2-D Hydrodynamic Modeling of Riverine Fish Habitat - Case Study: Assiniboine River Sites, Manitoba, Canada

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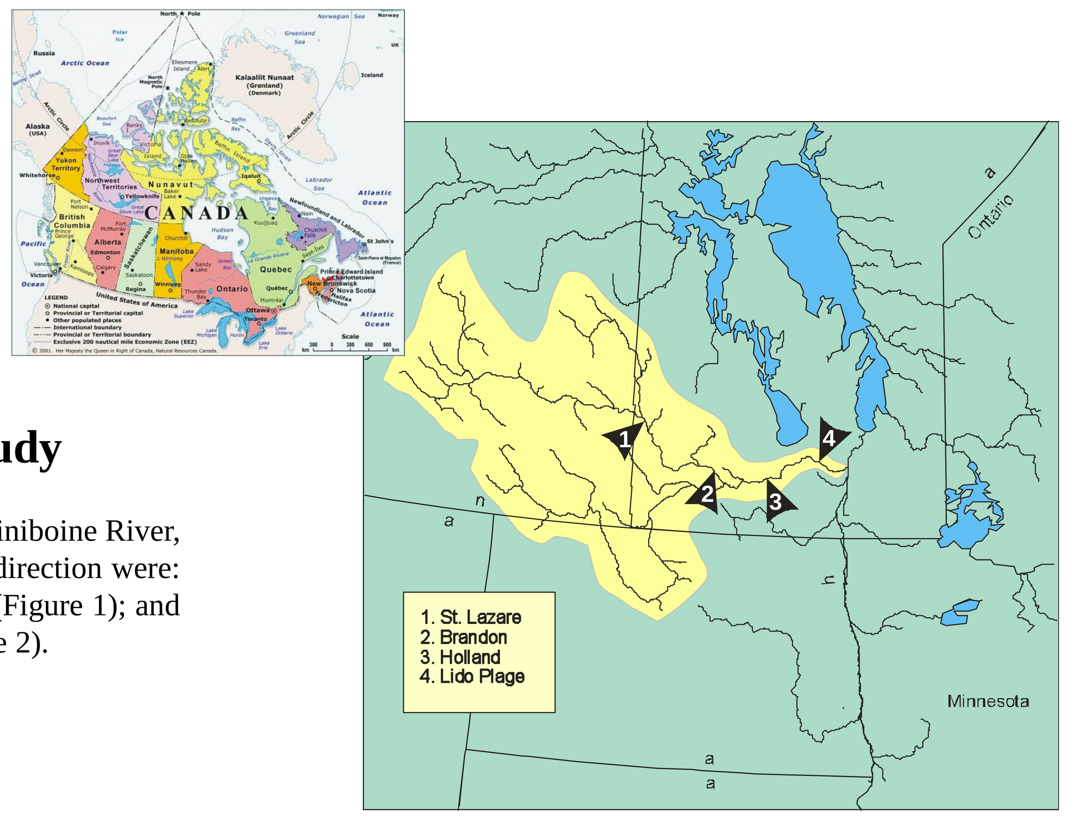
Abstract

Fish habitats represent some of the most difficult biological, topographic and hydrodynamic phenomena to evaluate and simulate in detail. However, computational advances may now allow reasonable and accurate hydraulic and biological model results in such challenging circumstances. The purpose of this study was to evaluate the suitability of habitat throughout a range of flows by combining detailed hydraulic modeling with species-specific habitat suitability criteria that can be used to protect or enhance fish life in the Assiniboine River, Manitoba, Canada. The two-dimensional finite element model, the RIVER2D (www.river2d.ca), was used to achieve these goals. Two reaches or study sites on the Manitoba portion of Assiniboine River were investigated. Model predictions were compared to detailed representative field measurements. The comparisons showed that the model performs reasonably well. The hydrodynamic results, coupled with biologically significant suitability metrics, were used to determine changes in fish habitat areas with discharge. This ichthyohydraulic simulation process provides water management guidance.

