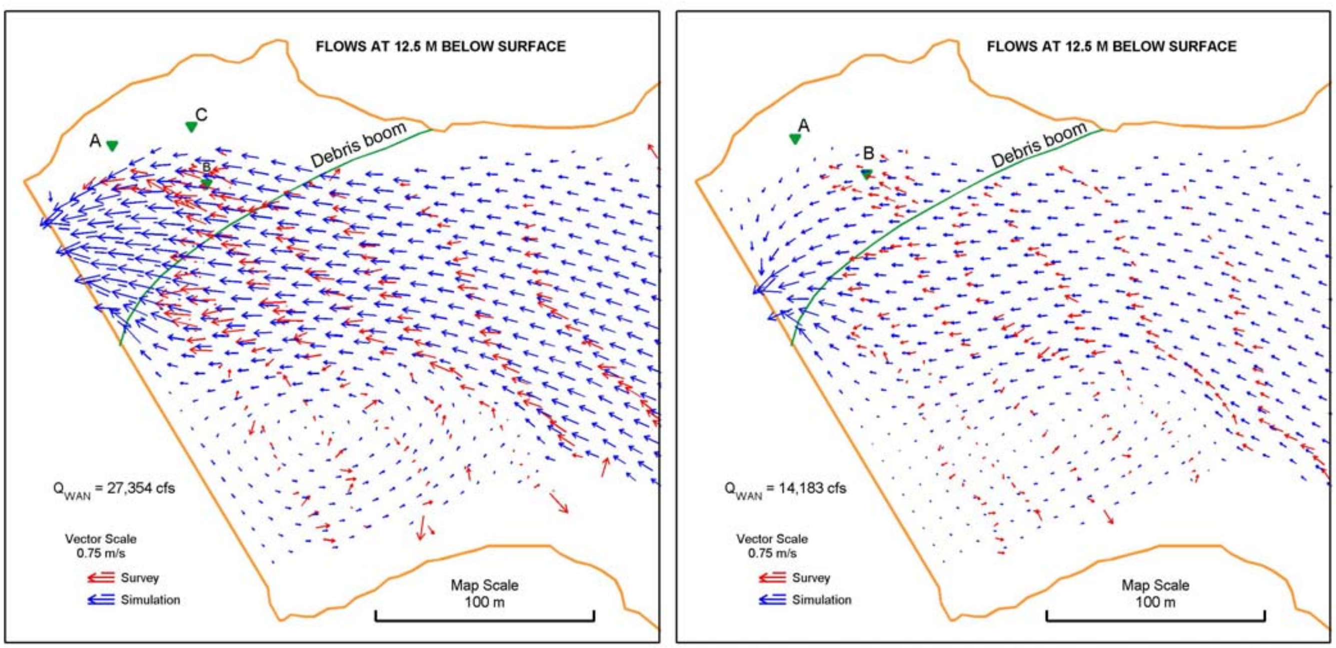

Figure 9: Modeled and observed results of the headpond velocities at 12.5 m depth for the calibration case (left panel) and the validation case (right panel).

After validation, the model was then applied to simulate the velocities in the headpond area for various combinations of discharges rates through the existing Waneta and WEP turbines, and the spillway. Figure 10 shows the model headpond velocities at 1 m above bottom for a case with an existing Waneta turbine discharge of 852 m^3/s and a WEP turbine discharge of 620 m^3/s. From these model results, it is found that that when WEP is in operation, the near-bottom velocities within the diversion channel attain speeds of up to 1.4 m/s or greater. At the entrance to the diversion channel approach within the existing headpond, where excavation will be required in building the approach to the WEP intake, the near-bottom flow speeds are of particular interest. The near-bottom velocities in this area (bounded by 5,428,170 and 5,428,193 UTM North coordinates and by 455,260 and 455,330 UTM East coordinates) range from 0.06 to 1.01 m/s, with median values of 0.20 m/s – 0.50 m/s.

