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Information to support the assessment of the Instream Flow Needs for Fish and Fish Habitat in the Saskatchewan River downstream of the E.B. Campbell Hydroelectric Station

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

The E.B. Campbell (EBC) Hydroelectric Station, owned and operated by SaskPower, was commissioned in 1963, and is operated as a hydropeaking facility on the Saskatchewan River near Nipawin, SK. SaskPower has requested a renewal of the Fisheries Act authorization for the station and the Fisheries and Oceans Canada Fisheries Protection Program is seeking science advice on Instream Flow Needs (IFN) to help inform a new Fisheries Act authorization. Prior to September 7, 2004 the station could release flows between ~0 m^3 s^{-1} to ~1,000 m^3 s^{-1}. A condition of the 2004 authorization was a minimum flow release of 75 m^3 s^{-1}. A DFO study report, as well as additional consultant reports, and primary literature publications are summarized in this Research Document to describe the impacts of EBC on downstream fish and fish habitat and to provide IFN recommendations to mitigate impacts on fish and fish habitat.

The natural hydrograph has been severely altered since the station was commissioned, in most part by upstream dams and diversions. EBC is a hydropeaking station and large areas of habitat are typically dewatered daily leading to stranding risk for different aquatic organisms and life stages. The size structure of the fish community downstream of EBC is biased toward large bodied fish, likely due to flow operation and the presence of the dam functioning as a barrier to fish movement. Habitat Suitability Criteria suggest minimum instantaneous flows >75 m^3 s^{-1} at specific Biologically Significant Periods may benefit fish. In addition, the recovery of Lake Sturgeon may profit from maintaining a high minimum instantaneous flow >700 m^3 s^{-1} during the first two weeks of the spawning period to maximize potential recruitment success. Rapid down-ramping is likely to increase the risk of fish stranding, specifically when discharges are <500 m^3 s^{-1}. Consequently, a down-ramping regulation could be established to minimize stranding. At flows >1,000 m^3 s^{-1}, the spillway is used. When spill flow resides, fish stranding occurs in the spillway. Adding continuous flow to the spillway could eliminate the need to conduct fish salvage within the spillway. This measure would also increase the available wetted habitat. Re-sculpturing the river edges and the riverbed in the former river channel to connect isolated pools and reduce the bed elevation to below 278.55 m above sea level may also be considered to reduce stranding. Allowing occasional flows >1,000 m^3 s^{-1} will provide additional flooding and connectivity in the Saskatchewan River Delta and the potential to increase fishery productivity in the Saskatchewan River system.

INTRODUCTION

Fisheries and Oceans Canada's Fisheries Protection Program (FPP) manages impacts on fisheries productivity related to habitat degradation or loss and alterations to fish passage and flow. For projects that are expected to have impacts on fisheries productivity, FPP administers letters of advice or Fisheries Act authorizations that provide guidance on how to avoid or mitigate any impacts and requirements for restoration and offsetting where impacts are unavoidable and cannot be mitigated.

The E.B. Campbell (EBC) Hydroelectric Station, owned and operated by SaskPower, is a hydropeaking facility on the Saskatchewan River near Nipawin, SK. SaskPower has requested a renewal of the EBC's Fisheries Act authorization. Consequently, FPP is seeking science advice on Instream Flow Needs (IFN) to help inform a new Fisheries Act authorization, including measures to avoid, mitigate, and as necessary, offset death of fish and alterations to fish habitat as a result of the ongoing operations of the existing facility.

EBC was commissioned in 1963 and operated as a hydropeaking station with no minimum flow requirements until September 7, 2004. Instantaneous flow through EBC may have been ~0 $m^3 s^{-1}$ and increased up to ~1,000 $m^3 s^{-1}$ on a given day. Flows out of Tobin Lake greater than approximately 1,000 $m^3 s^{-1}$ are released through the spillway channel, a ~5.6 km reach of the pre-1963 former river channel that is now bypassed by EBC. In 2003, Fisheries and Oceans Canada (DFO) Fish Habitat Management (FHM; now the Fisheries Protection Program (FPP)) and SaskPower completed negotiations to address an ongoing Harmful Alteration, Disruption or Destruction (HADD) of fish and fish habitat occurring in the Saskatchewan River downstream of EBC, which resulted in DFO issuing a formal authorization under Subsection 35(2) and Section 32 of the Fisheries Act that came into effect on August 30, 2005. A condition of the authorization was a minimum instantaneous release of 75 $m^3 s^{-1}$.

In addition, a Research Partnership Agreement was developed among SaskPower, DFO FHM, DFO Science, Saskatchewan Environment, Saskatchewan Watershed Authority, and the University of Regina to study the impacts of the new hydropeaking operation of 75 $m^3 s^{-1}$ minimum releases on fish and fish habitat. This research spanned from April 2005 to March 2007 and resulted in an unpublished 2008 DFO report. The results from this report, as well as additional consultant reports from studies initiated by SaskPower, theses, and primary literature publications are summarized in this Research Document.

In March 2012, DFO provided national guidance on IFN (i.e., +/- 10% of instantaneous flow; 30% of mean annual discharge), but cautioned that when data are available, a more detailed technical examination is required on the effectiveness of the recommended thresholds (DFO 2013). DFO (2013) also noted that these guidelines did not apply to hydropeaking plants. Consequently, the purpose of this Research Document is to describe the impacts of flow regulations at the EBC on downstream fish and fish habitat and to provide IFN recommendations.

The specific objectives are to:

1. Describe the Biological Significant Periods (BSP) and Habitat Suitability Criteria (HSC) for key fish species in the Saskatchewan River;
2. Analyze the changes in the natural hydrograph due to the hydropeaking operations of EBC;
3. Summarize the impacts of the flow alterations on fish, fish habitat, and the Saskatchewan River ecosystem and channel morphology; and,

4. Provide recommendations for adjustments to the hydropeaking operation to minimize impacts on fish and fish habitat.

E.B. CAMPBELL HYDROELECTRIC STATION

The 550 km long Saskatchewan River is a major river situated in Central Canada, flowing eastward across the provinces of Saskatchewan and Manitoba into Lake Winnipeg. Through its tributaries the North Saskatchewan and the South Saskatchewan, the 335,900 km^2 watershed of the Saskatchewan River encompasses much of the prairie regions of Central Canada, stretching westward to the Rocky Mountains in Alberta and north-western Montana in the United States. EBC is a hydroelectric power station on the Saskatchewan River owned by SaskPower, located near Nipawin, Saskatchewan, Canada (Figure 1). The Generating Station was commissioned in 1963 and has eight turbine units in total with a combined generating capacity of 289 MW. The construction of the dam created an artificial reservoir, Tobin Lake, and altered flows and the water levels in the Saskatchewan River up- and downstream of EBC. Tobin Lake has limited water storage, as the reservoirs water surface is maintained between 312-313.64 MASL (meters above sea level). EBC is essentially a run-of-the-river hydro facility. However, the Generating Station is operated on a hydropeaking regime to balance fluctuating power requirements for the Province of Saskatchewan on a daily or hourly basis. Consequently, EBC was operated on a hydropeaking regime that ranged from 0 to 1,000 m^3 s^{-1} prior to 2004 with a maximum outflow of ~1,000 m^3 s^{-1}. When the discharge out of Tobin Lake exceeds ~1,000 m^3 s^{-1}, the excess water is released over a spillway into a ~6 km section of former river channel. On September 7, 2004, the operation was changed to include a minimum flow of 75 m^3 s^{-1}and the station discharge ranges now from 75 to 1,000 m^3 s^{-1}.

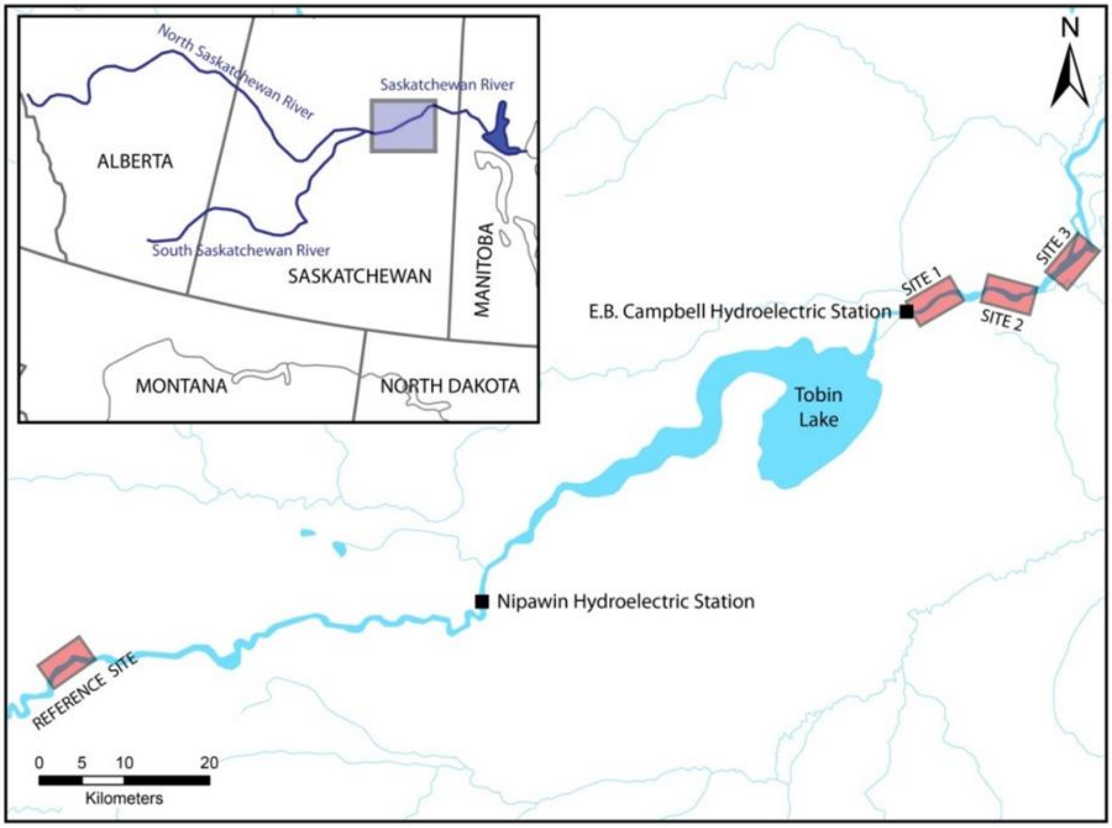

Figure 1. Map of study site locations in the Saskatchewan River, Saskatchewan (from Enders et al. 2017).

BIOLOGICALLY SIGNIFICANT PERIODS

In November 2005, a steering committee workshop was held in Prince Albert, SK to develop Biologically Significant Periods (BSP) for all life stages of the fish species of interest in the Saskatchewan River downstream of EBC by week of the year. Similar to “phases” developed by Enders et al. (2009), a BSP is a continuous period of time in which a specific combination of species and life stages/functions occurs. BSP are used in the evaluation of the impacts of flow alterations on fish and fish habitat.

Spawning temperature preference ranges for the different fish species were determined from literature and based on the experience of participants in the workshop. Four BSP were defined (Table 1). The choice of weeks for spawning BSP was based on the participants’ knowledge of regional norms of water temperature for the Saskatchewan River during spawning activities.

Based on the fact that floods could historically, arrive after June 24th which would coincide with the juvenile fish rearing period for many species spawning earlier in the year, a decision was made during the regional peer review of the Assessment of the Instream Flow Needs for fish and fish habitat in the Saskatchewan River downstream of EBC held on May 9-10, 2018 to extend BSP3 to July 24th, which is Day 205 and the time when flows would historically have begun declining.

The BSP was then used to partition flow records for modelling of fish habitat and to evaluate potential effects of hydropeaking on fish. To better approximate environmental variation year to year and within a year, BSP could be set based on environmental conditions such as running averages of water temperature and/or flow. These may be beneficial from a biological and operational standpoint.

Table 1. Biological Significant Periods for fishes in the Saskatchewan River based on the results of the November 2005 Prince Albert, SK workshop and a regional peer review in May 2018 in Winnipeg, MB (*).

Biological Significant Period	Period	Life Stage Function
1	15 Oct to 29 Apr	Fall and winter spawners; Overwintering
2	30 Apr to 27 May	Early spring spawners
3	28 May to 10 Jun	Lake Sturgeon spawning
	11 Jun to 24 Jul*	Spring spawners
4	25 Jul to 14 Oct	Growing season

ABIOTIC IMPACTS

HYDROLOGY

Flow is considered the “master variable” that connects important ecological functions and influences overall ecosystem function (DFO 2013). These include: hydrology, biology, geomorphology, connectivity (including the influence of groundwater), and water quality. Ecological flow requirements for fisheries should not be considered in isolation from other flow-related variables (e.g., temperature, dissolved oxygen, nutrients; DFO 2013). To understand the potential impacts of EBC on the aquatic ecosystem, a review of hydrological changes due to EBC operation is necessary.

The natural flow regime of a watershed is characterized by the magnitude of discharge, duration, frequency, timing, and rate of change (Poff et al. 1997). Flow regulates both the physical and the ecological processes of the river ecosystem and many channel and floodplain habitat features are formed and maintained by dominant seasonal discharges (Poff et al. 1997). In addition, the food organisms, nutrients, and other aspects of fish habitat that support fish production in rivers are controlled and influenced by flow (Junk et al. 1989, Poff et al. 1997). Alteration of flow in a river system can therefore have profound impacts on fish and fish habitat.

Historic flow records (ECCC 2018) can be compared to present day flow records to assess the changes that have taken place as a result of the operation of dams on the Saskatchewan River system. Prior to 1962, a gauge did not exist downstream of EBC. Therefore, the data from the South Saskatchewan River (05HG001) and North Saskatchewan River (05GG001) was combined to represent the 1912-1963 flow on the Saskatchewan River prior to the operation of EBC (Figure 2). Data from 1962 and 1963, the year EBC was commissioned, was not used as Tobin Lake was filling. Daily average discharge from 1964-2015 was used to summarize the hydrograph downstream of EBC (05KD003). Mean daily discharges were calculated to examine changes (1) prior to 1963, (2) post 1964 to September 6, 2004, and (3) from September 7, 2004 to 2015 (Figure 3).

The 1912-1963 South Saskatchewan River and North Saskatchewan River combined period of record had a mean daily discharge of 521 m^3 s^{-1}. During 1964-2004, the mean daily discharge was 443 m^3 s^{-1}. From 2004-2015, mean daily discharge was 538 m^3 s^{-1} (Figure 3). This wetter period since September 7, 2004 accounts for some of the differences observed between the 1964-2004 and 2004-2015 flow records.

The mean daily discharge for 1964-2004 and 2004-2015 has a threefold increase in BSP1 discharges while BSP2, 3, and 4 are all less than in the 1912-1963 period (Figure 3). This difference is attributable to a modification of the natural hydrograph upstream. In order of magnitude these include Coteau Creek Hydroelectric Station on the South Saskatchewan River starting in 1969, operation of the Brazeau and Bighorn dams in Alberta, commissioned in 1965 and 1972, respectively, as well as diversions in Alberta on the North Saskatchewan River, Alberta diversion from the South Saskatchewan River, and finally storage and diversion from Tobin Lake, SK. Recommendations to modify the annual hydrology will likely need to consider these dams and diversions upstream of EBC given their influence on the natural hydrograph.

Since September 7, 2004, BSP1 flows have remained similar to the 1964-2004 period but higher flows have been observed for the end of BSP3 and the beginning of BSP4 when large floods occurred. This overall increase in mean annual discharge since September 7, 2004 is important to consider when reviewing exceedance data as generally more water (~18%) has been available for management since the 1964-2004 period.

Hassanzadeh et al. (2017) studied the vulnerability of the Saskatchewan River Delta (Figure 2) to changing streamflow regime and irrigation expansion and found the flow regime in the Saskatchewan River Delta is more sensitive to upstream changes in annual flow volume than peak flow timing and/or irrigation expansion. The sensitivity to changes in flow volume may be intensified when combined with changes in peak timing as shifts in the upstream peak flow timing can alter the magnitude and timing of peak flow to the Saskatchewan River Delta. This can affect aquatic biota adapted to historical rhythmicity in peak flows and timing and results in more frequent isolation of lakes and wetlands from the main stream (Baschuk et al. 2012, Hassanzadeh et al. 2017). Discharges <1,000 m^3 s^{-1} result in water conveyed mostly through stream channels with little inundation occurring (Sagin et al. 2015). The flooded area during peak summer in the Saskatchewan River Delta has gradually declined over the past century, likely due to water capture and storage, followed by winter water releases, combined with declining inflows (St. Jacques et al. 2010). Declines in flows that allow for connectivity of floodplains can result in reduced fish productivity in regulated basins (van de Wolfshaar et al. 2011).

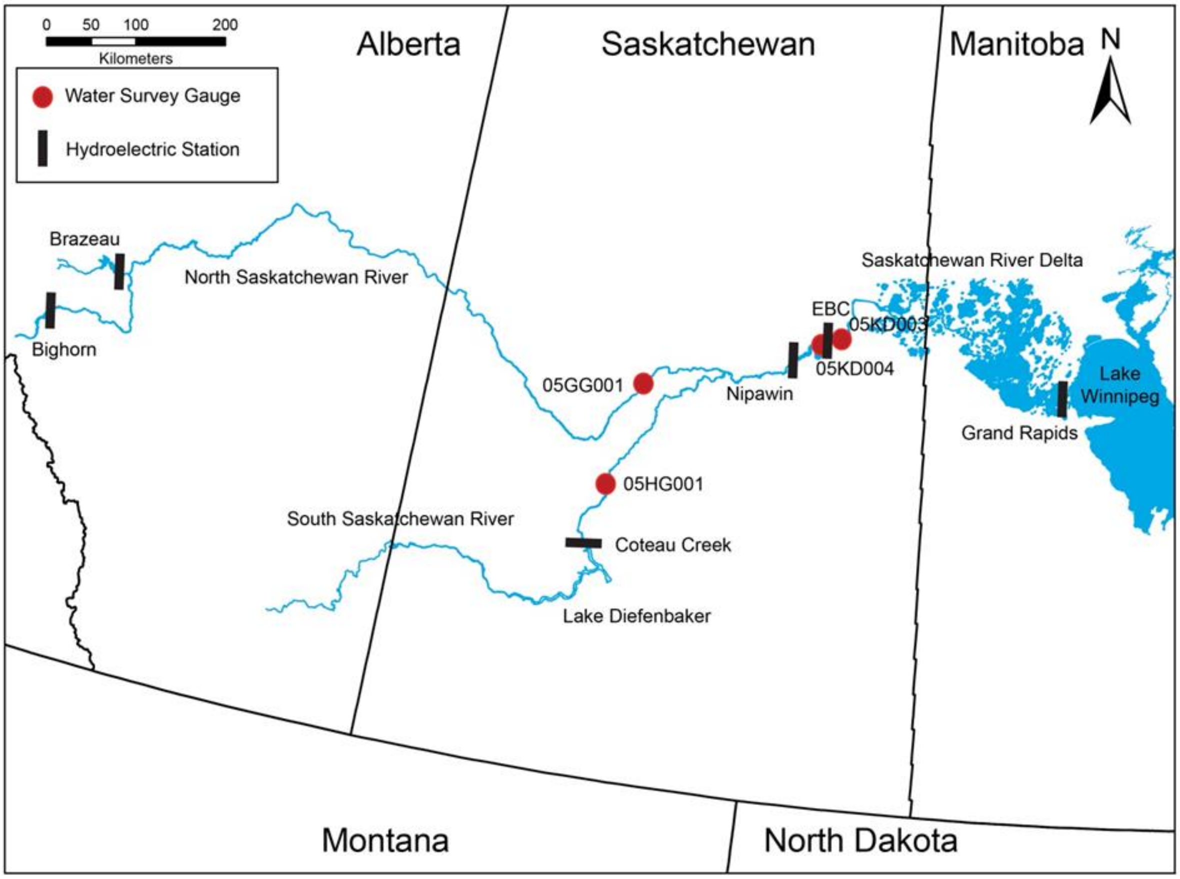

Figure 2. Map of the North Saskatchewan, South Saskatchewan, and Saskatchewan rivers as well as the Saskatchewan River Delta. Water survey gauges and hydroelectric stations referenced in this paper are indicated.

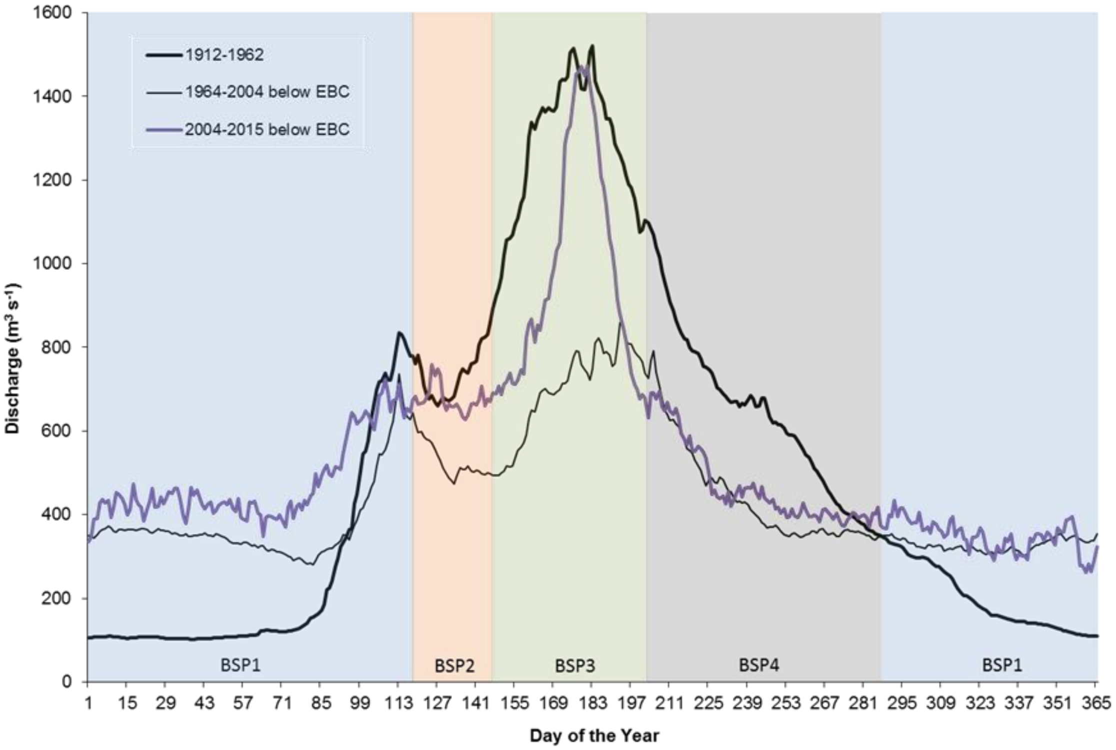

Figure 3. Comparison of the "natural flow" of the Saskatchewan River (South Saskatchewan and North Saskatchewan rivers combined) for 1912-1963 and recent flows for 1964-2003 and 2004-2015 downstream of E.B. Campbell.

HYDROPEAKING

Given that EBC is a hydropeaking station consideration needs to be given to not only seasonal, but also daily and hourly changes in discharge. Hourly discharge and water surface elevation data from 1996 to 2017 at the gauging station 05KD003 (Figure 2) was obtained (Environment and Climate Change Canada, National Hydrological Services, Water Survey of Canada, Stephanie Pow, personal communication). The records before 1996 are not digitized and therefore not considered in this document, however, they are available. In this document, we used the near continuous record from 2001 to 2017 for all subsequent summaries of hourly flow. Missing days were simply not included in the summary (i.e., 33 days prior to September 7, 2004; 47 days after).

The flow at EBC varies on a daily cycle with low flows typically occurring between late evening and early morning (Figure 4). Since the September 7, 2004 minimum flow requirement has been put in place, the median, 25th and 75th percentile flows increased across all hours in all BSP (Figure 4). Most of the minimum flows have also increased across nearly all hours and BSP with the exception of some time periods in BSP2. The minimum flow since September 7, 2004 has been <100 $m^3 s^{-1}$ for only 1.1% of all hourly discharges, this is higher than the prescribed minimum flow of 75 $m^3 s^{-1}$. The median flows have been >150 $m^3 s^{-1}$ across all BSP and most hours of the day with the exception of 8h00 to 12h00. The increase in flows is in part a response to the 2004-2017 period having higher average annual discharges (Figure 3).

DFO (2013) made recommendation for a rigorous assessment when alterations to flow were (1) +/- 10% of the magnitude of actual (instantaneous) flow and (2) flows can be reduced to <30%

mean annual discharge (i.e., ~160 $m^3 s^{-1}$; Figure 3). These flow rules were not intended for hydro peaking facilities. Hydro peaking flows are highly complicated both ecologically and economically, and the associated issues are typically unique to each situation (DFO 2013). A rigorous assessment should be conducted to evaluate potential flow impacts on ecosystem structure and function that support fisheries.

Water surface elevation changes at gauge 05KD003 are most significant in BSP1, 2, and 4 when seasonal flows are typically lower (Figure 5). Consequently, the risk of fish stranding may be higher in these BSP.

In addition to daily variation, flow also varies on a weekly basis with lower daily maximum and minimum flows being released on the weekend when demand for power is lower (Figure 6). Since some aspects of a fish's life history are sedentary (i.e., eggs, larva) and do not complete development within seven days, this underlying weekly cycle needs also to be considered when determining effects of hydropeaking.

When hourly discharge data are examined from 2001-September 6, 2004 and September 7, 2004-2017, the average daily minimum flows have increased for every day of the year from 65 to 315 $m^3 s^{-1}$. The maximum peaking flow is correspondingly higher for nearly every day in BSP2, 3, and 4 and most days in BSP1, with an average of 625 $m^3 s^{-1}$ for 2001-September 6, 2004 and 771 $m^3 s^{-1}$ for September 7, 2004-2017 (Figure 7). When minimum flow recommendations were made in 2004, it was predicted that with a minimum flow requirement, less water would be available to allow for large differences in daily peaking rates. As predicted, the range of flows for average peaking rates has generally decreased post implementation of the minimum flow regulations across all BSP with the most improvement occurring in BSP2 and 3 (Figure 8). These increases are not independent of the high annual discharges that have been observed since September 7, 2004. Floods have increased the mean minimum and maximum daily flows for the end of BSP1, all of BSP2 and 3, and the beginning of BSP4.

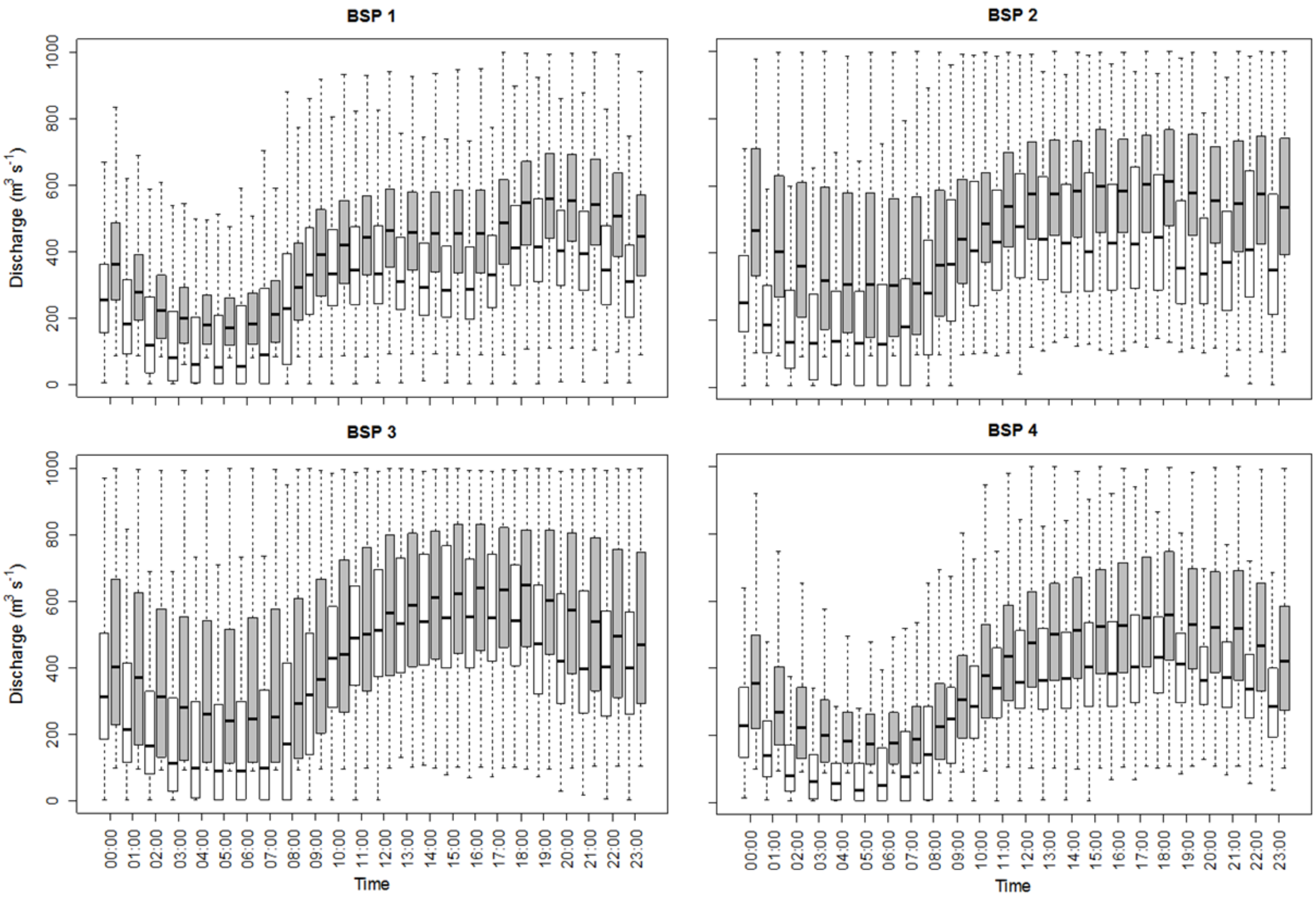

Figure 4. Hourly discharge for each BSP, pre (open bars) and post (grey bars) the September 7, 2004 minimum flow requirements of EBC, gauge 05KD003. The box extends from the 25th to 75th percentile of observations [interquartile range (IQR)], with the center line indicating the median. The bars define the upper and lower adjacent values, defined as 75th percentile + 1.5 IQR and 25th percentile – 1.5 IQR. Outliers were omitted from this plot.

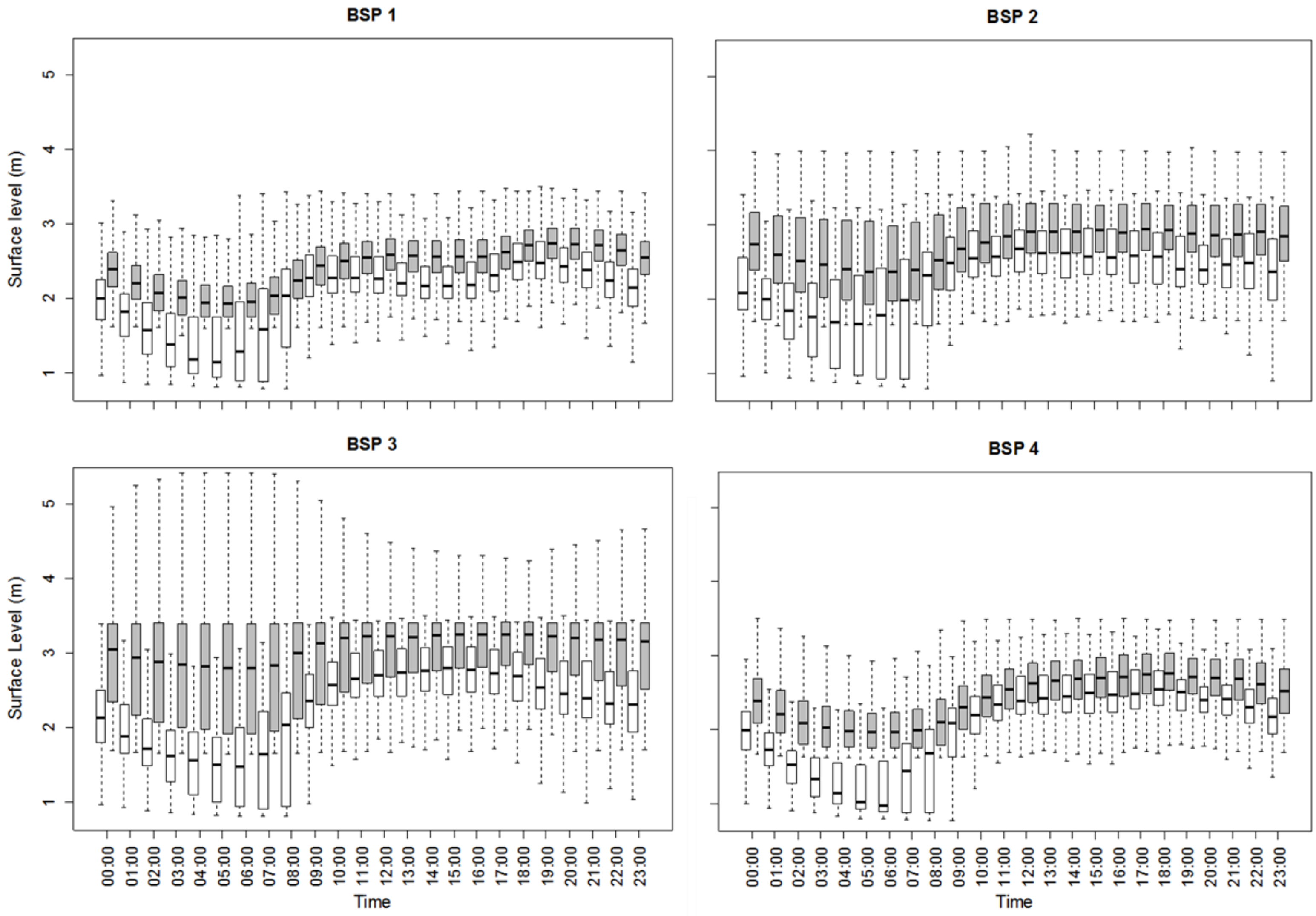

Figure 5. Hourly changes in water surface elevation for each BSP, pre (open bars) and post (grey bars) the September 7, 2004 minimum flow requirements of EBC, gauge 05KD003. The box extends from the 25th to 75th percentile of observations [interquartile range (IQR)], with the center line indicating the median. The bars define the upper and lower adjacent values, defined as 75th percentile + 1.5 IQR and 25th percentile – 1.5 IQR. Outliers were omitted from this plot.

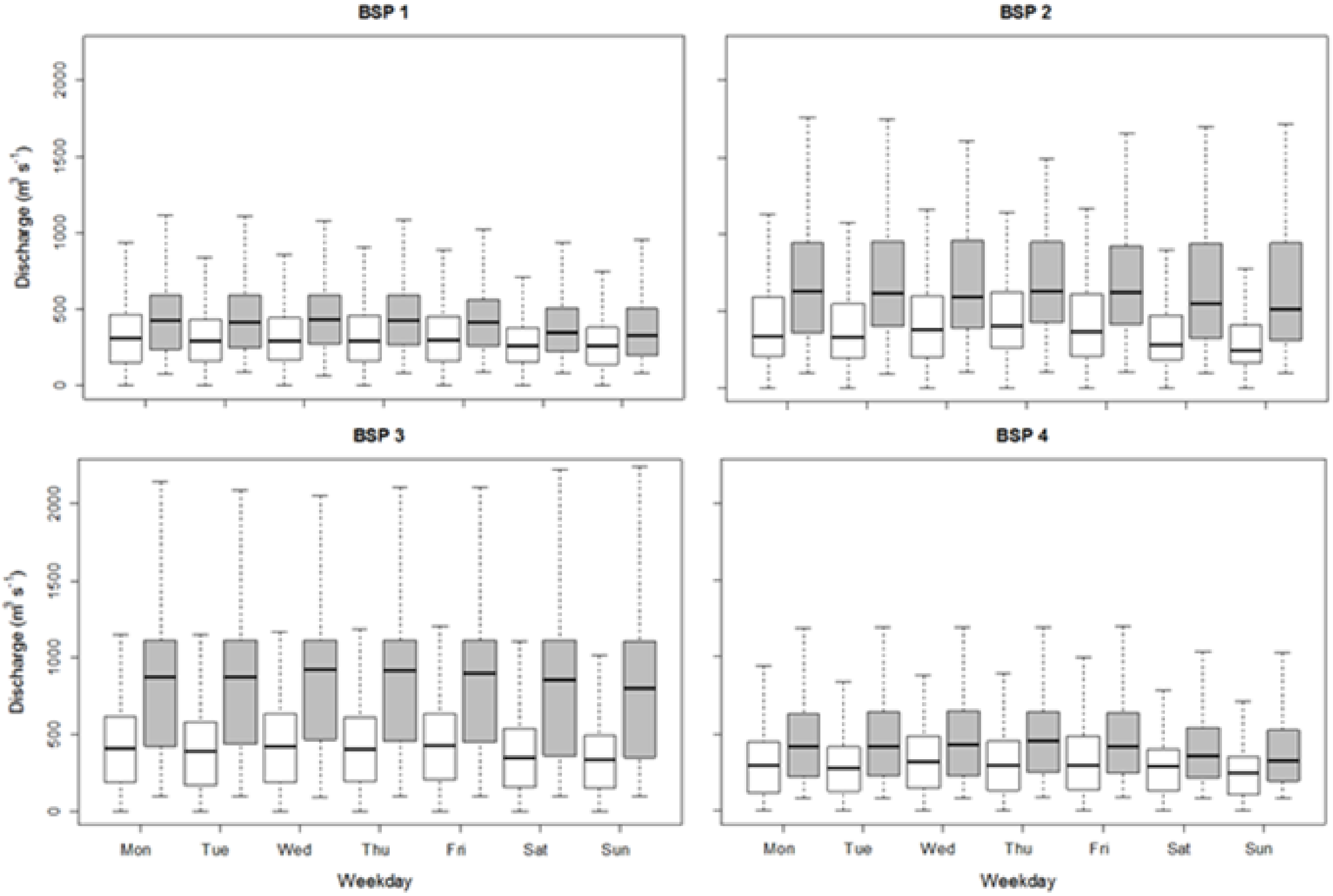

Figure 6. Bar plots of hourly discharge per day of the week, for each BSP, pre (open bars) and post (grey bars) September 7, 2004 minimum flow requirements, gauge 05KD003. The box extends from the 25th to 75th percentile of observations [interquartile range (IQR)], with the center line indicating the median. The bars define the upper and lower adjacent values, defined as 75th percentile + 1.5 IQR and 25th percentile – 1.5 IQR. Outliers were omitted from this plot.

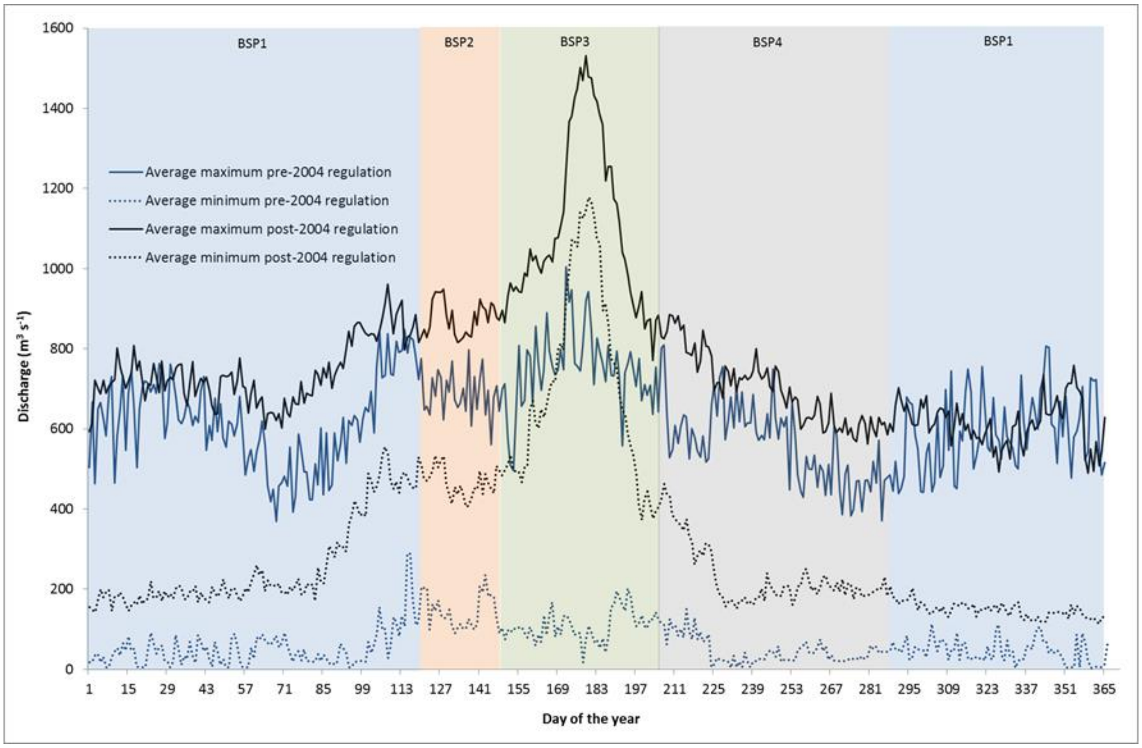

Figure 7. Average daily maximum and minimum discharge pre- and post-implementation of the minimum flow requirements on September 7, 2004, gauge 05KD003.

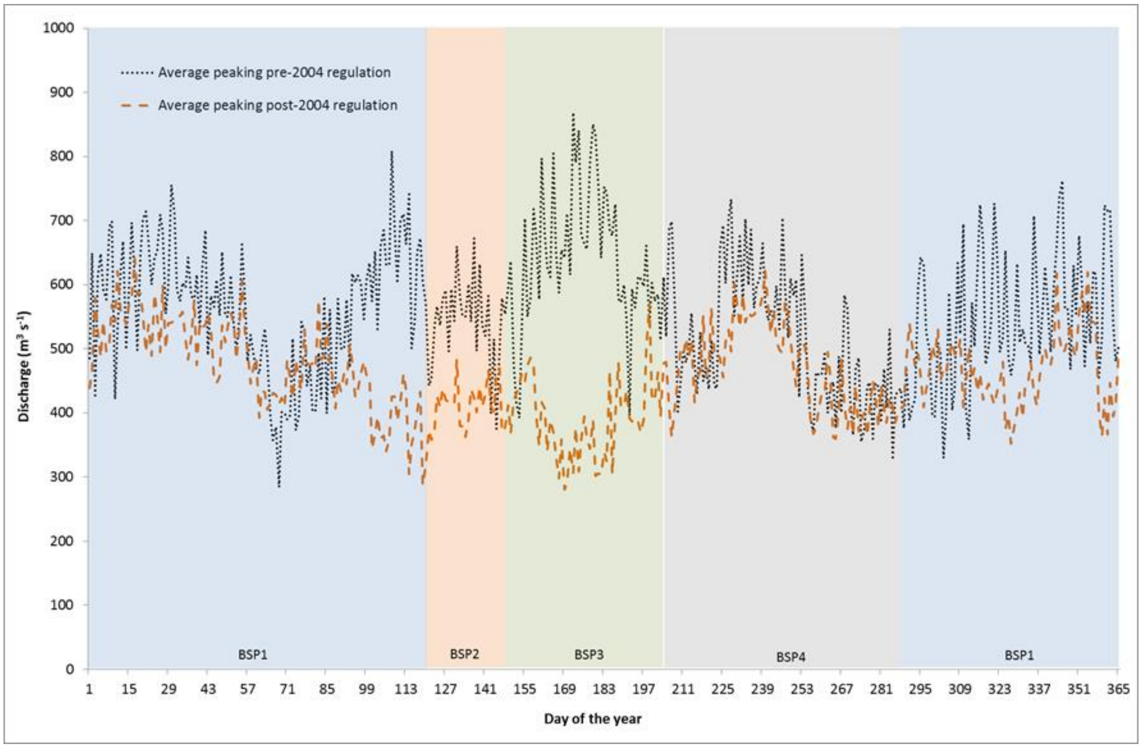

Figure 8. Average daily differences between minimum and maximum discharge pre- and post-implementation of the minimum flow requirements on September 7, 2004, gauge 05KD003.

RAMPING RATES

The exceedance or flow duration method is considered a flow frequency method or technique. It is used to evaluate the probability or risk of certain flows for given durations or return period. Ramping rate is the rate at which discharge is increased or decreased. In this section, we summarize the rate of change in flow. Since September 7, 2004, the hourly change in flow has decreased across nearly all flow frequencies, increasing and decreasing, with the exception of the extremes (0% and 100% exceedance; Figure 9). These reductions in ramping rates are likely related to a higher minimum flow requirement that reduces the difference in the daily minimum and maximum discharge as well as high mean annual flow since September 7, 2004. Flood events have resulted in extreme ramping rates at discharges >1,000 m^3 s^{-1} but these are rare events.

Hourly changes in water surface elevation have correspondingly decreased following the minimum flow requirement (Figure 10).

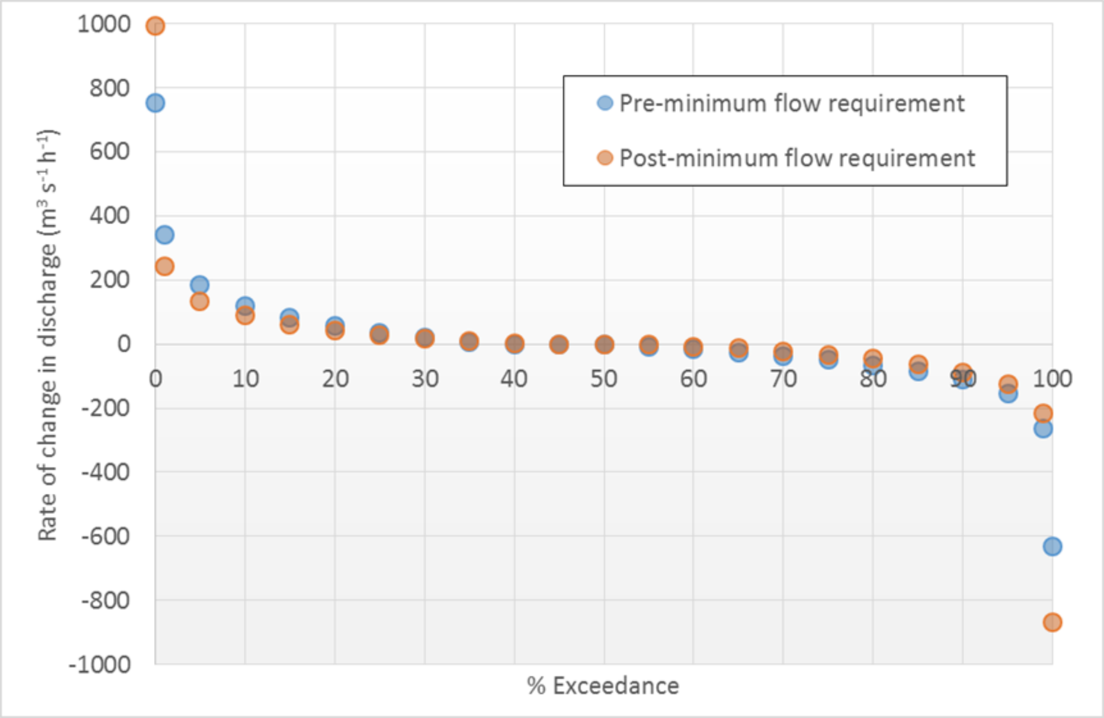

Figure 9. Percentage exceedance plot of hourly changes in discharge, increases and decreases, pre- and post-implementation of the minimum flow requirement on September 7, 2004, gauge 05KD003.