Sites under Study

The two sites located on the Assiniboine River, and moving in the downstream direction were: Reach 3, Hwy 34 near Holland (Figure 1); and Reach 2, Brandon Riffles (Figure 2).



Background

River engineering projects such as bridges, culverts, dams, water intake structures and channel modifications can potentially present harmful environmental conditions to fish, either by interrupting their migration routes or through changes to their natural habitat. 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 thus necessary, not only to model the physical features of the habitat, but also to understand other processes which can be limiting to fish existence. These parameters vary with discharge and as it is usually not feasible to take measurements for all possible discharges, hydraulic models many times are used to obtain estimates of these parameters for unmeasured flows.

While our understanding of the subtleties required to ensure a healthy and productive aquatic environment has improved through physical environmental research, the introduction of 2-dimensional numerical modeling offers the potential for analyzing the quality of complex aquatic habitats. Instream flow practitioners in provincial and federal agencies in Canada and the United States are becoming increasingly aware of the potential for use of 2-dimensional hydraulics in instream flow studies for better representation of instream habitat conditions.

The purpose of this study was to determine fish habitat suitability for two representative reaches on the Assiniboine River. The model RIVER2D and it's mesh generator were used to predict channel hydraulic characteristics such as the velocity, water surface elevation and depth for each reach of the study for wide range of applied discharges. Subsequently, the RIVER2D model with its mesh generation and habitat analysis utilities were used to quantify instream flow needs of the fish species for the study reaches on the Assiniboine River. 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

