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ESTIMATION OF INSTREAM FLOW NEEDS FOR RIVERINE FISH AND FISH HABITAT IN LOW-SLOPE RIVERS

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Abstract: As fish habitats represent some of the most difficult biological, topographic and hydrodynamic phenomena to evaluate, estimation of environmental flows or instream flow needs for fish and fish habitat becomes a challenging process to assess in detail. However, hydrodynamic models with habitat simulation features may now provide one tool to examine and analyze the quality and quantity of complex fish habitats in such challenging circumstances with reasonable accuracy. The purpose of this study was to estimate the instream flow needs that can be used to protect or enhance the fish and fish habitats in three sites of three low-slope Rivers in Canada. The River2D hydrodynamic model combined with fish species-specific habitat suitability criteria was used to achieve these goals. The model was used to predict channel hydraulic or physical habitat characteristics, mainly velocities, water depths and water levels. Model predictions were presented for a wide range of flows. The hydrodynamic model results, coupled with the biologically significant suitability metrics, were used to determine changes in fish habitat use areas with discharge, estimate weighted usable areas, and consequently estimate instream flow needs or environmental flows for several fish species. This ichthyohydraulic simulation process provides water management guidance to protect or enhance fish and fish habitats in these rivers.

1 INTRODUCTION

Instream flow needs (IFN) studies have been used to provide a means of assessing the adverse effects of different hydrotechnical projects on fisheries resources to provide guidelines for planners and designers. Numerous IFN assessment methods have been developed by biologists, environmentalists and engineers. Ghanem and Hicks (1992) examined the hydraulic techniques used within the IFN models.

Since complex river reaches often represent important fish habitat, it is essential to be able to simulate reasonably well natural hydraulic and biological conditions in these areas. A clear understanding and an accurate representation of the hydraulic characteristics of a fish habitat area are therefore necessary, not only to model the physical features of the habitat, but also to understand other processes which can be limiting presence of fish.

The introduction of two-dimensional numerical modeling offers the potential for analyzing the quality of complex aquatic habitats as they have the ability to more accurately define spatial hydrodynamic variations in rivers (Ghanem et al. 1996; Leclerc et al. 1995; Waddle et al. 2000). Instream flow practitioners are becoming increasingly aware of the potential of two-dimensional hydraulics in instream flow studies for better representation of instream habitat conditions (Christison et al. 1998).

The purpose of this study was to determine or estimate the instream flow requirements or needs for fish and fish habitat for different fish species for three representative reaches on three low-slope Rivers in Canada: one representative reach on the Athabasca River below Peter Lougheed Bridge at Fort Mackay, one representative reach on the North Saskatchewan River at Garden River, and one representative reach on the Assiniboine River at Brandon Riffles. The study reaches were selected based mainly on ecological criteria.

The RIVER2D (www.river2d.ca, Steffler and Blackburn 2002) model with its mesh generation and habitat analysis utilities were used to quantify instream flow needs for different fish species for the reaches under study. This was achieved by combining detailed hydraulic modeling with species specific habitat use criteria to determine the "usable" habitat throughout the applied range of flows.

2 STUDY REACHES

2.1 Reach of the Athabasca River

The location of the study site (57°08'06.0"N 111°36'35.0"W upstream to 57°09'33.2"N 111°37'42.6"W downstream) is on the Athabasca River below Peter Lougheed Bridge at Fort Mackay (Figure 1). The river reach has an average width of 480 m, and an average water slope of 0.000064. In the vicinity of the islands the river reach has an average width of 820 m. The reach is relatively mild but subject to mixed subcritical and supercritical flow regimes. The bed materials are basically sand with little cobble along the banks.