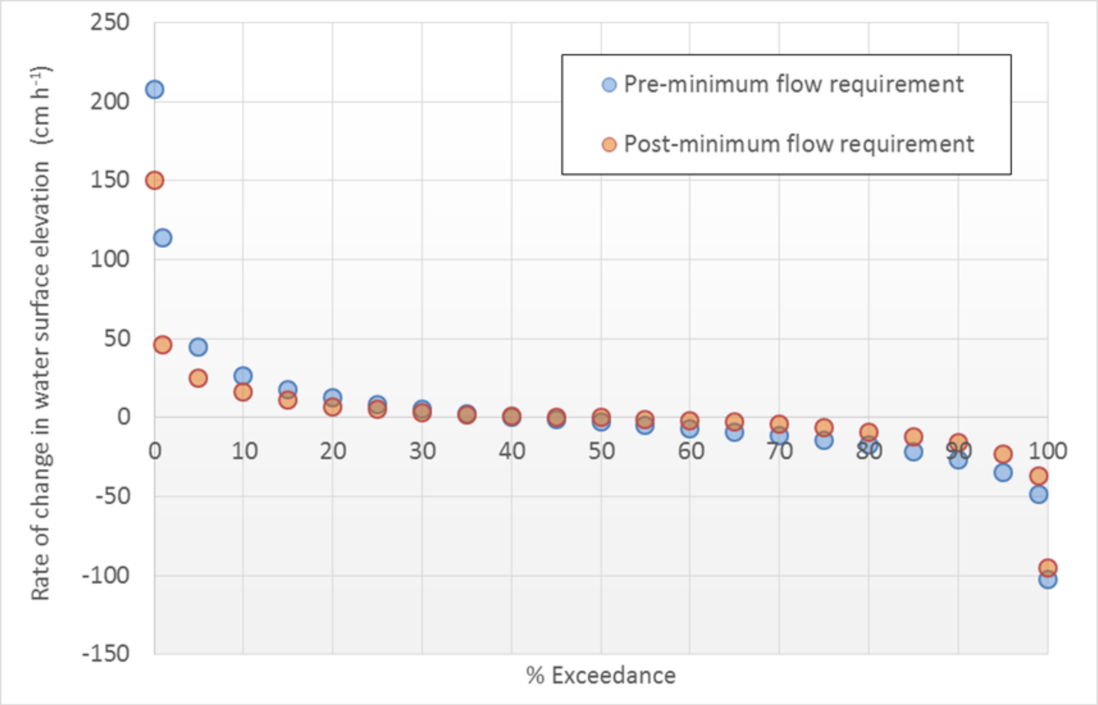

Figure 10. Percentage exceedance plot of hourly changes water surface elevation, increases and decreases, pre and post the minimum flow requirement on September 7, 2004, gauge 05KD003.

DISCHARGE ANALYSIS

Exceedance or flow duration curves were summarized for each BSP for the pre-dam period 1912-1963, by combining daily data from gauges 05GG001 on the North Saskatchewan River (Figure 2) with 05HG001 on the South Saskatchewan River (Figure 2), and for 1964-September 6, 2004. Hourly exceedance data was summarized for 2001-September 6, 2004 and September 7, 2004-2017. The 50-100% exceedance of the daily discharges was plotted to summarize changes in flow frequencies for each BSP (Figure 11). The 0-49% exceedance values were not plotted as they inflate the y-axis so relationships are difficult to discern for lower discharges, where more significant impacts on habitat are hypothesized to occur. In BSP1, flows since 1963 are typically twice as high as flows prior to 1963 when no large dams regulated flows on the Saskatchewan River system. BSP1 is the only period when historic flows were lower than flows since flow regulation began. This significant change in the seasonal hydrology is related to water storage upstream of dams in the watershed for winter power generation. The consequences are that BSP2-4 all have a higher frequency of low flows compared to pre-1964. Since September 7, 2004, BSP2 has had flow frequencies similar to 1912-1963, BSP3 and BSP4 continue to have flows at less than half pre-1964 flows. Improvements in all BSP are indicated since September 7, 2004, as nearly 10% of all hourly flows were near 0 $m^3 s^{-1}$, from 2001 to September 7, 2004 during these BSP. Higher frequency of flows >100 $m^3 s^{-1}$ are likely as a result of the wetter period since September 7, 2004.

A requirement of the 2005 *Fisheries Act* authorization was to maintain water surface elevation of Tobin Lake within 312-313.64 MASL (meters above sea level; gauge 05KD004 (Figure 2)). Since September 7, 2004, the water surface variation has been reduced, and the water surface has been maintained within the described operation range with the exception of five days (April 10-14, 2007) when the water level dropped as low as 311.75 MASL (Figure 12).

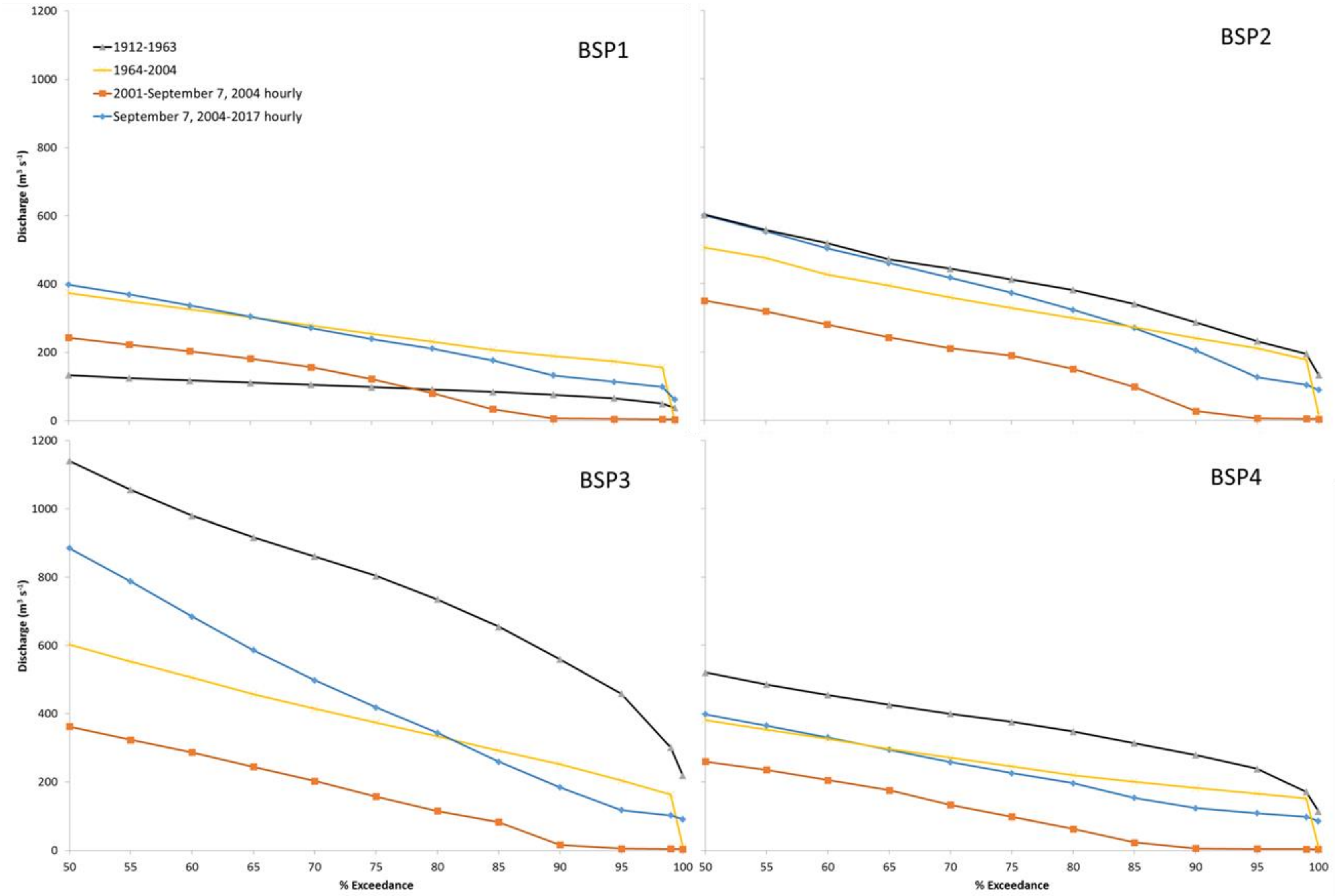

Figure 11. Exceedance (50-100%), mean daily discharge from 1912-1963 (South and North Saskatchewan rivers combined) and from 1964-2003 downstream of EBC. Hourly discharge for 2001-September 6, 2004 and September 7, 2004-2017 downstream of EBC for all four BSP.

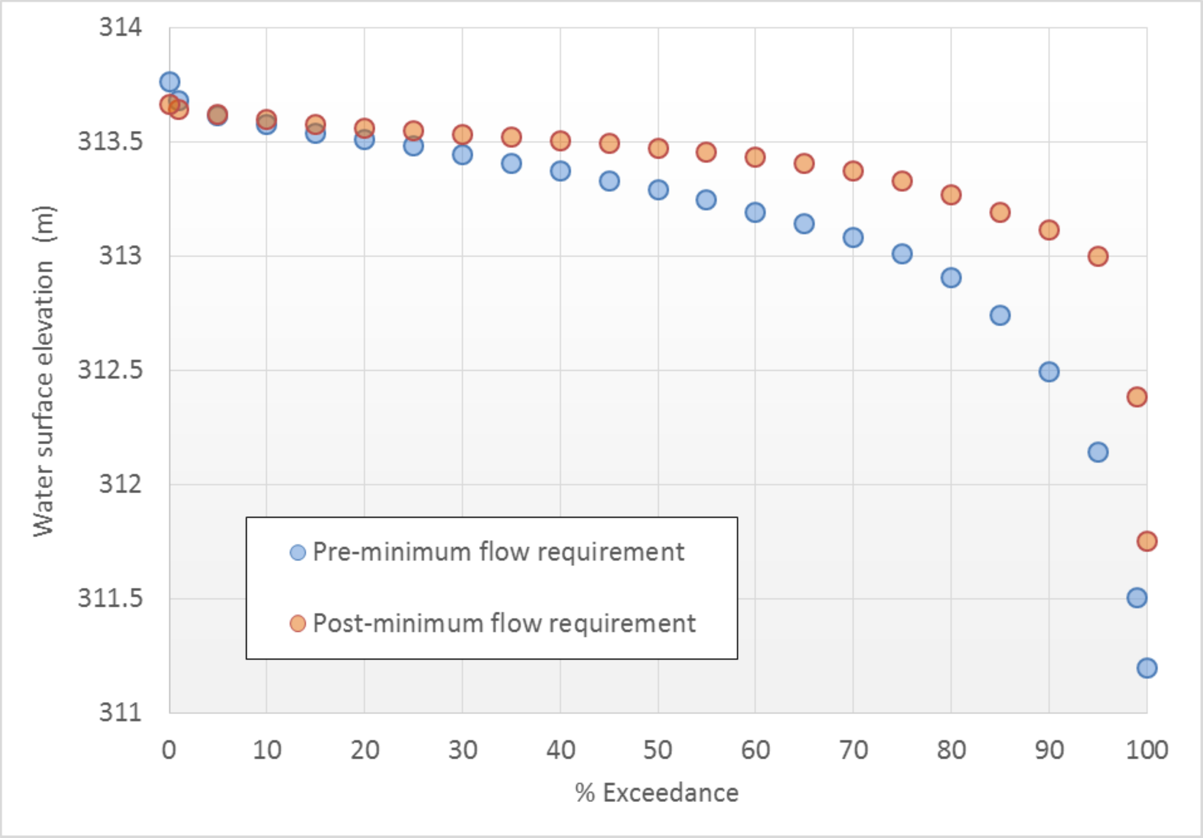

Figure 12. Percentage exceedance of daily water surface elevations at gauge 05KD004 on Tobin Lake, prior (1964 to September 6, 2004) and post to the minimum flow requirement (September 7, 2004 to 2016).

HABITAT AVAILABILITY

A field study was conducted in 2005-2007 in the frame of the Research Partnership Agreement. The aim of this study was to understand how seasonal, daily, and hourly changes in flow patterns are impacting the habitat availability for fish in Saskatchewan River downstream of EBC. Three study sites (~5 km long, Figure 1) were selected in the ~36 river km reach between EBC and the confluence with the Torch River. Three sites were selected as they had distinct substrates from one another. In addition, a Reference Site was chosen upstream of EBC.

Site 1 was 5.5 km long, single channel, located 0.2-5.7 km downstream of EBC. The site has a slope of 0.001, no defined thalweg, and substrate was dominated by cobble, gravel, and boulders.

Site 2 was 5.2 km long, located 11.6-16.8 km downstream of the EBC. This site had a mix of the same substrates present at Site 1, but sand was the most dominant substrate. The site has a slope of 0.00013 and a defined thalweg for much of the site. There were two vegetated islands that became isolated from the shoreline at flows >500 $m^3 s^{-1}$ and a third island that was isolated at 300-500 $m^3 s^{-1}$. At flows <150 $m^3 s^{-1}$ the site had numerous unvegetated sand bars.

Site 3 was 4.8 km long, located 18.5-23.3 km downstream of the EBC. The substrate throughout the site was sand, with limited clay and cobble deposits near the banks. The site has a slope of 0.0003, and a defined thalweg channel existed for much of the site. The site had two vegetated islands; one isolated at ~150 $m^3 s^{-1}$and the other at ~900 $m^3 s^{-1}$. At flows <250 $m^3 s^{-1}$ the site had numerous unvegetated sand bars.

A Reference Site was selected upstream of the influence of the Nipawin Hydroelectric Station and EBC. The Reference Site was 5.8 km long and located 56.4-62.2 km upstream of the Nipawin Hydroelectric Station (Figure 1). This site was chosen to represent the Saskatchewan River from both a physical habitat and fish community perspective as the site has no barriers to sediment transport or fish movement for hundreds of kilometers upstream. The site had a slope of 0.0013, a defined thalweg channel for much of the site, and substrate was dominated by cobble with gravel, boulder, sand, and silt.

HABITAT MAPPING

At each of these four sites, water depth and substrate type was collected with a boat mounted echo sounder. LiDAR data was collected at the downstream sites to allow for bed elevation data that extended beyond the sonar survey and to model higher discharges.

Water velocity was measured at several cross sections in each site using an Acoustic Doppler Current Profiler (ADCP). An additional 194 water velocity measurements were made with a hand held velocity meter at low flow conditions.

HABITAT MODELLING

River2D (www.river2d.ca; Ghanem et al. 1995), a two-dimensional shallow water numerical model was used to model the physical habitat (depth, water velocity, and substrate) at different flows at the three sites downstream of EBC and the Reference Site. A description of the model along with the solution of the 2D depth-averaged equations, underlying assumptions, and finite-element formulation is presented in Ghanem et al. (1996).

River2D was used to generate Wetted Useable Area curves for each of the study sites downstream of EBC, assuming a minimum depth of 20 cm was required to be considered fish habitat (Figure 13). For all three Study Sites, the changes in Wetted Useable Area with increasing discharge were highest at the lower discharges (i.e., 0-100 $m^3 s^{-1}$ for Site 1 and 2; 0-300 $m^3 s^{-1}$ For Site 3) relative to a 700 $m^3 s^{-1}$ flow (Figure 13, Table 2).

Changes in hydraulic habitat are predicted to occur in response to hydropeaking, since water depth and velocity will change with discharge. The average depth, velocity within a site was calculated for each of the model discharges (Figures 14-15). Depth and water velocity change over the range of flows typically released in a day yielded a ~500 $m^3 s^{-1}$ difference from the minimum to the maximum (Figure 8, ECCC 2018).

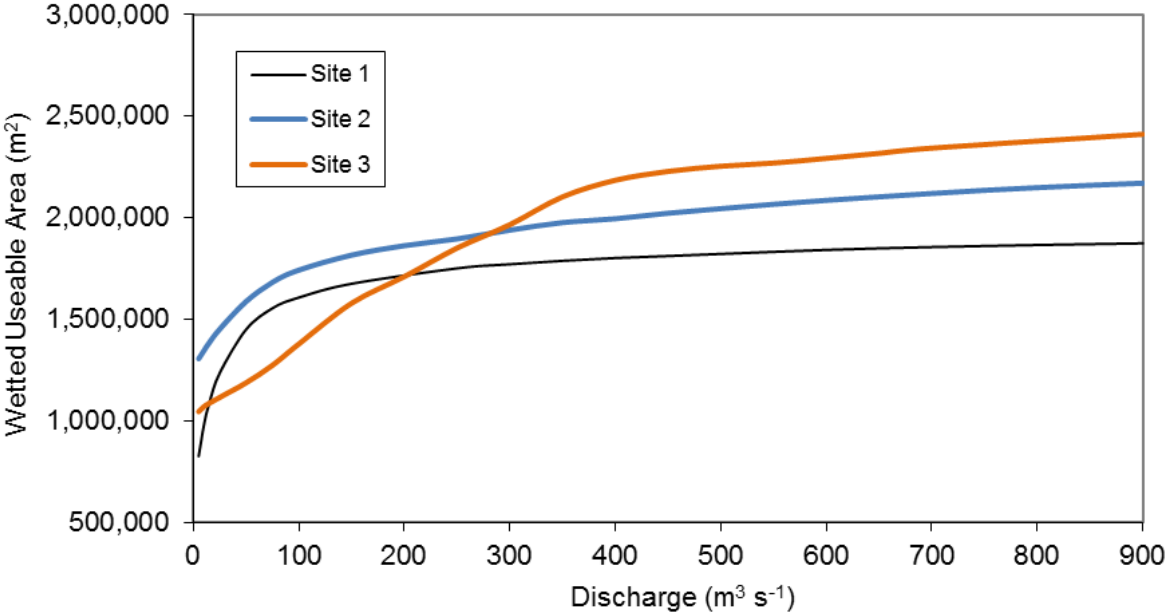

Figure 13. Wetted Useable Area at a minimum water depth of 20 cm at Site 1, 2, and 3 for different discharges.

Table 2. Wetted Useable Area at different discharges at the three sites downstream of E.B. Campbell relative to a 700 m³ s⁻¹ flow.

Discharge m^3 s^{-1}	**Site 1**		**Site2**		**Site3**	
	Total area (m^2)	**% wetted**	**Total area (m^2)**	**% wetted**	**Total area (m^2)**	**% wetted**
5	827,219	44.6	1,306,843	61.6	1,046,394	44.7
100	1,607,995	86.6	1,743,145	82.2	1,379,735	58.9
150	1,675,882	90.3	1,816,633	85.7	1,580,086	67.4
200	1,713,826	92.3	1,863,315	87.9	1,710,991	73.0
250	1,751,770	94.4	1,896,604	89.5	1,851,496	79.0
300	1,771,860	95.5	1,939,734	91.5	1,966,555	83.9
350	1,788,471	96.3	1,976,696	93.2	2,103,476	89.8
400	1,802,364	97.1	1,995,736	94.1	2,184,799	93.2
450	1,812,143	97.6	2,022,829	95.4	2,228,436	95.1
500	1,822,513	98.2	2,045,518	96.5	2,254,236	96.2
550	1,832,674	98.7	2,066,736	97.5	2,269,667	96.9
600	1,842,057	99.2	2,086,261	98.4	2,292,626	97.8
650	1,849,972	99.7	2,103,302	99.2	2,317,654	98.9
700	1,856,297	100.0	2,119,999	100.0	2,343,154	100.0

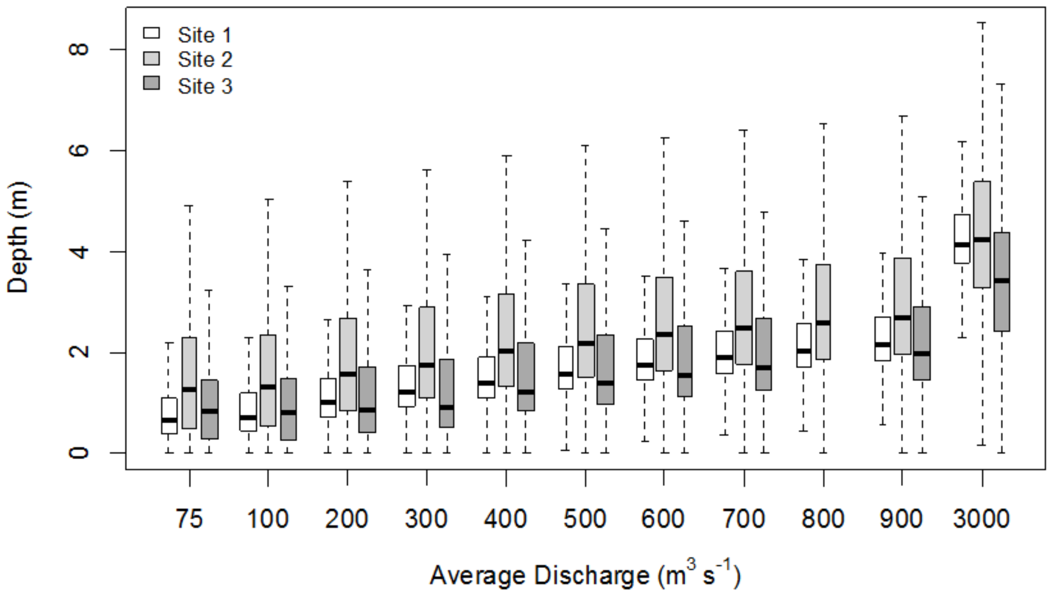

Figure 14. River 2D predictions of depth for different discharges at the three study sites downstream of the E.B. Campbell Hydroelectric Station. The box extends from the 25th to 75th percentile of observations [interquartile range (IQR)], with the center line indicating the median. The bars define the upper and lower adjacent values, defined as 75th percentile + 1.5 IQR and 25th percentile – 1.5 IQR. Outliers were omitted from this plot.

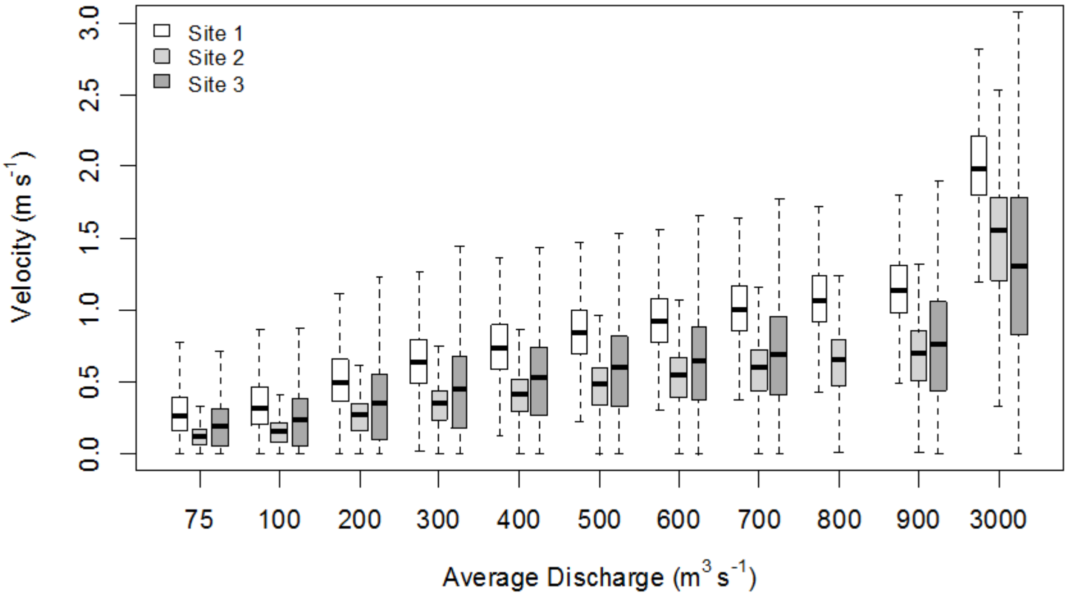

Figure 15. River 2D predictions of water velocity for different discharges at the three study sites downstream of the E.B. Campbell Hydroelectric Station. The box extends from the 25th to 75th percentile of observations [interquartile range (IQR)], with the center line indicating the median. The bars define the upper and lower adjacent values, defined as 75th percentile + 1.5 IQR and 25th percentile – 1.5 IQR. Outliers were omitted from this plot.

SEDIMENT AND TURBIDITY

EBC impounds most fluvial sediments that are transported to Tobin Lake and disrupts normal outflow patterns (Smith et al. 2016). The river channel up to rkm 81 downstream of EBC has coarsened and enlarged since closure in 1962. The reach immediately downstream of EBC (rkm 0-12) is now armored and has changed little in recent years (Smith et al. 2016). Recent floods that have occurred since 2003 have resulted in channel enlargement in the rkm 35-81 river segment, and the paucity of bedload has prevented degraded portions of the channel bed from replenishment following flooding. Sediment starvation is speeding the rate at which a single dominant channel is evolving, a process that will likely shift the patterns of flood inundation in the future (Smith et al. 2016).

Reductions in bedload and turbidity downstream of EBC are expected given the two upstream reservoirs, Codette and Tobin Lake. During the field study, turbidity was measured every day electrofishing occurred at the three sites downstream of EBC and the Reference Site. On July 20, 2006, a longitudinal survey of turbidity was conducted between 16h42 and 19h17 from EBC to 51.6 rkm downstream. During this time, discharges ranged between ~550-650 m^3 s^{-1}. A total of 15 Secchi depth measurements were taken. The highest Secchi disk measurement of 291 cm was observed immediately downstream of EBC and lowest of 140 cm at rkm 47.4 (Figure 16). The confluence of the Torch River also increased Secchi depth near rkm 36 (Figure 16).

The Reference Site had the lowest Secchi depth measured (45 cm) in August 2005 and the highest at Site 2 (320 cm) in July, 2006 (Table 3). The Secchi depths were all more than 100 cm in the sites downstream of EBC.

The observed changes in turbidity and bedload are not easily mitigated. However, examples of sustainable sediment management in reservoirs and regulated rivers exist and have been documented (Kondolf et al. 2014).

Table 3. Secchi depth measurements recorded during the electrofishing surveys in 2005 and 2006 at the Reference Site and the downstream Study Sites.

Site	**Date**	**Secchi depth (cm)**
Reference	August 4, 2005	45
Reference	August 5, 2005	46
Reference	August 6, 2005	48
Reference	August 7, 2005	48
Site 1	August 8, 2005	172
Site 1	August 9, 2005	182
Site 1	August 10, 2005	185
Site 3	August 11, 2005	148
Site 3	August 23, 2005	186
Site 1	May 16, 2006	125
Site 1	May 17, 2006	126
Site 1	May 18, 2006	126
Site 2	July 18, 2006	250
Site 2	July 19, 2006	300
Site 2	July 20, 2006	320

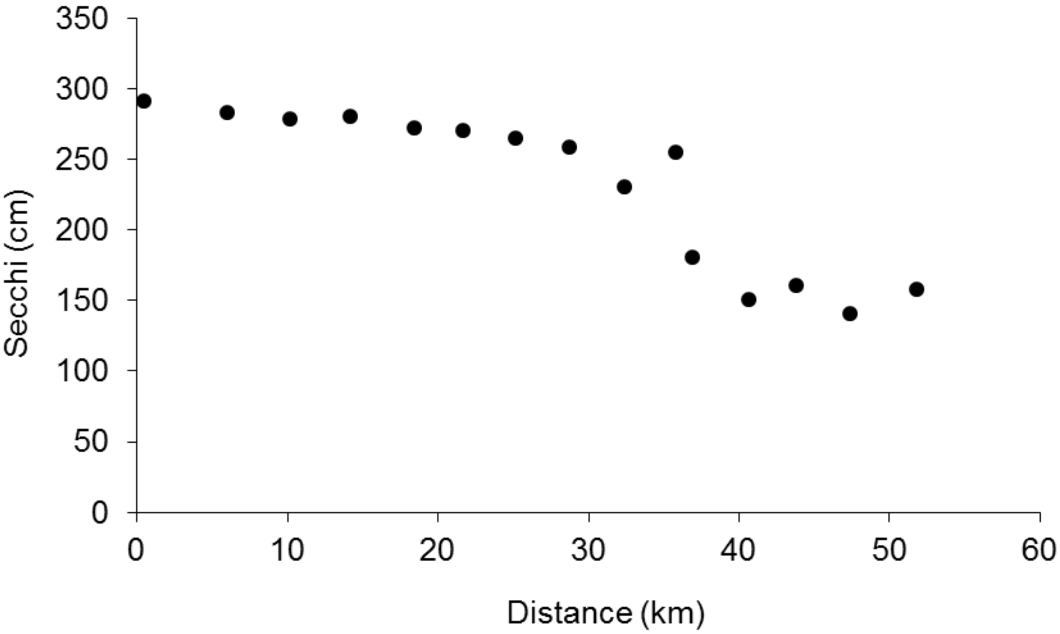

Figure 16. Secchi depth in the Saskatchewan River from E.B. Campbell Hydroelectric Station to 51.6 km downstream. Note the elevated Secchi depth due to the influence of the Torch River confluence at approximately river kilometer 36.

WATER TEMPERATURE

Water temperature has a significant influence on physiology, metabolism, susceptibility to disease, and life history traits of aquatic organisms (Sinokrot and Gulliver 2000, Forseth and Jonsson 2017), and influences many physiochemical properties of water (Wetzel 2001). Temperature can be a significant determinant of year class strength in riverine cyprinids (Mills and Mann 1985). Together with flow, temperature it is an important cue to trigger migration and spawning of a number of fish species (Heggberget 1988, Hembrel et al. 2001).

The highly variable discharge resulting from hydropeaking can result in large daily temperature fluctuations due to changes in discharge (Tonello and Nuhfer 2004). Conversely, river regulation can reduce daily temperature fluctuations in streams due to steady release of water from a more thermally stable reservoir (Webb and Walling 1993). High and stable flows can result in stable temperatures relative to low or fluctuating flows, can cool summer water temperatures, increase winter temperatures, and dampen seasonal patterns (Casado et al. 1989). Cooler summer and warmer winter temperatures can reduce invertebrate diversity. However, overall density can increase with disproportionate increases by some species (Boles 1981, Boon 1987, Rader and Ward 1990).

Water temperature was recorded hourly upstream of the Nipawin Hydroelectric Station at Wapiti, SK (Reference site) and downstream of EBC at Site 3 and Big Eddy from July 16 to August 22, 2014 (Mihalicz 2018). The maximum recorded water temperature was 25 °C recorded on August 8, 2014 at Wapiti (Figure 17).

Water temperature immediately downstream of EBC appeared to have lower daily fluctuations than Wapiti; the water temperature downstream of EBC is also lower by ~2 °C than Wapiti during this period. This difference in temperature is expected given the influence of Tobin Lake. Additional data would help in defining these differences both daily and seasonally.

Increases in flow likely dampened the difference in water temperature observed between the Reference and study sites. The Codette and Tobin Lake reservoirs also likely delay increases in water temperature in the spring and delay decreases in the fall and maintain higher temperatures below EBC during the winter. These changes in temperature do not likely exceed thermal tolerance limits for any native species and may benefit cool water species. The impacts are likely limited to modifications in spawning and migration cues and potentially overall system productivity of fish and invertebrates.

Satellite imagery (ZoomEarth) suggests that the first ~10 km downstream from EBC is typically ice free in the winter. This will likely have an impact on anchor and frazil ice formation.

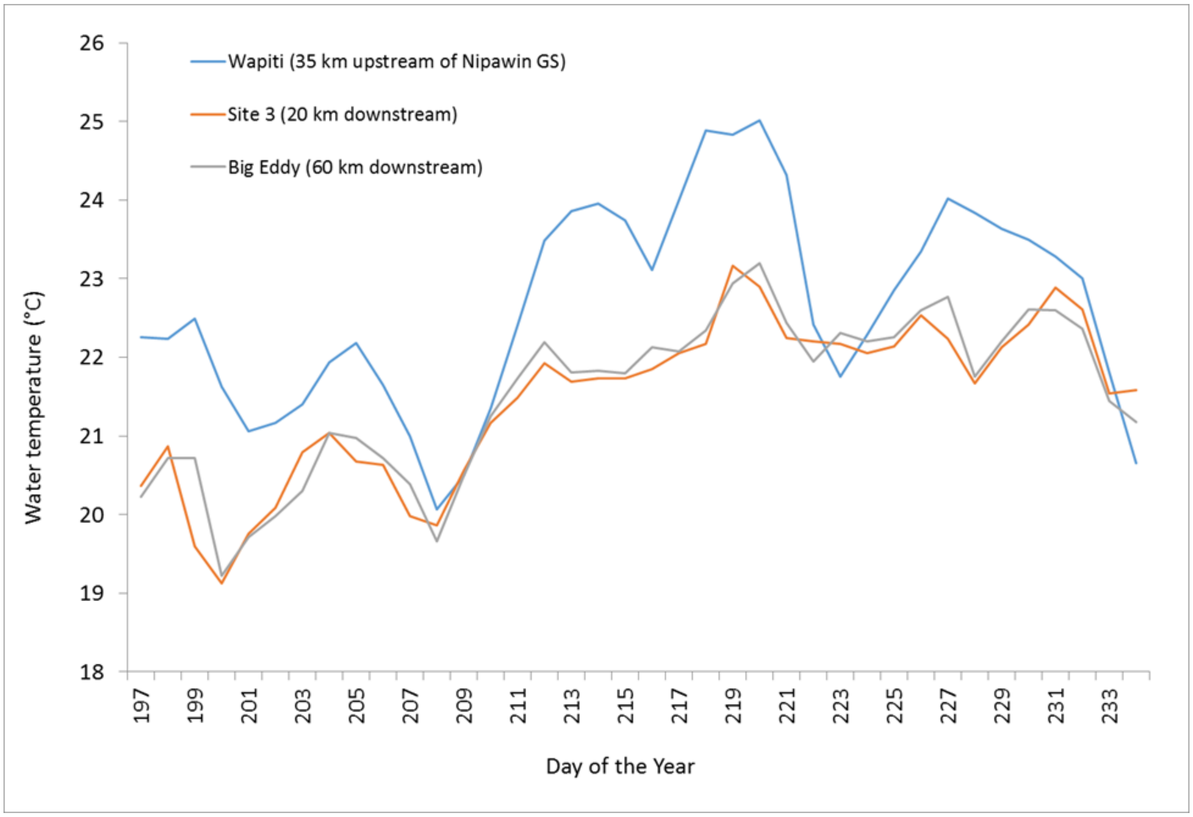

Figure 17. Comparison of daily water temperature among sites up- and downstream of EBC between July 16 to August 22, 2014 (Mihalicz 2018).

CHANGE IN NUTRIENT CONCENTRATIONS

Altered flow regimes have a significant, usually negative, impact on nutrient dynamics and nutrient availability in fluvial systems (Clarke et al. 2008). Sedimentation of organic particles, both allochthonous and autochthonous, occurs in the reservoirs, and lowers nutrient levels below them (Clarke et al. 2008). Specifically, reservoirs can act as sinks for phosphorus (Friedl and Wüest 2002) and silica (Conley et al. 2000), and to a lesser extent, nitrogen (Friedl and Wüest 2002). This change modifies the trophic structure of the tail water reaches, favouring invertebrate grazers, over shredders, collectors and detritivores, and is expected to generally result in reduced invertebrate diversity (Valentin et al. 1995). The density of invertebrates downstream of EBC tended to be higher than upstream sites (Figure 18) and the biotic index scores were higher across all months (Figure 19) suggesting a higher portion of the invertebrate community is taxa tolerant of disturbance (Mihalicz 2018).

Floodplain connectivity contributes significantly to river productivity, as the increase in the area of water during the floods transfers nutrients from the terrestrial into the aquatic components of the ecosystem, and vice versa (Bayley 1995, Ward et al. 1999). Lakes with greater connectivity to the main channel were characterized by higher pH, dissolved oxygen, nitrates, and sulfates and lower total nitrogen, total phosphorus, and ammonium (MacKinnon et al. 2016). These differences in connectivity and water chemistry might determine the suitability of these lakes as winter refuge for fishes (MacKinnon et al. 2016).

The creation of reservoirs on the Saskatchewan River has likely had an effect on biochemical cycles and nutrient transport from upstream to downstream reaches. This has created productive fisheries in the Codette Reservoir and Tobin Lake, but likely lead to overall decreases in the productivity of fisheries downstream of the reservoirs. North/South Consultants Inc. (2016) found that total phosphorus was similar to upstream reaches on the Saskatchewan River but total nitrogen was lower, resulting in lower chlorophyll levels. Mihalicz (2018) found that total phosphorus (Figure 20) and total nitrogen appeared similar (Figure 21) downstream of EBC on the Saskatchewan River. The impoundments on the Saskatchewan River have likely influenced downstream biota by influencing the structure and function of the lower food web (Clarke et al. 2008). Benthic chlorophyll appears somewhat higher downstream of EBC largely due to greater light penetration owing to lower turbidity (Figure 22; Mihalicz 2018).

Maintenance of the natural flow regime to the extent possible is the primary mitigation tool to reduce the disruption of nutrient distribution and dynamics in rivers (Clarke et al. 2008). To reduce losses of benthic biomass due to hydropeaking, Moog (1993) recommended avoiding hydropeaking operations and prescribed minimum flows to protect downstream areas from dewatering.

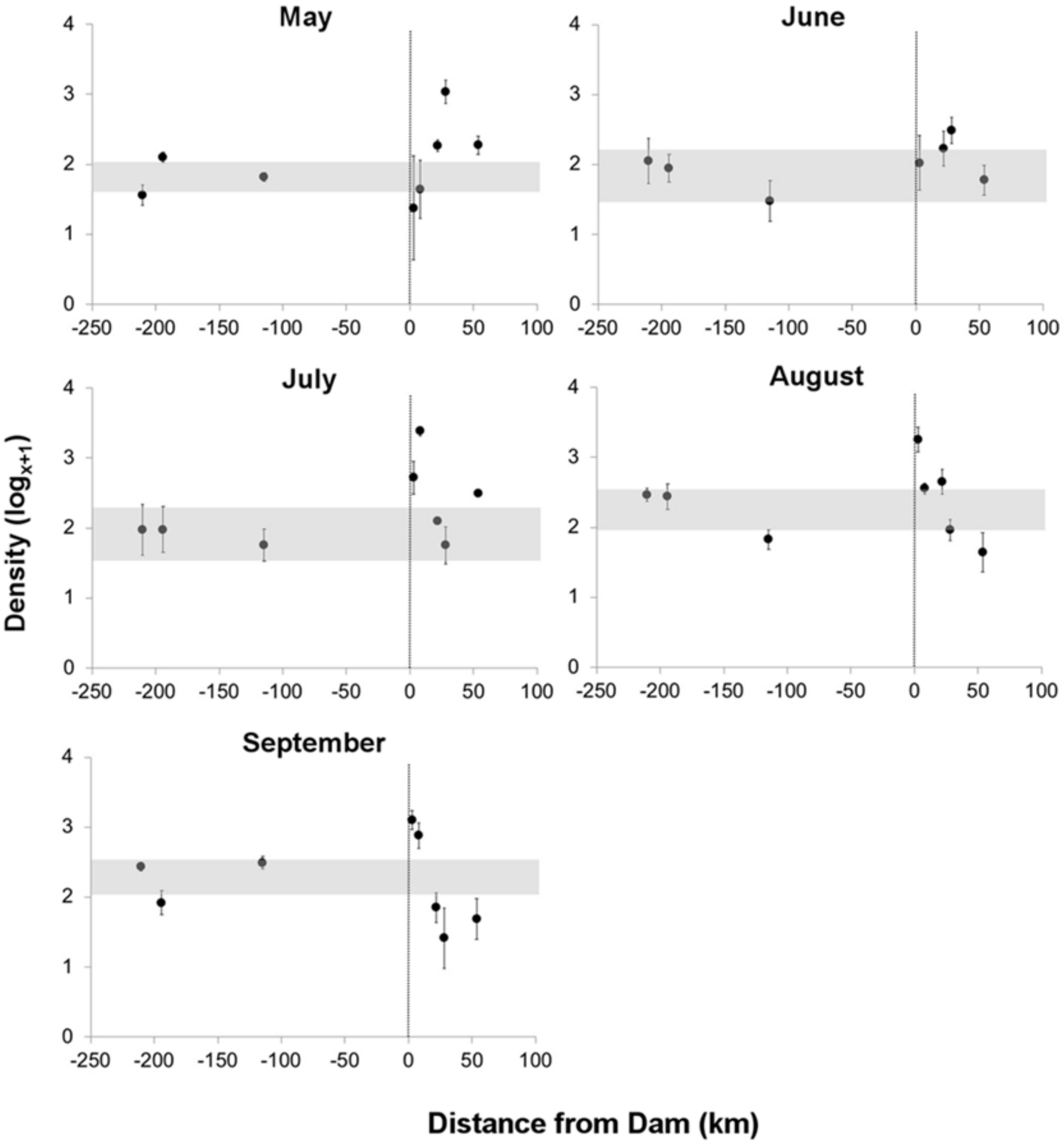

Figure 18. Changes in the benthic macroinvertebrates densities from May-September 2014 with the distance from E.B. Campbell Dam. Negative/positive distances represent kilometers upstream/downstream of the dam. Grey boxes represent the 95% CI for upstream densities. The vertical dotted line indicates the location of the dam (from Mihalicz 2018).

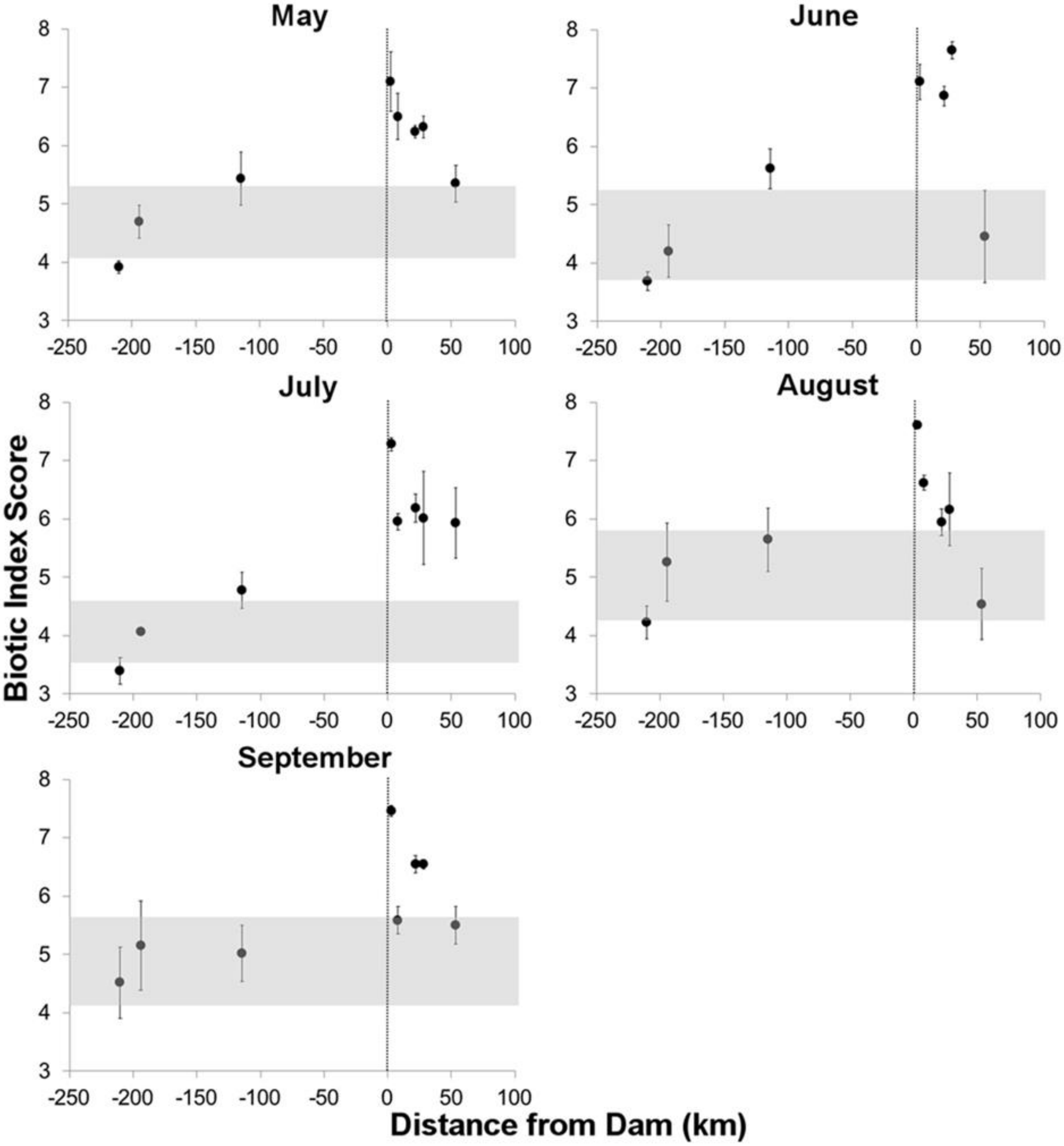

Figure 19. Changes in the Biotic Index Score for May-September 2014 with the distance to E.B. Campbell Dam. Negative/positive distances represent kilometers upstream/downstream of the dam. Grey boxes represent the 95% CI for upstream biotic index scores. The vertical dotted line indicates the location of the dam (from Mihalicz 2018).

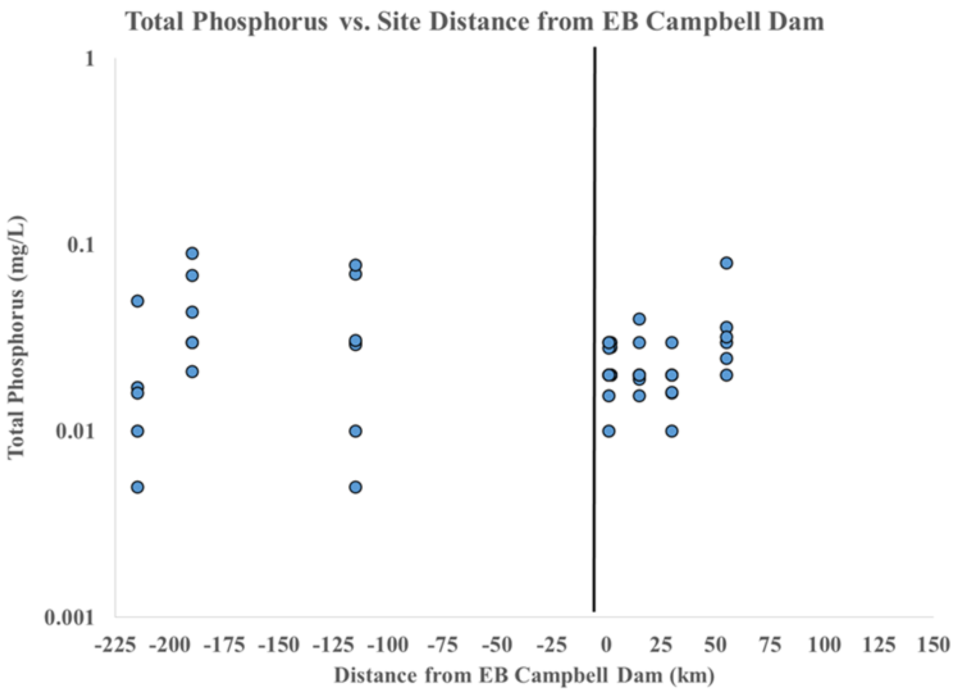

Figure 20. Comparison of total phosphorus versus sites up- and downstream of EBC (from Mihalicz 2018).