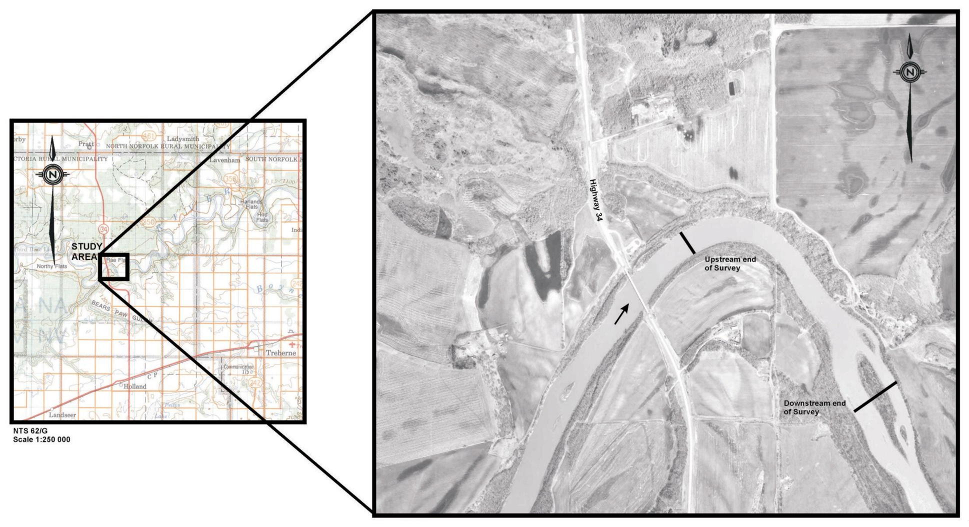


Figure 1 Aerial photo of Reach 3, Assiniboine River at Hwy 34 near Holland

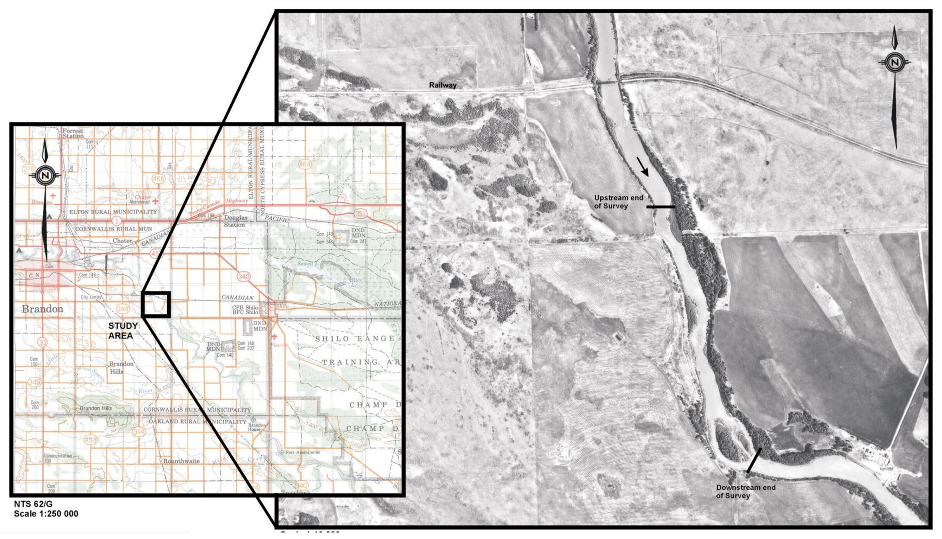


Figure 2 Aerial photo of Reach 2, Assiniboine River at Brandon Riffles

Methods

The model RIVER2D and it's mesh generator were used to predict channel hydraulic characteristics such as the velocity, water surface elevation and depth for each reach of the study for wide range of applied discharges. Subsequently, the RIVER2D model with its mesh generation and habitat analysis utilities were used to quantify instream flow needs of the fish species for the study reaches on the Assiniboine River. 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. The finite element mesh generated for each of the two reaches on the Assiniboine River are shown in Figures 3-4. The boundary conditions were specified, for all the study reaches, as subcritical inflow, subcritical outflow and no-flow across the side vertical walls. The upstream boundary condition supplied to the model is a uniformly distributed inflow discharge and the downstream boundary condition is a fixed downstream elevation. The no flow limits were defined at elevations above high water levels associated with the applied discharges.

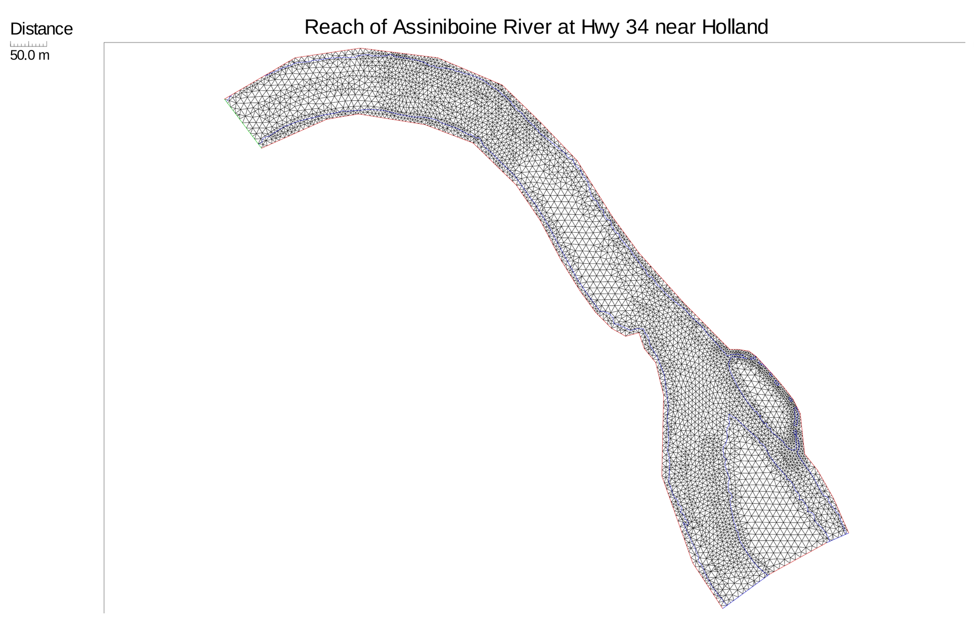


Figure 3 Finite element mesh generated for Reach 3, Assiniboine River at Hwy 34 near Holland

Figure 4 Finite element mesh generated for Reach 2, Assiniboine River at Brandon Riffles

Results

The output from the RIVER2D model was initially calibrated by comparing the simulated and measured flow water surface elevations along known cross-sections. This was performed by varying the bed roughness along each reach. The predicted water surface elevations along the reaches of study were compared to the corresponding field measurements, Figures 5 -6. The comparisons show that the model performs reasonably well.