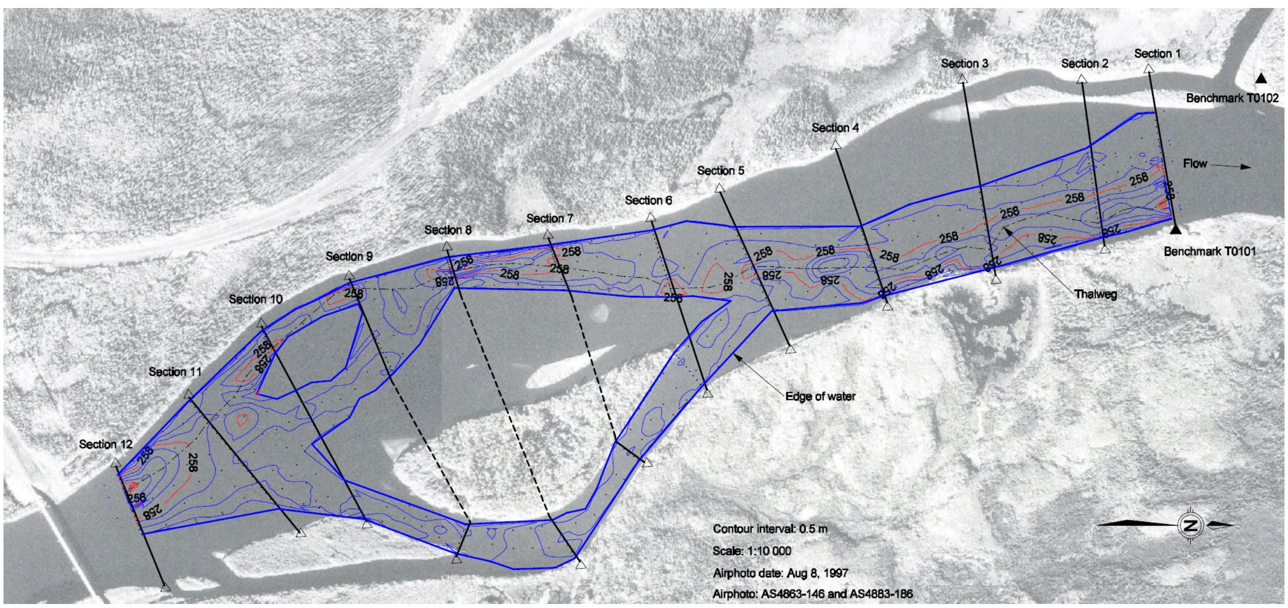


Figure 1: Layout of Athabasca River reach at Fort McKay below the Peter Lougheed Bridge

2.2 Reach of the Saskatchewan River

The location of the study site (53°14'40.8"N 105°19'04.2"W upstream to 53°14'57.0"N 105°17'20.3"W downstream) is on the North Saskatchewan River was at Garden River (Figure 2). The river reach has an average width of 190 m, and an average water slope of 0.00032. The bed materials are mainly cobble and boulders.

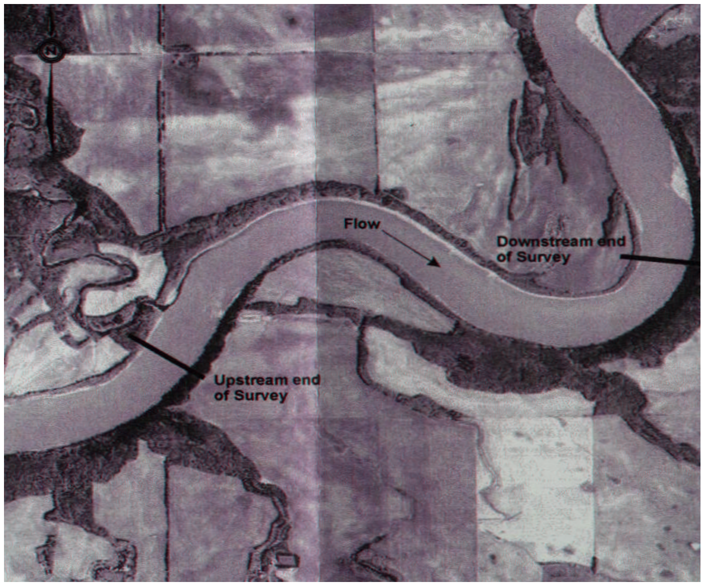


Figure 2: Aerial photos of Reach of North Saskatchewan River at Garden River

2.3 Reach of the Assiniboine River

The study site (49°49'10.1"N 99°48'33.6"W upstream to 49°48'17.5"N 99°48'07.2"W downstream) is located on the Assiniboine River at Brandon Riffles, Figure 3. The river reach has an average width of 55 m, and an average water slope of 0.002%. In the vicinity of the islands the river reach has an average width of 160 m. The bed materials are mostly large gravel, cobble and boulders. The reach is mild to steep and subject to mixed subcritical and supercritical flow regimes.