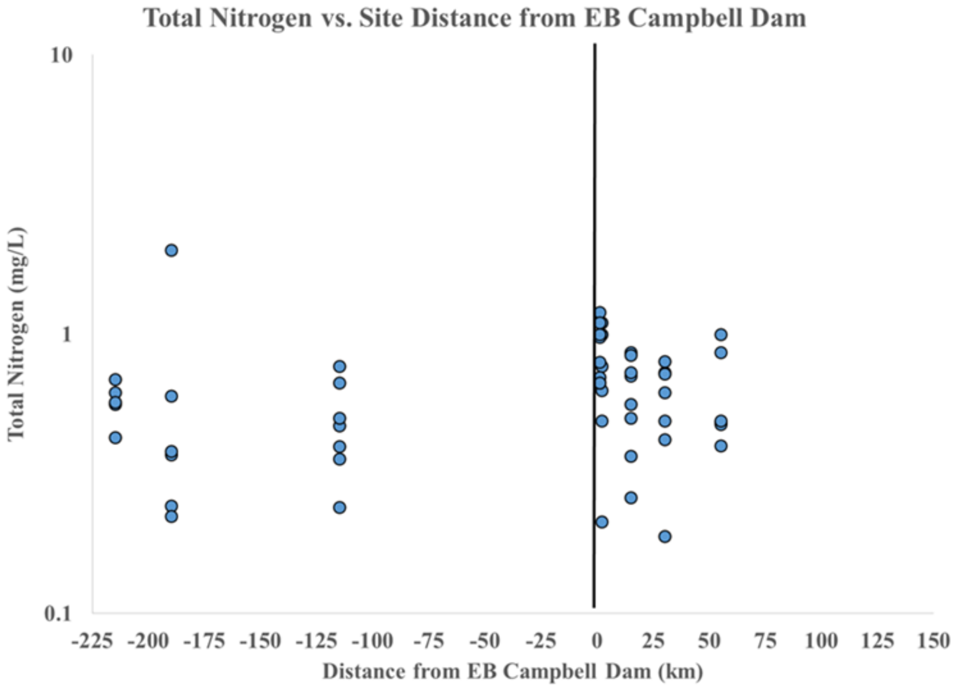

Figure 21. Comparison of total nitrogen versus sites up- and downstream of EBC. Negative/positive distances represent kilometers upstream/downstream of the dam. The vertical dotted line indicates the location of the dam (from Mihalicz 2018).

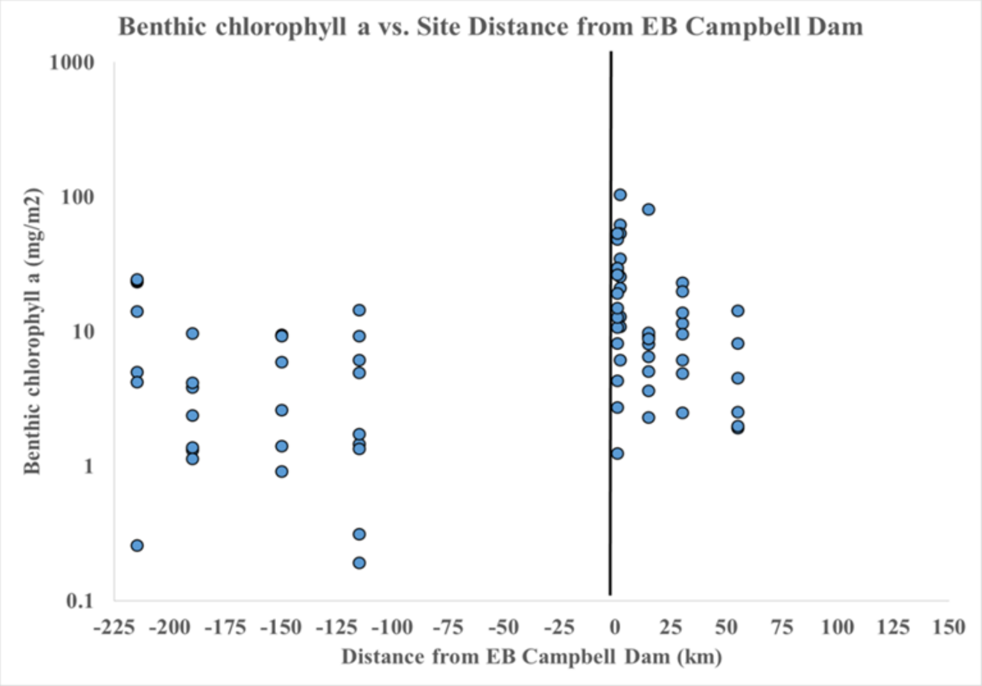

Figure 22. Comparison of benthic chlorophyll a in sites up- and downstream of EBC. Negative/positive distances represent kilometers upstream/downstream of the dam. The vertical dotted line indicates the location of the dam (from Mihalicz 2018).

MERCURY

Mercury (Hg) contamination can pose risks to human and animal health (Green et al. 2016). Reservoirs constructed in riverine systems produce flooded conditions amenable to Hg (II)-methylating bacteria, resulting in elevated Hg concentrations. Green et al. (2016) examined and compared the multi-decadal rates of biotic Hg decrease and contemporary factors affecting Hg in fish collected from Tobin Lake and Cumberland Lake (the largest lake in the delta) in Goldeye (*Hiodon alosoides*), Northern Pike (*Esox lucius*), Sauger (*Sander canadensis*), and Walleye (*Sander vitreus*). All showed a significant decrease in Hg over time and are now lower than Health Canada consumption guidelines (0.5 µg g^{-1}).

TOTAL DISSOLVED GAS SUPERSATURATION

Below the spillway, there is a risk of Gas Bubble Trauma (Disease), which can lead to direct mortality or stress that may result in the onset of other diseases or contribute to delayed mortality in a variety of taxa, often specific to a life history stage (Macdonald and Hyatt 1973, Weitkamp and Katz 1980, Heggberget 1984, Lutz 1995, Weitkamp et al. 2003). Total dissolved gas supersaturation (TDGS) was measured on May 09, 2011 downstream of EBC. Levels of supersaturation were below Canadian Water Quality Guidelines for the Protection of Aquatic Life (CCME 1999). High levels of TDGS are a function of the size of the spill (Muldoon 2012), among other factors, and only a small spill (<300 m^3 s^{-1}) occurring on May 09, 2011. Additional monitoring is warranted when large spill releases occur to understand if TDGS exceeds the Canadian Water Quality Guidelines. If TDGS levels are found to exceed guidelines, mitigations may include the installation of flow deflectors to reduce total gas pressure (Weitkamp and Katz 1980, Ruggles and Murray 1983).

BIOTIC IMPACTS

FISH COMMUNITY

Habitat Suitability Criteria (HSC) for Saskatchewan River fish species were developed in a combined stakeholder – Steering Committee workshop in November 2005 (Appendix 1). This workshop arrived at HSC by combining literature and personal experience using a consensus-based process to adjust published and unpublished data to create Category I Habitat Suitability Criteria (Bovee 1986). These HSC along with Category III HSC (Bovee 1986) developed by fishing in the sites were used independently for modelling changes in the availability of fish habitat for these species using the River2D hydrodynamic and habitat modeling software.

Electrofishing surveys were conducted in each site with a Smith-Root SR20-EH equipped with a GPP 5.0 set to 0–1,000 V, pulsed DC range, 8 A, and fished at 40% of the range. All fishing was single pass, in a downstream direction with two netters, during daylight hours. Each study site was randomly divided into cross sections ~1 river width apart. The electrofishing survey was conducted along seven transects that ran parallel to the banks extending from cross section to cross section. Looking downstream, the first transect was located along the left bank as close as the boat could safely manoeuvre along the bank, the second transect was 20 m from the left bank, the third transect was 75 m from the left bank, and the fourth transect was in the center of the river, and transects five to seven were 75 m, 20 m, and as close as the boat could safely manoeuvre to the right bank, respectively. Fish capture location was recorded as a spatial position that could be later associated with modeled River2D habitat data. Fish species, fork length, and sex; if possible, was recorded along with the capture location. Fin clips and weights were taken from the first 100 fish of any species at each site for aging. The first two dorsal fin spines were removed for Walleye, while for Northern Pike, Mooneye (*Hiodon tergisus*), Goldeye, and Lake Whitefish (*Coregonus clupeaformis*), the leading edge of their right pelvic fin was removed, and the right leading edge of the pectoral fin was removed for all sucker species. Sectioning and age analyses were done after the methods of Mills and Beamish (1980). Fish ages for all three sites downstream of EBC were combined for comparison with data from fish caught in the Reference Site.

A total of 5,194 fish were collected represented by 19 species (Table 4). Shorthead Redhorse (*Moxostoma macrolepidotum*) (n= 2,140) and White Sucker (n = 1,631) dominated the catch representing 72.6% of the total (Table 4). More than half of all fish sampled were caught in Site 1 in August 2005. This site also had the highest CPUE (Table 5). The highest species richness was found in Site 3 and the Reference Site (Table 4). In 2005, the electrofishing boat broke down part way into the survey and the complete survey in Site 2 was repeated in 2006, the data collected from both years is included in Table 4 and 5. Although Lake Sturgeon are present in the Saskatchewan River none where observed during our fish surveys. This is likely due to limitations of the collection method, or time of year, as we did not sample during the spawning period when Lake Sturgeon would have likely migrated to below EBC, and been present within the sampling sites.

Fish species collected downstream of EBC were mostly large individuals with very limited numbers of sub-adults (Figure 23-24). Walleye were the only exception to this pattern with all sizes caught downstream of EBC. In the Reference Site, both large (adult) and sub-adult individuals were common (Figure 23-24). No differences in size at age were observed (Figure 23). Possible explanations for the reduced number of juvenile fish downstream of EBC are (Enders et al. 2017):

1. Post hatch, larval fish drift downstream out of the study reaches and do not migrate back upstream until they are adults. The hydro facility acts as a barrier to downstream drift of larval fish upstream of EBC. Therefore, colonization by upstream spawning is not possible.
2. The habitat downstream of EBC is not suitable for juvenile fish.
3. The collection methods used were inappropriate for collecting juvenile fish; however, catches of sub-adult individuals were high in the Reference Site where turbidity would make capture even more difficult.
4. The spawning success of fish downstream of EBC is extremely low.
5. Intra- and/or inter-specific competition reduces the success or excludes juvenile fish from utilizing habitat downstream of EBC.

Table 4. Fish catches in 2005 and 2006 in each site by species.

Species	**2005**				**2006**		**Total**
	Site 1	**Site 2**	**Site 3**	**Reference**	**Site 1**	**Site 2**	
Goldeye	1	0	1	11	0	0	13
Mooneye	2	3	19	25	1	4	54
Emerald Shiner	11	18	132	119	2	42	324
Spottail Shiner	16	2	11	9	0	180	218
Fathead Minnow	0	0	2	0	0	0	2
Flathead Chub	0	0	0	11	0	0	11
Quillback	2	1	2	0	3	9	17
Longnose Sucker	112	0	0	251	8	0	371
White Sucker	933	13	116	62	366	117	1607
Silver Redhorse	1	1	19	30	1	71	123
Shorthead Redhorse	1469	29	104	297	84	91	2074
Northern Pike	5	5	19	1	1	42	73
Lake Whitefish	0	0	0	0	50	0	50
Trout-perch	0	0	2	0	0	0	2
Burbot	0	0	1	0	0	0	1
Spoonhead Sculpin	0	0	0	1	0	0	1
Yellow Perch	0	0	1	0	3	24	28
Sauger	0	0	2	36	0	3	41
Walleye	36	5	28	35	53	4	161
Total	**2588**	**77**	**459**	**888**	**572**	**587**	**5171**
Number of species	**11**	**9**	**15**	**13**	**11**	**11**	**19**
Effort (min)	**332.4**	**49.0**	**398.2**	**396.9**	**299.3**	**468.2**	**1943.9**

Table 5. Fish catch per unit effort (CPUE) and number of fish/min in 2005 and 2006 in each site by species.

Species	**2005**				**2006**		**Average CPUE**
	Site 1 CPUE	**Site 2 CPUE**	**Site 3 CPUE**	**Reference CPUE**	**Site 1 CPUE**	**Site 2 CPUE**	
Goldeye	0.003	-	0.003	0.028	-	-	0.0055
Mooneye	0.006	0.0612	0.048	0.063	0.003	0.009	0.0316
Emerald Shiner	0.033	0.367	0.332	0.300	0.007	0.090	0.1880
Spottail Shiner	0.048	0.0408	0.028	0.023	-	0.385	0.0873
Fathead Minnow	-	-	0.005	-	-	-	0.0008
Flathead Chub	-	-	-	0.028	-	-	0.0046
Quillback	0.006	0.020	0.005	-	0.010	0.019	0.0101
Longnose Sucker	0.337	-	-	0.632	0.027	-	0.1660
White Sucker	2.807	0.265	0.291	0.156	1.223	0.25	0.8321
Silver Redhorse	0.003	0.020	0.048	0.076	0.003	0.152	0.0503
Shorthead Redhorse	4.419	0.592	0.261	0.748	0.281	0.194	1.0826
Northern Pike	0.015	0.102	0.048	0.003	0.003	0.090	0.0434
Lake Whitefish	-	-	-	-	0.167	-	0.0278
Trout-perch	-	-	0.005	-	-	-	0.0008
Burbot	-	-	0.003	-	-	-	0.0004
Spoonhead Sculpin	-	-	-	0.003	-	-	0.0004
Yellow Perch	-	-	0.003	-	0.010	0.051	0.0106
Sauger	-	-	0.005	0.091	-	0.006	0.0170
Walleye	0.108	0.102	0.070	0.088	0.177	0.009	0.0924
Effort (min)	**332.4**	**49.0**	**398.2**	**396.9**	**299.3**	**468.2**	**1943.9**

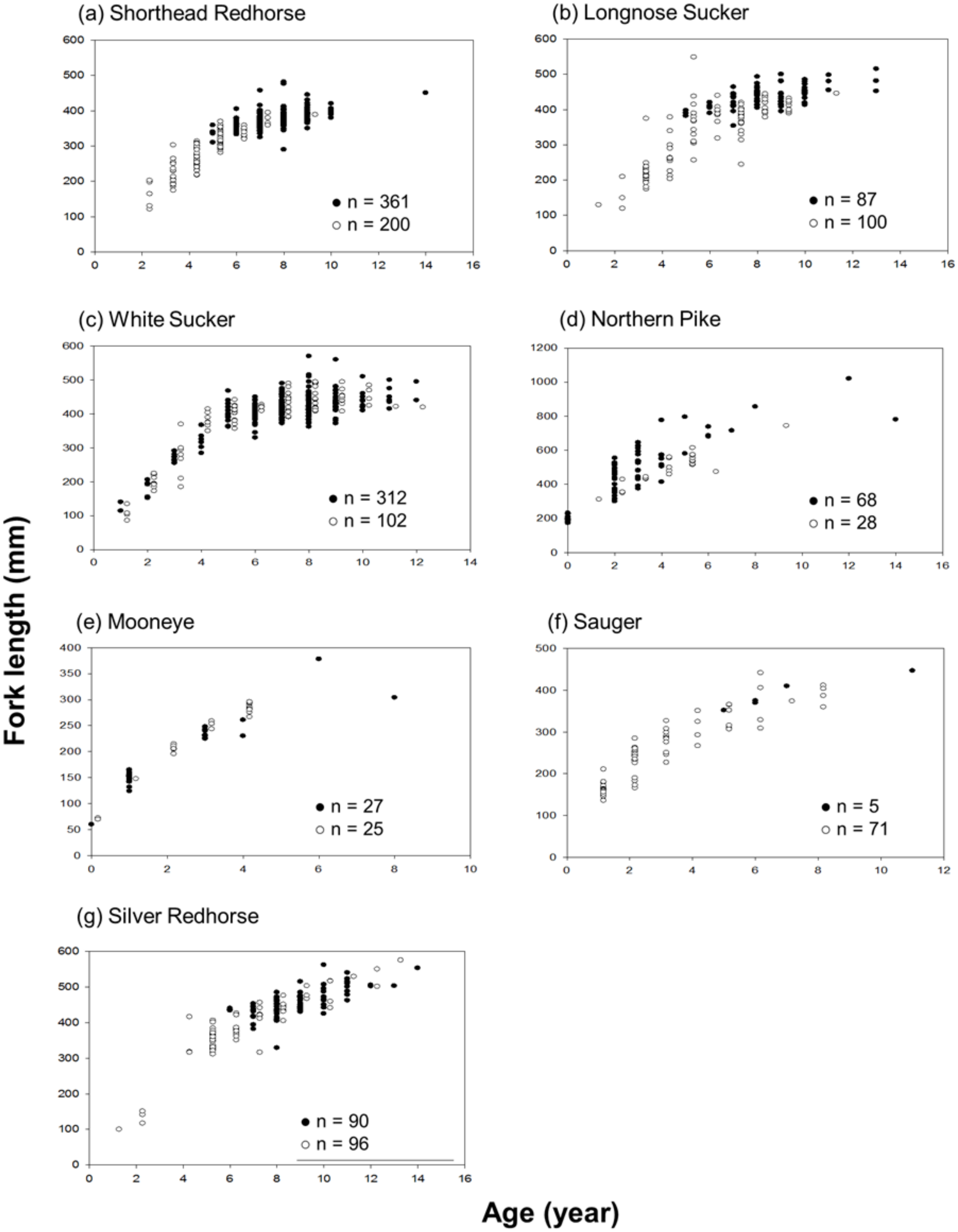

Figure 23. Age–length relationship for fish caught at the Sites 1–3 (solid symbols) and the Reference Site (open circles) (modified from Enders et al. 2017).

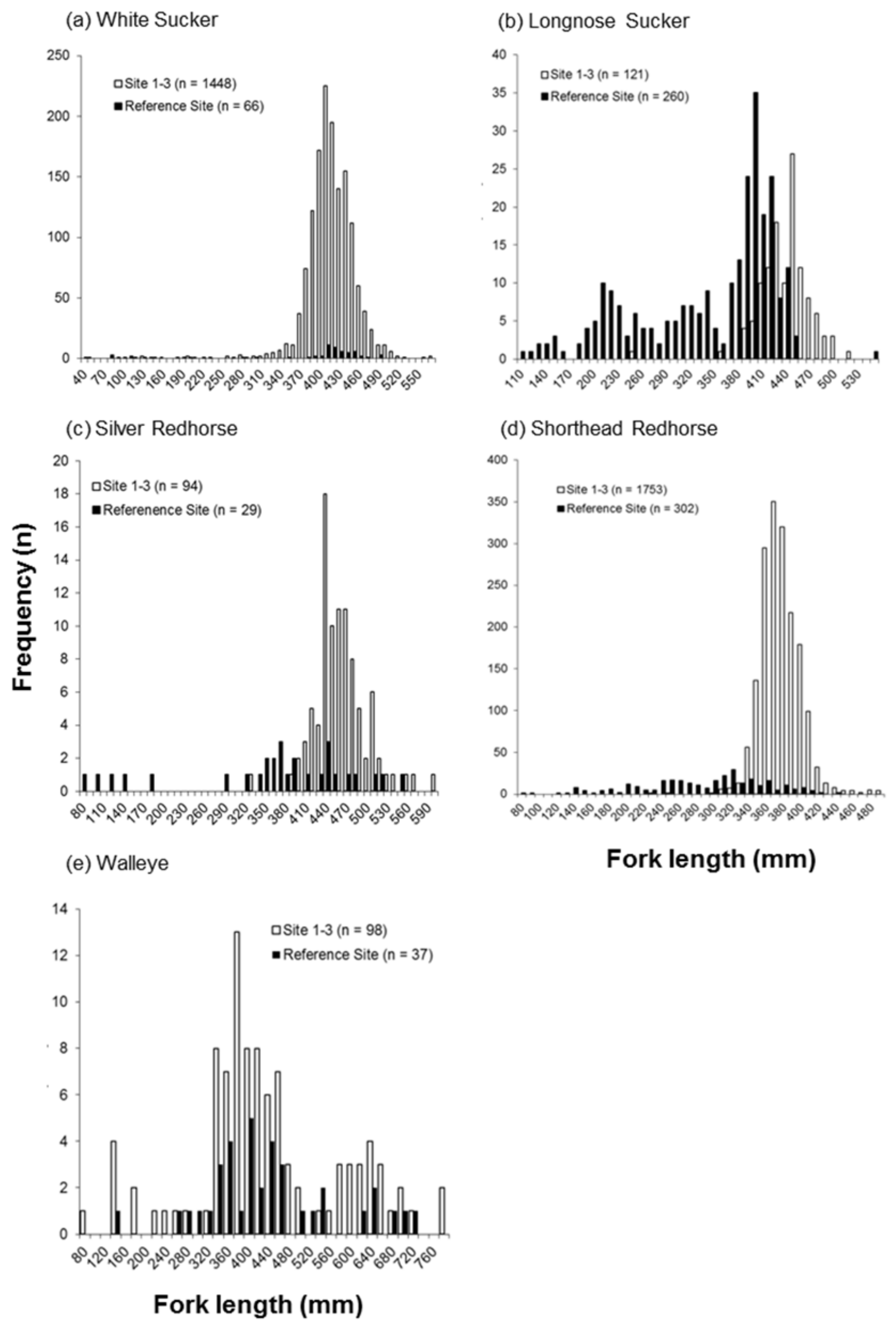

Figure 24. Length frequency distribution for (a) White Sucker, (b) Longnose Sucker, (c) Silver Redhorse, (d) Shorthead Redhorse, and (e) Walleye collected downstream of EBC (Sites 1-3) in open bars and at the Reference Site in solid bars (from Enders et al. 2017).

CALCULATION OF AVAILABLE AND UTILIZED FISH HABITAT – CATEGORY III HABITAT SUITABILITY CRITERIA DEVELOPMENT

Using spatially-referenced fish collection data, Category III Habitat Suitability Criteria (HSC) were developed to represent fish habitat use (Appendix 2). The GPS data was associated with depth, velocity, and substrate data for each spatial position extracted from the River2D model space. Each individual fish collected was assigned physical habitat (depth, velocity, and substrate) use data from the corresponding spatial positions modelled in River2D.

Development of HSC curves from catch data was limited to the BSP fishing was conducted in, fish that were considered adult (>250 mm in fork length) and species that had minimum sample sizes of n = 30 from a given site. Site 1 data during BSP4 in 2005 had suitable sample sizes for Longnose Sucker (*Catostomus catostomus*), White Sucker (*Catostomus catostomus*), Shorthead Redhorse, and Walleye. Site 1 data from BSP2 in 2006 had suitable sample sizes for White Sucker, Shorthead Redhorse, and Walleye. Site 2 data from BSP4 for both 2005 and 2006 had suitable sample sizes for Silver Redhorse (*Moxostoma anisurum*), White Sucker, and Shorthead Redhorse. Site 3 data from BSP4, 2005 had suitable sample sizes for White Sucker and Shorthead Redhorse.

A histogram approach was used to create habitat availability and use curves that could then be used to calculate HSC curves (Bovee 1986). The Sturges equation was used to set optimal bin sizes (Sturges 1926).

For depth, once the optimum value of 1, was reached, all depths greater than that value were then assigned a preference curve value of 1 as depth was not assumed to be limiting. River2D multiplies the depth, velocity, and substrate HSC values to calculate Weighted Useable Area for a particular species and life history stage.

WEIGHTED USEABLE AREA ANALYSIS

Weighted Usable Area (WUA) refers to the weighting of the suitability values of velocity, depth, and substrate for a particular fish species with respect to the area of habitat. The modelled hydrodynamic output results and the River2D habitat module were used to assess the variation in WUA with simulated discharges and subsequently quantify instream flow needs for various fish species at different life stages for the BSP the fish data was collected in.

In River2D, the fish habitat component is based on the WUA concept (Bovee 1982) used in the PHABSIM family of fish habitat models. The WUA is calculated in this study as the product of a Composite Suitability Index (CSI). Velocities and depths are taken directly from the hydrodynamic component of the model. The channel index values may depend on channel substrate or cover for different fish species and life stages.

Discharges that equate to the peaks of the WUA curves are calculated from the River2D model using Category I HSC derived from the 2005 Workshop and Category III HSC calculated from fishing in the three sites (Table 6). Appendix 2 contains the calculated WUA relationship across a range of discharges (5 to 3,500 $m^3 s^{-1}$).

Table 6. Discharge at peak Weighted Useable Area for several species/life stages for all sites using Workshop Category I (I) and on site fishing, Category III (III) HSC.*

Curve type:	**Site 1**		**Site 2**		**Site 3**	
	I	**III**	**I**	**III**	**I**	**III**
Walleye adult	250		350		450	
Walleye adult, BSP2 spawning, 2006 Site 1 only		450	-			-
Walleye adult all BSP4		400		300		400
Lake Sturgeon adult	900		900+		700+	
Lake Sturgeon spawning	450		750			
Lake Sturgeon juvenile	75		150		50	
Northern Pike adult	50		75		15	
Northern Pike adult all BSP4		200		200		400
Goldeye adult	200		350		400	
White Sucker adult BSP2 spawning, 2006 Site 1 only		400		-		-
White Sucker all BSP4		600		950		900
Shorthead Redhorse adult	250		750		900	
Shorthead Redhorse adult Spring BSP2, 2006 Site 1 only		300		-		-
Shorthead Redhorse all BSP4		900		950		950
Longnose Sucker all BSP4		750		950+		-
Silver Redhorse all BSP4		-		200		75
Most Sensitive for site	LS	SHRH	LS	SVRH	SHRH	SVRH

* Note: The values refer to the peak discharge ($m^3 s^{-1}$) that maximizes the Wetted Useable Area curve. “All BSP4” Category III HSC are calculated from combined data for all catches at all sites downstream of EBC. “Most Sensitive” refers to the species/life stage with the highest discharge requirement for the given site. Species abbreviations are: Lake Sturgeon (LS), Shorthead Redhorse (SHRH), and Silver Redhorse (SVRH).

STRANDING

Hydropeaking power generating stations use an up- and down-ramping operating regime to match power production with market demand. This results in daily increasing and decreasing flows downstream of the generating station, which from a fisheries perspective may negatively impact aquatic resources over several river kilometers (Hauer et al. 2017). One of the effects is that down-ramping potentially strands fish. Stranding occurs when fish get separated from flowing water as a result of the decreasing water level from rapid down-ramping. Juvenile fish and small-bodied fish are more vulnerable to potential stranding because of their weaker swimming ability and typical habitat preference to river margins (Moore and Stanley 1988). When stranded, fish become exposed to predation, desiccation (Bradford et al. 1995), thermal stress or freezing (Flodmark et al. 2002, Hoffarth 2004, Nagrodski et al. 2012). Eggs and embryos of autumn spawners are also at risk to freeze during low flow periods in cold temperate climates in regulated rivers with large seasonal variations as they have no capacity to move (Casas-Mulet et al. 2014). Similarly, for invertebrates, the risks of drift and stranding might be higher compared to fish due to their low mobility; however, some taxa are able to access refugia in the sediment (Bruno et al. 2009).

In general, the potential for stranding is dependent on local site characteristics. Factors such as hydropeaking characteristics (e.g., peak amplitude, ramping rate), river channel configuration (e.g., shore slope), substrate composition, time of day, water temperature, and fish behavior (species and life stage specific) all determine the stranding potential (Bradford et al. 1995, Saltveit et al. 2001). Several fish stranding experiments have shown, for example, that the stranding risk is elevated in areas of the river channel that have relatively low-gradient, where side channels exist in the river channel or where side pockets and potholes are present on a gravel bank (Auer et al. 2017) in comparison to rivers confined to a single channel with steep banks (Bradford 1997, Tuhtan et al. 2012). Fish may get entrapped in a side channel or pool, caught above the water line as it decreases, leaving them stranded on land or by subsurface dewatering of interstitial spaces within coarse substrates utilized by fish. The potential for fish stranding is lower in areas with minimal shelter, fine substrate, and few resting places for fish (Halleraker et al. 2003).

Whereas some studies found that stranding potential was highest during the day due to concealment behavior of juveniles salmonids (Bradford et al. 1995, Halleraker et al. 2003), others found higher stranding occurrence at night (Bradford 1997). For example, a study on European Grayling (*Thymallus thymallus*) demonstrated that nocturnal hydropeaking events significantly increased drift and stranding of juveniles (Auer et al. 2017). Water temperature and seasonality also affect stranding potential with increasing stranding rates at lower water temperatures and during winter (Saltveit et al. 2001). Experiments on Brown Trout (*Salmo trutta*) in artificial channels in Norway concluded that water temperature was the most important factor determining the magnitude of stranding, with the highest stranding incidents occurring under conditions that included cold water, coarse substrate, low gradient, and high water velocity (Halleraker et al. 2003).

While fish mortality as a result of stranding is well documented, less is known about the sub-lethal and long-term consequences of stranding on growth and population dynamics (Nagrodski et al. 2012) and only few investigations focused on the fish community level (Smokorowski et al. 2011).

FISH STRANDING DOWNSTREAM OF E.B. CAMPBELL HYDROELECTRIC STATION

The river sections downstream of EBC are located in a relatively flat terrain with low river slopes and a braided river system. Given the topography, the hydropeaking operating regime has the potential to result in fish stranding. In 2009, SaskPower in collaboration with North/South Consultants Inc. examined the effects of existing operational hydropeaking procedures on fish stranding in the tailrace of EBC including (1) the determination of where dewatering occurs and quantification of fish and egg mortality related to each daily dewatering event and (2) extrapolation of the total number of mortalities occurring throughout the open-water season based on the frequency of each dewatering event and known (or likely) time periods when each species is present (North/South Consultants Inc. 2010). During the five surveys conducted (late May; early June; mid-July; mid-September; and late October), 194 fish of 22 different fish taxa were found stranded but no eggs were recovered. Small sized fish (<100 mm) stranded more frequently than larger fish. The risk incidence of stranding was somewhat higher in the last three surveys. Extrapolating the number of stranding fish based on the actual discharge, SaskPower estimated that as many as 10,540 (8,563 small fish and 1,977 large fish) fish were potentially stranded in the time period from May 01, 2009 to October 31, 2009 on the survey site. This suggests that ~32 small and ~8 large fish are stranded per day. Up to 40% of large fish were trapped in pools and could potentially survive the stranding but it was observed that many of the trapped fish were subject to predation by birds and small mammals. The stranding survey was repeated during the Cisco (*Coregonus artedi*) spawning period in Fall 2010 with similar findings (North/South Consultant Inc. 2011). As fish trapped in the interstices are not easily observed, the stranding assessments made directly downstream of EBC have likely not quantified this type of stranding, suggesting that the stranding mortality associated with hydropeaking may be underestimated (Steele and Smokorowski 2000).

Impacts of flow fluctuations are typically greatest in the reach immediately downstream of the facility and decline with distance downstream (Kinsolving and Bain 1993). Consequently stranding rates typically decline further downstream due to flow attenuation (Connor and Pflug 2004). However, attenuation is dependent on river morphology and gradient (Kinsolving and Bain 1993) as observed downstream of EBC. The maximum change in water surface elevation is smallest at 5.8 km downstream of EBC and largest at 9.3 km downstream (Figure 25). The risk of stranding is likely lower downstream from site 2 as the substrate particle size is considerably finer. However, despite the finer sediment in these reaches exceptions are noted where the river's channel becomes more complex, for example, in side channels. In 2005, stranding of young-of-the-year fishes (Cisco, Yellow Perch (*Perca flavescens*), White Sucker, and Walleye) was noted (observed) in a side channel in Site 2 (Figure 26). This channel is only wetted at flows >400 m^3 s^{-1} allowing emergent vegetation to establish, thereby increasing the complexity of the habitat and likely increasing the potential for stranding. Factors contributing to this stranding event likely include the fact flows had been large enough to wet this site for the previous two days and the down-ramping rate was >300 m^3 s^{-1} h^{-1} in the first hour and averaged ~160 m^3 s^{-1} h^{-1} (~-0.28 m h^{-1} decrease in water surface elevation at 05KD003) over the first three hours flows were decreased at gauge 05KD003 (Figure 27). This rate of down-ramping occurred 4.4% of all flows from 2001 to September 6, 2004 and 2.8% of all flows since September 7, 2004 (Figure 10). Identifying ramping rates that mitigate stranding may be the most important consideration for flow management to minimize death of fish. Stranding within these side channel habitat is likely influenced by season and time of day, as a result of fish behavior and habitat selection (Cushman 1985, Hunter 1992). In 2014, Green (2017) noted stranding in Site 2 in the main channel (Figure 28).

The average daily change in discharge downstream of EBC is ~500 m^3 s^{-1}, so stranding is possible every day of the year (Figure 8). For example, if discharge is 600 m^3 s^{-1} and decreases to 100 m^3 s^{-1} at sites 1, 2, and 3, there are loses to Wetted Useable Area of 13, 16, and 39% respectively, resulting in the exposure of large areas of stream bed each night. Site 1 loss of wetted habitat occurs in the main channel as well at both banks, whereas Site 2 and 3 lose wetted habitat down both banks as well as side channels (Figures 29-31). Since this magnitude of both change in flow and inundation of side channels is common at all sites further research is warranted to understand the risk of stranding in more complex habitats like side channels as well as the first 12 km downstream of EBC where the bank is dominated by coarse rocky substrate.

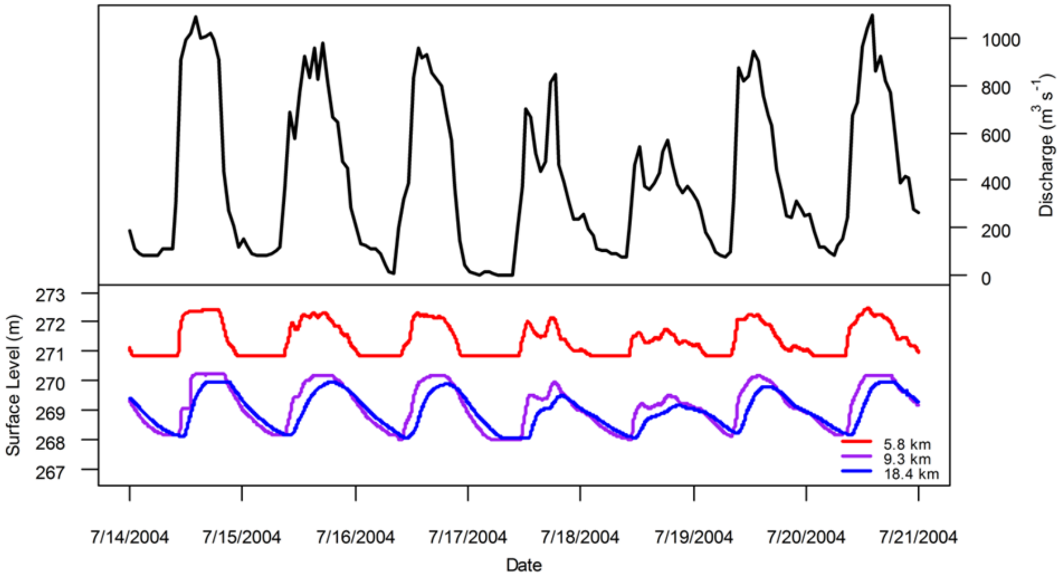

Figure 25. Changes in discharge and the resulting changes in water surface elevation at 5.8, 9.3, and 18.4 km downstream of EBC.

Figure 26. Small bodied fish stranded at ~6:50 h, July 21, 2005 in a Site 2 side channel. Photo Credits: Doug Watkinson.

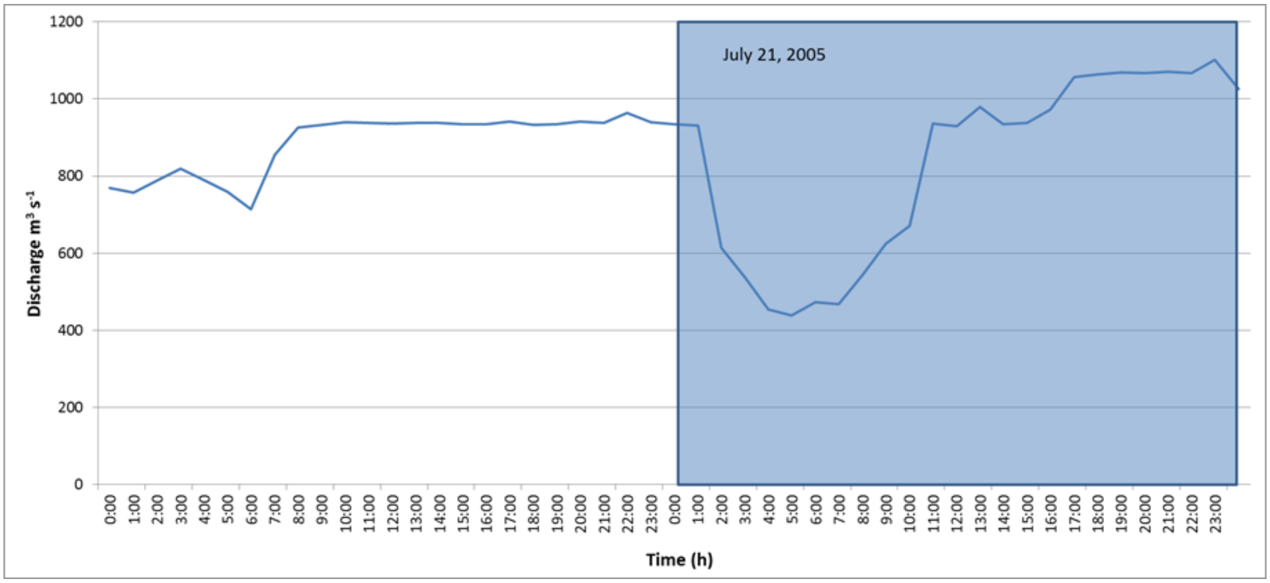

Figure 27. Hourly discharge at gauge 05KD003 downstream of EBC for July 20-21, 2005. The blue box represents July, 21, 2005.

Figure 28. Stranded fish observed downstream of the E. B. Campbell Dam in BSP4 of 2014. Photo Credits: Derek Green.

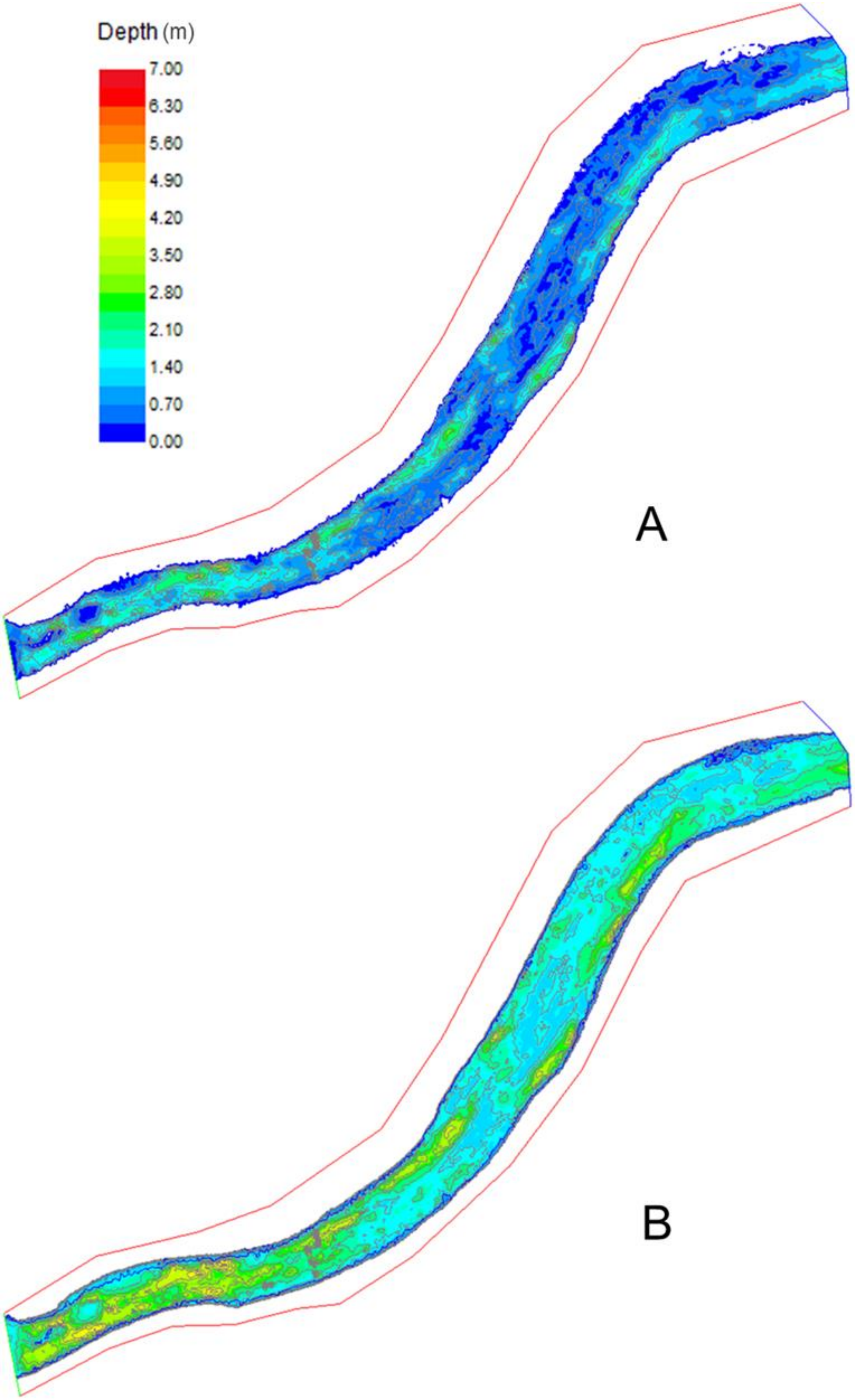

Figure 29. Modelled water depth in Site 1 at a (A) 100 m^3 s^{-1} and (B) 600 m^3 s^{-1} discharge.

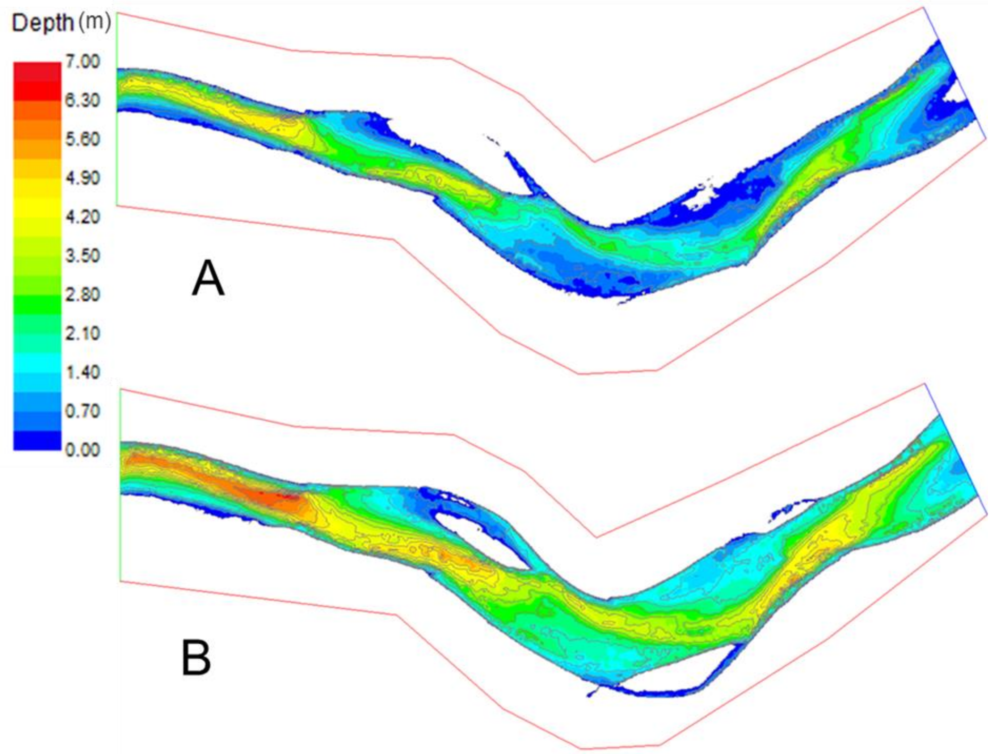

Figure 30. Modelled water depth in Site 2 at a (A) 100 $m^3 s^{-1}$ and (B) 600 $m^3 s^{-1}$ discharge.

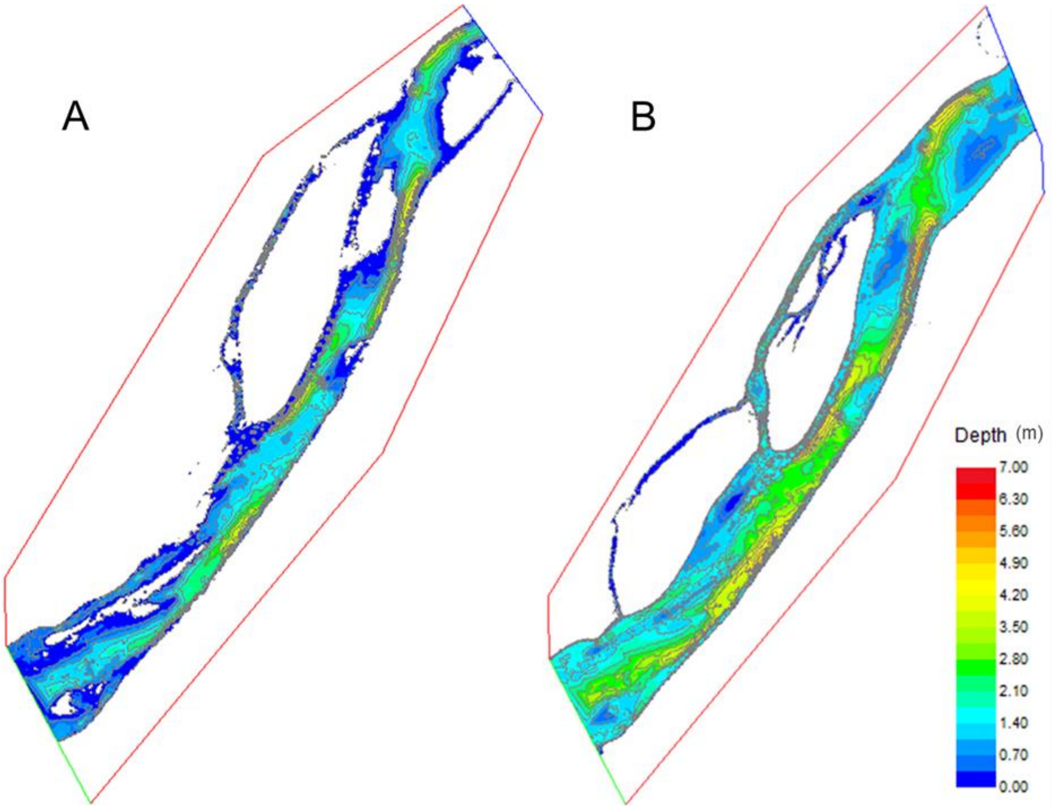

Figure 31. Modelled water depth in Site 3 at a (A) 100 $m^3 s^{-1}$ and (B) 600 $m^3 s^{-1}$ discharge.