Once the roughness distribution was calibrated, the model was run for different discharges, varying from 0.5 m^3/s to 100 m^3/s. The criteria for applying different discharges were that each discharge should fall within the given rating curve and that the output model results should be as accurate as possible. Figures 7-8 show examples of predicted water surface, depth, and velocity contours along the study reaches for different applied flows.

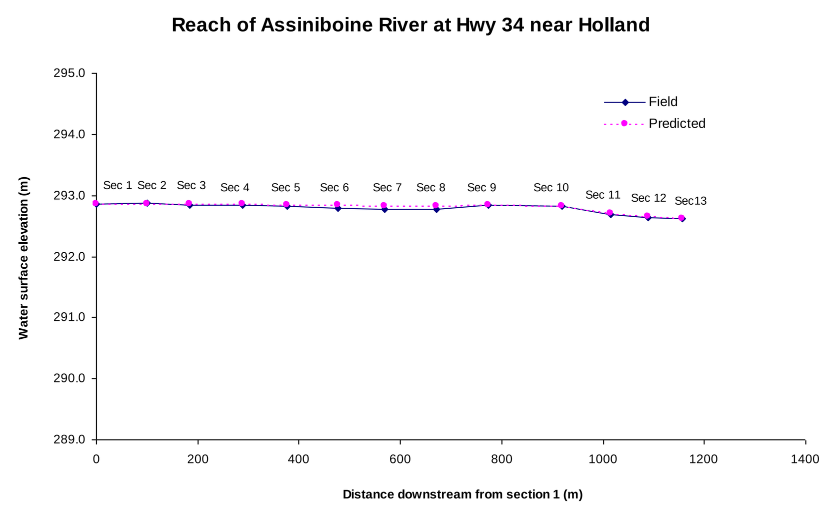


Figure 5 Comparison between the predicted and field water surface elevations for the calibration discharge at Reach 3, Assiniboine River at Hwy 34 near Holland

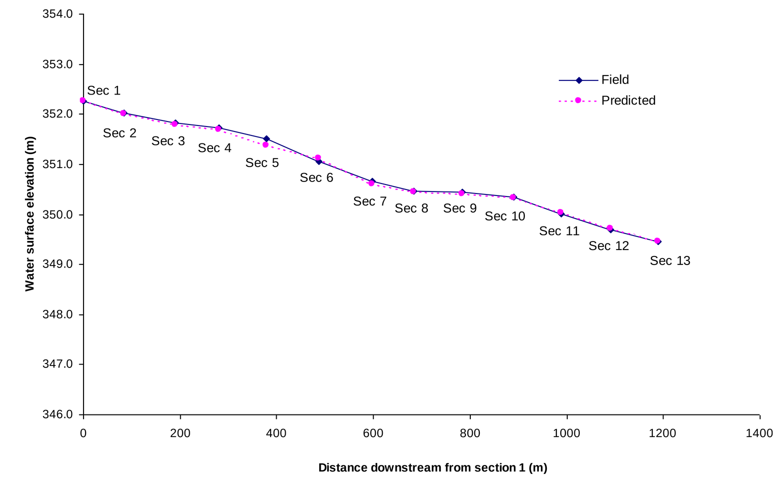


Figure 6 Comparison between the predicted and field water surface elevations for the calibration discharge at Reach 2, Assiniboine River at Brandon Riffles