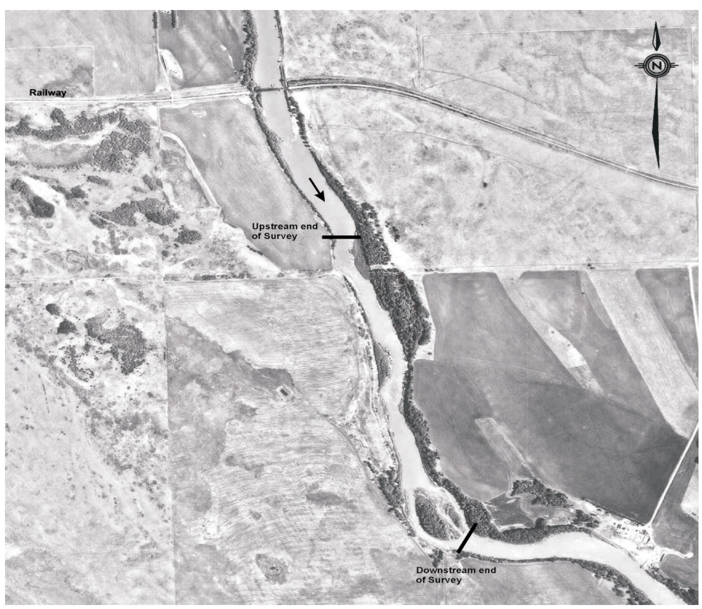


Figure 3: Aerial photos of Assiniboine River at Brandon Riffles

3 HYDRODYNAMIC MODELING

For each of the study reaches the River2D model was calibrated by comparing the predicted and measured water surface elevations along known cross-sections for the measured or surveyed flows (a single surveyed flow measured for each reach) (Figures 4 to 6). This was performed by varying the bed roughness along each reach until the simulated water surface elevation corresponded best with the measured water surface elevation. The model was considered calibrated when the difference between simulated and measured results was approximately 7% of the absolute average error and the root mean square error. The percentages of the average absolute error (%AAE) and root mean square error (%RMSE) in predicting the water surface were calculated as follows:

[1] $$\%AAE = \left(\frac{1}{N} \sum_{i=1}^{N} \left| \frac{WS_{Field}^{i} - WS_{Predicted}^{i}}{Depth_{Field}^{i}} \right| \right) \times 100$$

[2] $$\%RMSE = \left(\sqrt{\frac{1}{N} \sum_{i=1}^{N} \left(\frac{WS_{Field}^{i} - WS_{Predicted}^{i}}{Depth_{Field}^{i}} \right)^{2}} \right) \times 100$$

where *i* is the node number; *N* is the total number of nodes; *WS* is the water surface elevation; *Depth* is the water depth; *Field* is the measured value; and *Predicted* is the simulated value obtained by the River2D model. Subsequently, the adjusted bed roughness was used in all further modelling exercises. Figures 4 to 6 show the calibrations for the three reaches that compare fairly well between the predicted water surface profiles and the measured water surface elevation.

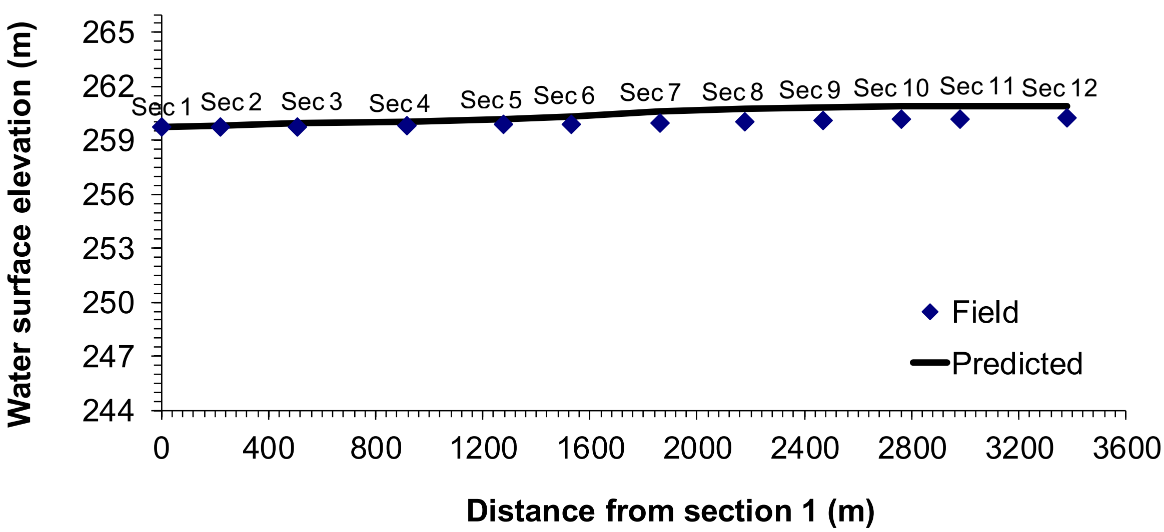


Figure 4: Comparison between the predicted or calibrated and field water surface elevations at Athabasca River at Fort Mackay