MITIGATIONS FOR STRANDING AND IMPLEMENTATION OF RAMPING CONTROLS

Understanding how different environmental and operational factors affect fish downstream of hydropeaking generating stations can improve mitigation and minimize the risk of stranding through improved management. If the objective is to avoid fish stranding, one measure could be to sufficiently slow down the rise and fall in water level during hydropeaking to allow fish to migrate to safe areas (Schmutz et al. 2015, Auer et al. 2017, Melcher et al. 2017). Measures to mitigate the effects of hydropeaking include the reductions of the ramping rate for the power plant outlet into rivers, which has been recommended based on stranding experiments and biotope model simulations (Bradford et al. 1995, Saltveit et al. 2001, Halleraker et al. 2003, Borsanyi 2005). To provide guidelines for hydropeaking operations, Halleraker et al. (2003) conducted stranding experiments with juvenile Brown Trout (0+, 1+, and 2+) at >60, 20, and <10 cm h^{-1} and found daytime stranding rates decreased by more than half at 20 cm h^{-1} for 0+, and did not occur for 1+ and 2+ fish. At rates <10 cm h^{-1}, daytime stranding rates of 0+ were reduced even further, nearly 90%. Fish stranding caused by ramping rates >15 cm h^{-1} are likely responsible for fish community degradation in Austrian hydropeaking alpine rivers (Schmutz et al. 2015). Since these studies were conducted on cold water salmonid species in high gradient system, the results of these studies are not necessarily transferable to the Saskatchewan River system. Based on such stranding investigations, some European hydropower plants have introduced site-specific schemes controlling the ramping rates and timings when reducing discharge or closing the power plant (e.g., Dale Power Plant operated by BKK in Norway; Charmasson and Zinke 2010, Johnson et al. 2010).

Down-ramping rates >10 and >15 cm h^{-1} occur 18 and 10% of flow releases at gauge 05KD003 within Site 1, respectively (Figure 10). DFO developed more protective ramping standards for non-peaking hydro stations in British Columbia (BC) that vary based on the season. During spawning, from 0-2.5 cm h^{-1} during the day and 2.5-5 cm h^{-1} during the night, rearing 0-2.5 cm h^{-1} during the day and 5-10 cm h^{-1} during the night, and winter 0 cm h^{-1} during the day and 0-5 cm h^{-1} during the night (Cathcart 2005). Similarly, Washington State has seasonal ramping rate standards. During spawning, from 0 cm h^{-1} during the day and 0-5.1 cm h^{-1} during the night, rearing 0-2.5 cm h^{-1} during the day and night, and winter 0-5.1 cm h^{-1} during the day and night (Cathcart 2005).

The importance of ramping rate might be highly dependent on other abiotic factors such as seasonal and diel patterns in light intensity, temperature, and season, which should be considered when implementing mitigation strategies. Juvenile salmonids tend to seek shelter in substrate during daylight hours when water temperatures are colder, which decreases their readiness to move (Saltveit et al. 2001). Similar behavioral patterns of shelter seeking and avoidance of predators are common among many juvenile fishes (Magoulick and Kobza 2003). Although juvenile salmonids are not a major component of the fish community, for EBC an appropriate mitigation strategy could be to ramp down during night hours and more slowly during winter than in summer but no site specific information is available to confirm these decision rules.

A stranding study detailed the incidence of fish stranding in the former river channel just north of the powerhouse both seasonally and under different flows and found that a minimum flow of 275 $m^3 s^{-1}$ would continually wet two zones (Zone 3 and 80% of Zone 4) that have currently the highest incidence of stranding (North/South Consultants Inc. 2010). Contouring of the stream channel to an elevation of 278.55 MASL to reduce dewatering and connecting pockets of wetted habitat, was also suggested as a potential mitigation option (North/South Consultants Inc. 2010). The effects of ramping rate on stranding downstream of EBC has not been studied but may be an important cause leading to the direct mortality of fishes that occupy habitat downstream of the generation facility. Reducing the ramping rate when flows were <480 m^3 s^{-1} could additionally help to reduce the stranding of fish near the power house (North/South Consultants Inc. 2011). This is further supported by the Wetted Useable Area calculations for Study Sites 1, 2 and 3 (Figure 13). Above 500 m^3 s^{-1} the channel in most sites is bank full and losses of wetted area are minimal with changing discharge (Figure 13). Flows ranging from 75 to 500 m^3 s^{-1} represent the majority of dewatering events and likely have a corresponding increased risk of stranding.

Additional fish stranding occurs when the spillway is used and the spillway channel (former river channel) conveys flow. To reduce stranding in the spillway channel, adding continuous flow could eliminate the need to conduct fish salvage immediately below the spillway and would likely reduce stranding over the length of the spillway channel. This would also increase wetted habitat available to fish downstream of EBC.

LAKE STURGEON RECRUITMENT

Successful Lake Sturgeon (*Acipenser fulvescens*) larval-hatch is considered contingent on sufficient aeration via oxygenated water (Scott and Crossman 1973, Beamesderfer and Farr 1997). When dewatering and subsequent desiccation of eggs occurs during the incubation period 100% mortality is assumed (Ferguson and Duckworth 1997, Caroffino et al. 2010). As well, sudden and large changes in flow should be avoided; as they trigger changes in water velocities that can disrupt spawning behavior and dislodge eggs and embryos (Dumont et al. 2011). Flow velocities of 0.8-1.5 m s^{-1} were found to be preferred for egg deposition (LaHaye et al. 1992, Dumont et al. 2011). These water velocities are reached in the area downstream of EBC at a ~600 m^3 s^{-1} flow (Figure 32b). Hrenchuk (2011) examined velocities of ~0.1, 0.3, and 0.5 m s^{-1}, 8 cm from the substrate in a field-laboratory study and found both the 0.3 and 0.5 m s^{-1} treatments were suitable for successful hatch, while lower velocities were deemed inferior due to sedimentation, predation, and fungal infection. Consequently, flows that result in velocities <0.3 m s^{-1} near the substrate may potentially be detrimental to egg development and survival.

Lake Sturgeon spawning was observed immediately downstream of EBC in 2014 (North/South Consultants Inc. 2014). This was the only site that spawning was investigated downstream of EBC. To provide examples of environmental conditions available for Lake Sturgeon spawning at different discharges we used River2D, to model average water column velocities in Site 1 at 100 and 600 m^3 s^{-1} (Figure 32). Water velocities were also modeled at 8 cm from the bottom using the Velocity Defect Law of the wall (Crowe et al. 2009) for 100 m^3 s^{-1}, and summarized area within the reach where velocities are <0.3 m s^{-1} (Figure 33). A 100 m^3 s^{-1} discharge limits habitat with sufficient water velocities and may potentially be reducing egg development and larval emergence. Minimum flows that maintain water velocity >0.3 m s^{-1}, 8 cm from the substrate should be considered to assist in recovery of Lake Sturgeon populations.

Sampling for juvenile Lake Sturgeon was conducted in the Saskatchewan River between EBC and Cedar Lake, MB during the Fall, 2015 (North/South Consultants Inc. 2016). This sampling collected 149 fish that were aged from the first pectoral fin ray and summarized in a cohort analysis (North/South Consultants Inc. 2016). The authors of this report concluded 2009, 2011, and 2014, all had particularly strong age cohorts and that high discharge during spawning in 2014 for example may have contributed to successful recruitment in the Saskatchewan River downstream of EBC. Dumont et al. (2011) also found an association between flow and year class strength for this species in the Des Prairies River, Quebec. To investigate this further, we examined the cohort abundance of Lake Sturgeon from North/South Consultants Inc. (2016) in relation to mean daily discharge and mean minimum daily discharge from the hourly flow record in BSP3. The cohorts for which the gear was considered effective was 2005-2014 (North/South

Consultants Inc. 2016), so only fish spawned in those years are considered in the analysis and the abundances were not adjusted for mortality. A total of 136 of the 149 Lake Sturgeon were assigned to the 2005-2014 cohorts. Cohort abundance increased with both average daily and minimum average daily flow (Figure 34). A Lake Sturgeon spawning study conducted immediately downstream of EBC in 2014 confirmed spawning occurred at the beginning of BSP3 in Site 1 (North/South Consultants Inc. 2014). We also considered the first 14 days of BSP3 and made the same comparison to represent the spawning and egg development period. The r^2 values were higher for the first 14 days of BSP3 (Figure 35). Consequently, higher flow seems to have a positive effect on cohort abundance and that spawning and egg development to the larval stage, which mostly occurs near the beginning of BSP3. No relationship was observed with cohort strength and the larval drift and dispersal period, which tends to occur toward the end of BSP3 (Figure 36). In the years Lake Sturgeon abundance was highest, 2011 and 2014, flows were never <1,000 $m^3 s^{-1}$ during BSP3.

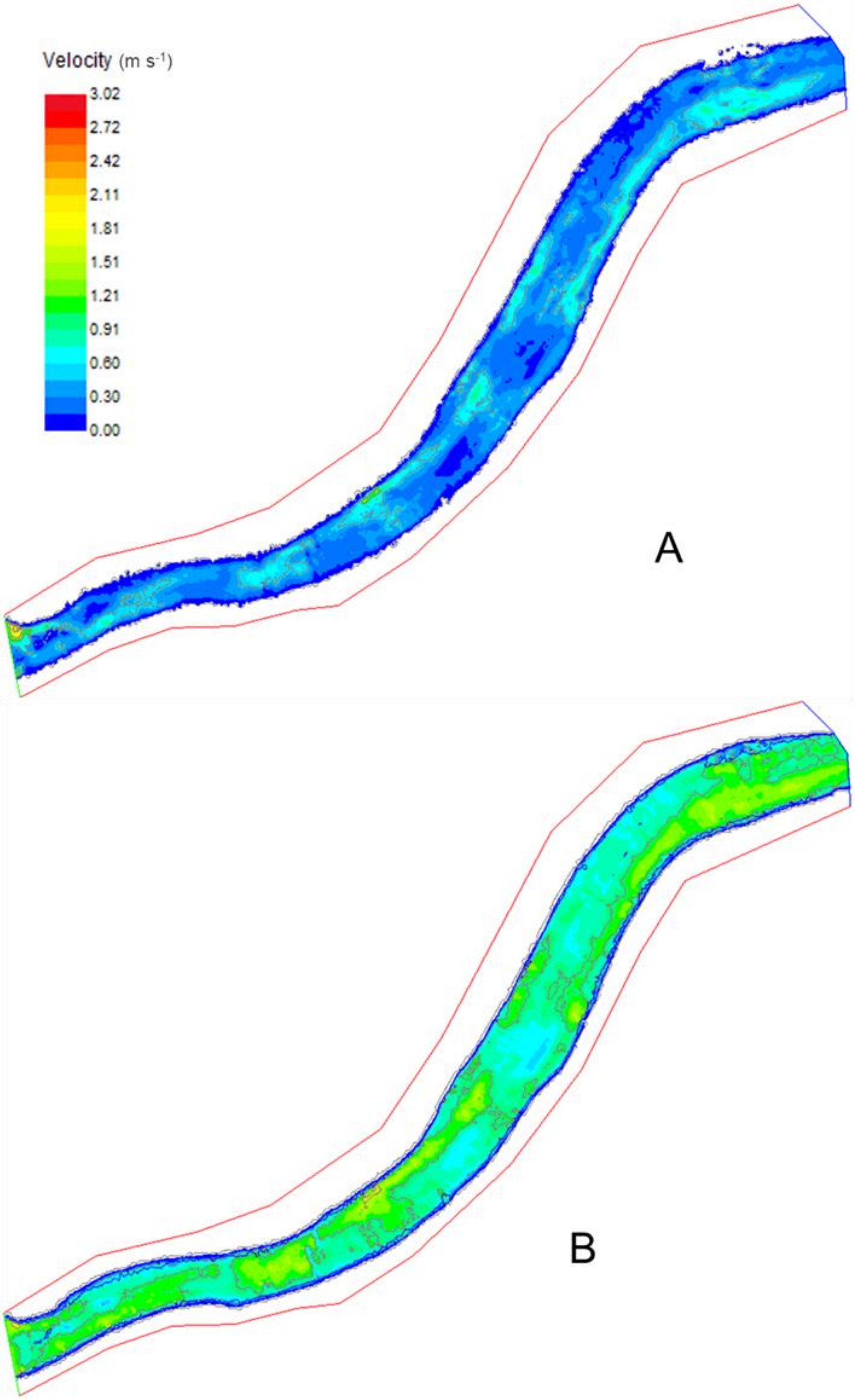

Figure 32. Average water velocity at (A) 100 m^3 s^{-1} and (B) 600 m^3 s^{-1}discharge at Site 1.

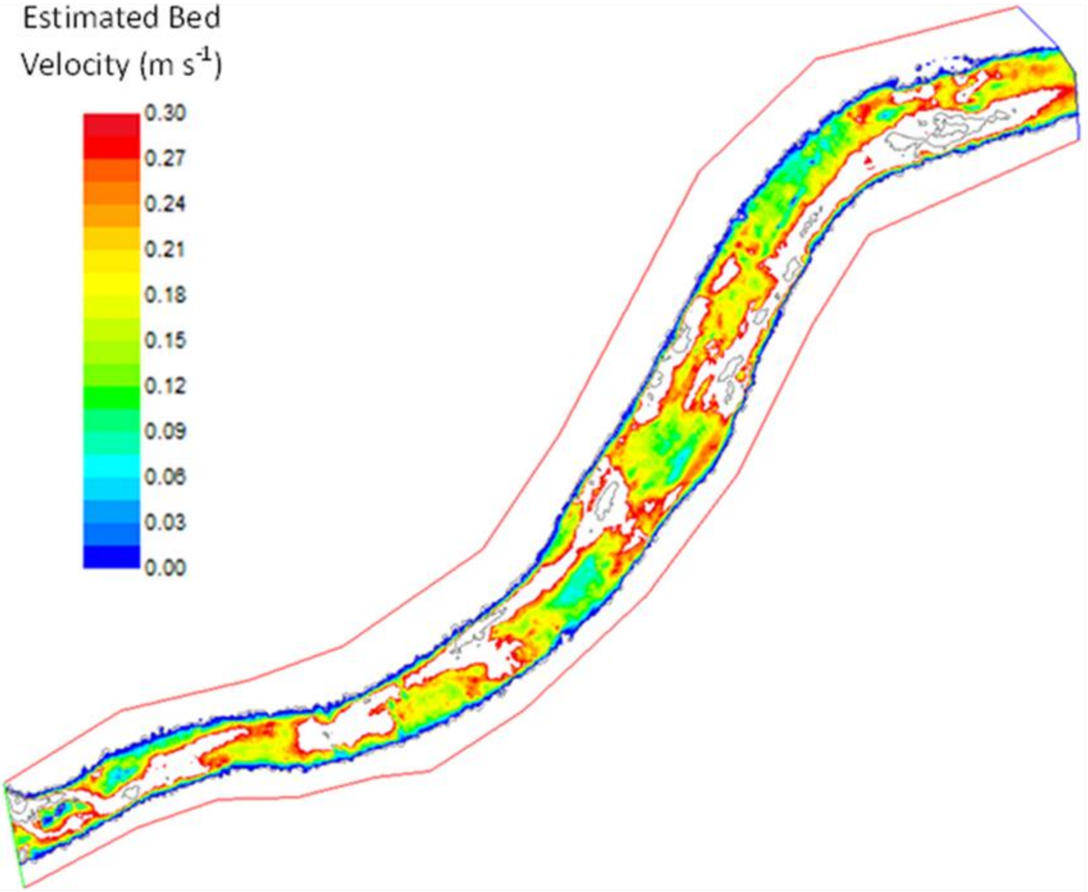

Figure 33. Water velocity <0.3 m s^{-1}, at 100 m^3 s^{-1}, 8 cm from the bottom in Site 1. Areas in white are >0.3 m s^{-1}.

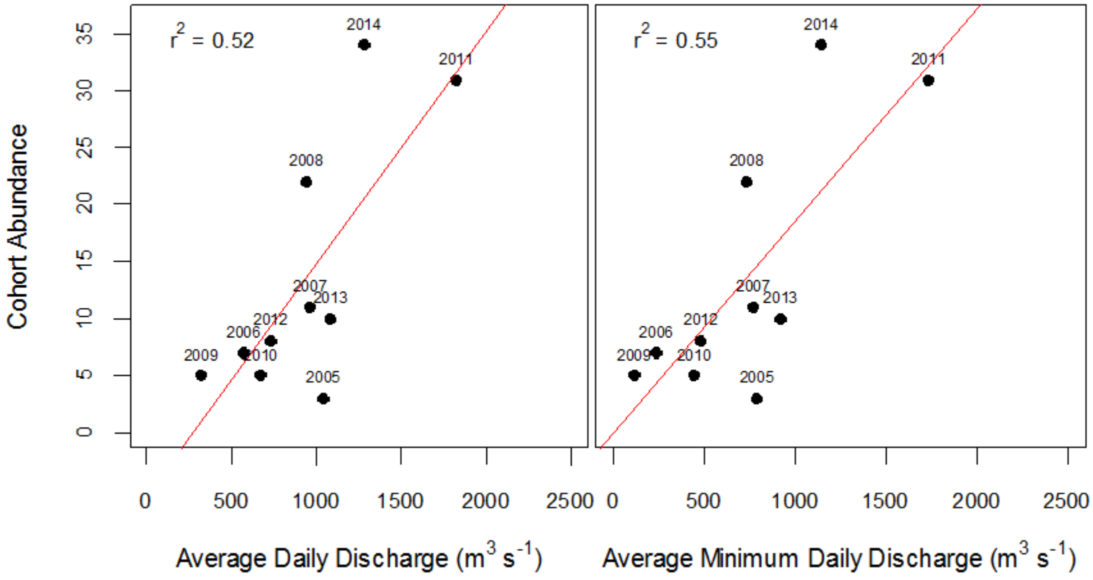

Figure 34. Relation between average daily discharge and average minimum daily discharge and Lake Sturgeon cohort abundance from North/South Consultants Inc. (2016) in BSP3 for 2005-2014.

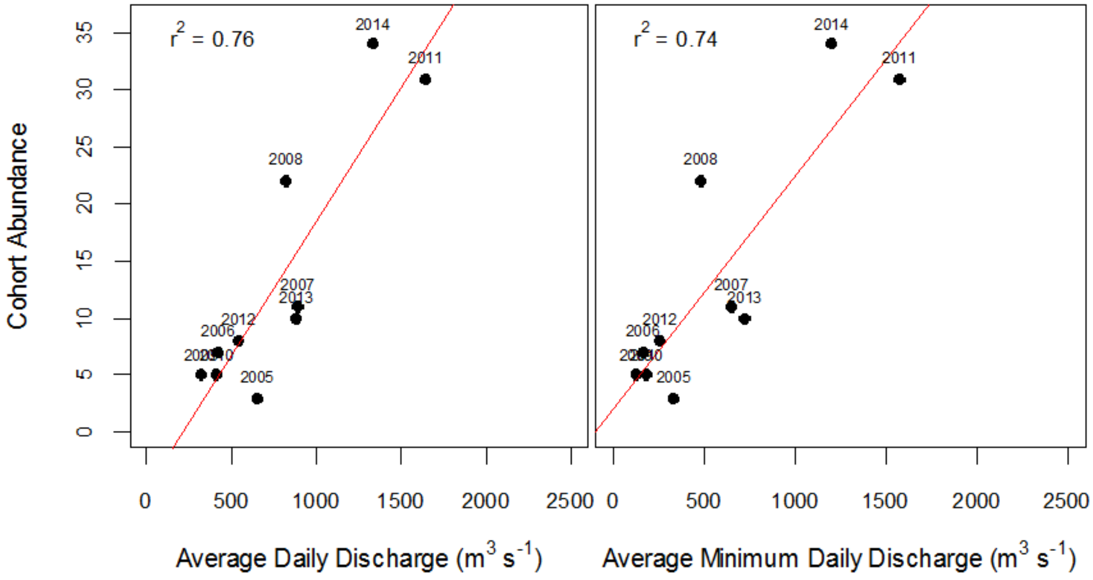

Figure 35. Correlation coefficients of Lake Sturgeon cohort abundance from North/South Consultants Inc. (2016) compared to average daily and average minimum daily discharges for the first 14 d of BSP3 for 2005-2014.

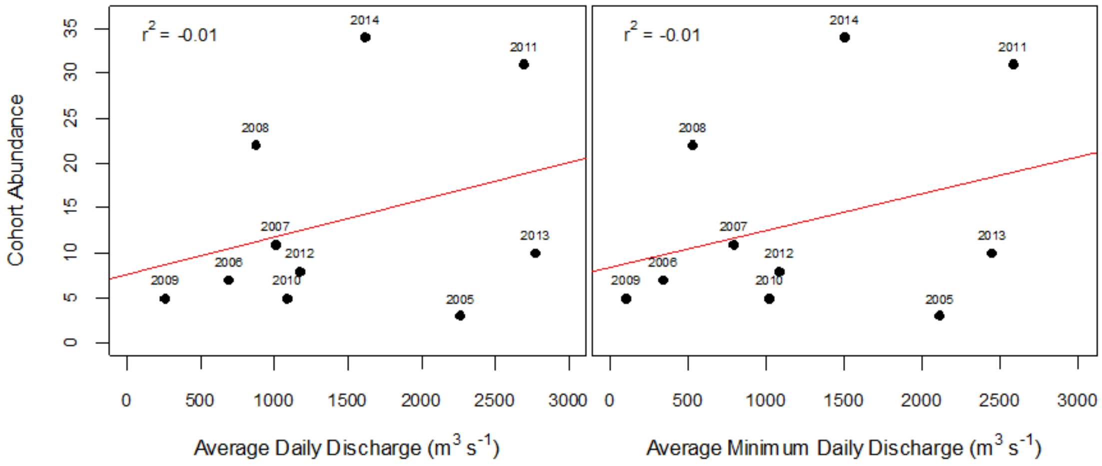

Figure 36. Correlation coefficients of Lake Sturgeon cohort abundance from North/South Consultants Inc. (2016) compared to average daily and average minimum daily discharges for the last 14 d of BSP3 for 2005-2014.

LAKE STURGEON LARVAL DRIFT

Larval Lake Sturgeon typically occupy gravel substrate to avoid predation during development (Auer and Baker 2002, Hastings et al. 2013). Following yolk-sac absorption, larval fish emerge from the substrate and disperse downstream (LaHaye et al. 1992, Auer and Baker 2002, Smith and King 2005). Larval Lake Sturgeon typically drift between 22h00 and 03h00 approximately 13-24 d after the peak of spawning (Smith and King 2005, Dumont et al. 2011). It is notable that the time of day that larval Lake Sturgeon disperse corresponds with the lowest hourly discharges downstream of EBC (Figure 4). Consequently, the reduced flows during night in BSP3 may affect the dispersal of larval Lake Sturgeon. Reduced dispersal could result in higher direct mortality from predation and reduced long-term survival if larval fish have increased intraspecific competition due to higher densities from poor downstream dispersal. Based on the observed relationship between cohort strength and discharge this may not be a concern (Figure 36).

CHANGE IN ACCESS TO HABITATS

EBC is a barrier to upstream movement and likely limits downstream safe dispersal of fishes either though the power house or over the spillway. This may have had an effect on both species diversity and population size structure (Enders et al. 2017). A fish movement study concluded relatively high levels of fish entrainment do occur for Walleye (22%) and Northern Pike (9.1%) in Tobin Lake during a ~28 month study (North/South Consultants Inc. 2016). The risk of entrainment was highest when spilling occurred and may be lower in low discharge years (North/South Consultants Inc. 2016). Entrainment may modify the fish community composition both upstream and downstream of EBC.

FISH BIOENERGETICS

Increasing energy spent on metabolism via an increased activity cost due to a change in flow could impact growth and reproduction (Clarke et al. 2008). Food availability typically changes with a change in flow, affecting energy available. Metabolic costs may also vary with change in foraging costs, affecting the energy available for growth and reproduction (Clarke et al. 2008). The change in the temperature regime in most years will delay spring spawning.

Sampling conducted in 2005-2006 did not observe any differences in size at age of fish sampled downstream of EBC and at the Reference Site on the system, suggesting that fish grew at the same rates (Figure 23; Enders et al. 2017).

POTENTIAL STUDIES ADDRESSING KNOWLEDGE GAPS AND UNCERTAINTIES

To address some of the remaining knowledge gaps and uncertainties of the effects of the hydropeaking operation of EBC on fish and fish habitat, the following research studies may be considered:

- Study fish stranding in the three study reaches downstream of EBC and further downstream where flow changes remain detectable, to understand the impact on fish species and life stages, habitat and ramping rates on the risk of stranding;
- Investigate spring and fall spawning/incubation areas in the Saskatchewan River downstream of EBC and evaluate success of spawning relative to flow;
- Study fish recruitment in relationship to stranding downstream of EBC to understand why juvenile fish abundance is low;
- The fish data collected in 2005 and 2006 is largely representative of site conditions prior to the implementation of the 75 $m^3 s^{-1}$ minimum flow so information on the current population size/age structure is not known. Repeated sampling of the fish community is needed to understand the current fish community;
- Embrace traditional knowledge to understand system behaviour and help reduce uncertainties;
- Study ice dynamics downstream of EBC to determine if it is a concern for fish and fish habitat;
- Study sediment restoration and management options to potentially mitigate sediment starvation in the downstream reaches and the delta.

MITIGATION OPTIONS TO CONSERVE AND PROTECT FISH AND FISH HABITAT

Consideration could be given to the release of compensation flows (Bergkamp et al. 2000) for the maintenance of the ecosystems downstream of EBC. Compensation flows were traditionally continuous minimum flow release that had to be maintained throughout the year such as the minimum flow required downstream of EBC. Regulators have begun to require that operators vary flow seasonally to mimic the natural seasonal variation in flow (Bergkamp et al. 2000) to consider ecosystem-level requirements (Enders et al. 2009). Flow management may need to follow the natural hydrological cycle; to assess the amount, timing, and conditions under which water should be released (Scruton and LeDrew 1997, Bergkamp et al. 2000). Timing of a flood release should consider both fish and fish habitat, as well as the Saskatchewan River Delta as shifts in peak flow timing can alter the magnitude and timing of flow to the delta, and increased rates of isolation of lakes and wetlands from the Saskatchewan River (Hassanzadeh et al. 2017). Given the complexity of water management in terms of both infrastructure and jurisdictions, flow management may need to start in the headwaters (Alberta) and there would be impacts to other upstream users in both Alberta and Saskatchewan as well as downstream in Manitoba.

Considering a review of the literature, data collected on site, and the results of the study and analyses conducted, we highlight a number of potential mitigation options based on our current understanding of the Saskatchewan River system.

1. Wetted Useable Area is dependent on discharges and differs for the three sites downstream of EBC likely due to differences in their channel morphology and slope. Flows to maintain ≥95% of Wetted Useable Area relative to a 700 $m^3 s^{-1}$ flow would be 300 $m^3 s^{-1}$ in Site 1, 450 $m^3 s^{-1}$ in Site 2, and 450 $m^3 s^{-1}$ in Site 3 (Table 2).
2. Hydropeaking leads to flows that vary much more throughout a given day than they would naturally. It is recommended that the minimum flow in each BSP is not lower than the natural 95% exceedance flow for the 1912-1963 flow record. The 95% exceedance values for daily average flows pre-dam construction were 66, 232, 459, and 239 $m^3 s^{-1}$ for BSP1, 2, 3, and 4, respectively (Figure 11). The higher minimum flows in BSP2 and 3 could be protective of spawning periods for the majority of fish species in the Saskatchewan River. Reducing the hydropeaking operations during this time period should ensure successful egg incubation and larval drift. The higher minimum flows would also reduce the stranding risks.
3. Weighted Useable Area calculation determined that BSP2 and 3 may be the most sensitive time periods to flow changes as the eggs and larva of most species are not mobile. For example the maximum Weighted Useable Area for Lake Sturgeon during spawning in Site 1 using Category I HSC was 450 $m^3 s^{-1}$ (Table 6, Appendix 1).
4. Lake Sturgeon is a species of significant cultural importance. COSEWIC has listed Lake Sturgeon in the Saskatchewan River as endangered. It is currently under consideration for listing under the Species at Risk Act. The recovery of Lake Sturgeon may benefit from maintaining a minimum flow during the first two weeks of BSP3 that maximizes potential recruitment success. Based on the analysis of cohort strength, this minimum instantaneous flow is likely >500 $m^3 s^{-1}$ and mean daily discharges >1,000 $m^3 s^{-1}$ (Figure 35). These flows may not be available all years but in wet years flow should managed so these flows can occur.
5. Rapid down-ramping is one of the factors that increase the risk of fish stranding. Downstream of EBC, down-ramping when flows <500 $m^3 s^{-1}$ result in the largest Wetted Useable Area changes, and were found to increase the risk of stranding. Down-ramping rate rules that limit water surface elevation changes to when discharges are <500 $m^3 s^{-1}$ should be studied to determine the feasibility of restricting down-ramping to minimize its effects on stranding. Specific research could determine if this threshold is appropriate by conducting additional stranding studies at the study site examined by North/South Consultants Inc. (2010, 2011) as well as other reaches within study Sites 1, 2, and 3 and areas further downstream where hydropeaking flow alterations are measureable.
6. Additional fish stranding occurs when flows exceed 1,000 $m^3 s^{-1}$ and the spillway (former river channel) is used. To reduce stranding in the spillway, adding continuous flow to the spillway could eliminate the need to conduct fish salvage immediately below the spillway after each spill event and would likely reduce stranding over the length of the entire spillway channel. This would also increase the wetted habitat available to fish downstream of EBC. Ramping rates for the spillway flows should also be considered.
7. Re-sculpturing the river bed in the former river channel to connect isolated pools and reduce the bed elevation to below 278.55 MASL should be considered in combination with mitigation related to flow to reduce stranding in this discrete area.
8. Flow >1,000 $m^3 s^{-1}$ downstream of EBC should provide additional flooding and connectivity in the Saskatchewan River Delta (Sagin et al. 2015) and the potential to increase fisheries productivity. This would reconnect backwaters and side channels in the upper delta, creating additional seasonal habitat for juvenile sturgeon and other

species. Additionally, this may benefit Lake Sturgeon recruitment. Management of the hydrograph to allow for prescribed “floods” in BSP2 or 3 would also be beneficial for the entire downstream river system from an ecological and geomorphological perspective.

9. To minimize the influence of environmental variability on both fish and power production, the dates adopted for the recommended minimum flow values could be adjusted for each BSP in response to mean daily water temperatures that correspond to known spawning periods of fish species.
10. Given that annual flow is variable, flexibility in the minimum could be adjusted either down or up depending on the conditions that year. A percentages approach whereby a percent of flow into Tobin Lake could be used to set a variable minimum flow value. This percentage could be specific for each BSP to be either more or less protective and would take into account annual variation in the hydrograph. A ramping rate rule should remain fixed regardless of available daily flow.

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APPENDIX 1: RESULTS FROM THE WORKSHOP HELD IN PRINCE ALBERT, SASKATCHEWAN (NOVEMBER 7-9, 2005) TO DEVELOP HABITAT SUITABILITY CRITERIA FOR FISHES IN THE SASKATCHEWAN RIVER DOWNSTREAM OF THE E.B. CAMPBELL HYDROELECTRIC STATION

INTRODUCTION

One of the objectives of the EB Campbell Steering Committee was to determine the relationship between flow and habitat for the Saskatchewan River downstream of E.B. Campbell (EBC) Hydroelectric Station. As part of this process, a fish habitat modeling workshop was held to determine how various fish species use habitat within the Saskatchewan River. An expert group was assembled that consisted of local fishers, biologists, and engineers to participate in this workshop. This appendix describes the synopsis of the workshop discussions.

For the purposes of the Habitat Suitability Workshop, the term “Advice of Fishers” not “Traditional Knowledge” was used as the proper process for First Nations consultation was not followed. If required, a practical methodology could be implemented to gather oral knowledge from elders and other participants in the future. The workshop participants were: Marcy Bast (SaskPower), Debbie Nielsen (SaskPower), Rick Courtney (DFO), Terry Dick (University of Manitoba), Bill Franzin (DFO), Chris Katopodis (DFO), Rob Wallace (Saskatchewan Environment), Doug Watkinson (DFO), Dave Evans (DFO), Darcy Lightle (DFO), Murray Koob (Saskatchewan Environment), Akira Watanabe (University of Regina), Dan Beveridge (Saskatchewan Water Security Agency), Lennard Morin (Cumberland House First Nation), Robert McAuley (Cumberland House First Nation), John Carriere (Cumberland House First Nation), Naomi Carriere (Cumberland House First Nation), Barry Carriere (Cumberland House First Nation), and Angus McKenzie (Cumberland House First Nation).

During Habitat Suitability Workshop, concerns were raised about the limitations on the extent of the study area to the reach downstream of EBC and that effects of the dam operations on the Saskatchewan River Delta may not be captured with the 2005-07 DFO field study. Therefore, an Issues Committee comprised of DFO, SaskPower, Saskatchewan Water Security Agency, and Saskatchewan Environment was established to address future concerns as required. For the purposes of Habitat Suitability Workshop, it was decided to focus exclusively on the existing study area downstream of EBC.

GENERAL OBSERVATIONS/DISCUSSION POINTS

- A shift in the invertebrate population has been observed. Specifically, *Hexagenia* and *Ephoron* mayflies have decreased in recent years.
- Increased clam and crayfish predation by Northern River Otter (*Lontra canadensis*) leading to competition for food sources with Lake Sturgeon.
- Pelican (*Pelecanus onocrotalus*) and Cormorant (*Phalacrocorax auritus*) numbers are increasing and birds are arriving earlier each season.
- Limited information on juvenile life stages for all species noted, suggested that backpack electro-fishing/seine netting should be conducted in the future to collect more information.
- The importance of eddies was emphasized for station-holding fish. The idea of identifying how many and how big eddies are at different flows was discussed.

ASSUMPTIONS

Eleven assumptions were used to guide habitat suitability curve development for an Instream Flow Needs assessment on the Athabasca River and the South Saskatchewan River Basin (SSRB) (see Clipperton et al. 2003 for details). The following 11 assumptions were presented to the group by Rick Courtney:

1. Relatively simple straight-line plots (opposed to smooth curve plots) were used to describe habitat suitability.

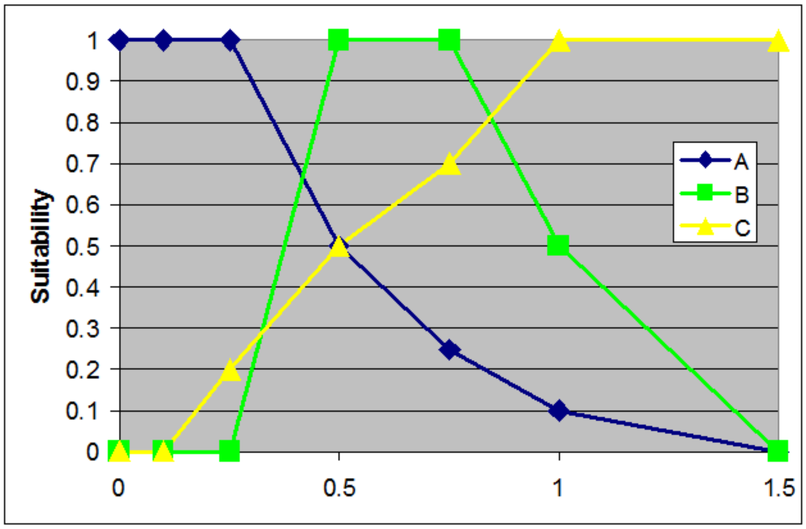


Figure A1.1. Graphical representation of simple straight line plots to describe habitat suitability.

2. Each curve has only one peak.

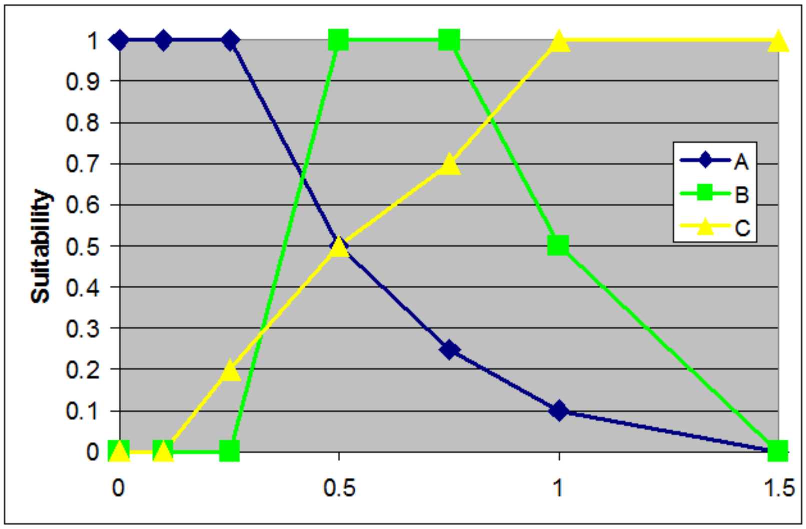


Figure A1.2. Graphical representation of each suitability curve with only one peak.

3. Depth suitability is zero at least until water is deeper than the depth of the body of the fish species/life stage considered.

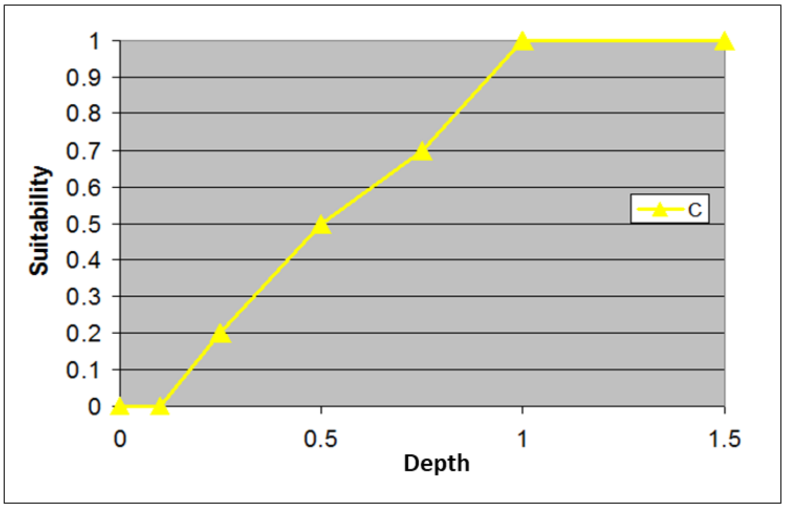


Figure A1.3. Graphical representation of depth suitability at zero until water depth is more than the depth of the body of the fish species/life stage considered.

4. The depth suitability does not necessarily return to zero. Adult fish could always use deep water in the river. Juveniles may not avoid deep-water habitat, but limited food or increased risk of predation may make deep-water habitat lower quality. Depth data often do not represent actual fish habitat use due to sampling or habitat availability issues.
5. A velocity of zero can have a suitability greater than zero.

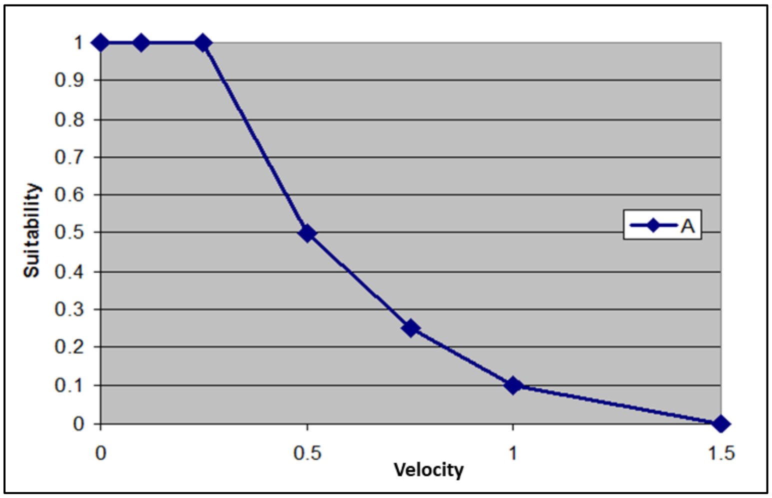


Figure A1.4. Graphical representation showing that a velocity of zero can have a greater than zero suitability.

6. All of the velocity curves have a suitability of zero at an upper velocity. Considered maximum observations from other studies to define this upper limit are used.
7. Mean column velocity is a weakness in the habitat modeling. The mean column velocity is greater than the nose velocity where fish are actually found. Different sized fish can occupy

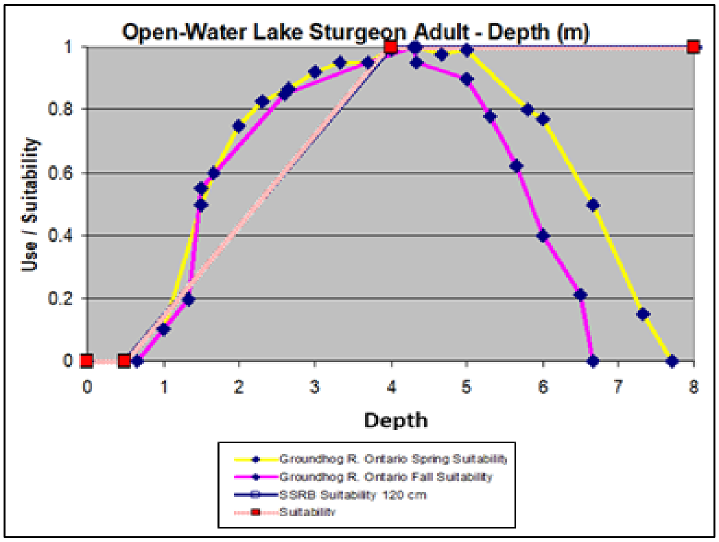
different sized cover, probably explaining why juveniles can be found in high mean column velocities, sometimes where adults are not found.

8. The fry life stage includes fish just emerging with no swimming ability up to fish at the end of their first growing season that are capable of maintaining a position in the water column. This will likely result in a shift in depth and velocity suitability as they grow. The habitat suitability curves actually represent the larger fry. This assumption was accepted based on the lack of knowledge or viable way to divide large and small fry.
9. Personal experience of the workshop participants was used in addition to the habitat data available from previous studies.
10. When considering the habitat data, the workshop curve could have a lower suitability than one or more of the habitat curves based on personal experience and evaluation of the quality of the habitat data.
11. Based on the experience from South Saskatchewan River Basin (SSRB) study, no channel index (i.e., substrate and/or cover) suitability curves were used for the Athabasca River study. A comparison of results with and without channel index found little difference for Trout and Whitefish on the Highwood River except for spawning. Also, the SSRB channel index data were in bad shape and it was too much work to go back to the field notes to fix it. However, the SSRB study did use an abbreviated version of substrate for spawning habitat. This assumption was rejected by the group.

RESULTS AND CONCLUSIONS

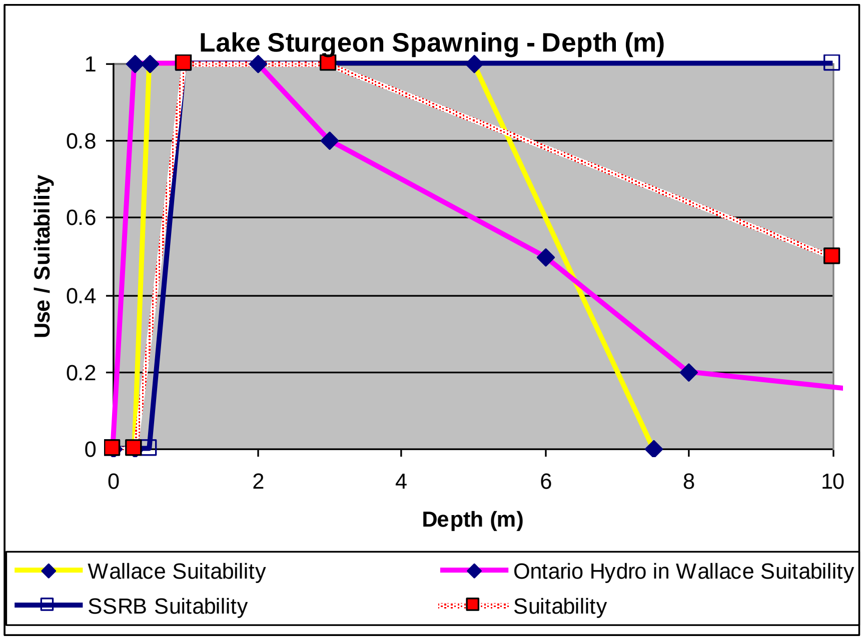
In conclusion, the first ten assumptions were accepted by the workshop participants but assumption number 11 was rejected and substrate suitability curves were instead generated for the channel index parameter.

The following habitat suitability curves were developed for a number of life history stages of Lake Sturgeon, Shorthead Redhorse, Walleye, Northern Pike, and Goldeye:



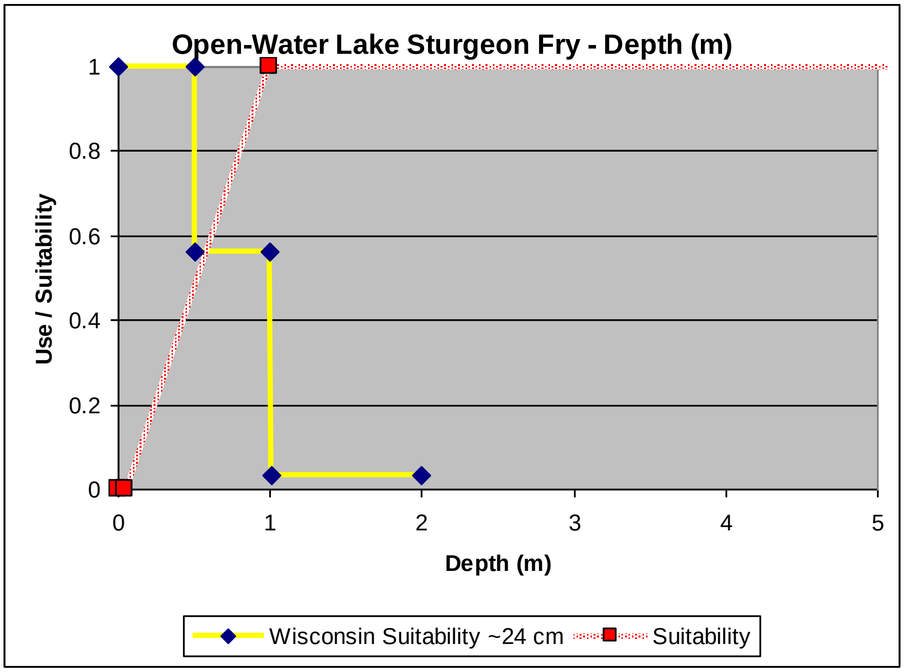
Depth (m)	Suitability
0	0
0.5	0
4	1
8	1

Figure A1.5. Habitat suitability curve for Lake Sturgeon adults in the open water (depth (m)). At the workshop, depth was determined to be non-limiting for adult Lake Sturgeon. Lake Sturgeon were also known to be more readily captured in the Saskatchewan River downstream of E.B. Campbell when water levels are decreasing than when increasing.