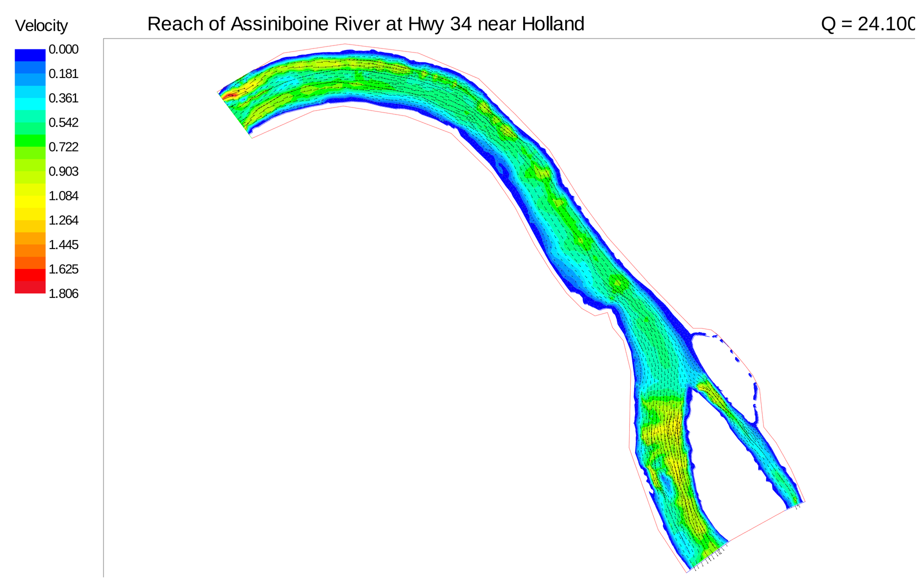


Figure 7 Predicted velocity contours along Reach 3, Assiniboine River at Hwy 34 near Holland (Q = 24.1 m^3/s)

Figure 8 Predicted water surface contours along Reach 2, Assiniboine River at Brandon Riffles (Q = 15.9 m^3/s)

Weighted Usable Habitat Areas

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 adopted habitat preference curves for the study reaches were those used by the Manitoba – DFO Assiniboine River IFN Working Group. The habitat requirements of twenty-five fish species or life stages were investigated and the results are illustrated in Figures 9-10. These figures show that typically for most species, as the discharge increases the WUA increases to a possible peak; 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. These WUA graphs suggest that critical or optimal flows for fish habitat, where the curves peak at or are close to a peak, lie in the following ranges for each site: Reach 3, at Hwy 34 near Holland (Figure 9), 5 to 24 m^3/s; and Reach 2, at Brandon Riffles (Figure 10), 5 to 30 m^3/s.