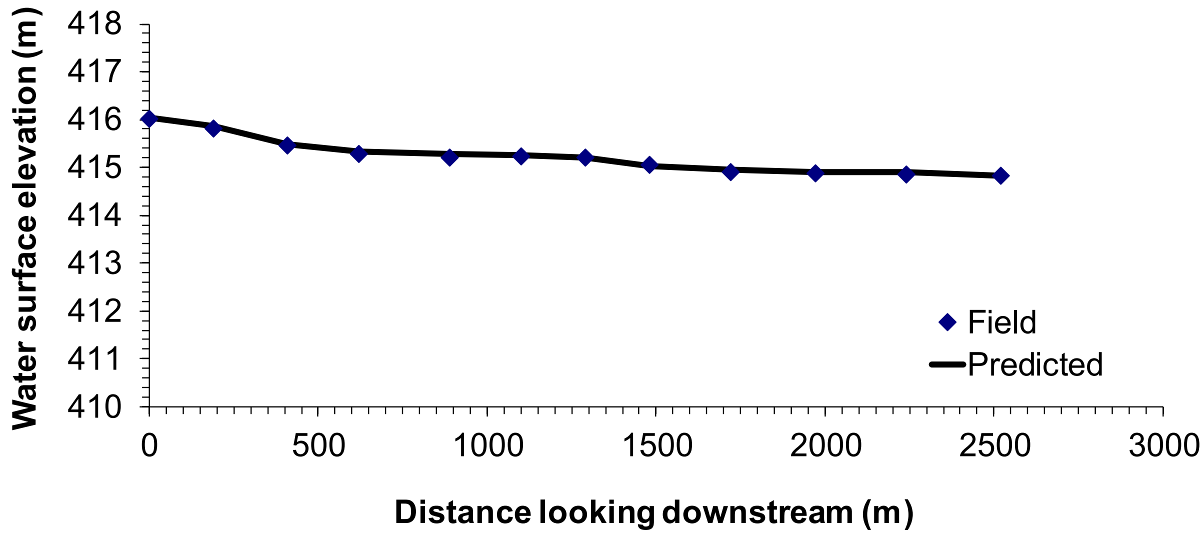


Figure 5: Comparison between the predicted or calibrated and field water surface elevations at Reach of North Saskatchewan River at Garden River

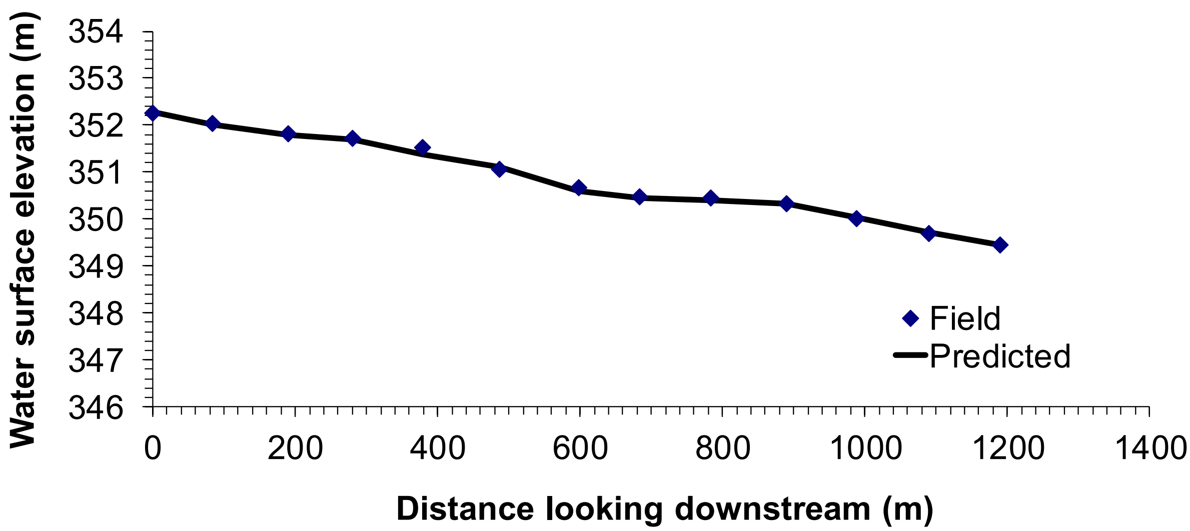


Figure 6: Comparison between the predicted or calibrated and field water surface elevations at Assiniboine River at Brandon Riffles