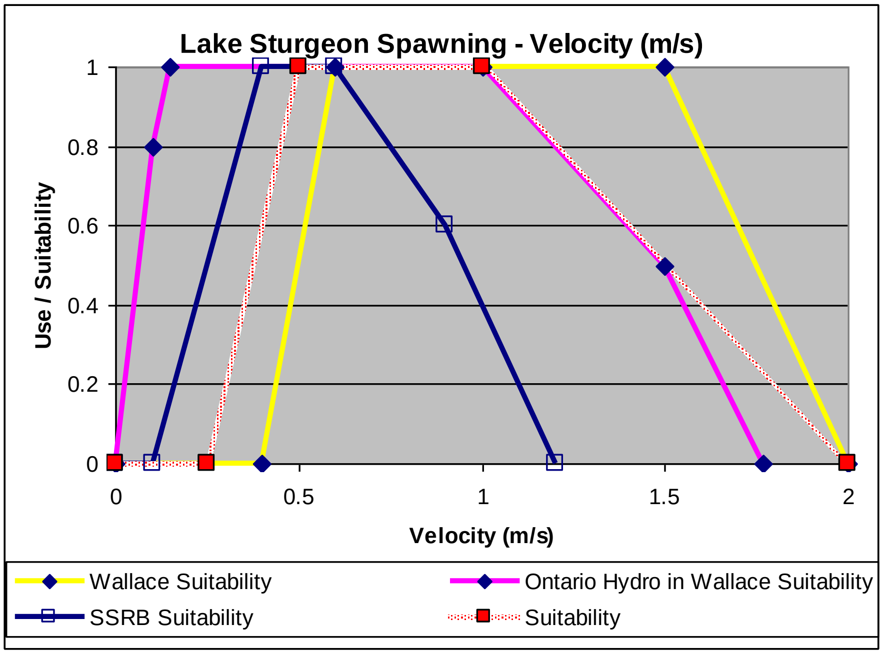
Depth (m)	Suitability
0	0
0.3	0
1	1
3	1
10	0.5

Figure A1.6. Habitat suitability curve for Lake Sturgeon spawning in the open water (depth (m)). At the workshop, it was determined that the minimum depth of water must cover at least the fish's back (~30 cm). Concerns were raised that velocities at greater depth are too low for spawning. In May, 18 out of 19 males found expelling sperm, which correlated with the budding leaves.



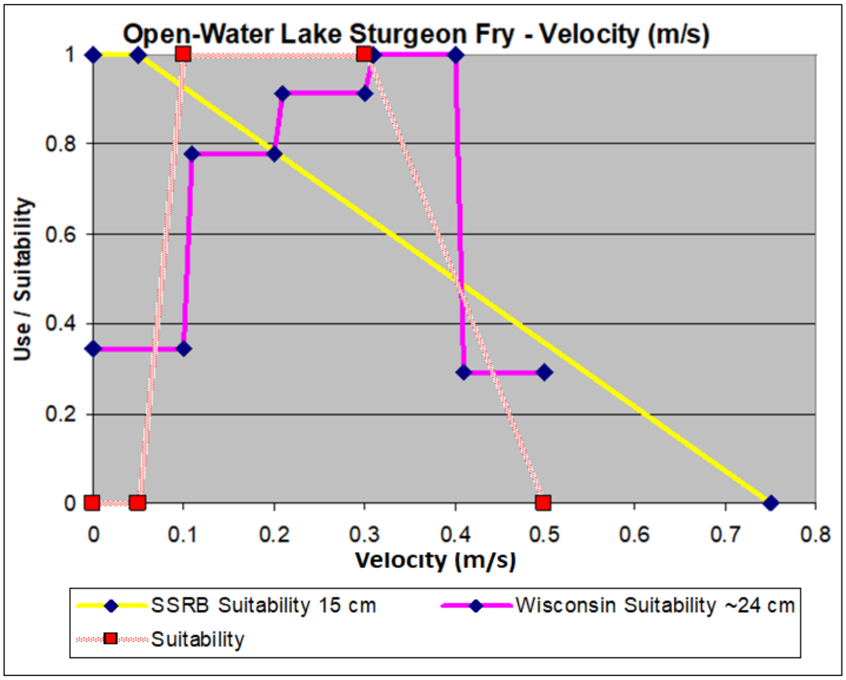
Depth (m)	Suitability
0	0
0.05	0
1	1
10	1

Figure A1.7. Habitat suitability curve for Lake Sturgeon fry in the open water (depth (m)). At the workshop, depth was determined that 3-4 m is optimal for fry, based on shallow water data from Wisconsin (might due to sampling limitations).Occurrence in deeper water is likely more limited by predation.



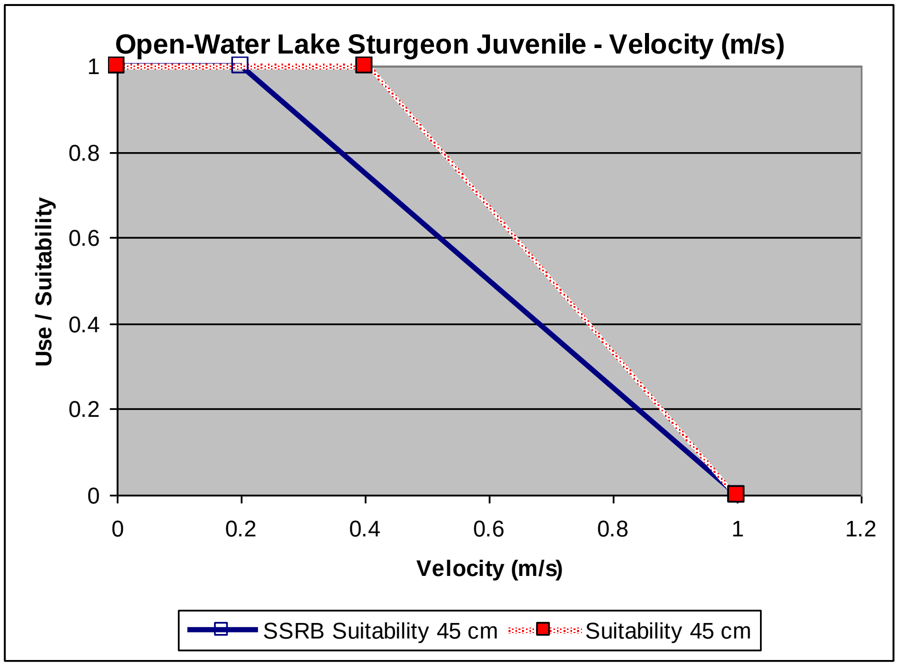
Velocity (m/s)	Suitability
0	0
0.25	0
0.5	1
1	1
2	0

Figure A1.8. Habitat suitability curve for spawning Lake Sturgeon (velocity (m/s)). At the workshop, it was determined that nose velocity vs. mean column velocity was assumed, therefore used 2 m/s instead of 1.75 m/s as reported by Rob Wallace.



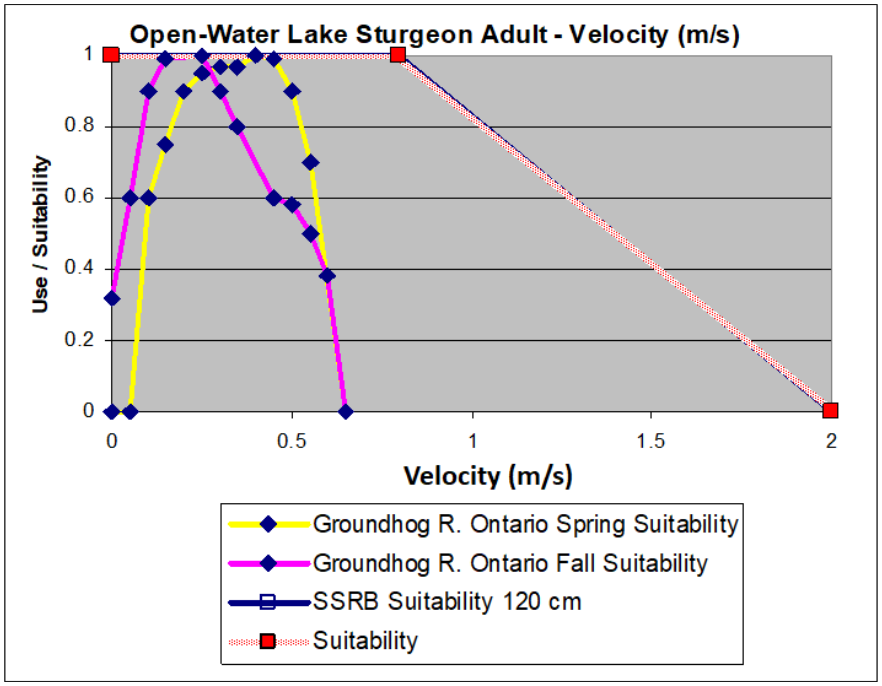
Velocity (m/s)	Suitability
0	0
0.05	0
0.1	1
0.3	1
0.5	0

Figure A1.9. Habitat suitability curve for spawning Lake Sturgeon fry in open water (velocity (m/s)). At the workshop, it was determined that Lake Sturgeon fry require low velocities in their first year of life.



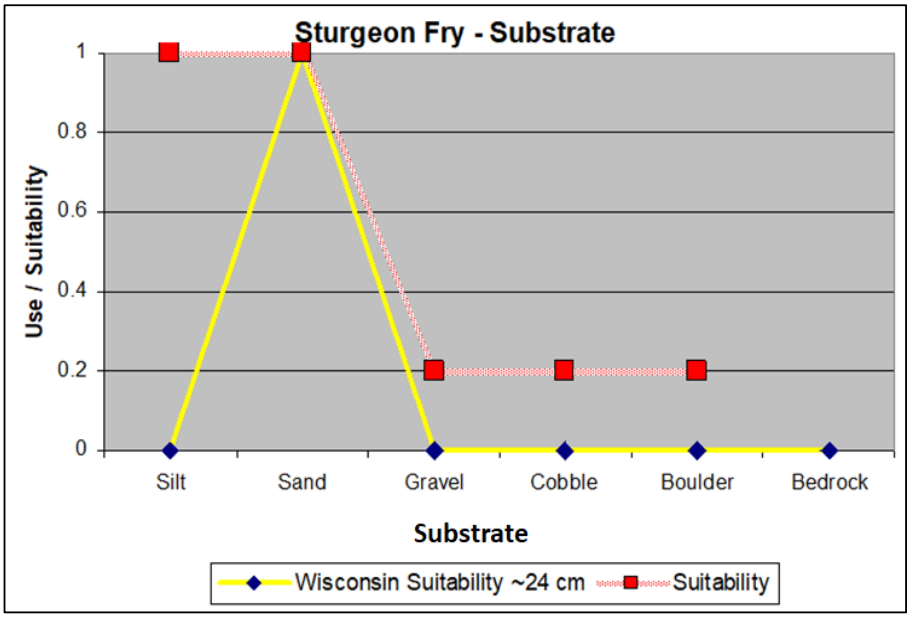
Velocity (m/s)	Suitability 45 cm
0	1
0.4	1
1	0

Figure A1.10. Habitat suitability curve for juvenile Lake Sturgeon (velocity (m/s)). For juvenile Lake Sturgeon with a body length >45 cm.



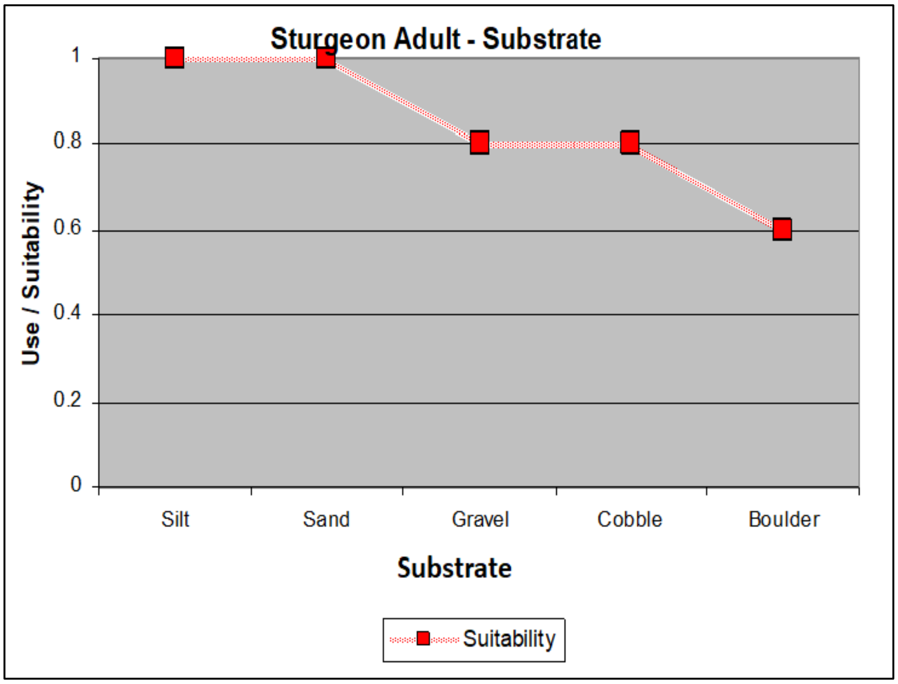
Velocity (m/s)	Suitability
0	1
0.8	1
2	0

Figure A1.11. Habitat suitability curve for Adult Lake Sturgeon in open water (velocity (m/s)). Input data based on flume studies.



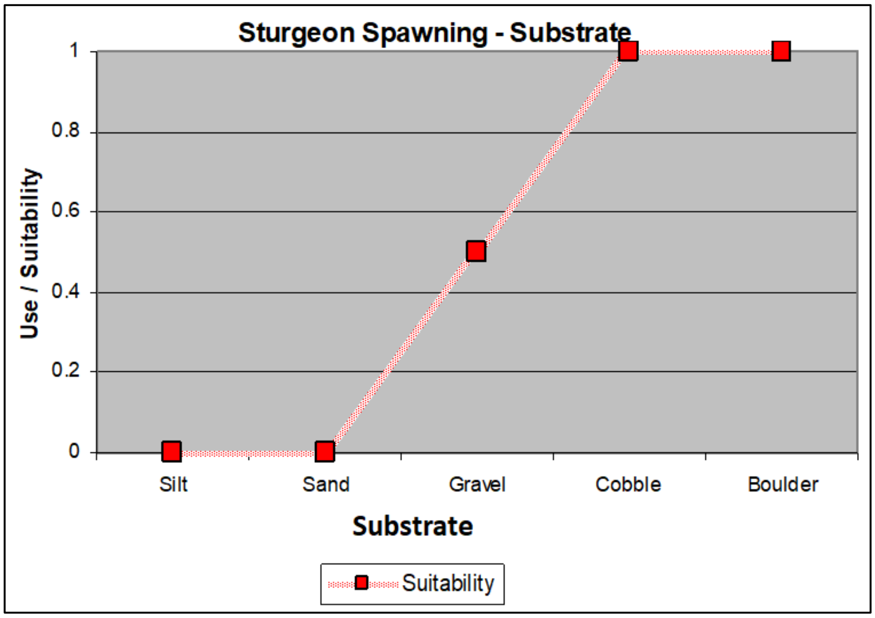
Substrate	Suitability
Silt	1
Sand	1
Gravel	0.2
Cobble	0.2
Boulder	0.2

Figure A1.12. Habitat suitability curve for Lake Sturgeon fry substrate.



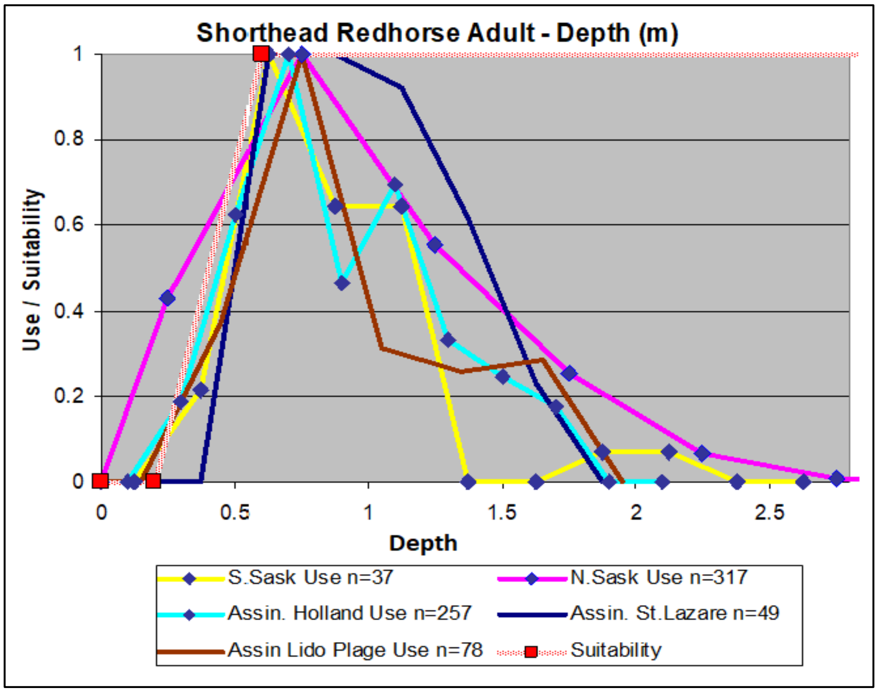
Substrate	Suitability
Silt	1
Sand	1
Gravel	0.8
Cobble	0.8
Boulder	0.6

Figure A1.13. Habitat suitability curve for Adult Lake Sturgeon substrate. Fishers have targeted mussel beds and areas with crayfish both preferred prey species for Lake Sturgeon. Fishers have reported high numbers of crayfish and clams in recent years. Water column feeding observed in some individual adult Lake Sturgeon.



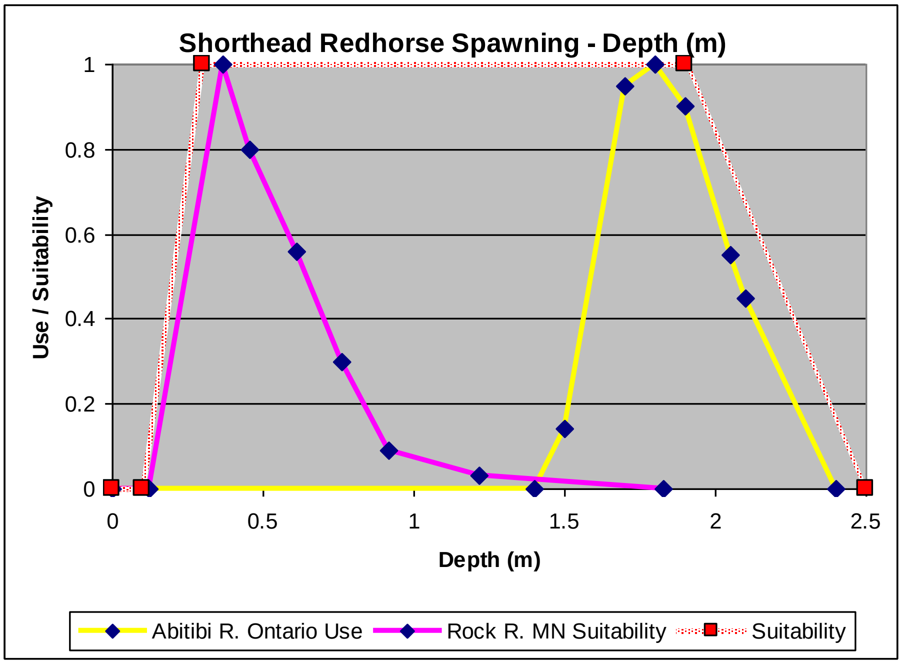
Substrate	Suitability
Silt	0
Sand	0
Gravel	0.5
Cobble	1
Boulder	1

Figure A1.14. Habitat suitability curve for spawning Lake Sturgeon substrate.



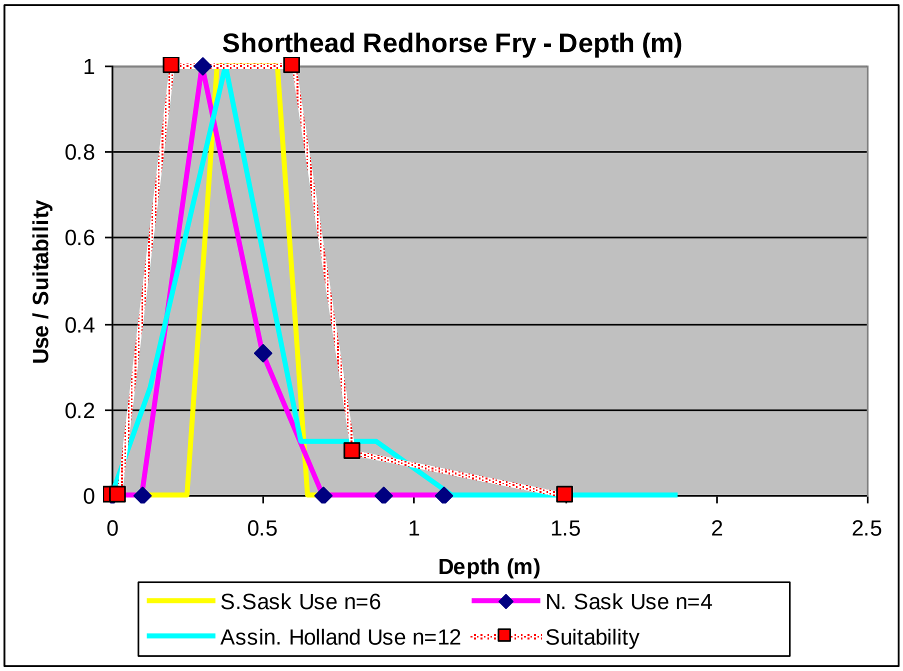
Depth (m)	Suitability
0	0
0.2	0
0.6	1
5	1

Figure A1.15. Habitat suitability curve for Shorthead Redhorse adults in the open water (depth (m)). Winter netting from First Nations describes 2.8 m optimal depth. At the workshop, depth was determined to be likely limited only by predation. Depth >0.2 m to ensure fish backs is under the water surface.



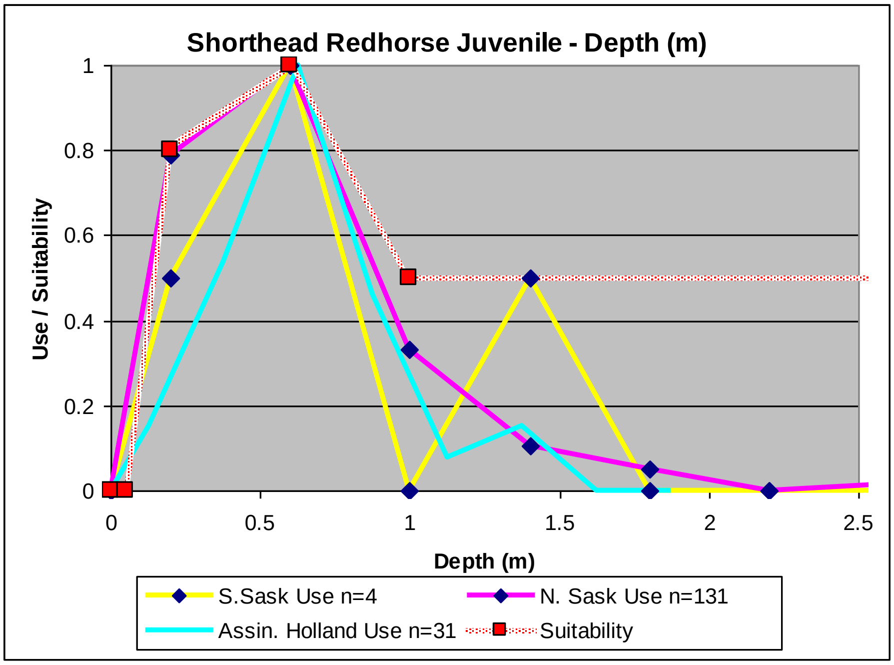
Depth (m)	Suitability
0	0
0.1	0
0.3	1
1.9	1
2.5	0

Figure A1.16. Habitat suitability curve for spawning Shorthead Redhorse adults in the open water (depth (m)). The curve adjusted to incorporate both existing datasets.



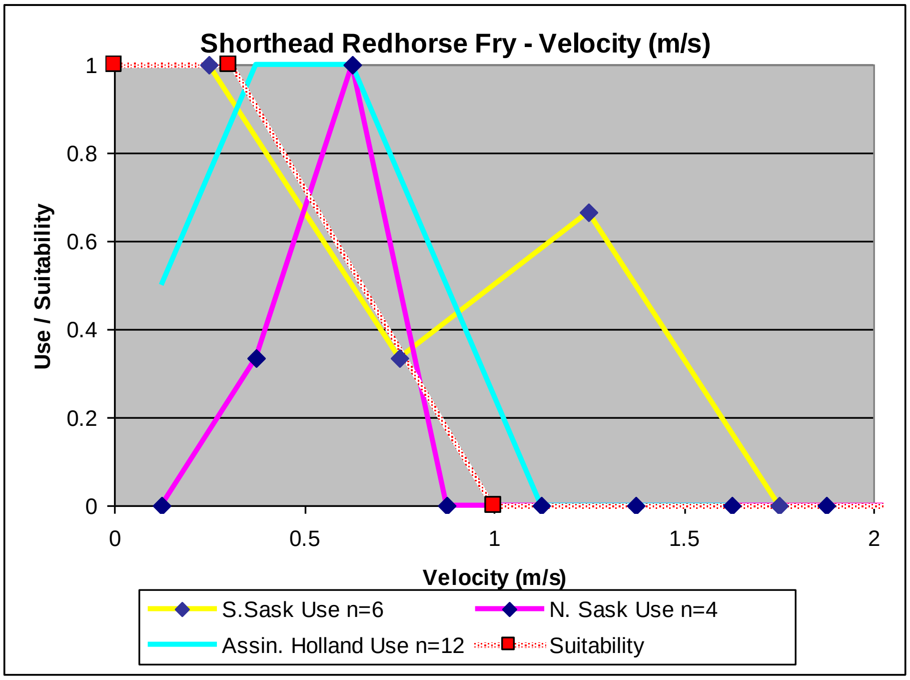
Depth (m)	Suitability
0	0
0.02	0
0.2	1
0.6	1
0.8	0.1
1.5	0

Figure A1.17. Habitat suitability curve for Shorthead Redhorse fry in the open water (depth (m)). This Includes actively swimming fry (>30 mm).



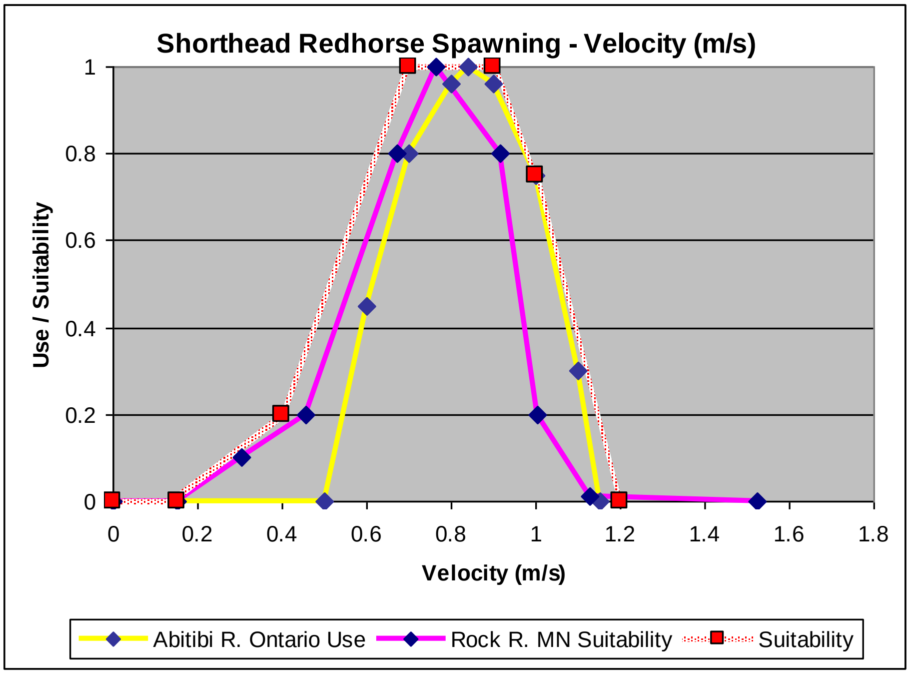
Depth (m)	Suitability
0	0
0.05	0
0.2	0.8
0.6	1
1	0.5
10	0.5

Figure A1.18. Habitat suitability curve for Shorthead Redhorse juveniles in the open water (depth (m)). Associated with algae and macrophyte growth. Data was gathered only from electrofishing as juveniles are not targeted by anglers or fishers.



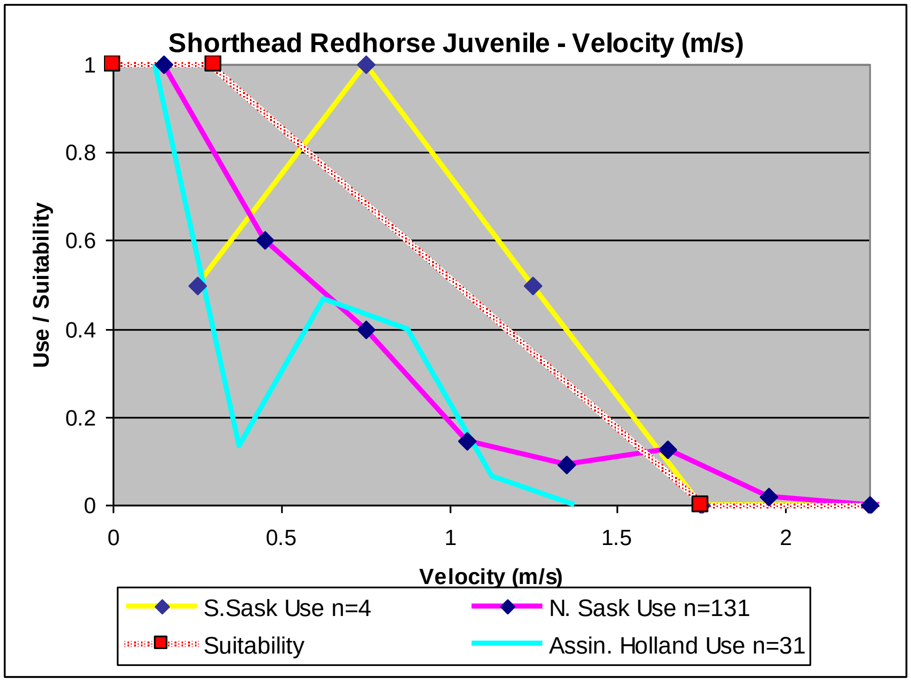
Velocity (m/s)	Suitability
0	1
0.3	1
1	0
5	0

Figure A1.19. Habitat suitability curve for Shorthead Redhorse Fry in open water (velocity (m/s)). Velocities approaching 1 m/s are too fast based on swimming capabilities of fry (body length/s).



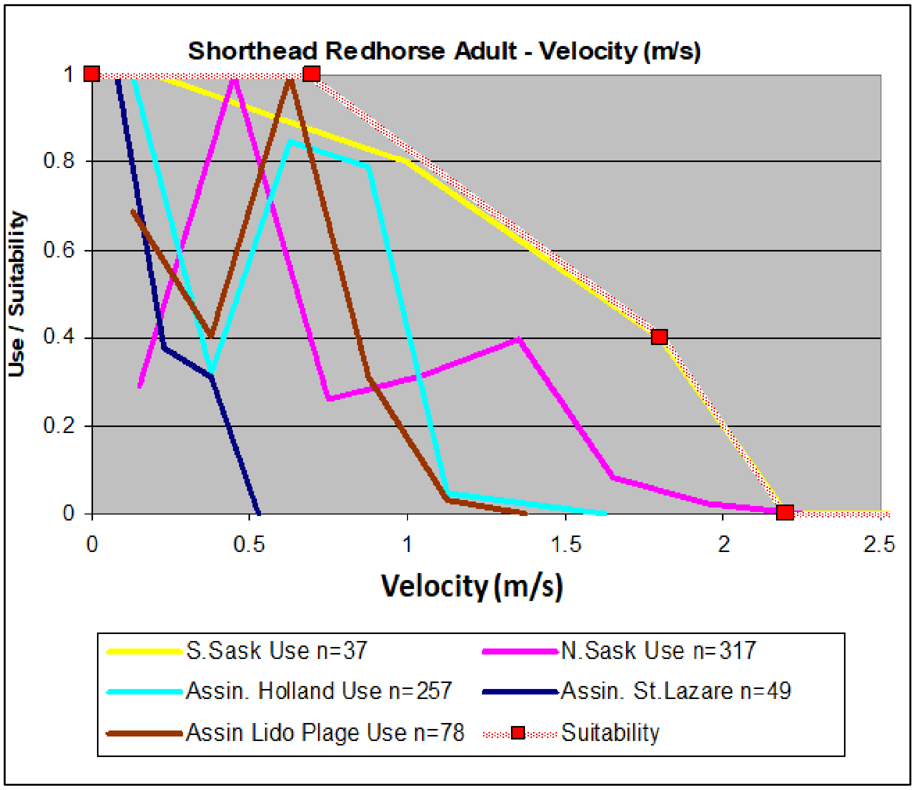
Velocity (m/s)	Suitability
0	0
0.15	0
0.4	0.2
0.7	1
0.9	1
1	0.75
1.2	0

Figure A1.20. Habitat suitability curve for spawning Shorthead Redhorse in open water (velocity (m/s)).



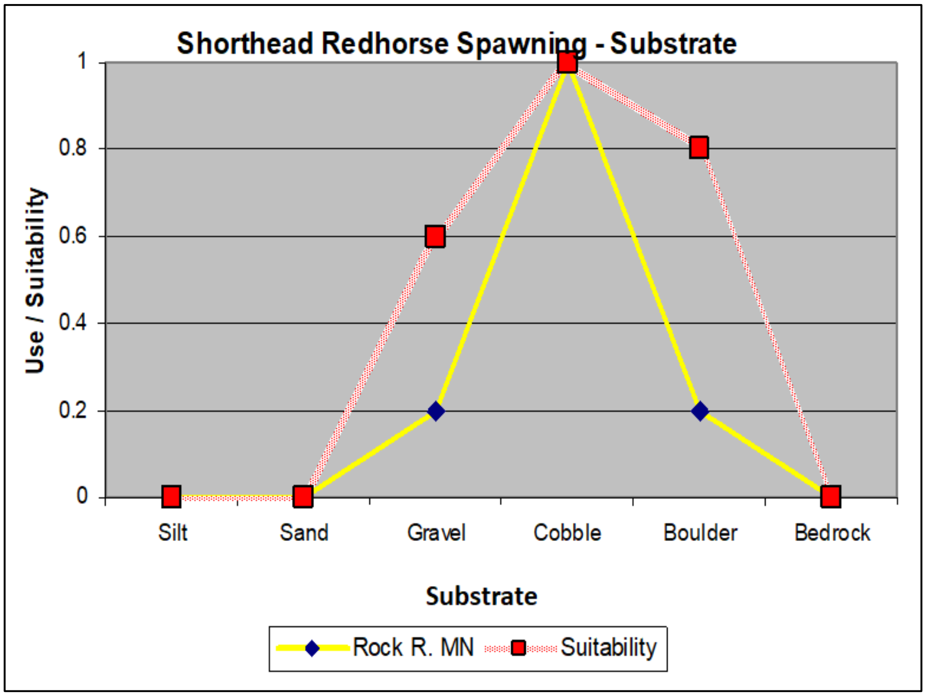
Velocity (m/s)	Suitability
0	1
0.3	1
1.75	0
5	0

Figure A1.21. Habitat suitability curve for Shorthead Redhorse juveniles in open water (velocity (m/s)). Incorporated existing data from the South Saskatchewan River but weighted lower due to limited observations.



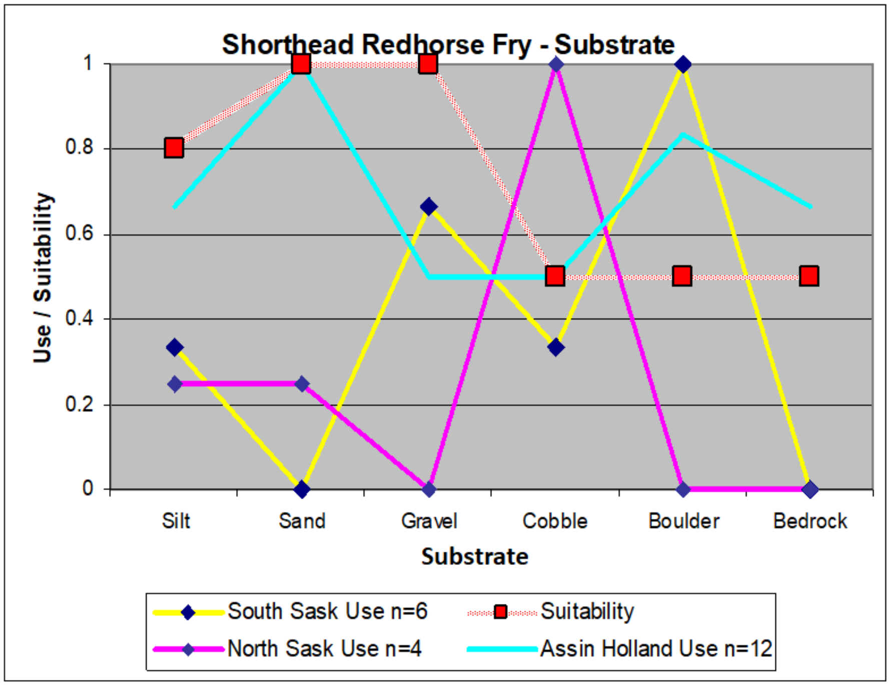
Velocity (m/s)	Suitability
0	1
0.7	1
1.8	0.4
2.2	0
5	0

Figure A1.22. Habitat suitability curve for Shorthead Redhorse juveniles in open water (velocity (m/s)).



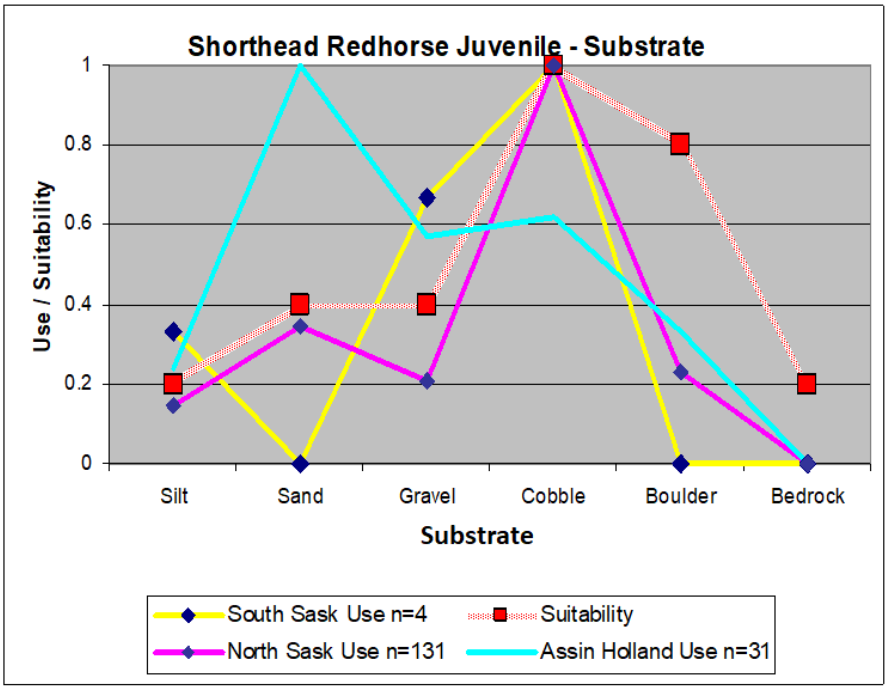
Substrate	Suitability
Silt	0
Sand	0
Gravel	0.6
Cobble	1
Boulder	0.8
Bedrock	0

Figure A1.23. Habitat suitability curve for spawning Shorthead Redhorse substrate. There was increased gravel/cobble from existing data based on First Nations observations.



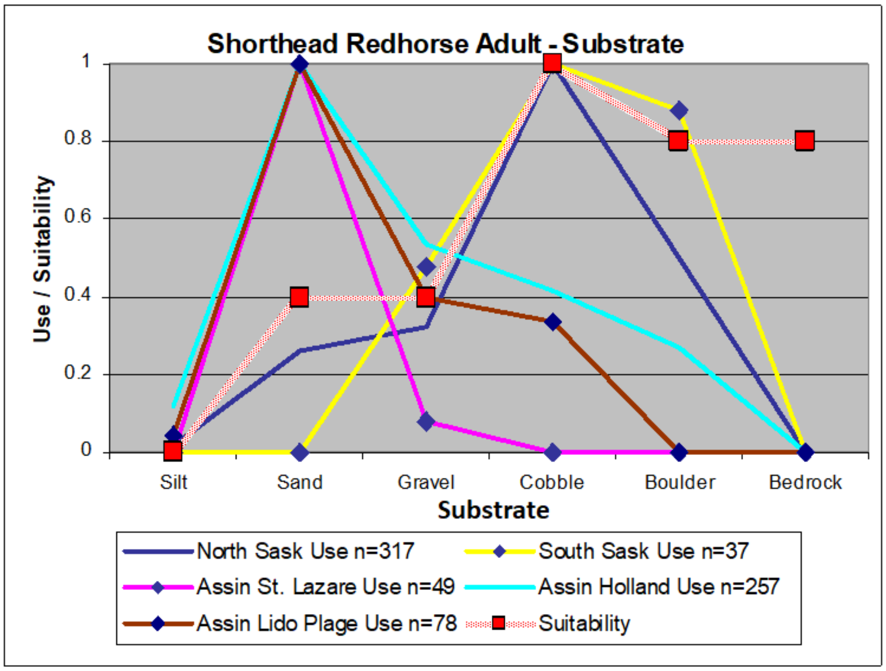
Substrate	Suitability
Silt	0.8
Sand	1
Gravel	1
Cobble	0.5
Boulder	0.5
Bedrock	0.5

Figure A1.24. Habitat suitability curve for Shorthead Redhorse fry substrate. Water velocity was used to guide substrate composition. There was limited data available for fry in general. During the workshop,a suggestion was made to use alternative sampling techniques (backpack electro-fishing/seine netting) to target fry. Did not go to zero for larger substrate as interstitial spaces could be used for cover.



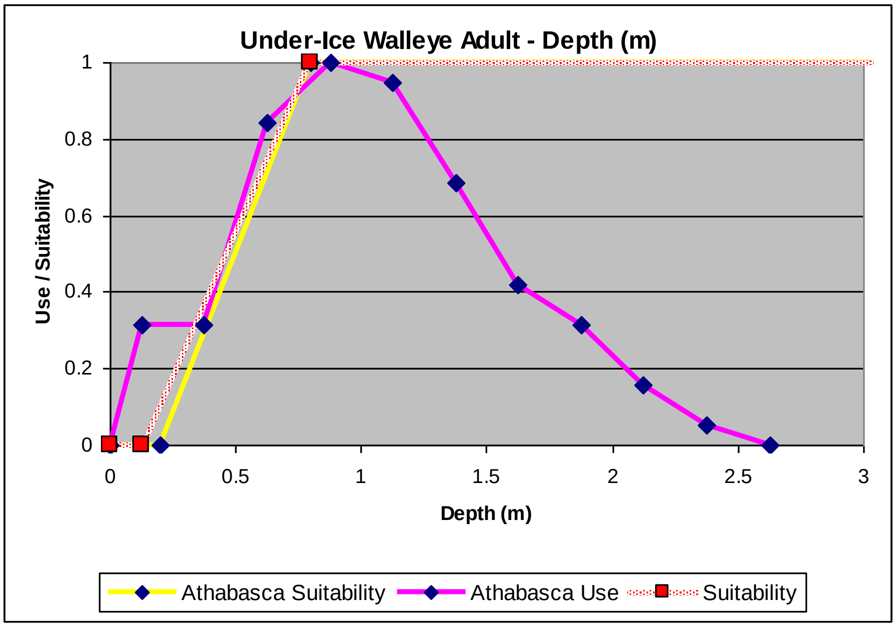
Substrate	Suitability
Silt	0.2
Sand	0.4
Gravel	0.4
Cobble	1
Boulder	0.8
Bedrock	0.2

Figure A1.25. Habitat suitability curve for Shorthead Redhorse juvenile's substrate.



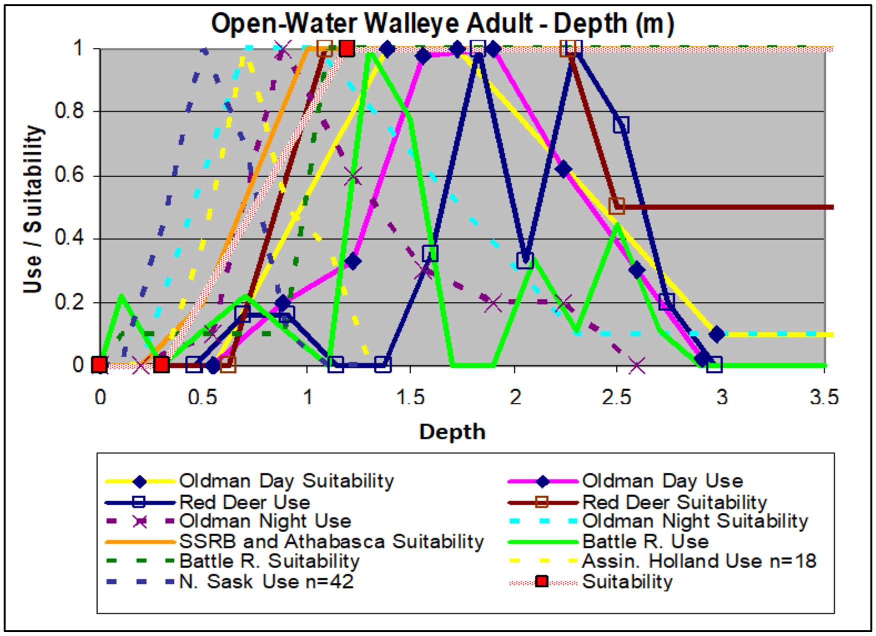
Substrate	Suitability
Silt	0
Sand	0.4
Gravel	0.4
Cobble	1
Boulder	0.8
Bedrock	0.8

Figure A1.26. Habitat suitability curve for Shorthead Redhorse Adults substrate based on First Nations input. Bedrock rated high due to observations in fractured bedrock.