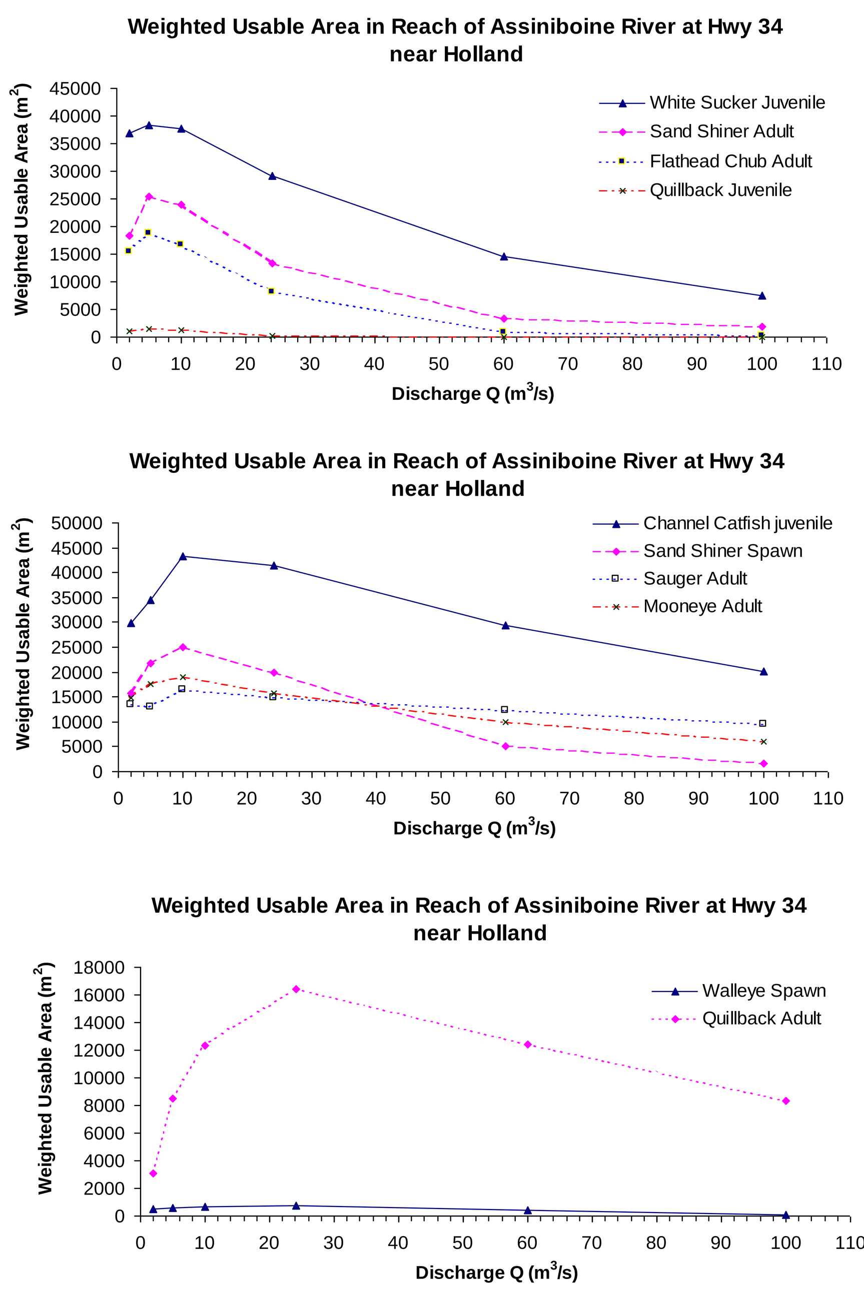


Figure 9 Combined Weighted Usable Area in Reach 3, Assiniboine River at Hwy 34 near Holland