Once the roughness distributions were calibrated, the River2D model with its mesh generator were used for the different reaches under study to predict channel hydraulic characteristics such as the velocity, water surface elevation and depth for wide range of applied discharges, varying from 0.5 m^3/s to 2000 m^3/s.

For each study reach, model runs were set by specifying the boundary conditions as subcritical inflow and outflow, and no flow across the lateral river edge boundaries was applied. The upstream boundary condition supplied to the model was a uniformly distributed inflow discharge and the downstream boundary condition was a fixed downstream elevation. Model runs were iterated until steady-state solutions were achieved. Unstructured triangular finite element computational meshes were generated that best represented the field data inside each study reach. Typically, each reach was first defined by overlaying the entire surveyed area with a uniform spacing of nodes. Additional nodes were later placed around specific channel features considered important to the hydraulics and habitat of the different reaches of the study.

4 ESTIMATION OF INSTREAM FLOW NEEDS

The River2D model with its mesh generation and habitat analysis utilities were used to quantify the instream flow needs to meet the habitat suitability of the investigated fish species for the different study reaches. This was achieved by combining the detailed hydrodynamic modeling results coupled with expert-based biologically significant suitability metrics or with specific habitat use criteria to determine the “usable” habitat throughout the applied range of flows. The usable habitat was evaluated in a similar way to the IFIM Methodology’s PHABSIM (Bovee et al. 1998).

4.1 Weighted Usable Area Calculations

Weighted usable area refers to the weighting of the suitability values of velocity, depth and substrate or cover for a particular species or group of species with respect to the area of the habitat. The habitat requirements of nearly 25 fish species or life stages were investigated. Some examples of the results are illustrated in Figures 7 to 9.

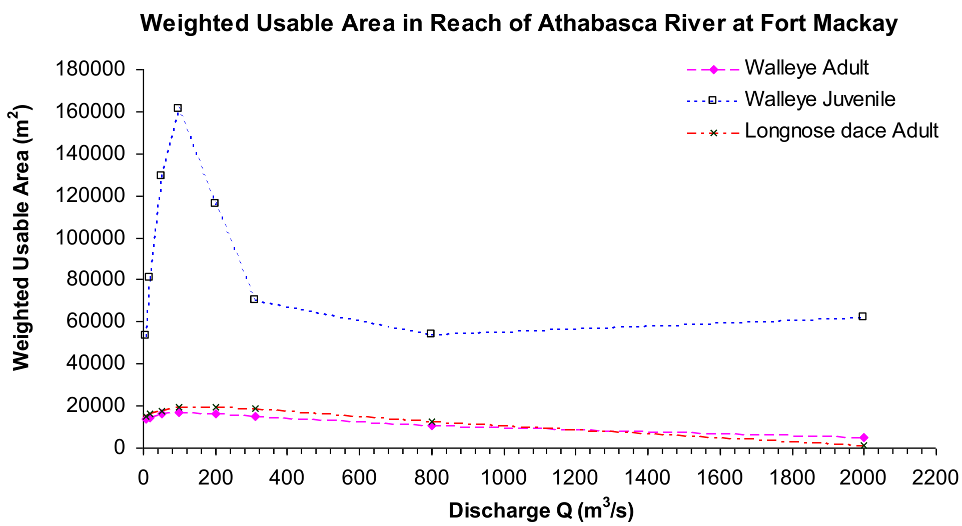
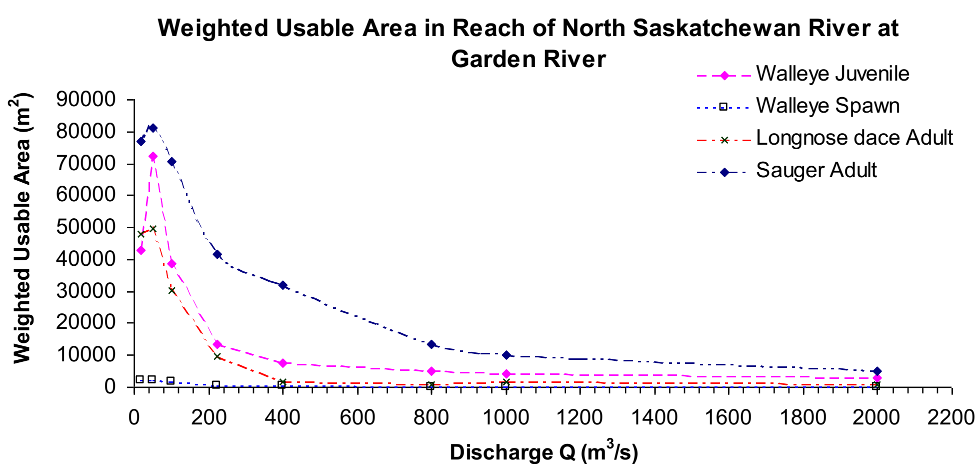