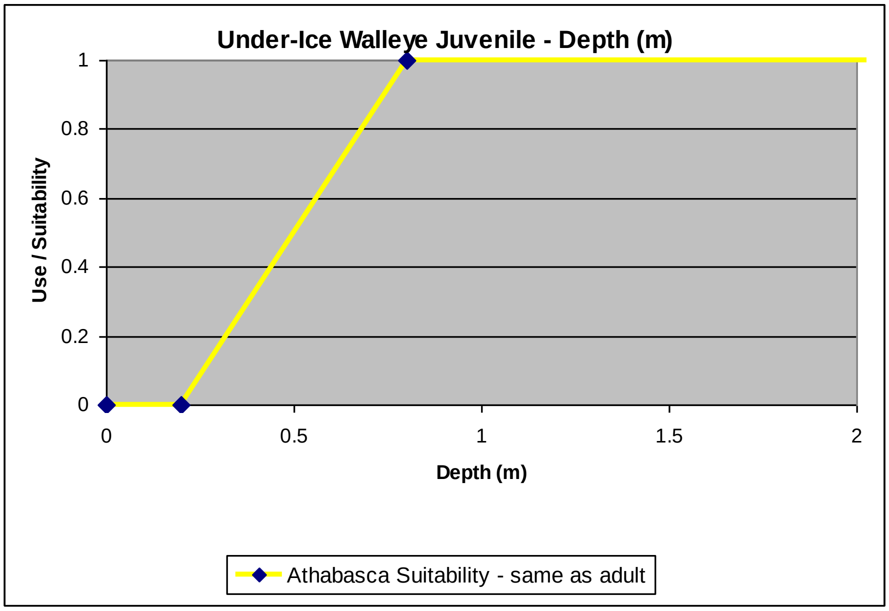
Depth (m)	Suitability
0	0
0.125	0
0.8	1
10	1

Figure A1.27. Habitat suitability curve for Walleye adults under-Ice (depth (m)). Depths refer to water depth not to ice depth. Depth is likely not limiting for adult Walleye.



Depth (m)	Suitability
0	0
0.3	0
1.2	1
10	1

Figure A1.28. Habitat suitability curve for Walleye adults in open water (depth (m)). Depth is not limiting for adults, cover and food source are more likely to drive habitat use.



Depth (m)	Suitability
0	0
0.2	0
0.8	1
10	1

Figure A1.29. Habitat suitability curve for Walleye juveniles in under-ice (depth (m)) based on First Nations netting as at 30 inches under ice catches are almost exclusively Walleye.

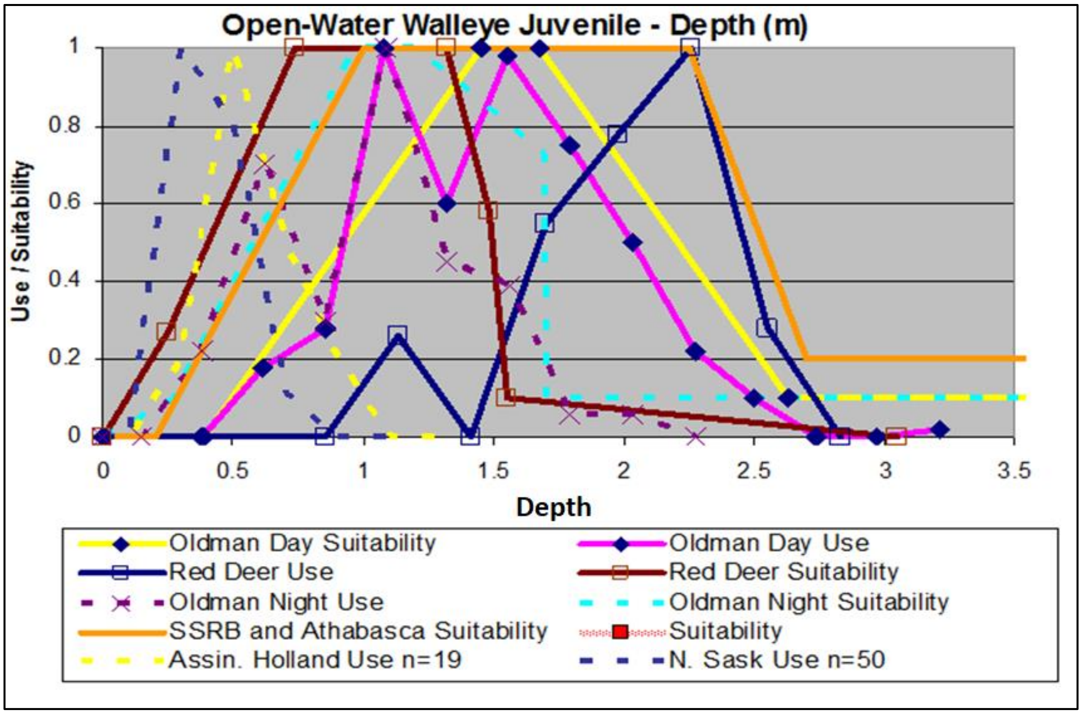


Figure A1.30. Habitat suitability curve for Walleye juveniles in open water (depth (m)). HSC curve was not developed.

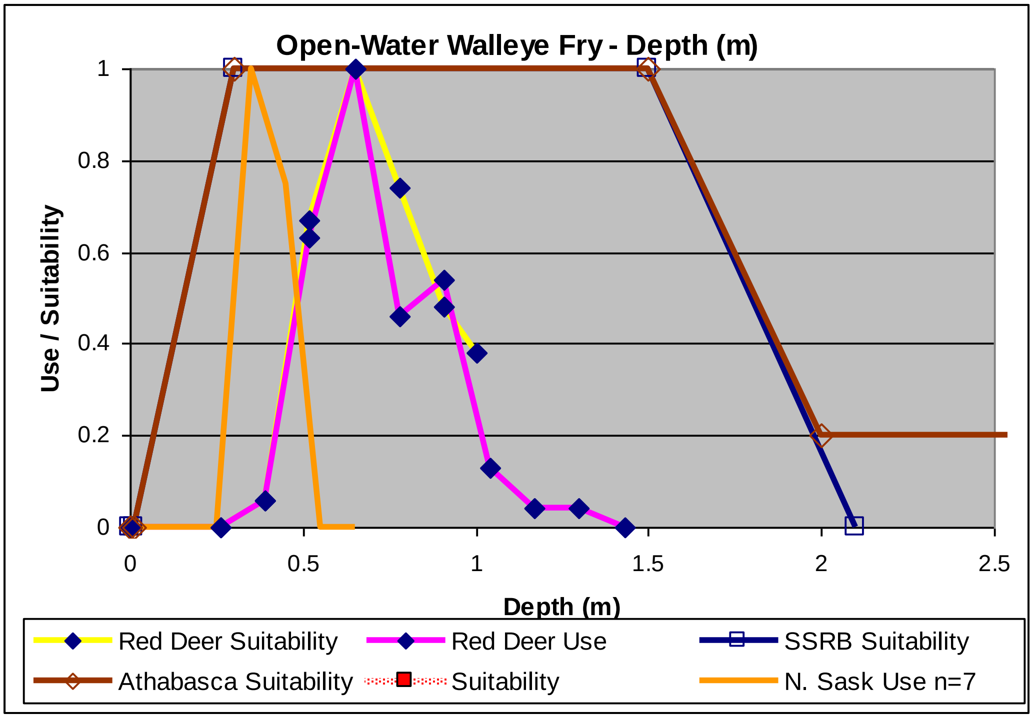
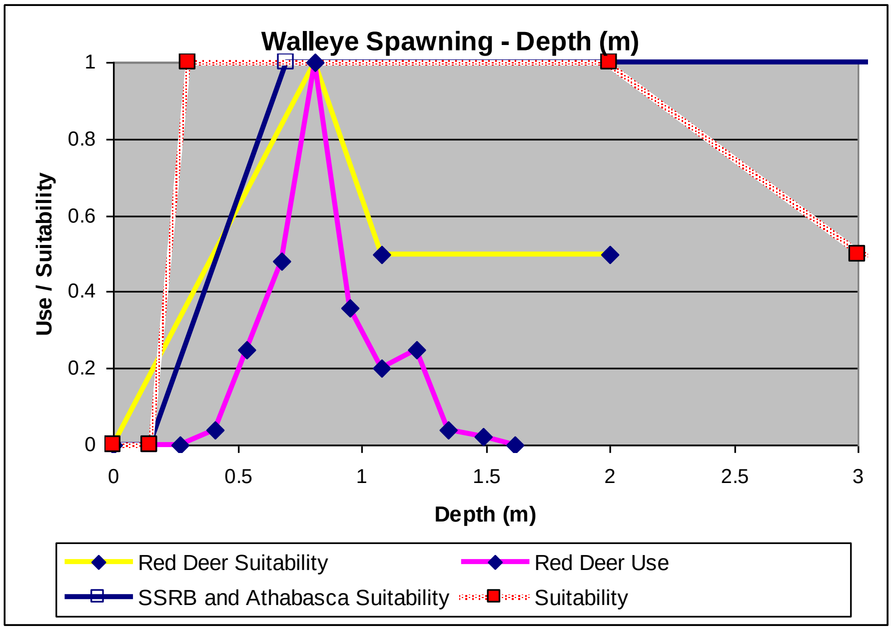
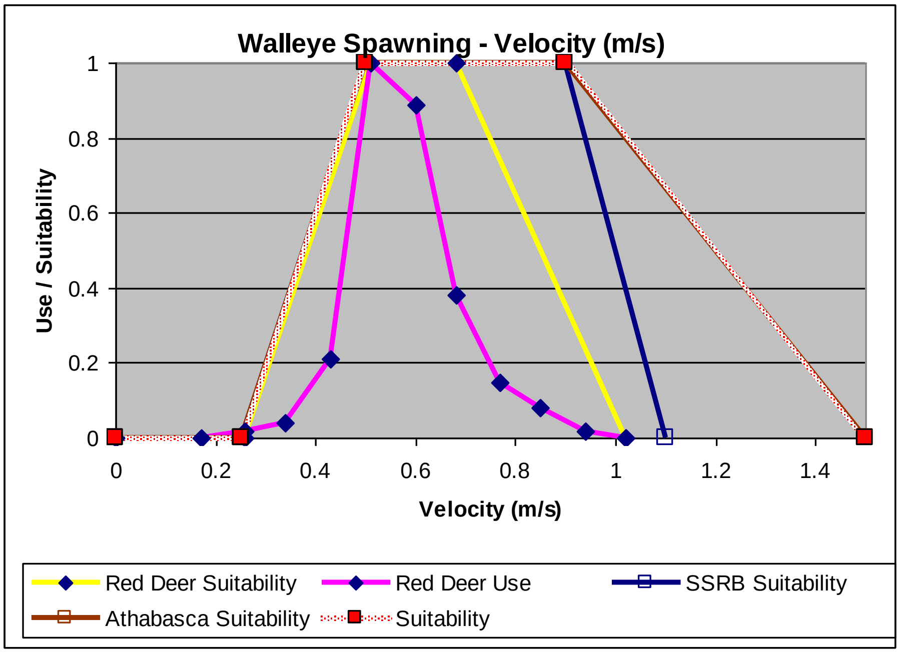


Figure A1.31. Habitat suitability curve for Walleye fry in open water (depth (m)). HSC curve was not developed.



Depth (m)	Suitability
0	0
0.15	0
0.3	1
2	1
3	0.5
10	0.5

Figure A1.32. Habitat suitability curve for spawning Walleye (depth (m)). Extended beyond existing depth data because velocity or substrate are likely more limiting.



Velocity (m/s)	Suitability
0	0
0.25	0
0.5	1
0.9	1
1.5	0

Figure A1.33. Habitat suitability curve for spawning Walleye (velocity(m/s)). Walleye are spawning in lakes but not in zero velocity due to wave action.

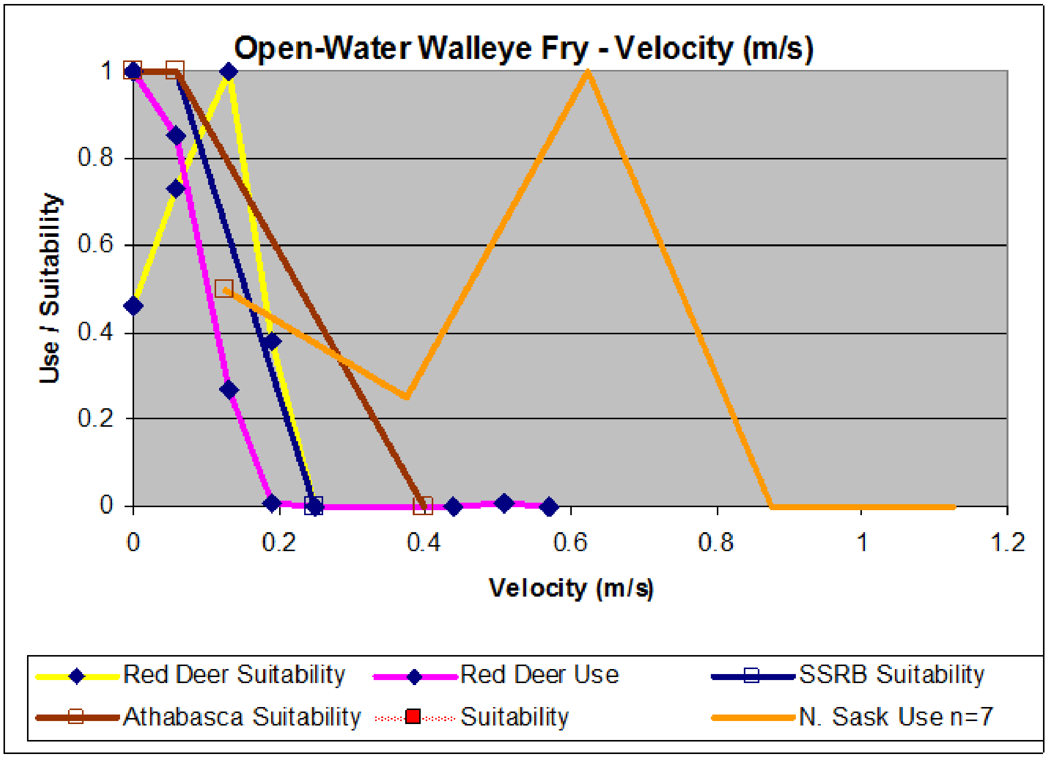


Figure A1.34. Habitat suitability curve for Walleye fry in open water (velocity(m/s)). HSC curve was not developed.

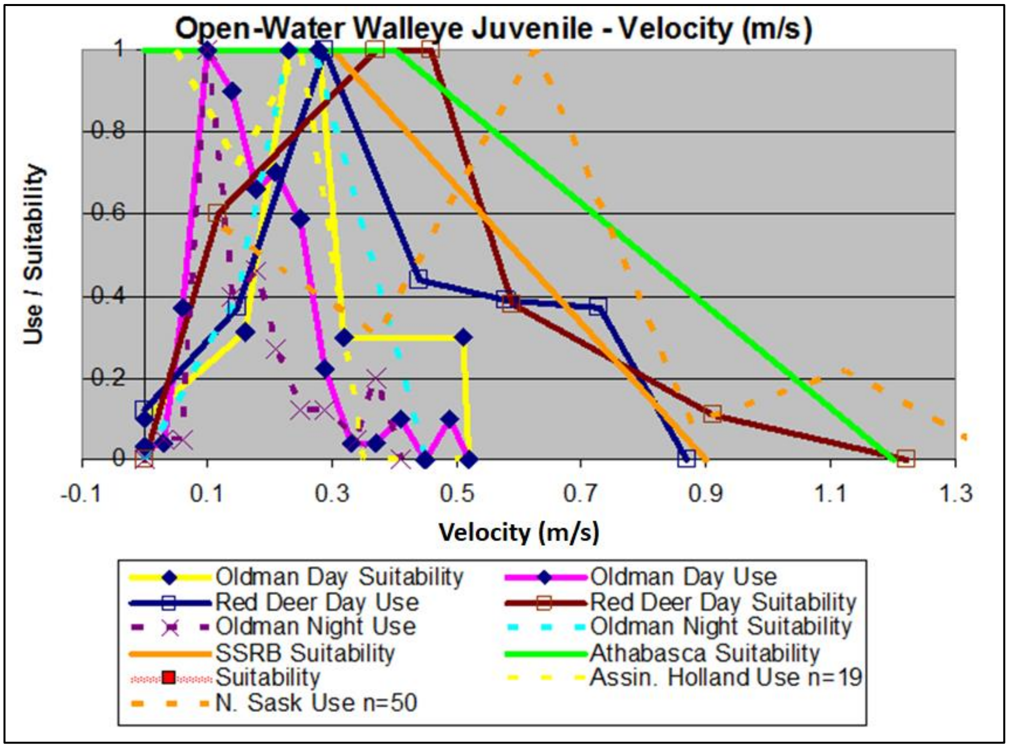


Figure A1.35. Habitat suitability curve for Walleye juveniles in open water (velocity(m/s)). HSC curve was not developed.

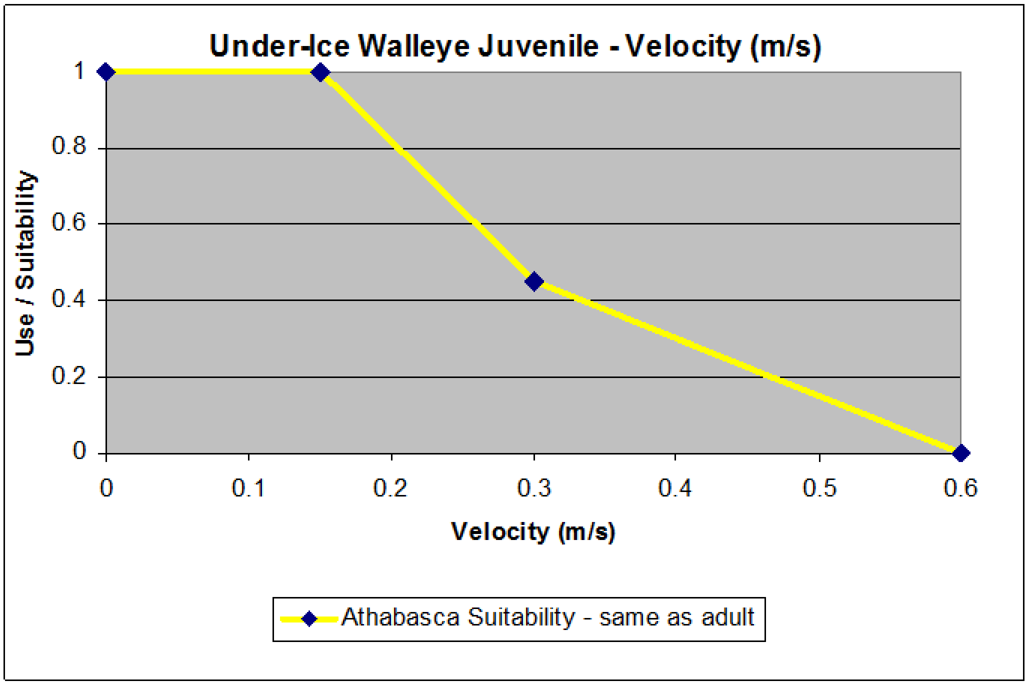
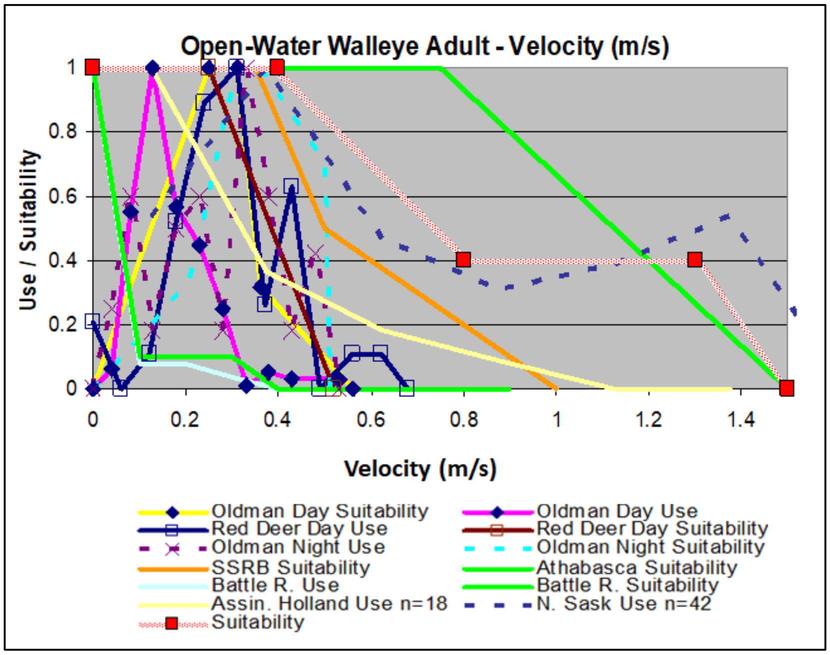
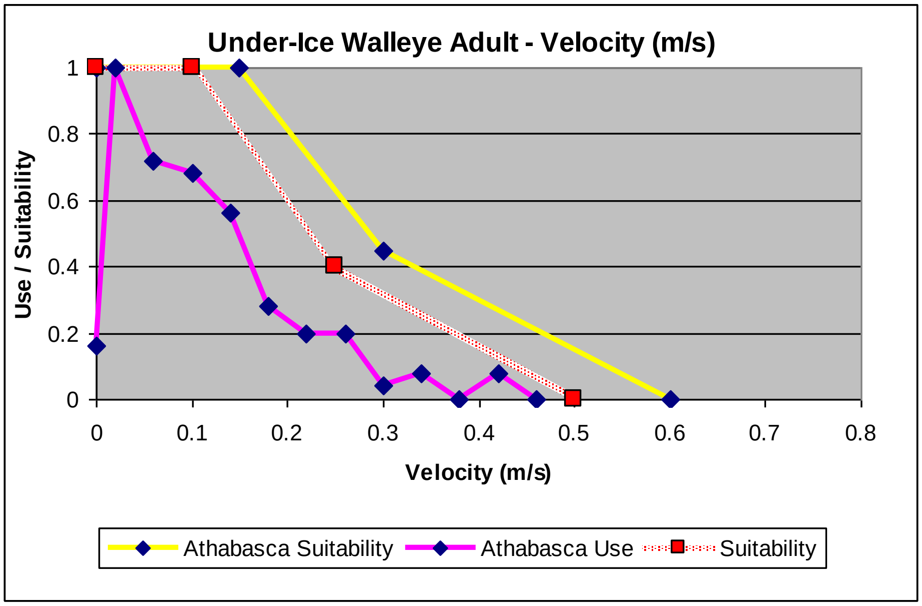


Figure A1.36. Habitat suitability curve for Walleye juveniles under ice (velocity(m/s)). HSC curve was not developed.



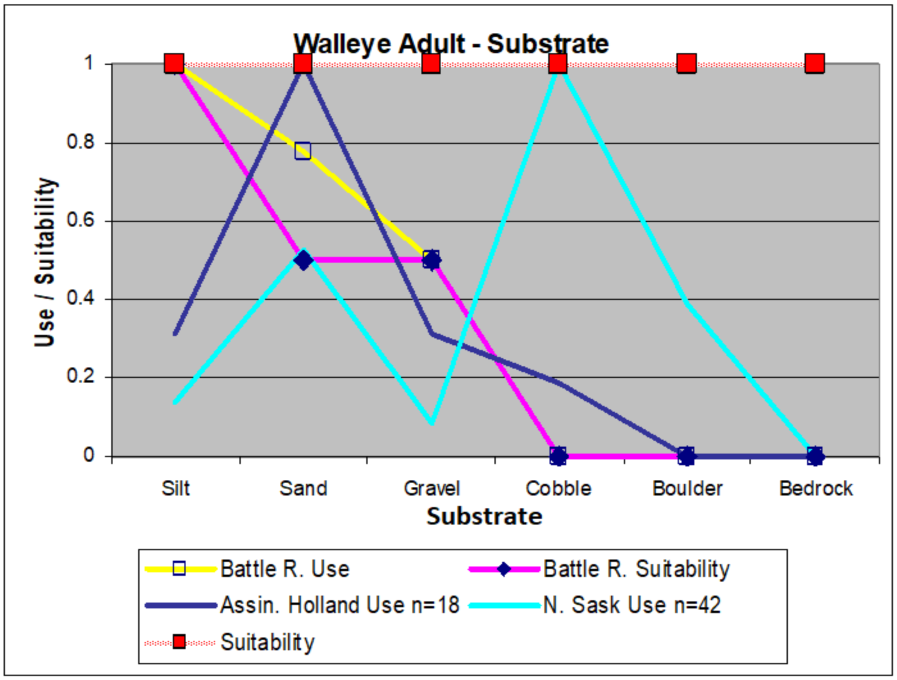
Velocity (m/s)	**Suitability**
0	1
0.4	1
0.8	0.4
1.3	0.4
1.5	0

Figure A1.37. Habitat suitability curve for Walleye adults in open water (velocity(m/s)). Following Athabasca and North Saskatchewan River HSC curves to some extent.



Velocity (m/s)	Suitability
0	1
0.1	1
0.25	0.4
0.5	0

Figure A1.38. Habitat suitability curve for Walleye adults under ice (velocity(m/s)). Following Athabasca River curve with slightly lower velocity guided by First Nations input.



Substrate	Suitability
Silt	1
Sand	1
Gravel	1
Cobble	1
Boulder	1

Figure A1.39. Habitat suitability curve for Walleye adults substrate. Adult Walleye may use any type of substrate, habitat use likely more driven by cover, food availability, and velocity.

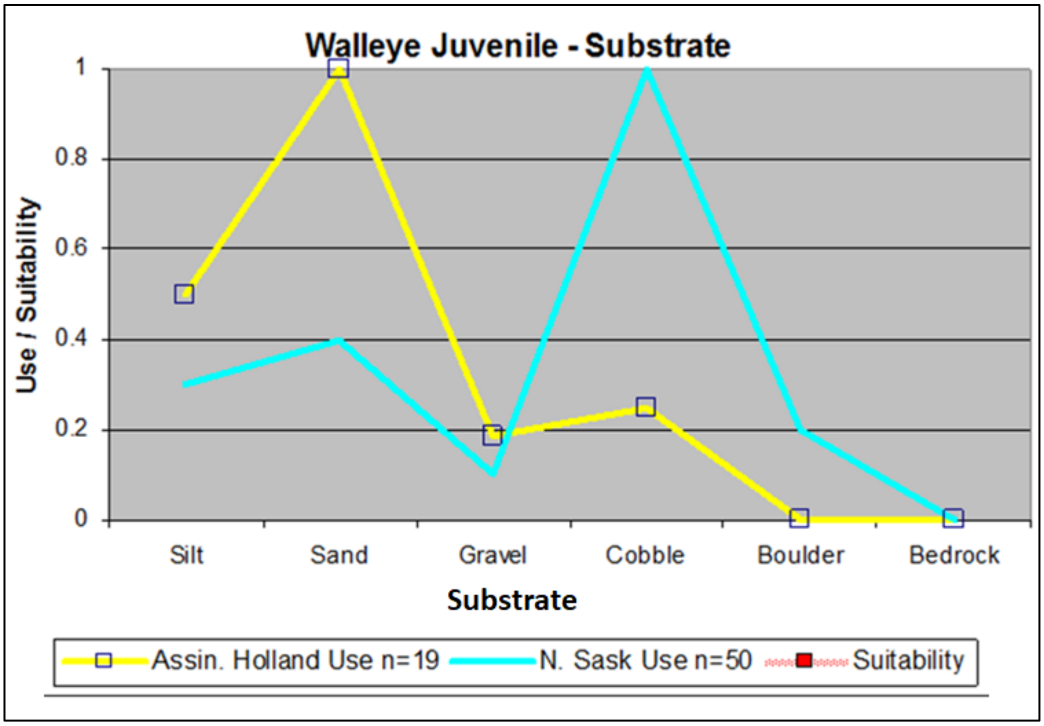


Figure A1.40. Habitat suitability curve for Walleye juveniles substrate. HSC was not developed.

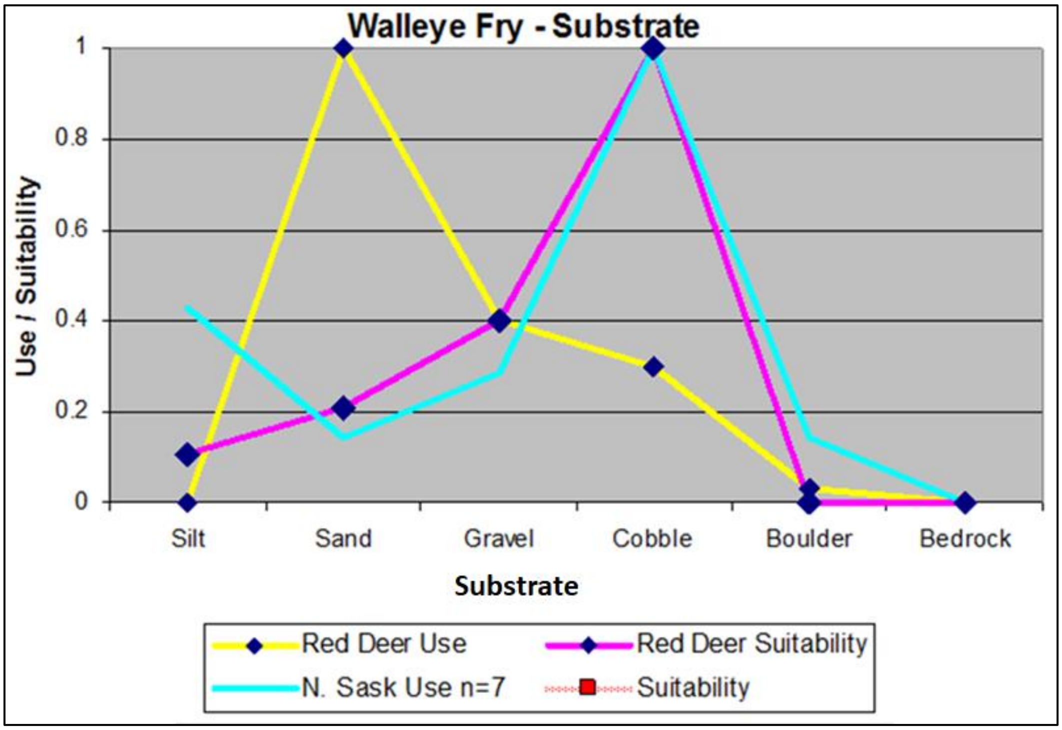
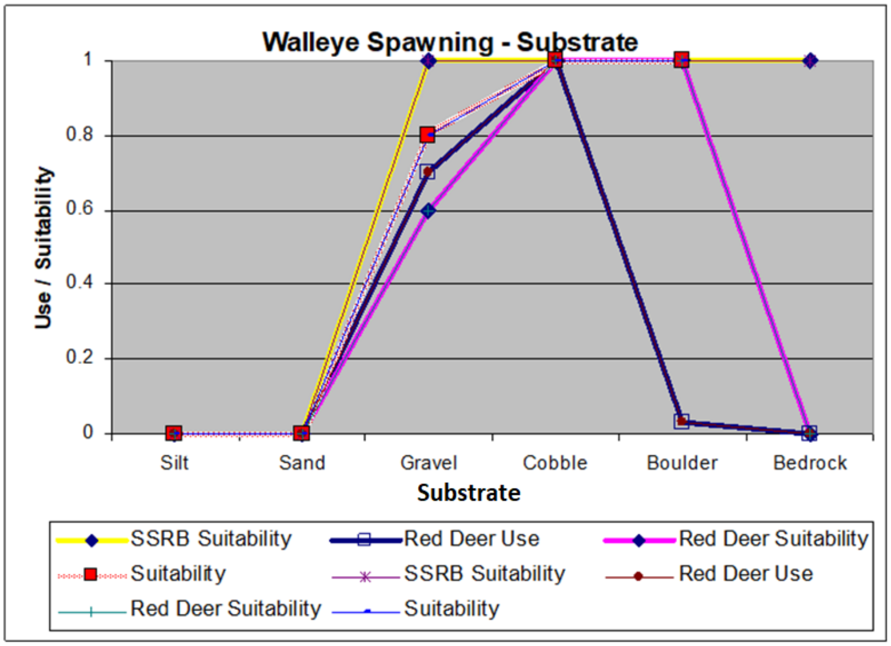
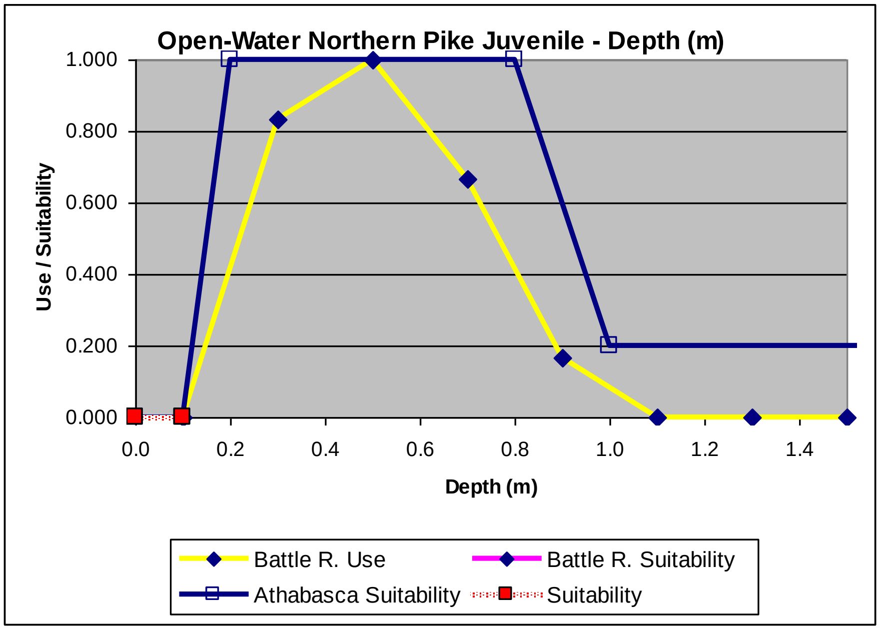


Figure A1.41. Habitat suitability curve for Walleye fry substrate. HSC was not developed.



Substrate	Suitability
Silt	0
Sand	0
Gravel	0.8
Cobble	1
Boulder	1

Figure A1.42. Habitat suitability curve for spawning Walleye substrate. Walleye prefer boulder associated with cobble for spawning. No bedrock was observed in the study area.



Depth (m)	Suitability
0	0
0.1	0

Figure A1.43. Habitat suitability curve for Northern Pike juveniles in open water (depth (m)). HSC curve was not developed.

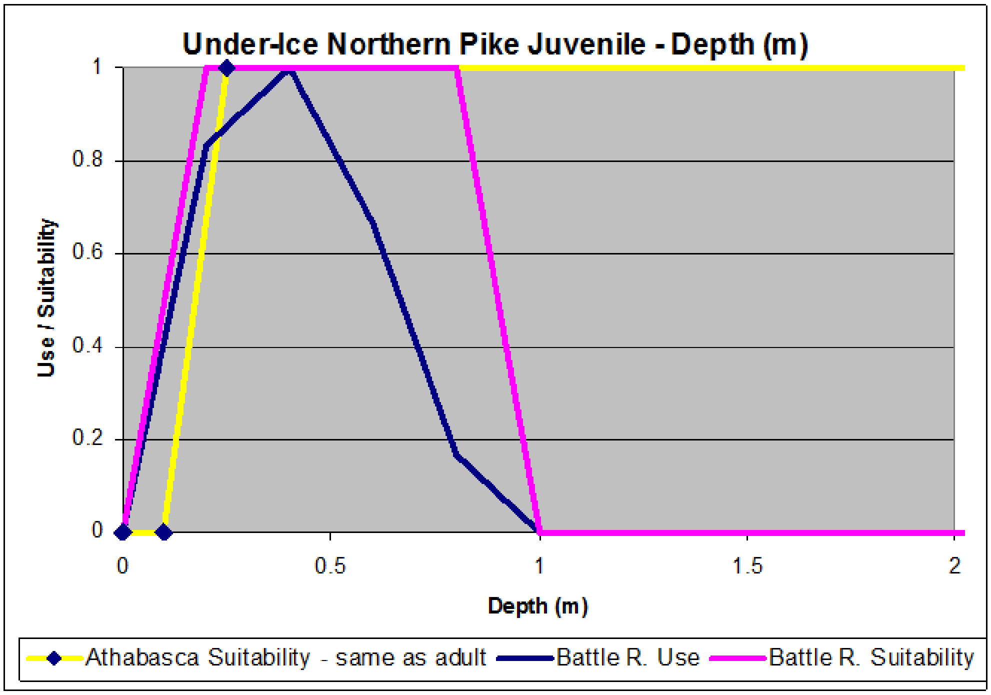
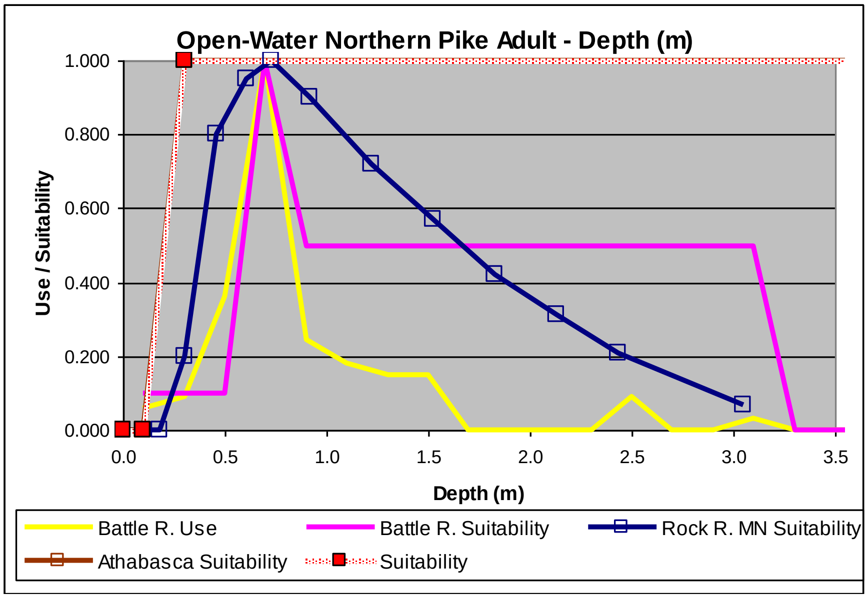
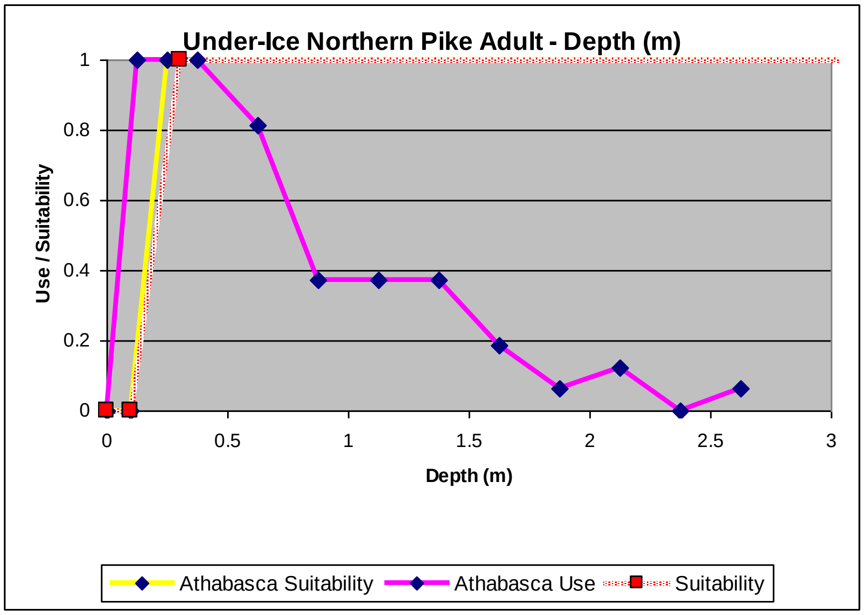


Figure A1.44. Habitat suitability curve for Northern Pike juveniles under ice (depth (m)). HSC curve was not developed.



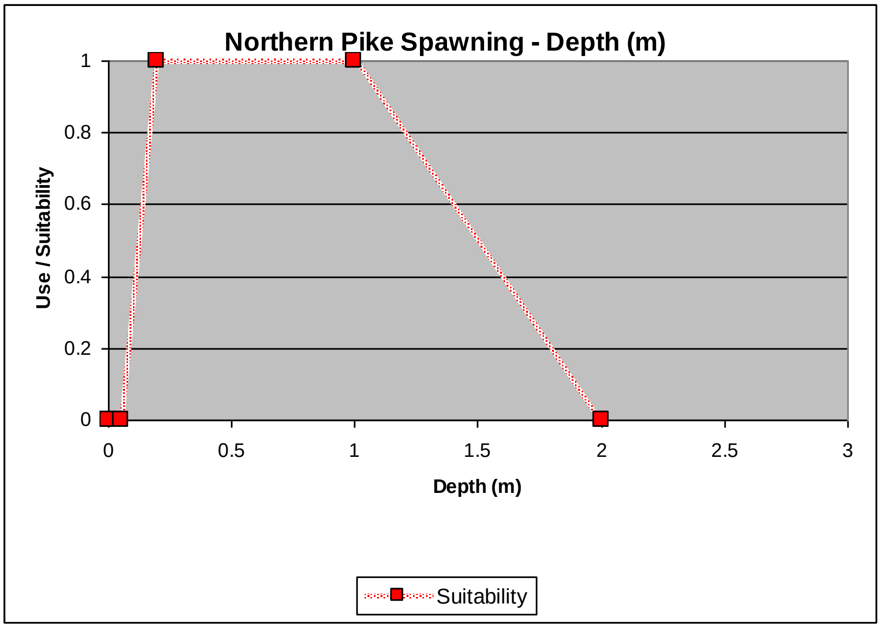
Depth (m)	Suitability
0	0
0.1	0
0.3	1
10	1

Figure A1.45. Habitat suitability curve for Northern Pike adults in open water (depth (m)). Main depth requirement is to ensure fish submerged in water. Not limited by depth.



Depth (m)	Suitability
0	0
0.1	0
0.3	1
10	1

Figure A1.46. Habitat suitability curve for Northern Pike adults under ice (depth (m)). Winter HSC curve for depth is the same than the summer depth HSC.



Depth (m)	Suitability
0	0
0.05	0
0.2	1
1	1
2	0

Figure A1.47. Habitat suitability curve for spawning Northern Pike (depth (m)). Spawning depth is lower based on observations from First Nations.

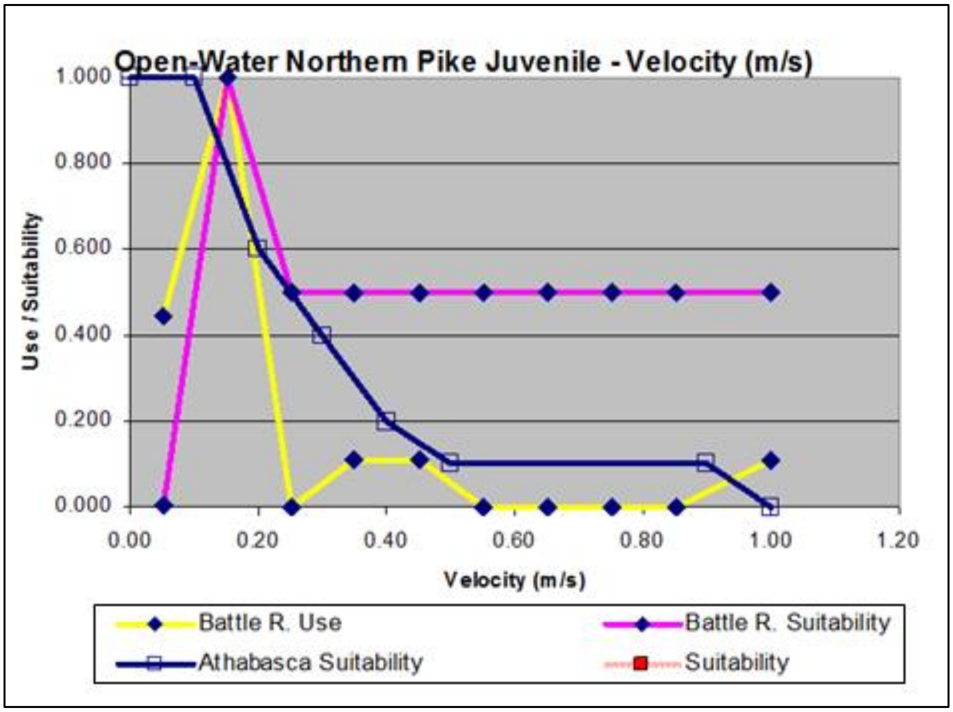


Figure A1.48. Habitat suitability curve for Northern Pike juveniles in open water (velocity(m/s)). HSC curve was not developed.