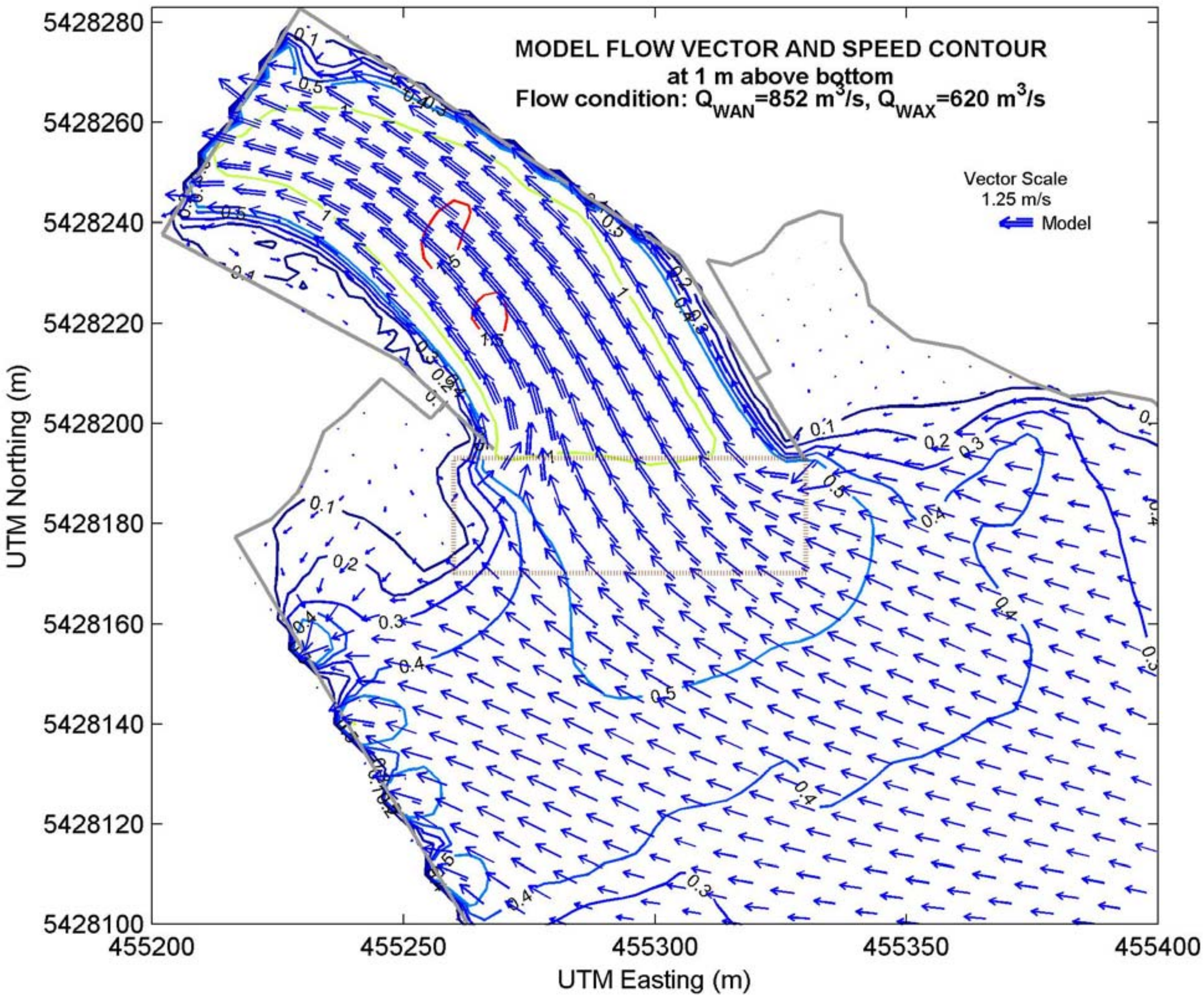

Figure 10: Model results of the headpond velocities at 1 m above bottom for a case with an existing Waneta turbine discharge of 852 m^3/s and a WEP turbine discharge of 620 m^3/s.

5. SUMMARY AND CONCLUSIONS

The high resolution, 3-D coastal circulation numerical model COCIRM was successfully adapted and optimized through extensive calibration and validation processes in supporting the WEP environmental approval and engineering. A key issue of the WEP environmental assessments is the potential effects of the WEP operations on the flows in the confluence area of the Columbia and Pend d'Oreille rivers, which provide important habitats for white sturgeon, such as the deep water, low-speed Waneta Eddy for sturgeon rearing and feeding and the jet-like high-speed Pend d'Oreille River outflow for sturgeon spawning and egg deposition. In 2003, the 3-D model COCIRM was accepted as an acceptable basis for the WEP environmental assessment purposes by the Canadian regulatory agencies and First Nation groups based on a favourable peer review of the model by an anonymous numerical modeller of the Department of Fisheries and Oceans, Canada. The potential impacts of the WEP on the flows in the confluence area were examined using extensive model predictions with numerous flow combinations from the Columbia River, the existing Waneta Dam and the WEP. These predicted results show either positive or minor negative impacts of the WEP operations on the fishery habitats in the confluence area. Based in part on these numerical model studies, environmental approval for the WEP was granted in 2007.

In supporting the WEP engineering, the developed 3-D model was used to simulate the water elevations in Pend d'Oreille River and the near-bottom velocities in the Waneta headpond area under the impact of the WEP operations. The model was validated for both applications using the field survey data. It is found that the 3-D model is a useful tool for the WEP engineering issues in terms of good agreements between modeled and observed water elevations in Pend d'Oreille outflow, and velocities in the headpond area. In Pend d'Oreille River, the model results provide detailed information of water elevations at the existing and WEP tailraces as well as water surface profiles in the outflow area, which are essential for appropriate WEP tailrace design and construction. In the headpond area, the model provides detailed predictions of the changes in the near-bottom velocities resulting from the WEP operations. These predictions serve as a useful guide for the WEP diversion channel design, excavation, and necessary measures to prevent the bottom sediment contaminants from being resuspended during the construction of the WEP diversion channel and at the new flow conditions when the WEP is in operation.

6. ACKNOWLEDGEMENTS

We wish to express our appreciation to the Columbia Power Corporation for the opportunity to undertake this study, especially Bill Freeman, Victor Jameff, Elroy Switlishoff, Robert Teichroew, Wally Penner, Wally Malkinson and Theodora Borissov. We would also like to thank John Nunnm Radmila Krzman and Robin Fitzgerald of Klohn Crippen Berger Ltd. for providing the model inputs and overall direction, and Larry Hildebrand of Golder Associates Ltd. (formerly R.L. & L. Environmental Services Ltd.) for insights and advise related to the fisheries and biological issues. Thanks also extend to our colleagues Rick Birch, Dave Billenness, Vincent Lee, Dave English, Keath Borg, Rob Bowen and Bernadette Fissel for providing detailed field data, and graphic, mapping and administrative assistance.

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