Figure 7: Examples of combined Weighted Usable Areas in in Reach of Athabasca River at Fort Mackay



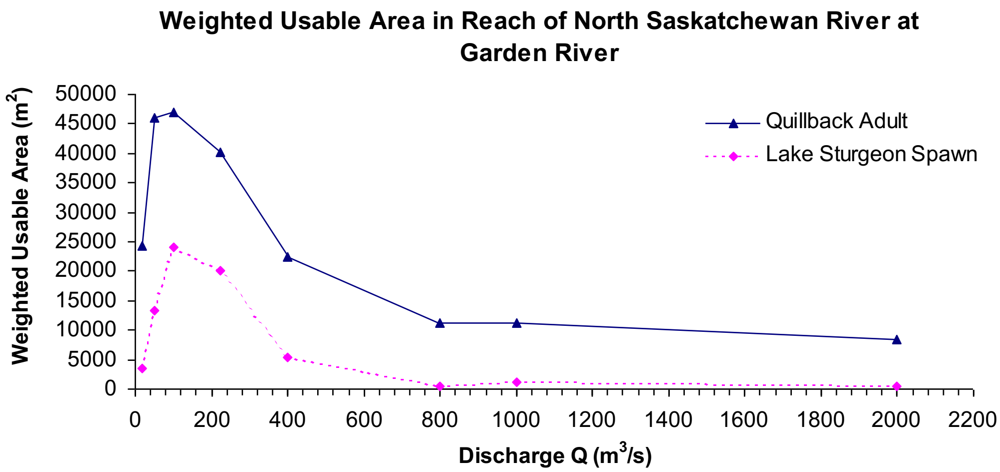


Figure 8: Examples of combined Weighted Usable Areas in Reach of North Saskatchewan River at Garden River