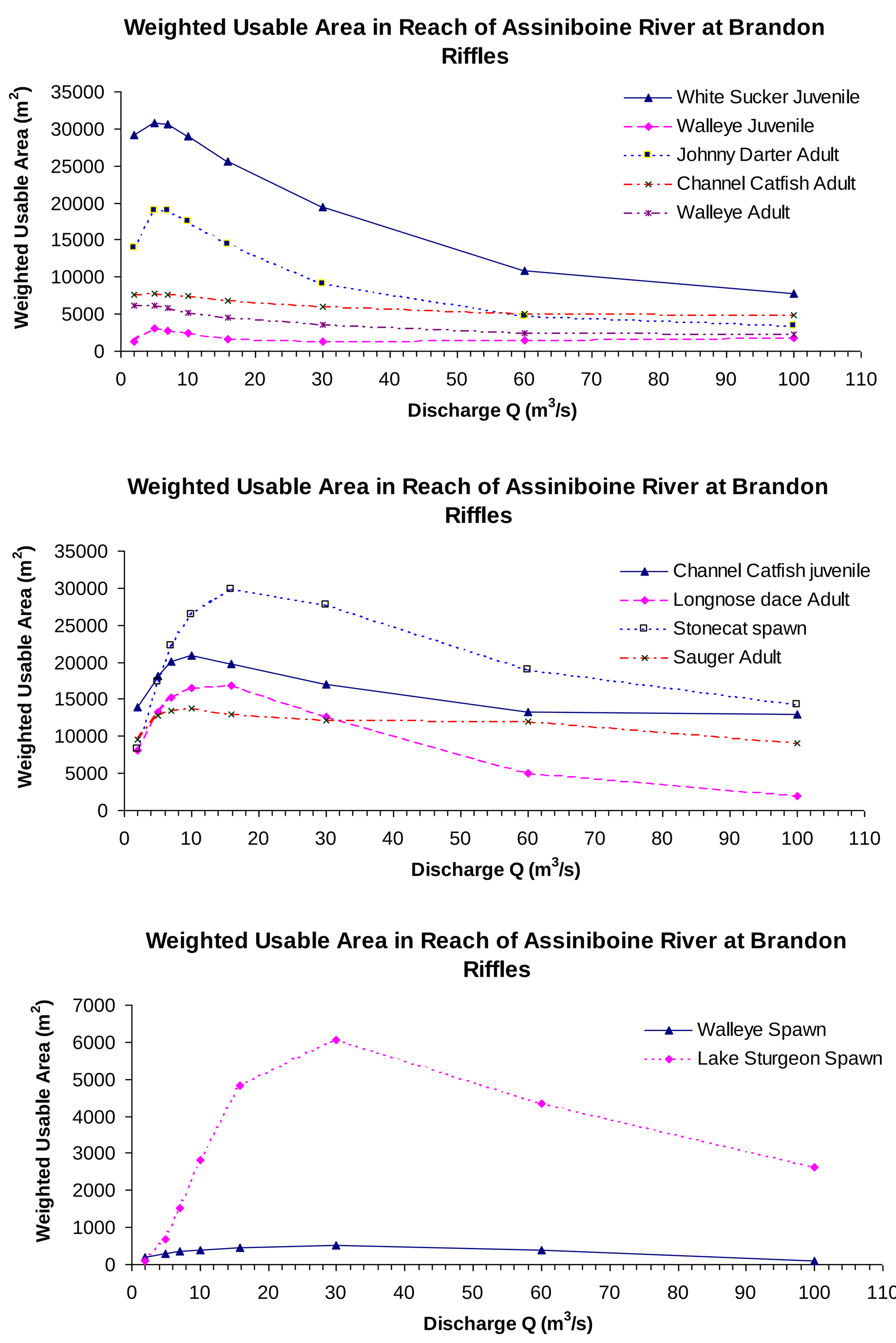


Figure 10 Combined Weighted Usable Area in Reach 2, Assiniboine River at Brandon Riffles

Conclusions

The complexity of channel geometry of the study sites on the Assiniboine River and the advantages of 2D hydrodynamic models, justified the use of RIVER2D for the analysis of hydraulic and habitat characteristics. After calibration with survey data, the model was used to predict river hydraulic and physical habitat characteristics for each of the two reaches in the Assiniboine River for unmeasured flows. A key element in this numerical simulation was the computational mesh. The RIVER2D automatic mesh generation routine was utilized to develop the two-dimensional finite element meshes. In all cases, the finite element grids were designed to have a fine enough mesh for reasonable accuracy while avoiding very long execution times.

The output from the RIVER2D model was initially calibrated by comparing the simulated and measured water surface elevations along known cross-sections. Generally, a good agreement was obtained between the numerical predictions and the experimental measured data. Once the roughness distribution had been adjusted to give a satisfactory match, the model was run for various discharges, ranging from 0.5 to 100 m^3/s. The model was then used to predict channel hydraulic characteristics, mainly discharges, velocities, depths and water levels. It can be concluded that the 2-D model appears to be able to reproduce the flow field with reasonably high accuracy.

The RIVER2D model, with its mesh generation and habitat analysis utilities, was also used to quantify the instream flow needs of fish for the two study reaches on the Assiniboine River. For the reach of Assiniboine River at Hwy 34 near Holland, further upstream, it was found that the instream flow needs for the 'usable' habitat areas range from 5 to 24 m3/s. A similar range of instream flows, from 5 to 30 m3/s, were also found for the further downstream reach of Assiniboine River at Brandon Riffles. The suitability of two-dimensional modeling methodologies for fish habitat evaluation was confirmed.