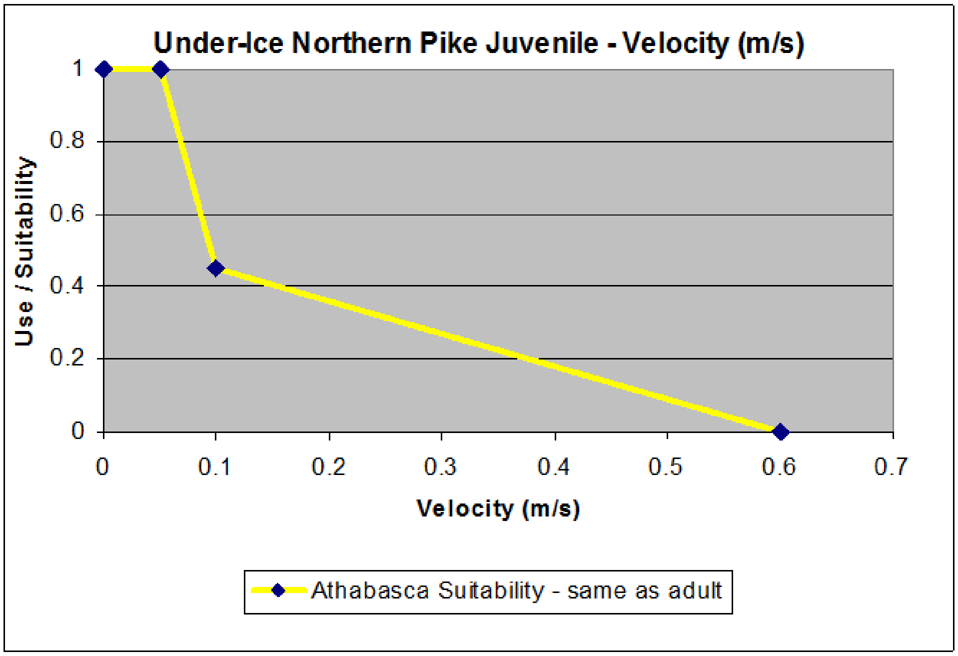
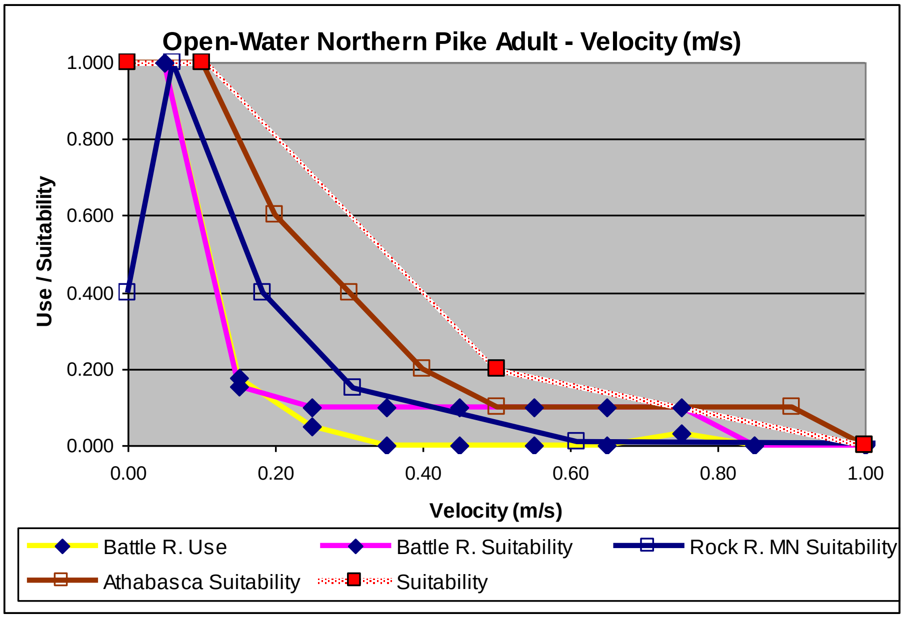
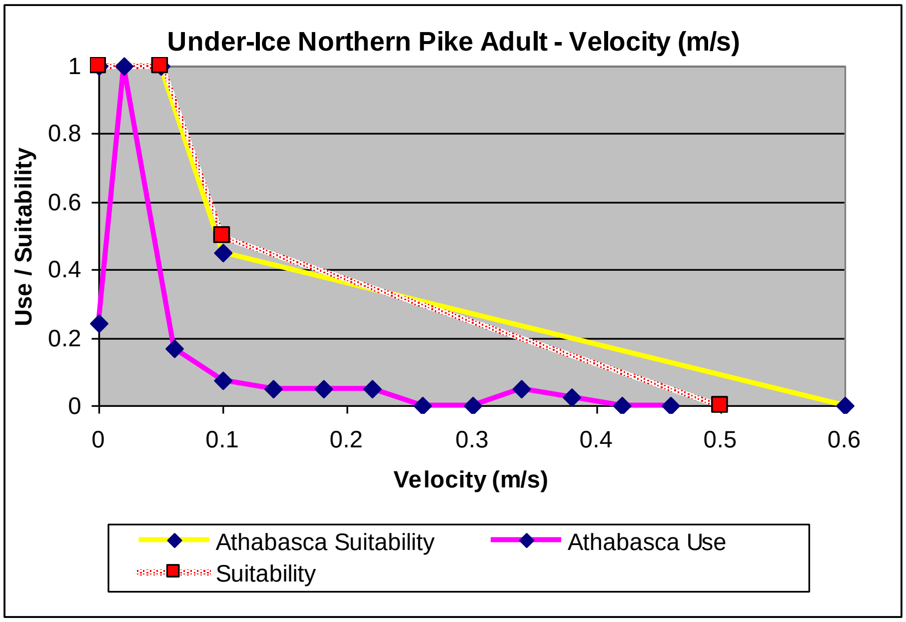


Figure A1.49. Habitat suitability curve for Northern Pike juveniles under ice (velocity(m/s)). HSC curve was not developed.



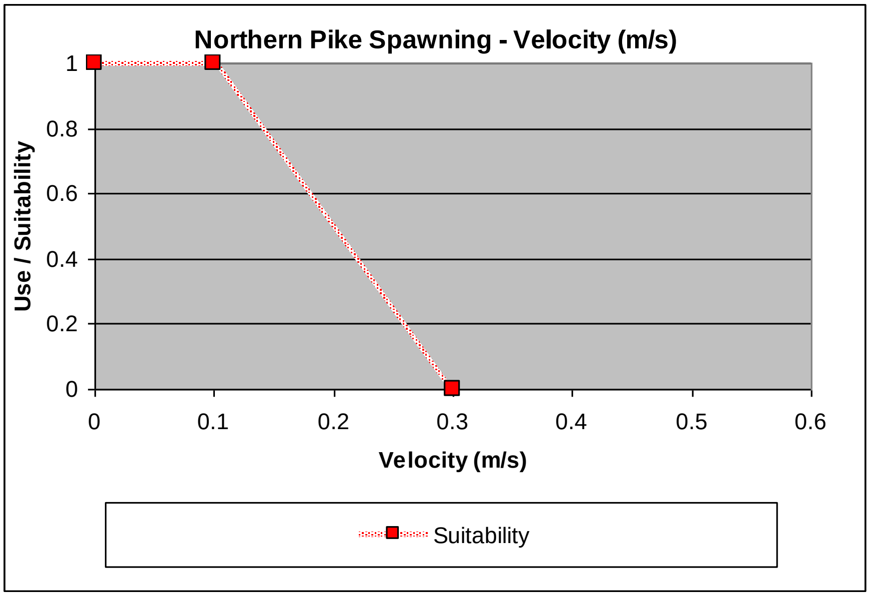
Velocity (m/s)	Suitability
0	1
0.1	1
0.5	0.2
1	0

Figure A1.50. Habitat suitability curve for Northern Pike Adults in open water (velocity(m/s)). Adult Northern Pike are only occasionally observed in velocities >0.5 m/s for feeding.



Velocity (m/s)	Suitability
0	1
0.05	1
0.1	0.5
0.5	0

Figure A1.51. Habitat suitability curve for Northern Pike Adults under ice (velocity(m/s)). Lower HSC values in winter than the summer based on energy conservation in winter.



Velocity (m/s)	Suitability
0	1
0.1	1
0.3	0

Figure A1.52. Habitat suitability curve for spawning Northern Pike (velocity(m/s)). HSC curve was not developed.

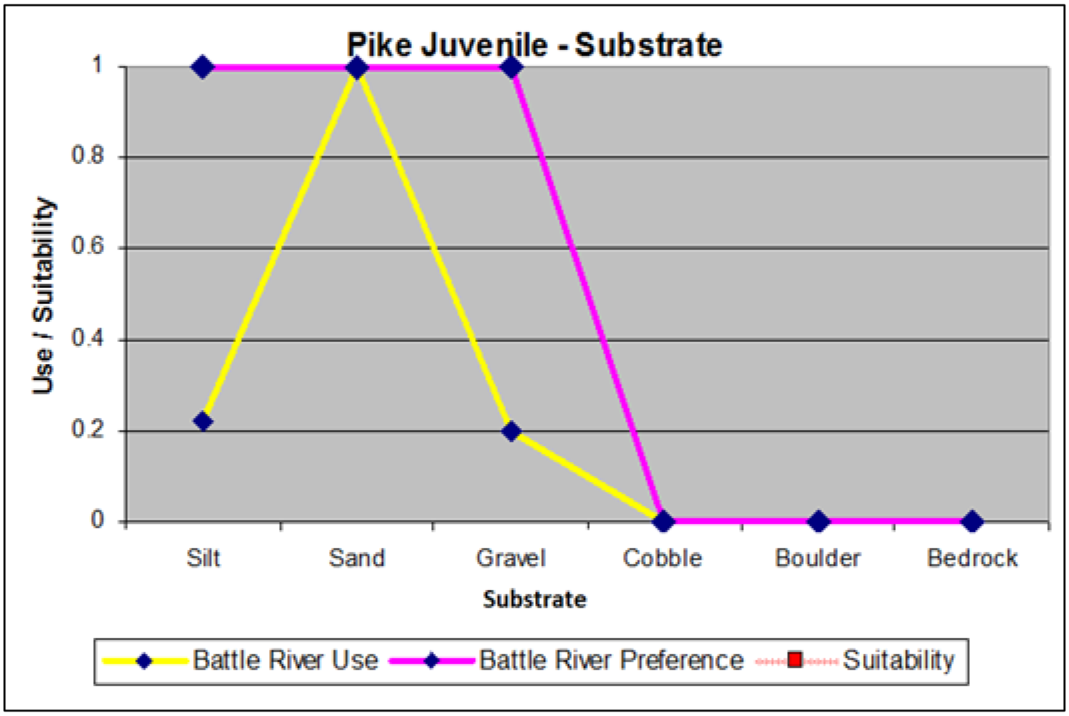


Figure A1.53. Habitat suitability curve for Northern Pike juveniles based on substrate. Likely based more on cover than substrate. HSC curve was not developed.

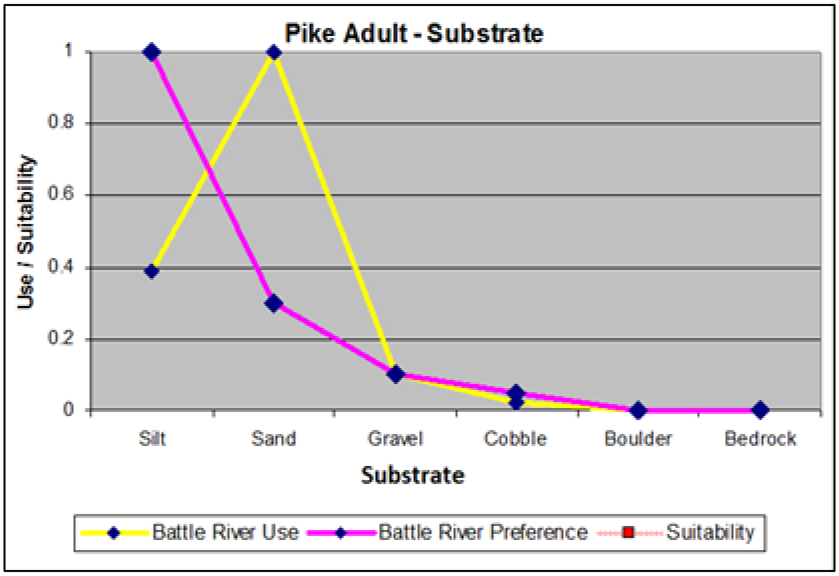
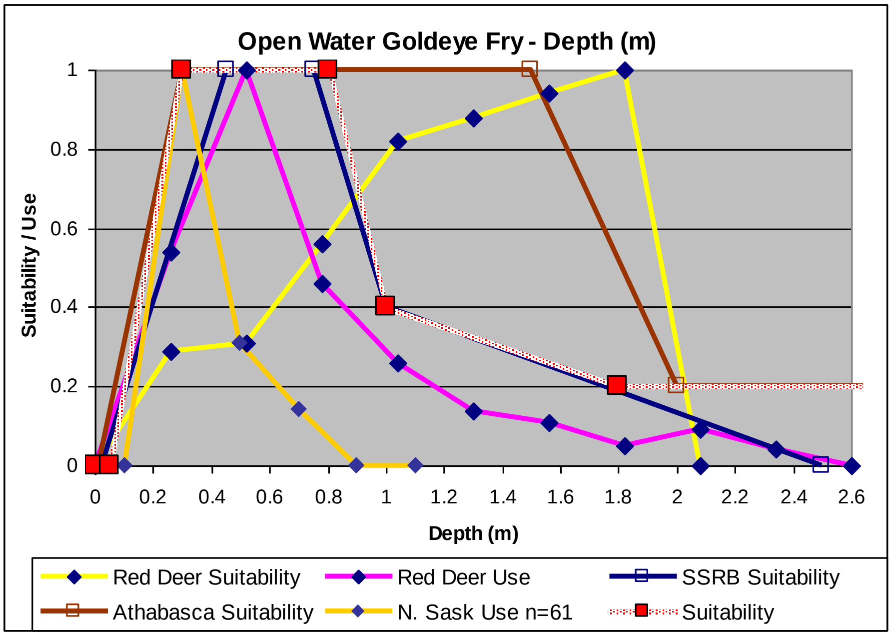
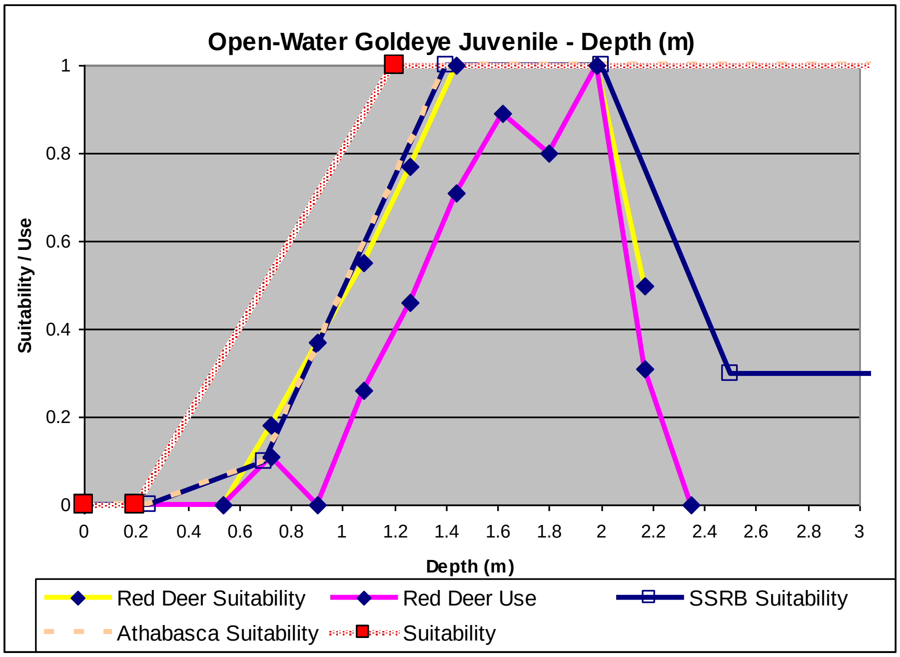


Figure A1.54. Habitat suitability curve for Northern Pike adults based on substrate. Likely based more on cover than substrate, finer substrates more likely to contain vegetation favoring adult Northern Pike that could still use large substrate for cover. HSC curve was not developed.



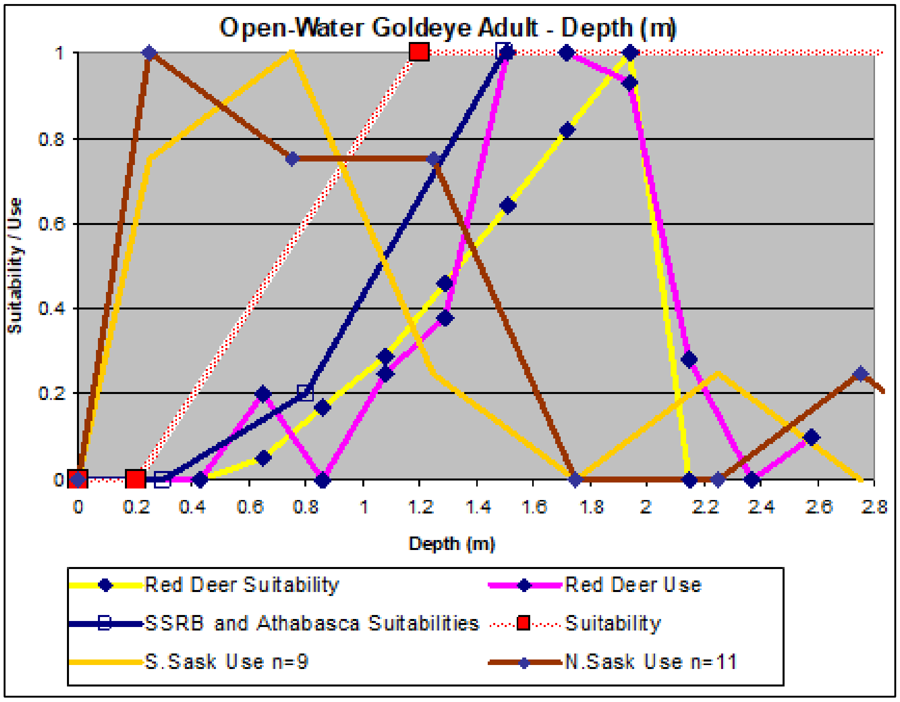
Depth (m)	**Suitability**
0	0
0.05	0
0.3	1
0.8	1
1	0.4
1.8	0.2
5	0.2

Figure A1.55. Habitat suitability curve for Goldeye fry in open water (depth (m)). Based on South Saskatchewan River Basin and North Saskatchewan River curves.



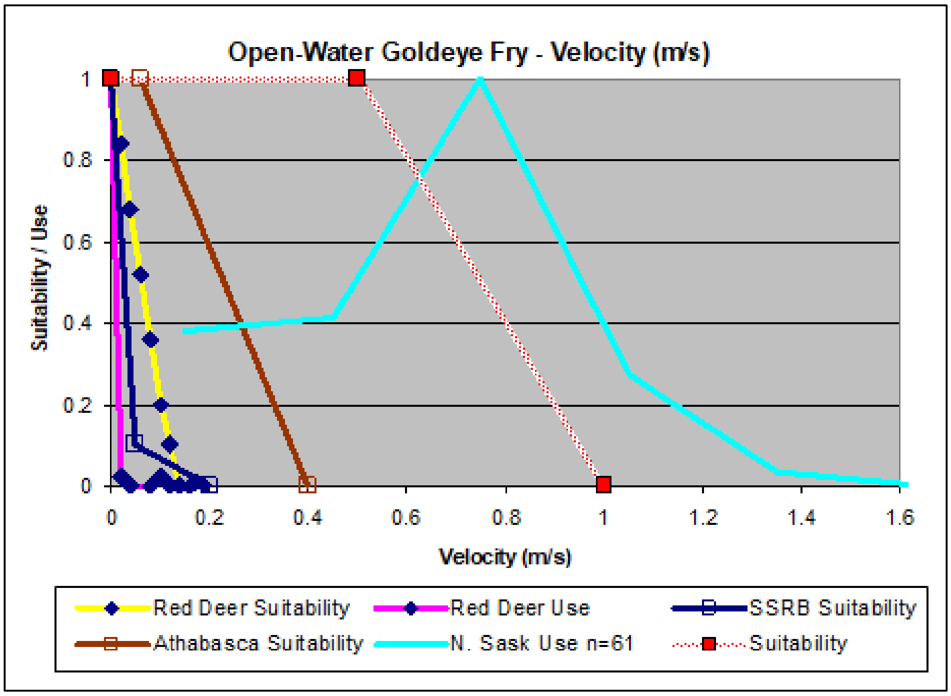
Depth (m)	Suitability
0	0
0.2	0
1.2	1
5	1

Figure A1.56. Habitat suitability curve for Goldeye juveniles in open water (depth (m)). Same than depth HSC curve for adult Goldeye.



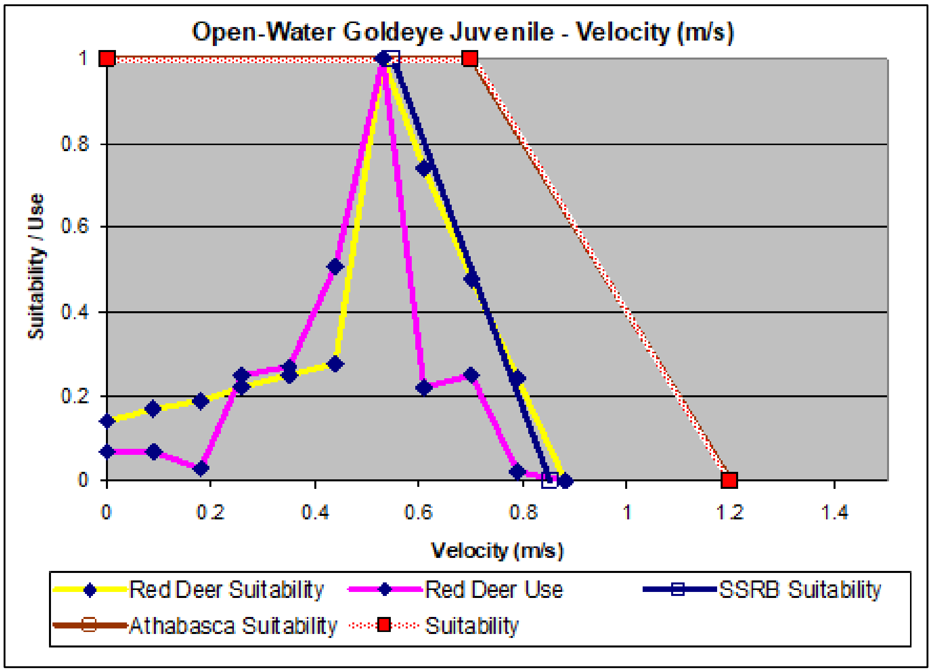
Depth (m)	Suitability
0	0
0.2	0
1.2	1
5	1

Figure A1.57. Habitat suitability curve for Goldeye adults in open water (depth (m)). Based on information from the Athabasca River. Eddies were determined to be the primary locations for catching Goldeye (and other species).



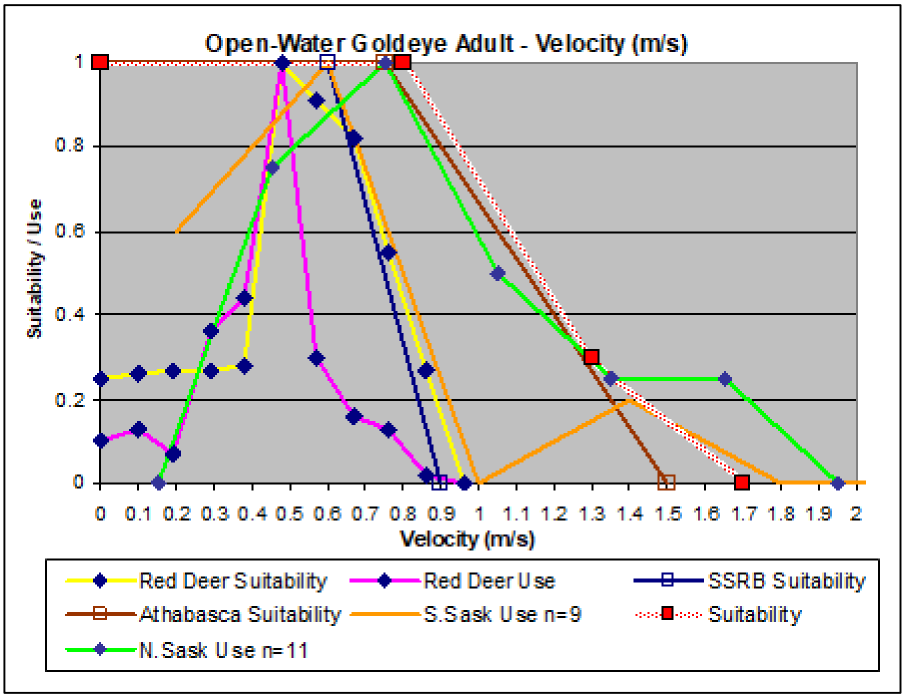
Velocity (m/s)	Suitability
0	1
0.5	1
1	0

Figure A1.58. Habitat suitability curve for Goldeye fry in open water (velocity (m/s)).



Velocity (m/s)	Suitability
0	1
0.7	1
1.2	0

Figure A1.59. Habitat suitability curve for Goldeye juvenile in open water (velocity (m/s)). Based on information from the Athabasca River.



Velocity (m/s)	Suitability
0	1
0.8	1
1.3	0.3
1.7	0

Figure A1.60. Habitat suitability curve for Goldeye adults in open water (velocity (m/s)). Velocities were scaled up due to increased size of adults.

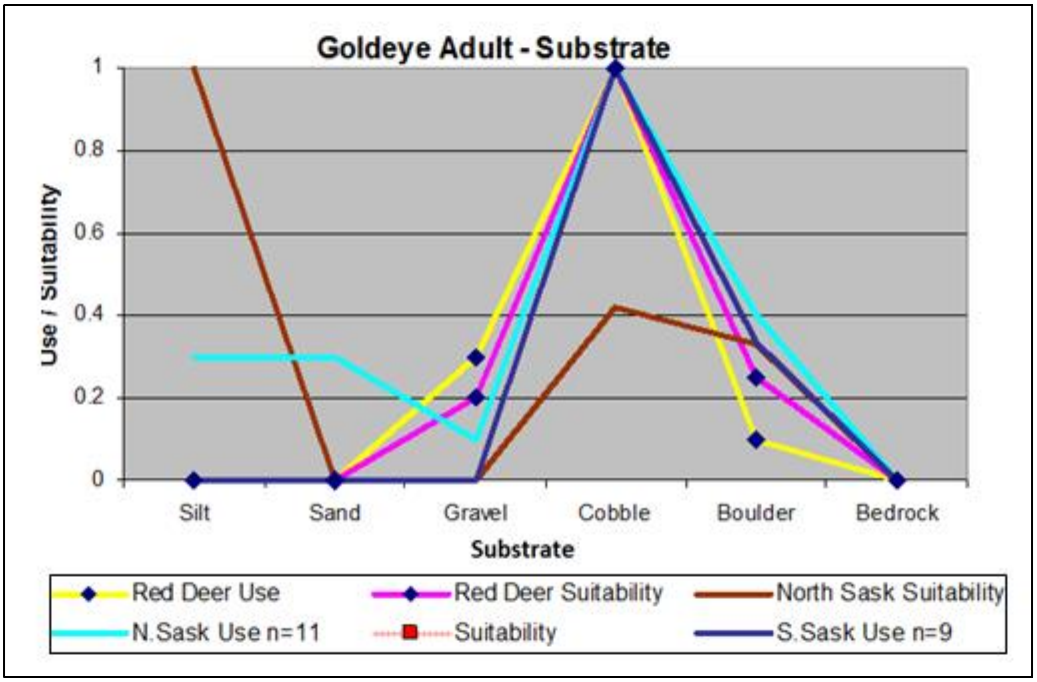


Figure A1.61. Habitat suitability curve for Goldeye adults based on substrate. HSC curve was not developed.

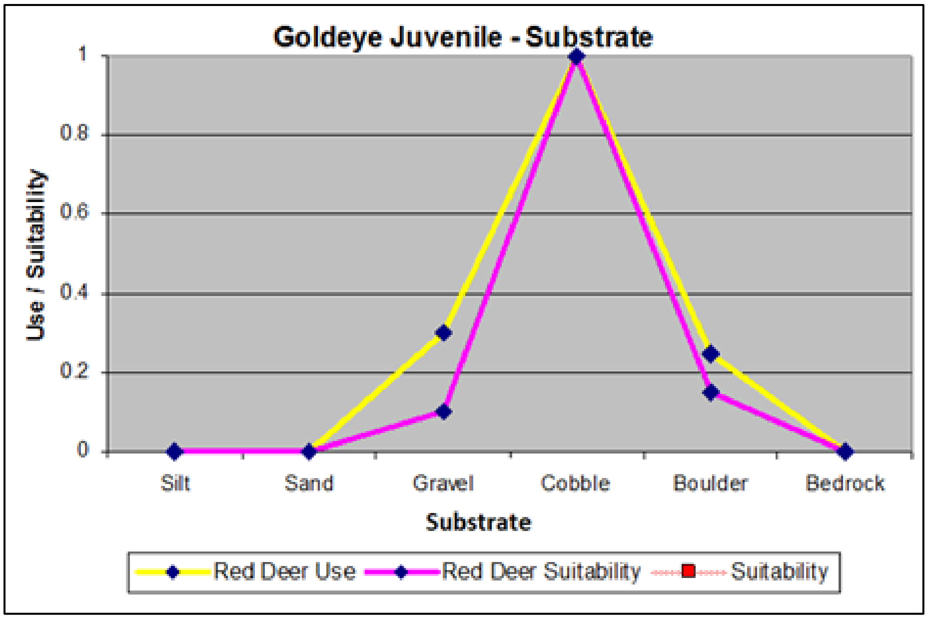


Figure A1.62. Habitat suitability curve for Goldeye juveniles based on substrate. HSC curve was not developed.

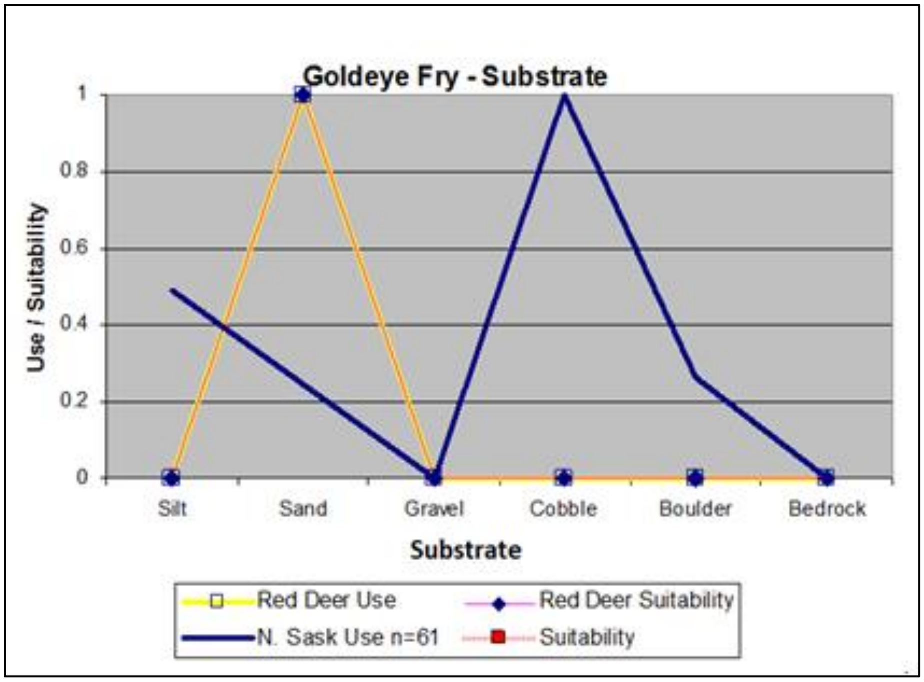


Figure A1.63. Habitat suitability curve for Goldeye fry based on substrate.

REFERENCE CITED

Clipperton, G.K., Koning, C.W., Locke, A.G.H., Mahoney, J.M., and Quazi, B. 2003. Instream flow needs determinations for the South Saskatchewan River Basin, Alberta, Canada. Alberta Environment, Edmonton, AB. 271 pp.

APPENDIX 2: CALCULATION OF AVAILABLE AND UTILIZED FISH HABITAT – HABITAT SUITABILITY CRITERIA (HSC) CURVE DEVELOPMENT

Habitat Suitability curves using the spatial fish sampling data were developed to represent fish habitat use. The boat tracks collected with the GPS during the electrofishing transects was used to describe the available habitat. Each GPS data file collected during the electrofishing runs was opened in Pathfinder Office. The data was then exported to a uniquely named *.csv format file. The appropriate *.cdg file for a given site and a discharge representative of the discharge reported when the fishing sampling was conducted was opened in River2D. Using the “Extract points to a *.csv file” function the electrofishing *.csv file had depth, velocity, and substrate data for each spatial position extracted from the River2D model space and a new *.csv file was created. The spatial position data collected every second now had corresponding habitat availability data and the spatial fish capture data had corresponding fish habitat use data. Each individual fish collection record collected in a given site, on a given day, at a given time, in a cross section, transect, and fish tub was assigned physical habitat (depth, velocity and substrate) use data from the corresponding spatial fish capture data.

Development of habitat suitability curves from catch data was limited to fish that were considered adult (>250 mm fork length) and species that had minimum sample sizes of 30 from a given site:

- Site 1 data from BSP 4, 2005 had suitable sample sizes for Longnose Sucker, White Sucker, Shorthead Redhorse, and Walleye.
- Site 1 data from BSP 2, 2006 had suitable sample sizes for White Sucker, Shorthead Redhorse, and Walleye.
- Site 2 data from BSP 4, 2005 and 2006 had suitable sample sizes for Silver Redhorse, White Sucker, and Shorthead Redhorse.
- Site 3 data from BSP 4, 2005 had suitable sample sizes for White Sucker and Shorthead Redhorse.

A histogram approach was used to create availability and use curves that could then be used to calculate habitat suitability curves (Bovee 1986). The Sturges equation was used to set optimal bin sizes:

$$X = (D_{max} - D_{min})(1 + 3.322 * \log(n))$$

where D_{max} is the maximum observed value, D_{min} is the minimum observed value, and n is the sample size (Sturges 1926).

The substrate component of habitat is described only by the dominant substrate for a given spatial position in the River2D model. The description of substrate use and available substrate from the model output limited the analysis to the dominant substrate in the observations. Substrate was summarized as a proportional use for each species of fish in each site. The available substrate was calculated for the transects fished within each site as the proportion available.

The habitat suitability criteria were calculated using the methods described by Bovee (1986) using the following ratio equation:

$$S_i = U_i / A_i$$

where S_i is the unnormalized index of suitability at X_i, U_i is the relative frequency of occurrence at X_i for a particular fish species, A_i is the relative frequency of occurrence at X_i availability based on the total observations, and X_i is the interval of the parameter X. The ratio calculated is then normalized to a 0 to 1 scale with the following equation:

$$S_i = \frac{S_i}{MaxS}$$

where S_i is the normalized suitability index at the interval of the variable and *MaxS* is the maximum suitability index for the range of the variable S_i.

When a suitability value for a particular interval was lower than both immediately adjacent intervals a three point moving average was calculated to smooth the data. In some instances, a second three point moving average was necessary to remove bimodal distribution.

For depth suitability curves once the optimum value of 1 was reached for a given depth all depths greater than that value were then assigned a value of 1 as depth was not assumed to be limiting at any depths greater than the value used in these preference curves. River2D multiplies the depth, velocity, and substrate suitability values to calculate Weighted Useable Area (WUA) for a particular species and life history stage.

The different sites contained different combinations of available habitat in terms of depth, velocity, and substrate. To capture a fish habitat use pattern representative of the Saskatchewan as a whole in the first 30 km downstream of E.B. Campbell Hydroelectric Station the data collected in the Sites 1, 2, and 3 during BSP 4 were combined to calculate a single habitat suitability criteria for each species.

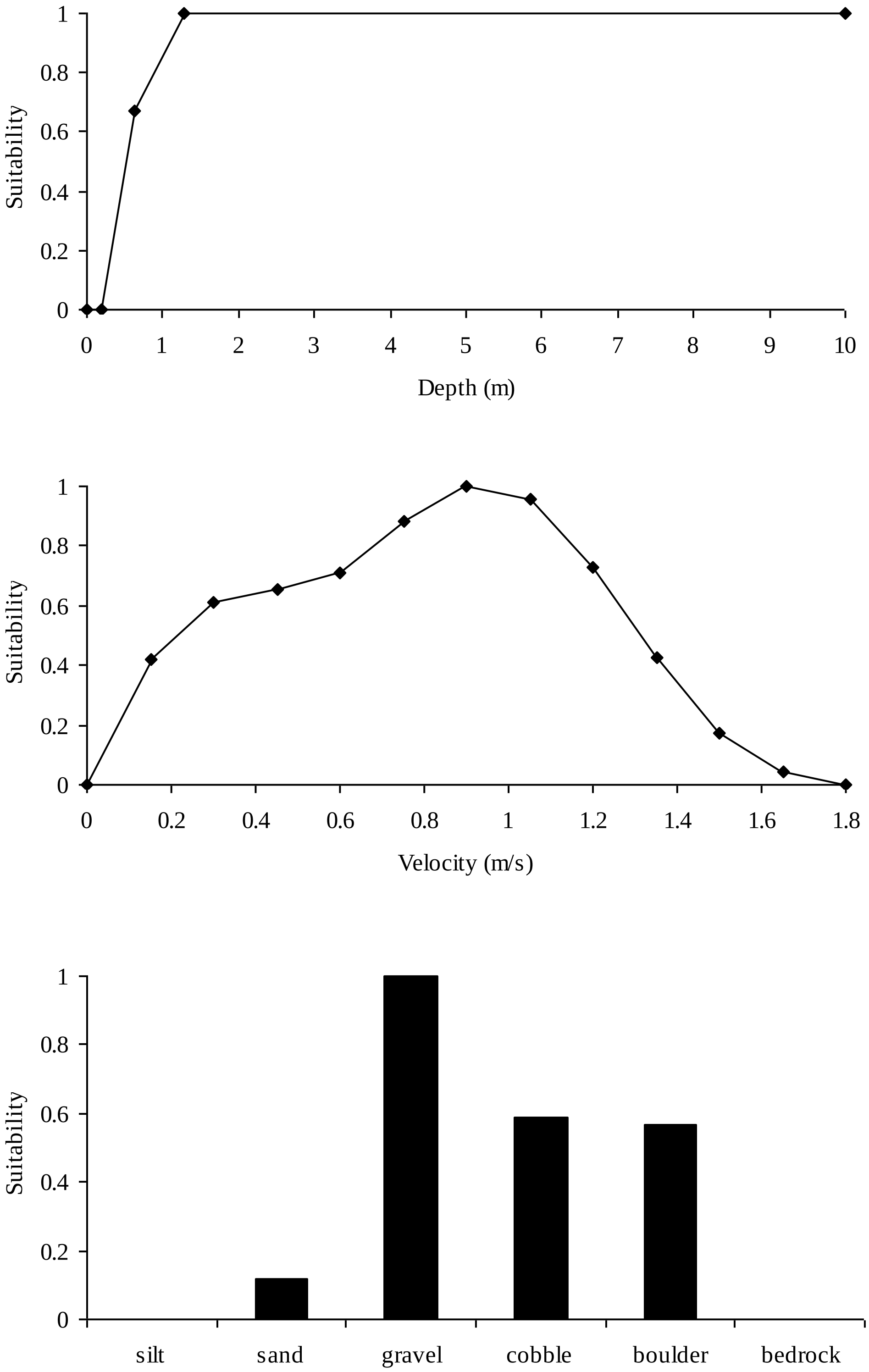


Figure A2.1 Habitat Suitability Criteria calculated for White Sucker from the 2005 and 2006 data collected in BSP 4 in Sites 1, 2, and 3.

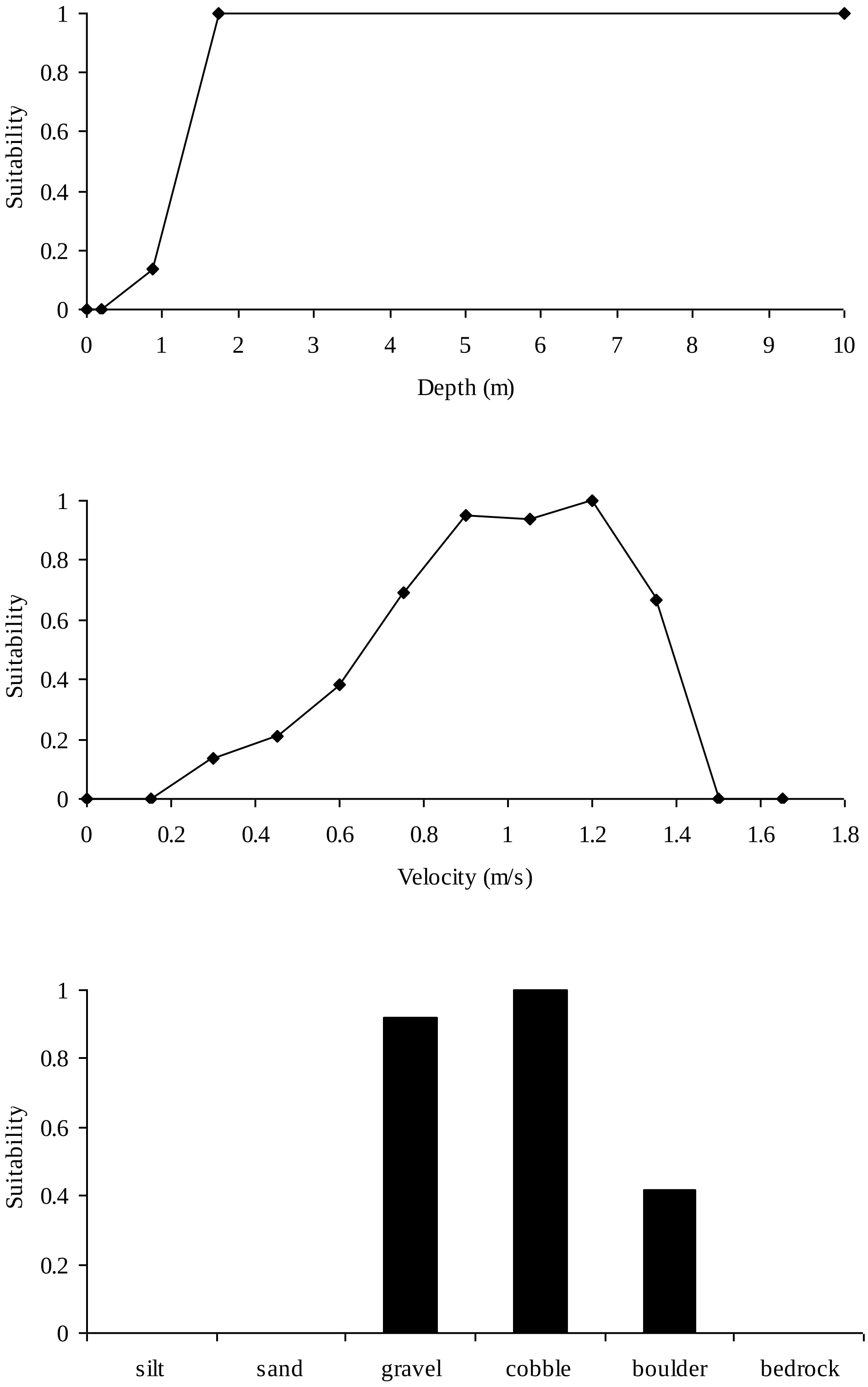


Figure A2.2. Habitat Suitability Criteria calculated for Longnose Sucker from the 2005 and 2006 data collected in BSP 4 in Sites 1, 2, and 3.

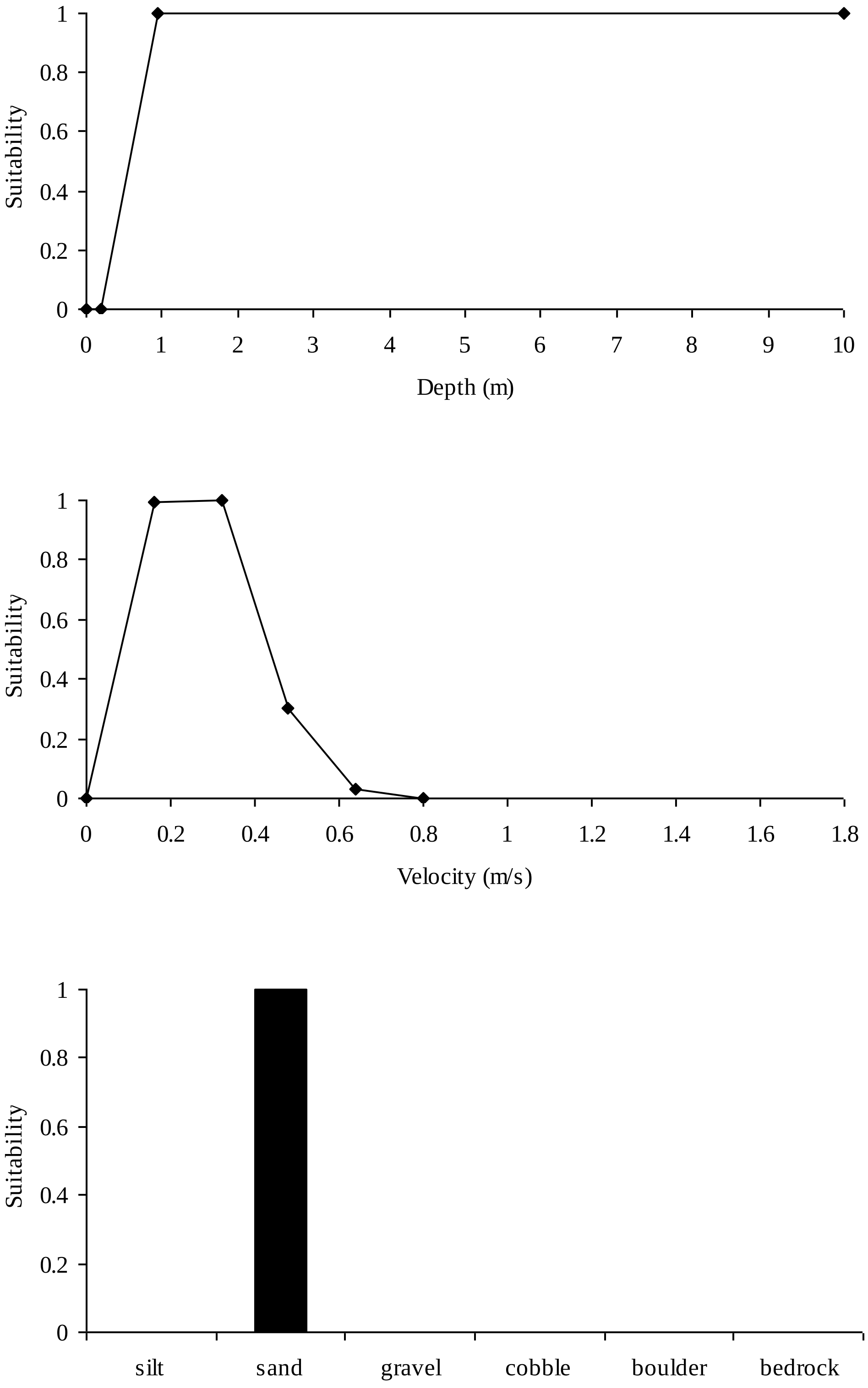


Figure A2.3. Habitat Suitability Criteria calculated for Silver Redhorse from the 2005 and 2006 data collected in BSP 4 in Sites 1, 2, and 3.