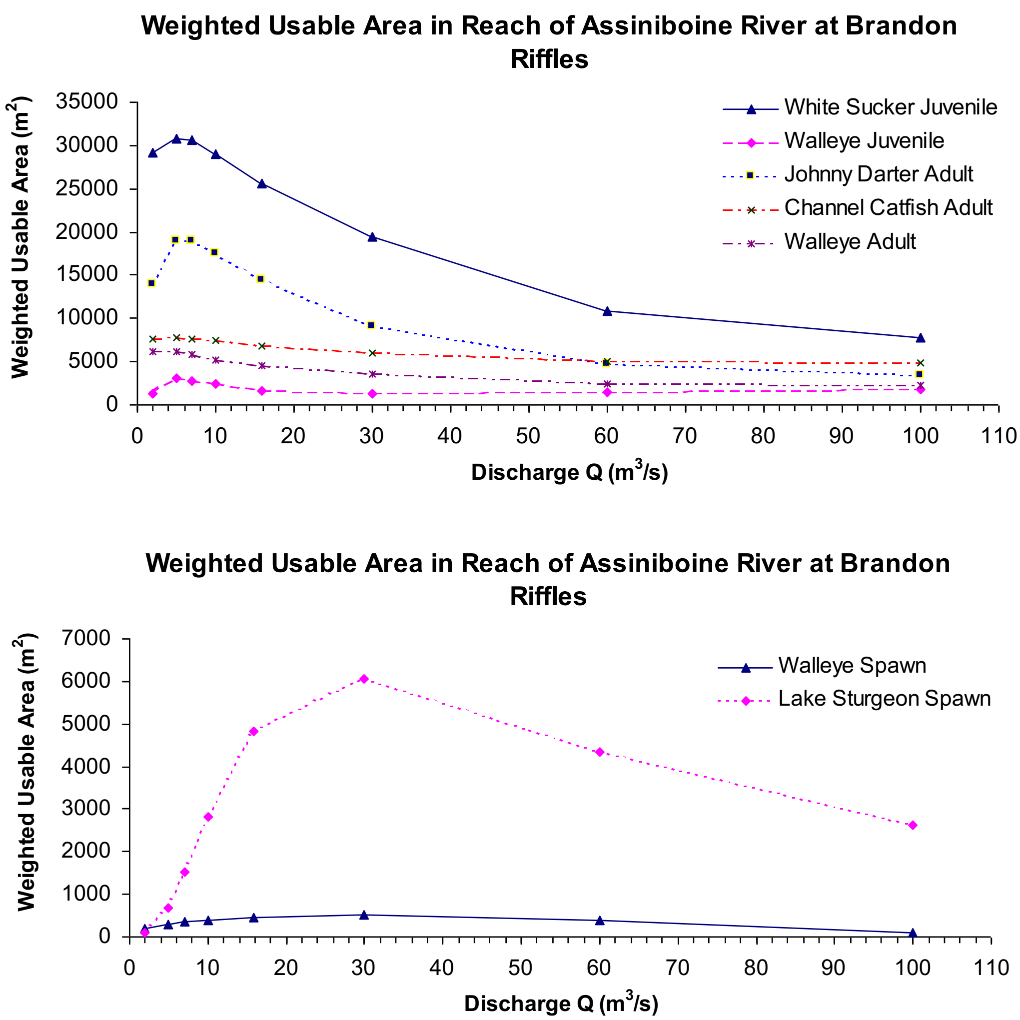


Figure 9: Examples of combined Weighted Usable Areas in Reach of Assiniboine River at Brandon Riffles

Figures 7 to 9 illustrates that, as the discharge increases the WUA increases to a possible peak for 90% of species; as the discharge increases further the WUA decreases. Discharge regimes for protecting individual species or life stages may be estimated from these curves. The same figures illustrate curves for different species, where WUA curves tended to peak at similar discharges. The output WUA graphs and Figures 7 to 9, suggest that critical or optimal instream flow needs (IFN) for fish habitat, where the curves peak at or are close to a peak, lie in the following ranges for each site: at Fort Mackay around 100 m^3/s; at North Saskatchewan River at Garden River, 20 to 100 m^3/s; and at Brandon Riffles, 5 to 30 m^3/s. This ichthyohydraulic simulation process should then predict the impact of different water management policies on the available habitat and lead to water management guidance.

5 CONCLUSIONS

The estimation of the instream flow needs (IFN) to protect or enhance fish life in three sites on the Athabasca, Assiniboine, and Saskatchewan Rivers in Canada was carried out in this study: one representative site on the Athabasca River below Peter Lougheed Bridge at Fort Mackay, one representative site on the North Saskatchewan River at Garden River, and one representative site on the Assiniboine River at Brandon Riffles. The typical complex channel geometry of the adopted study sites made it necessary to adopt a 2D hydrodynamic model for analyzing their different hydraulic and habitat characteristics, and consequently estimate instream flow needs for their different fish species.

The two-dimensional finite element model, River2D, was used to predict the channel hydraulic and physical habitat characteristics for the study sites. The model was run for various discharges, varied from 0.5 to 2000 m^3/s and was used to predict mainly discharges, velocities, depths and water levels. The model with its mesh generation and habitat analysis utilities were used to quantify the instream flow needs for several fish species for the three study sites. Almost twenty five fish species were investigated.

For the site of Athabasca River below Peter Lougheed Bridge at Fort Mackay, it was found that the instream operating flow needs for the ‘usable’ habitat areas ranges around 100 m^3/s. For the site of North Saskatchewan River at Garden River, it was found that the instream operating flow needs for the ‘usable’ habitat areas ranges from 20 to 100 m^3/s. For the site of Assiniboine River at Brandon Riffles, it was found that the instream operating flow needs for the ‘usable’ habitat areas ranges from 5 to 30 m^3/s. This ichthyohydraulic simulation process should then predict the impact of different water management policies on the available habitat and lead to water management guidance.

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