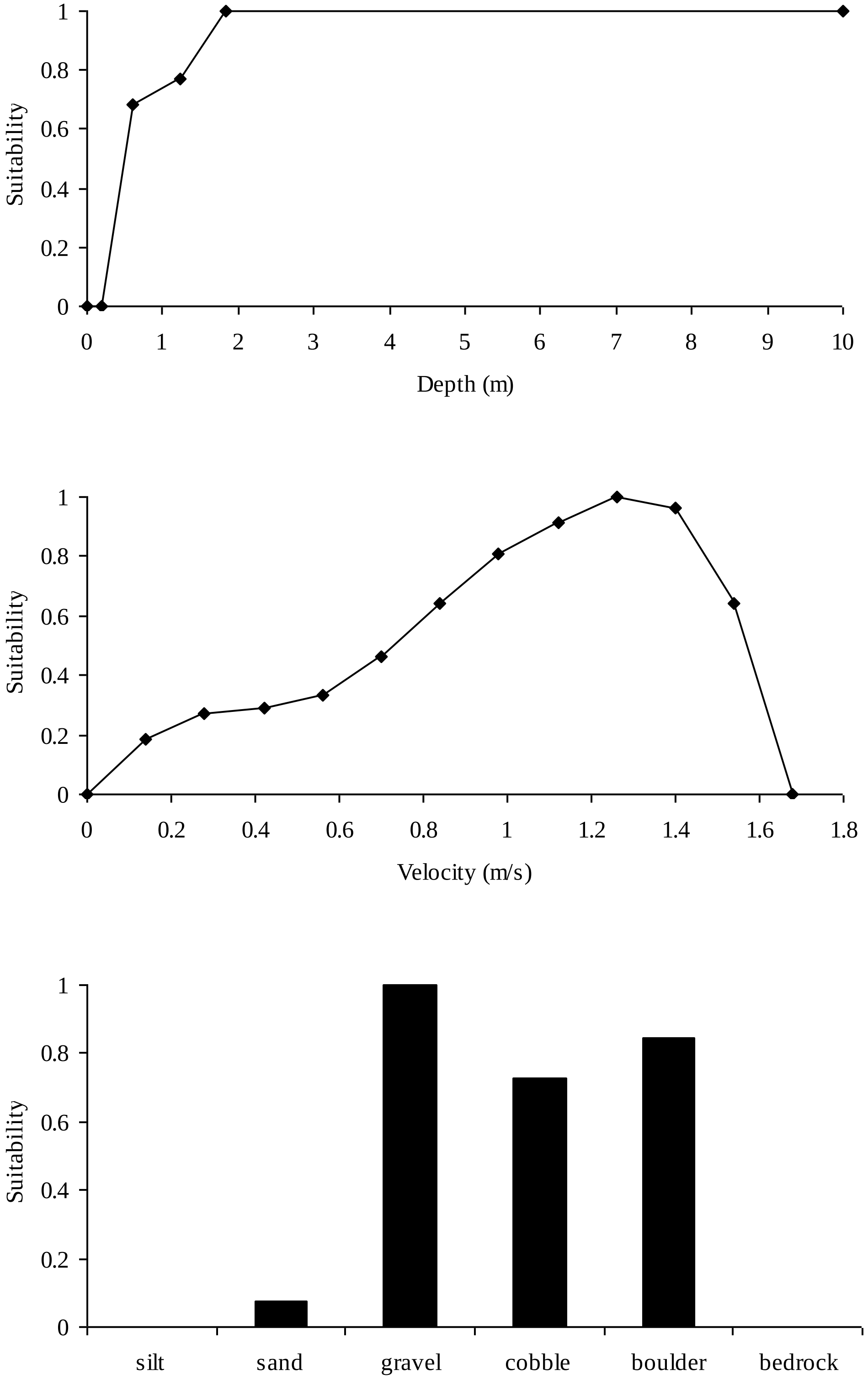


Figure A2.4. Habitat Suitability Criteria calculated for Shorthead Redhorse from the 2005 and 2006 data collected in BSP 4 in Sites 1, 2, and 3.

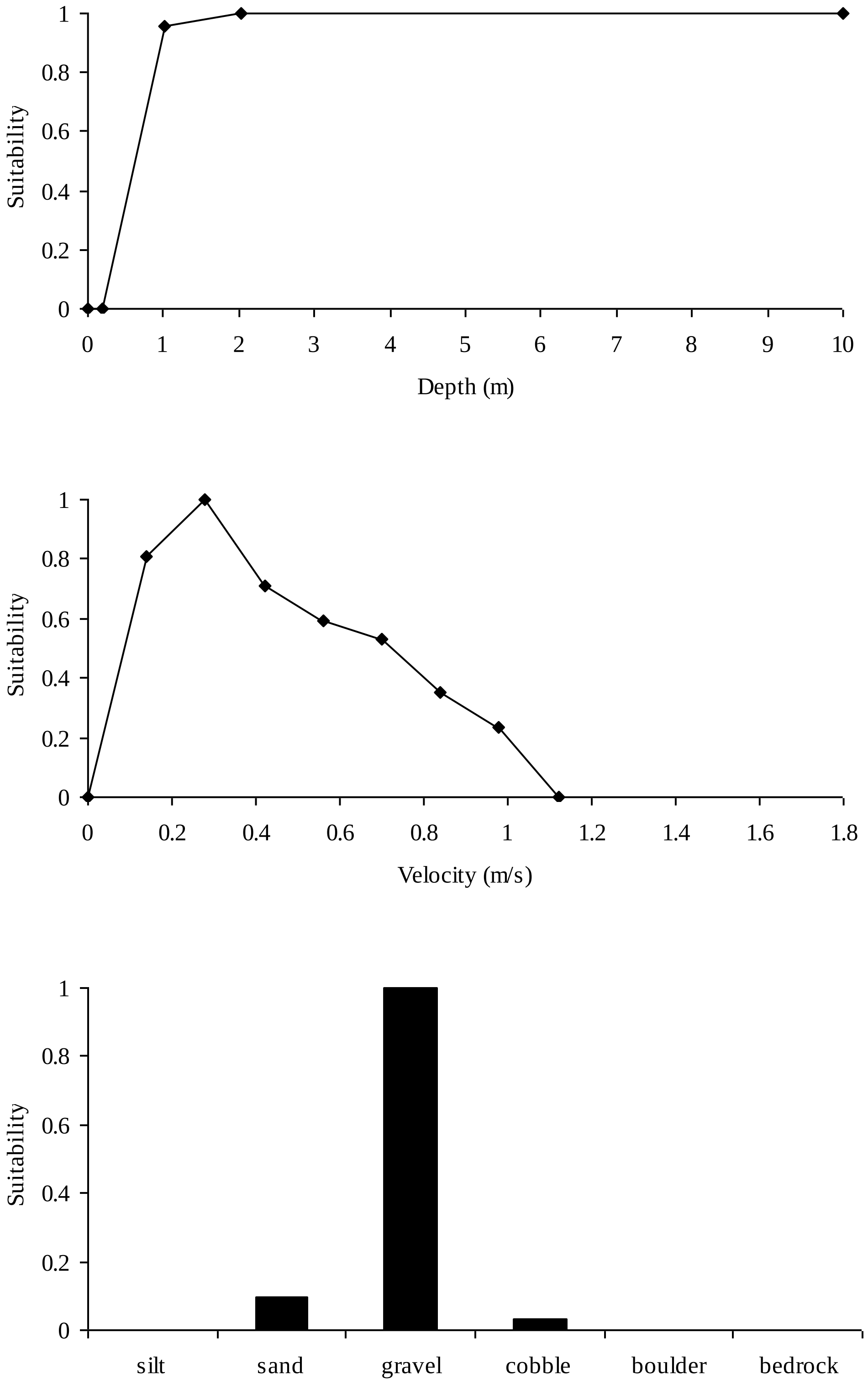


Figure A2.5. Habitat Suitability Criteria calculated for Walleye from the 2005 and 2006 data collected in BSP 4 in Sites 1, 2, and 3.

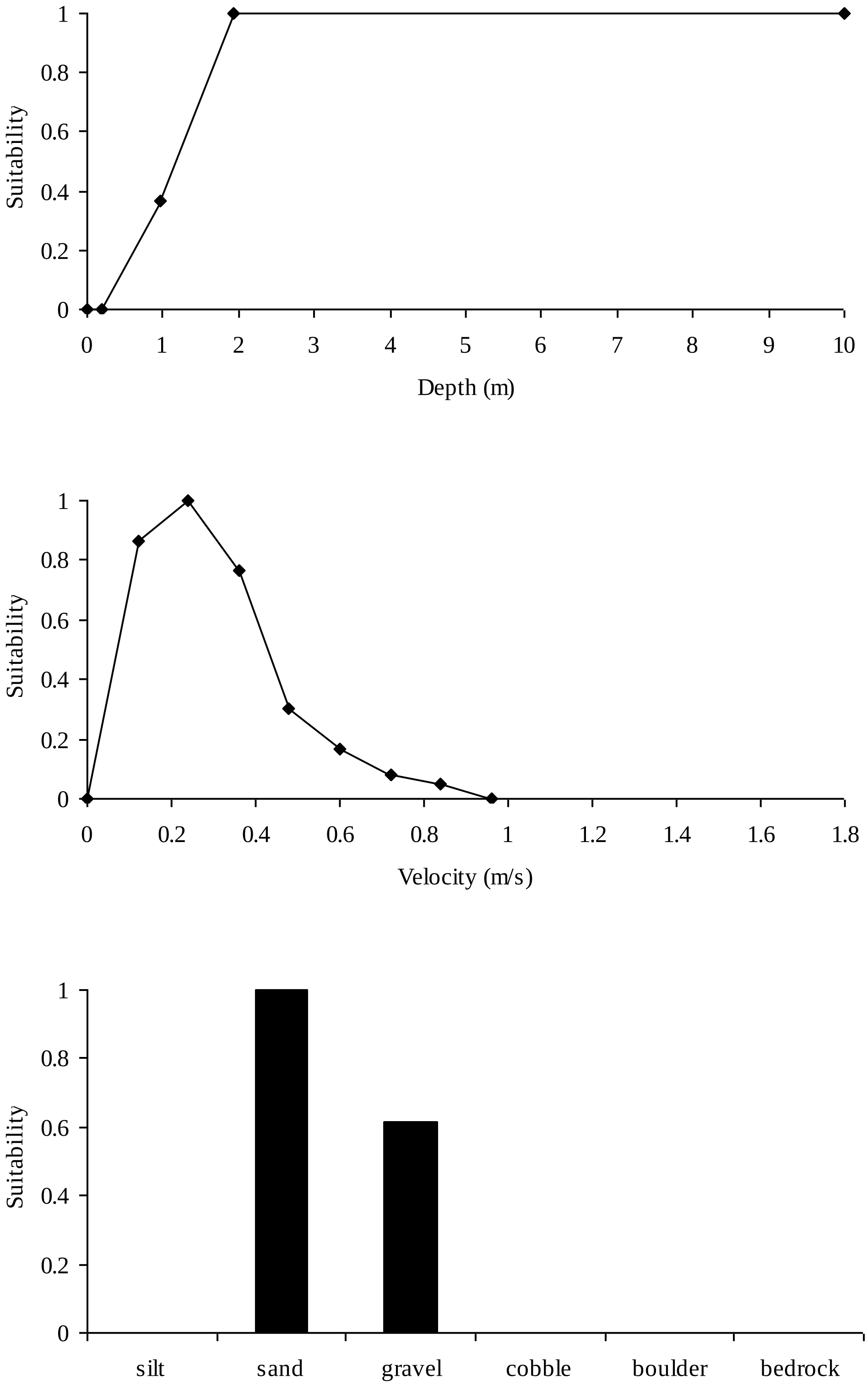


Figure A2.6. Habitat Suitability Criteria calculated for Northern Pike from the 2005 and 2006 data collected in BSP 4 in Sites 1, 2, and 3.

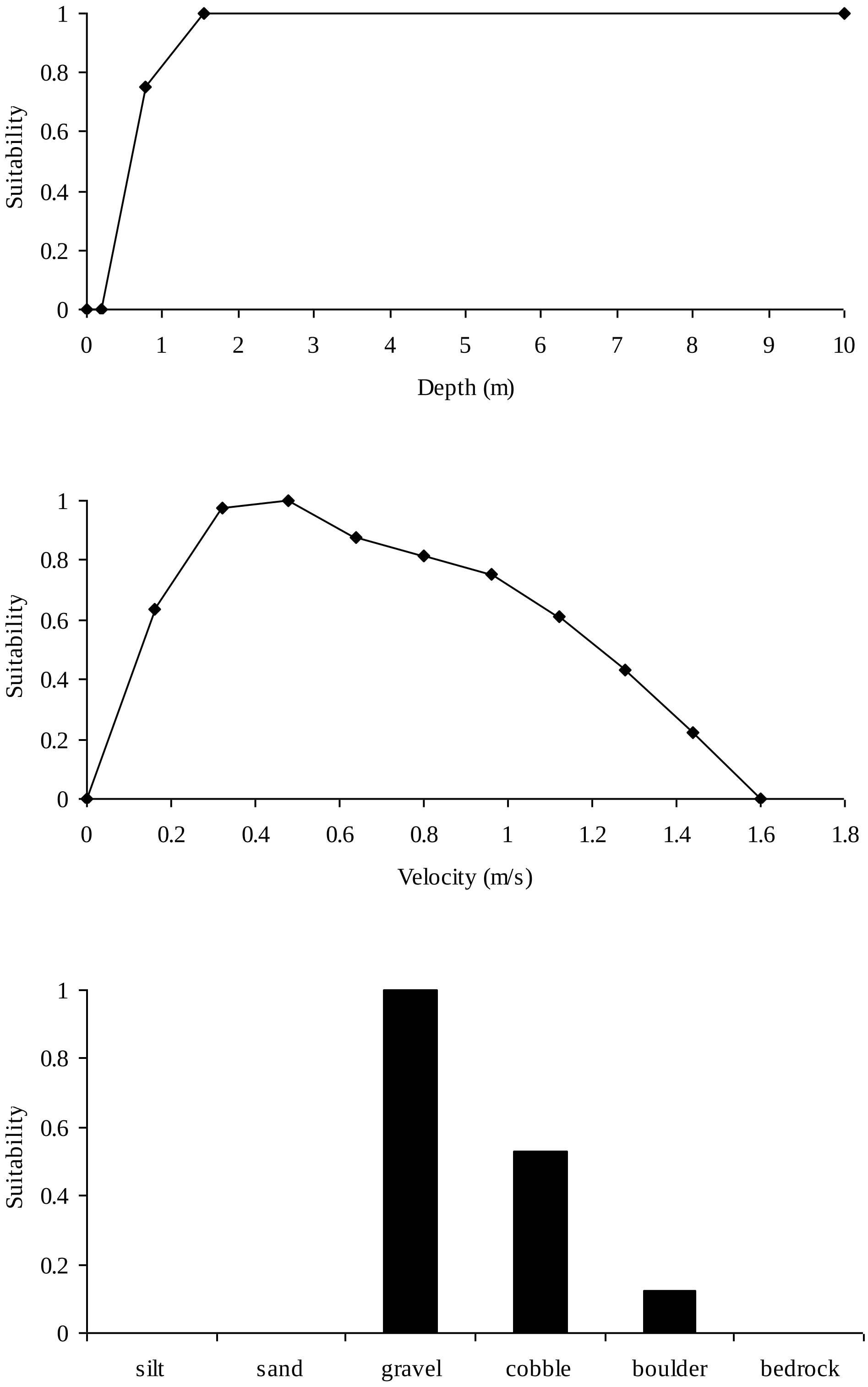


Figure A2.7. Habitat Suitability Criteria calculated for White Sucker from the 2006 data collected in BSP 2 in Site 1.

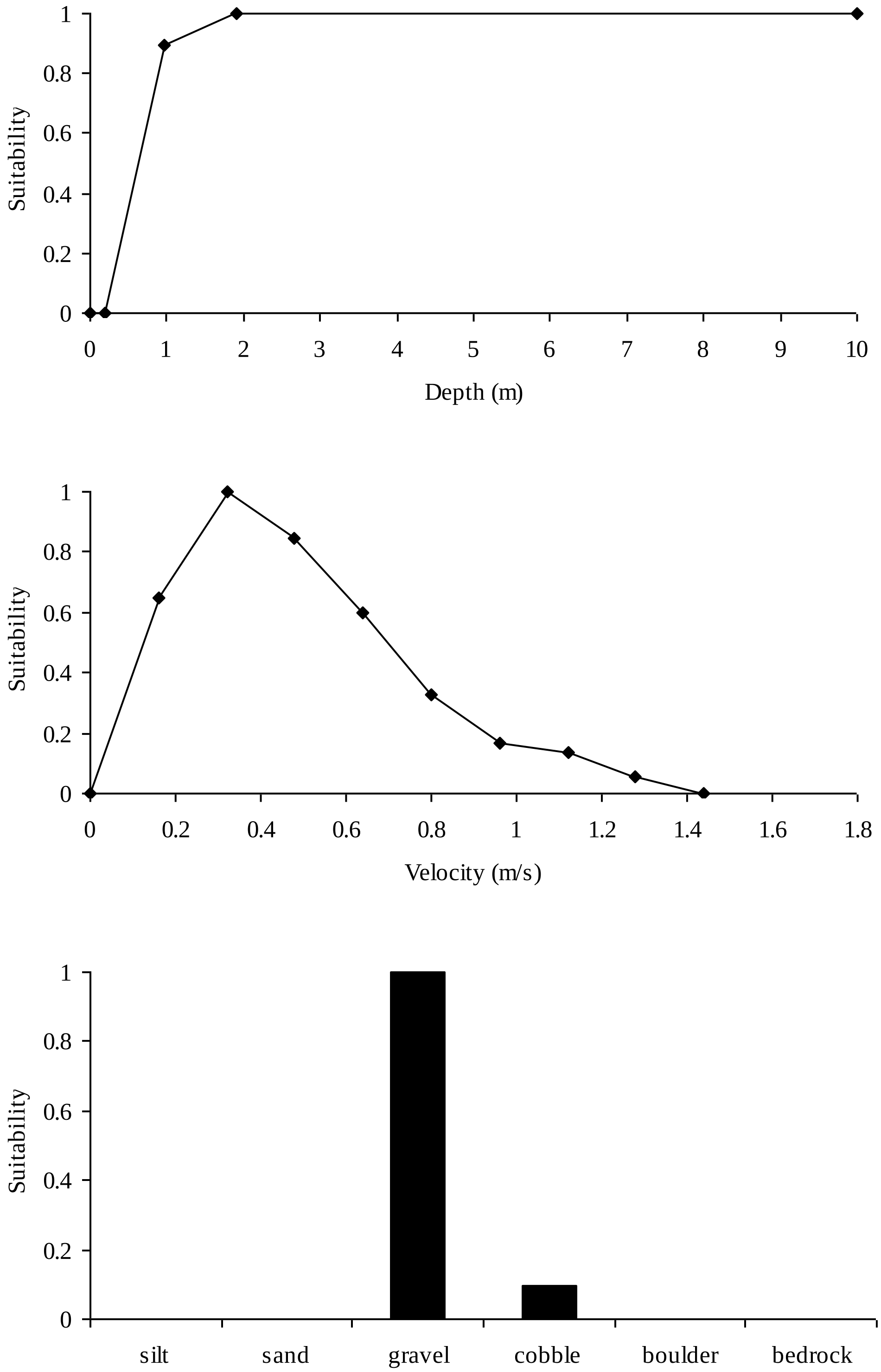


Figure A2.8. Habitat Suitability Criteria calculated for Shorthead Redhorse from the 2006 data collected in BSP 2 in Site 1.

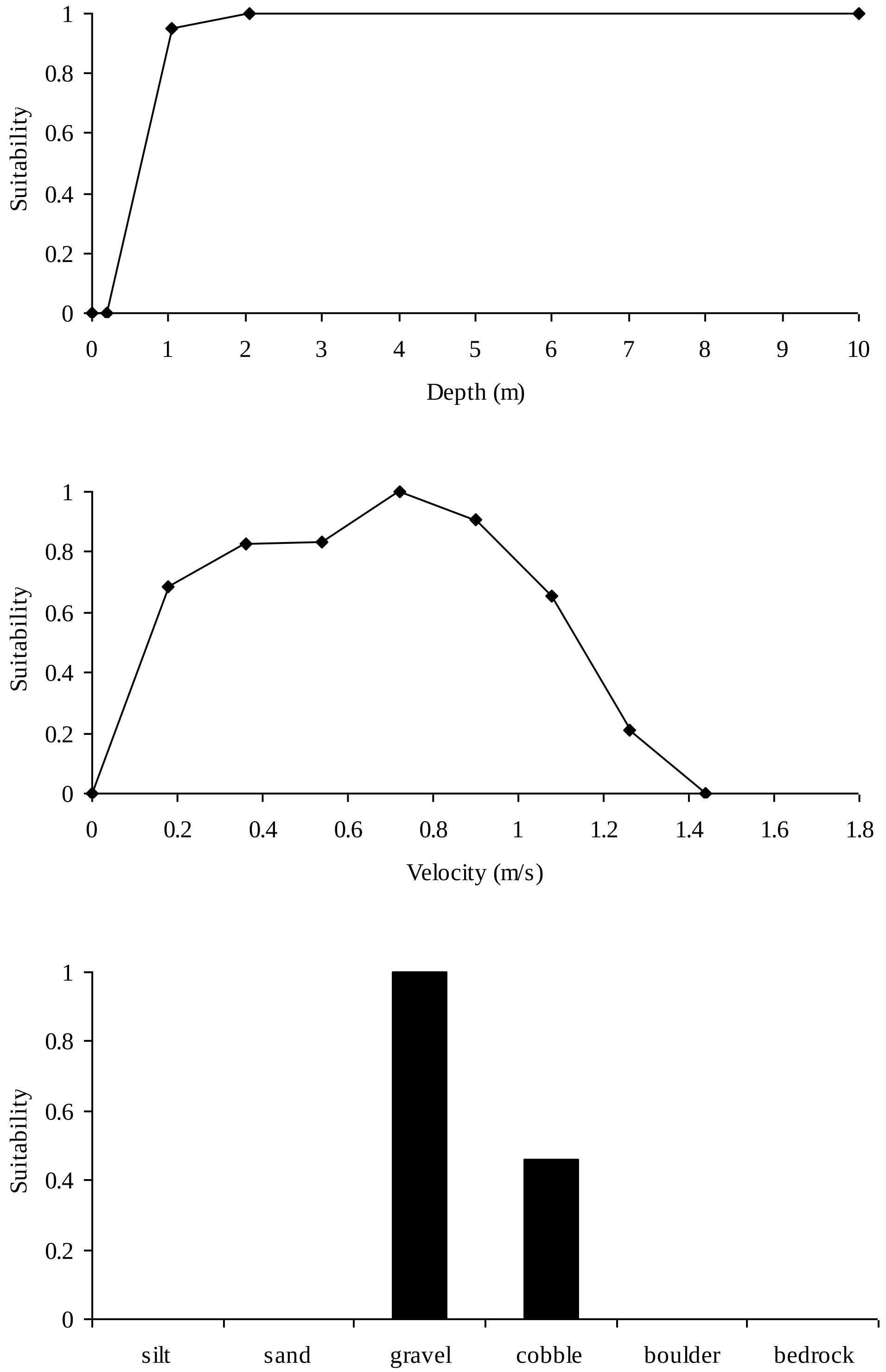


Figure A2.9. Habitat Suitability Criteria calculated for Walleye from the 2006 data collected in BSP 2 in Site 1.

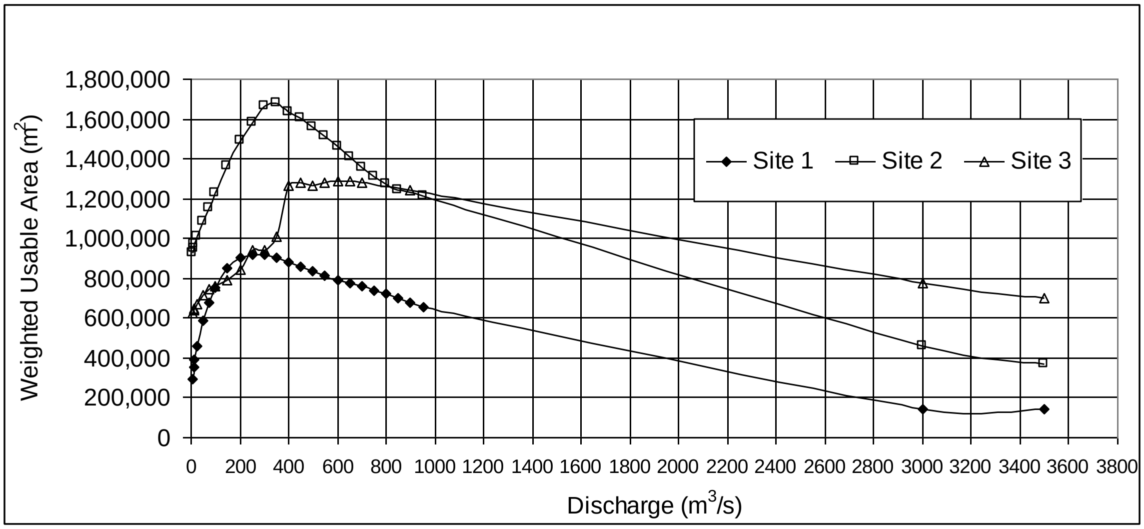


Figure A2.10. Weighted Useable Area calculations using habitat suitability criteria from the HSC workshop for adult Walleye at Sites 1, 2, and 3.

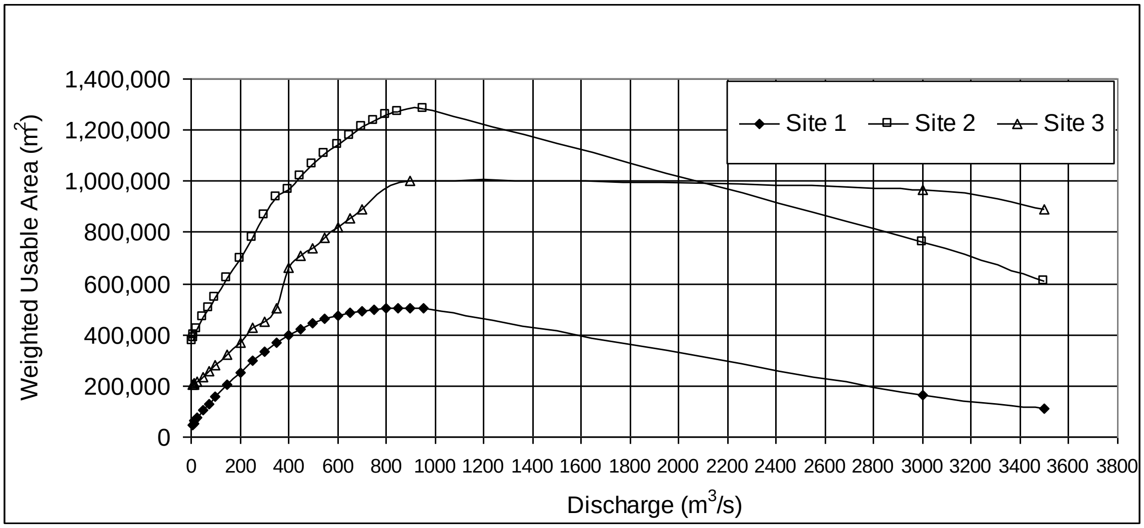


Figure A2.11. Weighted Useable Area calculations using habitat suitability criteria from HSC workshop for adult Lake Sturgeon at Sites 1, 2 and 3.

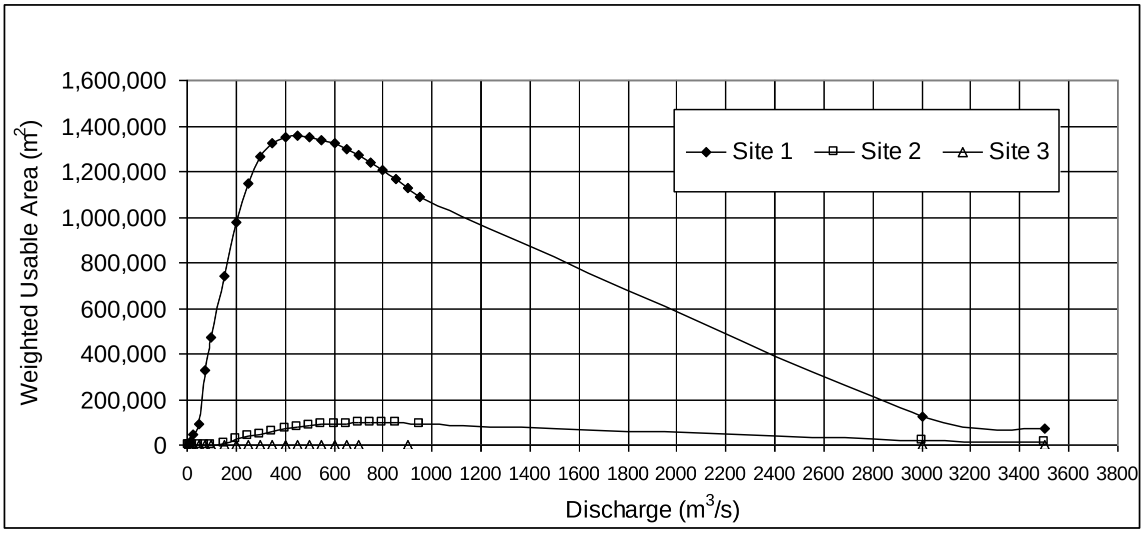


Figure A2.12. Weighted Useable Area calculations using habitat suitability criteria from the HSC workshop for spawning Lake Sturgeon at Sites 1, 2, and 3.

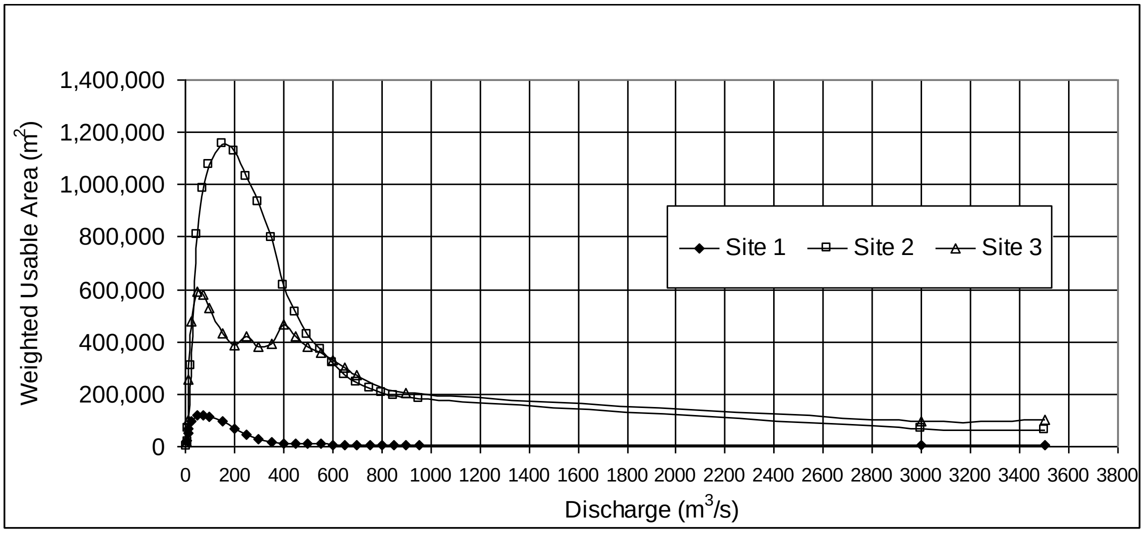


Figure A2.13. Weighted Useable Area calculations using habitat suitability criteria from the HSC workshop for juvenile Lake Sturgeon at Sites 1, 2, and 3.

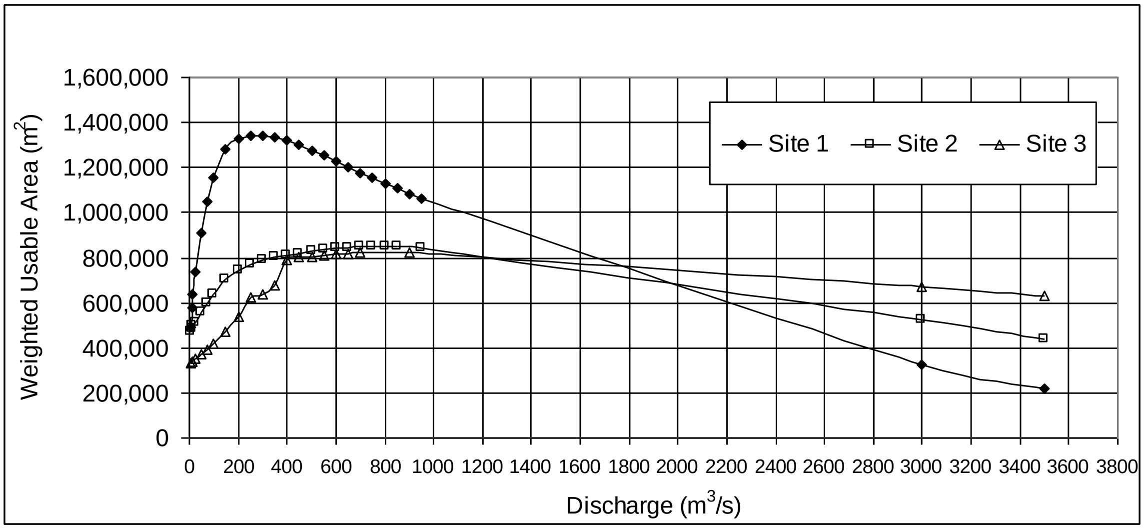


Figure A2.14. Weighted Useable Area calculations using habitat suitability criteria from the HSC workshop for adult Shorthead Redhorse at Sites 1, 2, and 3.

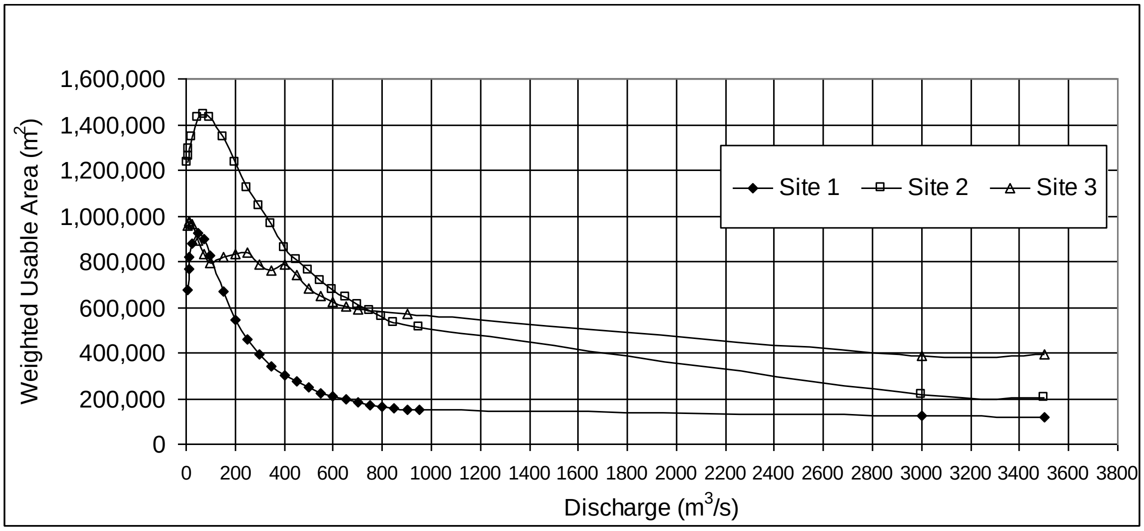


Figure A2.15. Weighted Useable Area calculations using habitat suitability criteria from the HSC workshop for adult Northern Pike at Sites 1, 2, and 3.

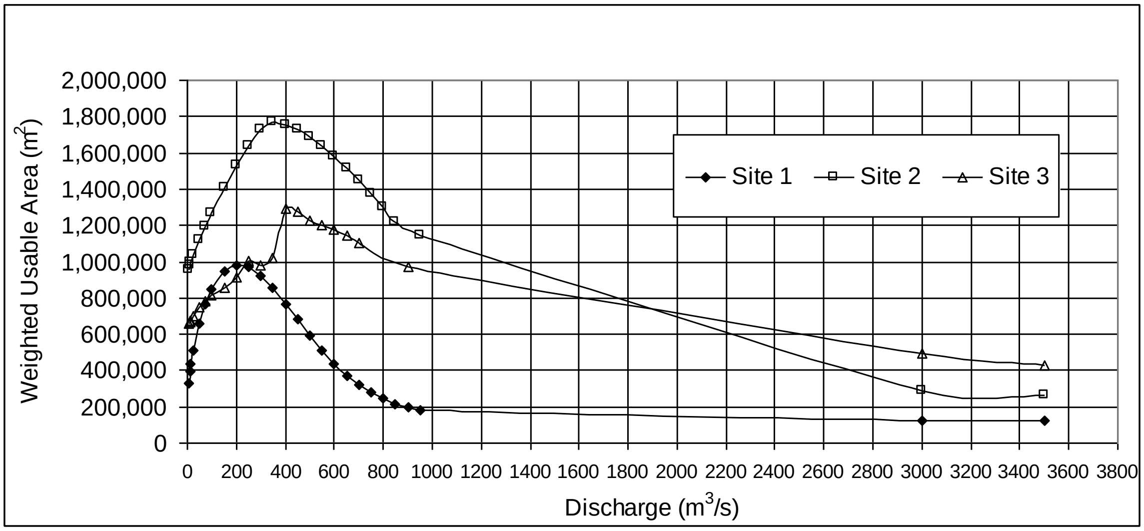


Figure A2.16. Weighted Useable Area calculations using habitat suitability criteria from the HSC workshop for adult Goldeye at Sites 1, 2, and 3.

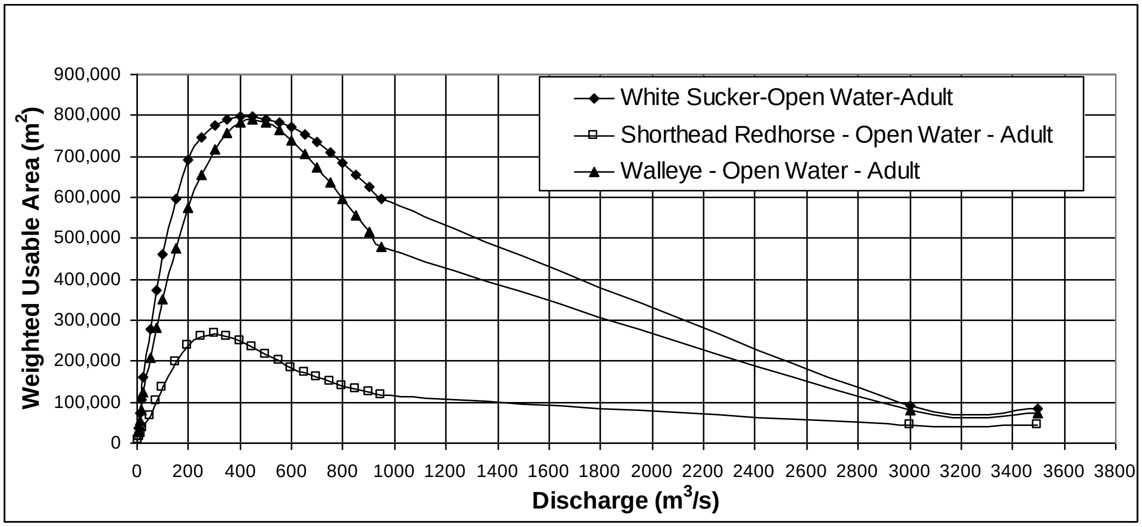


Figure A2.17. Weighted Useable Area calculations using habitat suitability criteria from the HSC workshop for White Sucker, Shorthead Redhorse, and Walleye at Site 1 with data collected during BSP 2 in 2006.

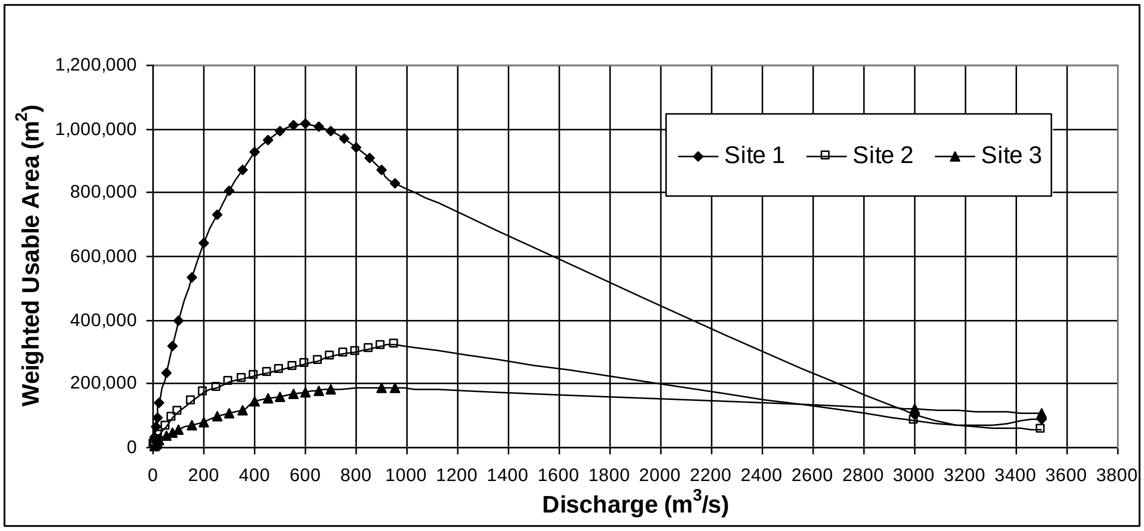


Figure A2.18. Weighted Useable Area calculations using habitat suitability criteria from the HSC workshop for White Sucker at Sites 1, 2, and 3 with data collected during BSP 4 in 2005 and 2006.

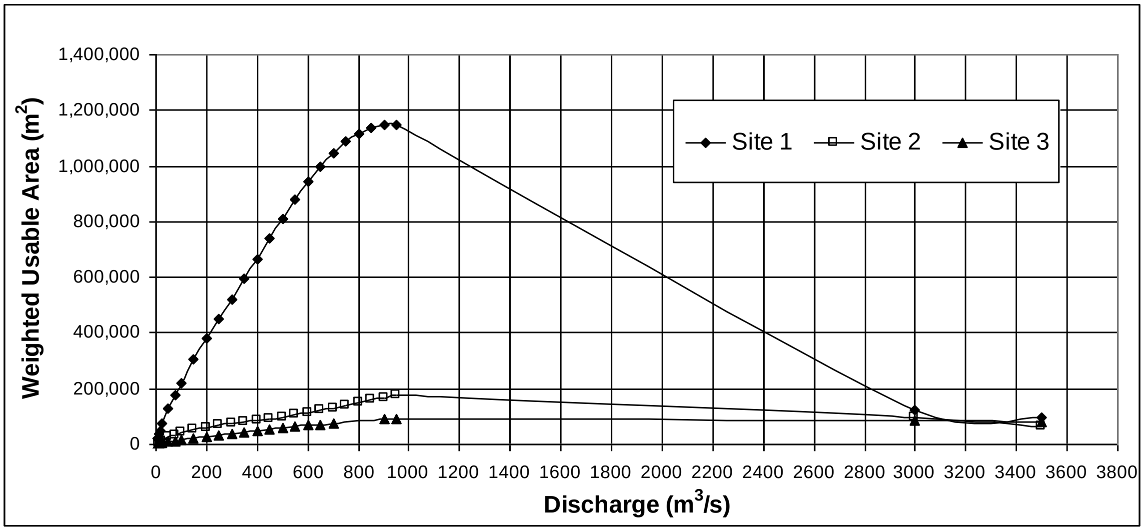


Figure A2.19. Weighted Useable Area calculations using habitat suitability criteria from the HSC workshop for Shorthead Redhorse at Sites 1, 2, and 3 with data collected during BSP 4 in 2005 and 2006.

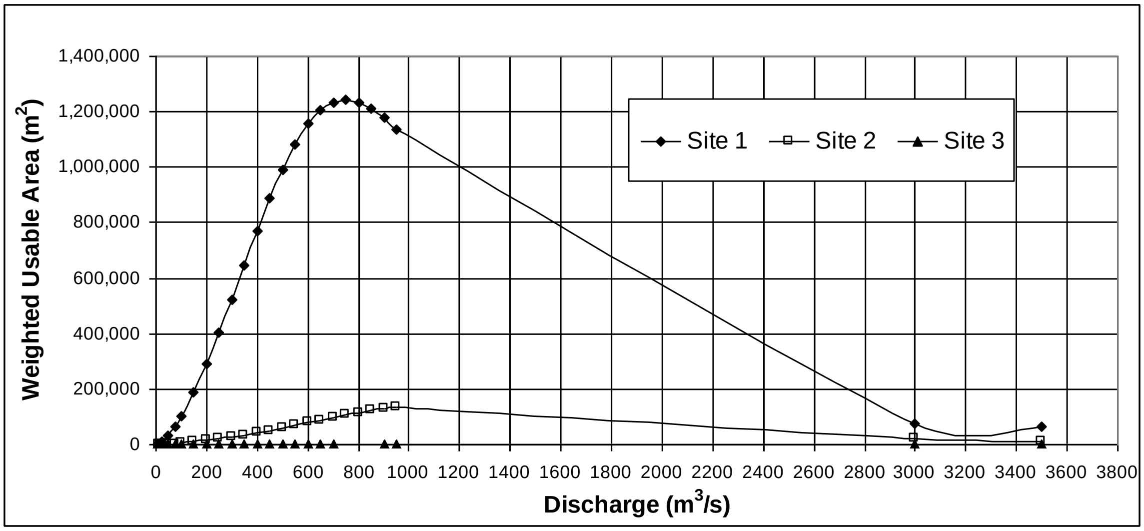


Figure A2.20. Weighted Useable Area calculations using habitat suitability criteria from the HSC workshop for Longnose Sucker at Sites 1, 2, and 3 with data collected during BSP 4 in 2005 and 2006.

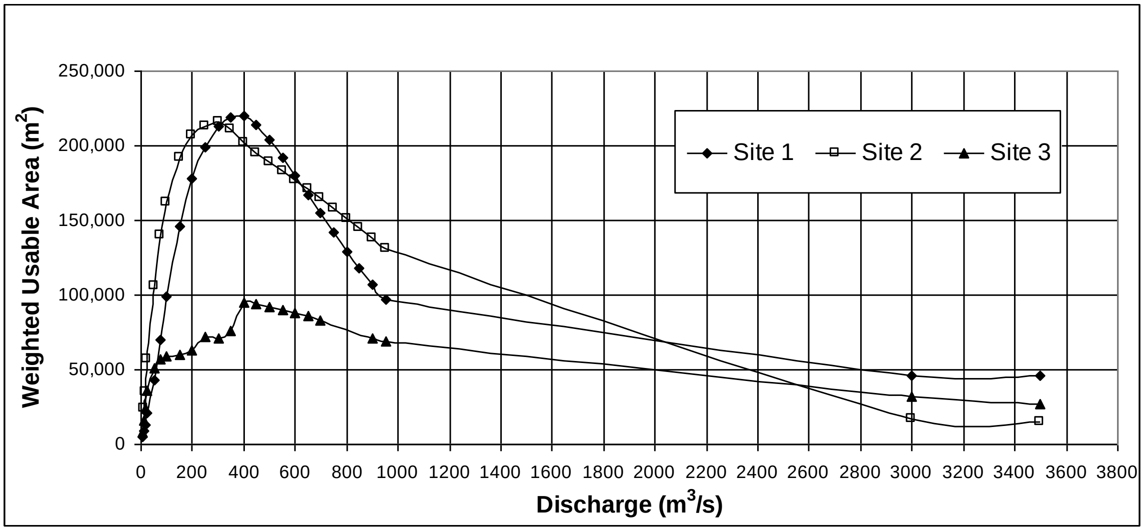


Figure A2.21. Weighted Useable Area calculations using habitat suitability criteria from the HSC workshop for Walleye at Sites 1, 2, and 3 with data collected during BSP 4 in 2005 and 2006.

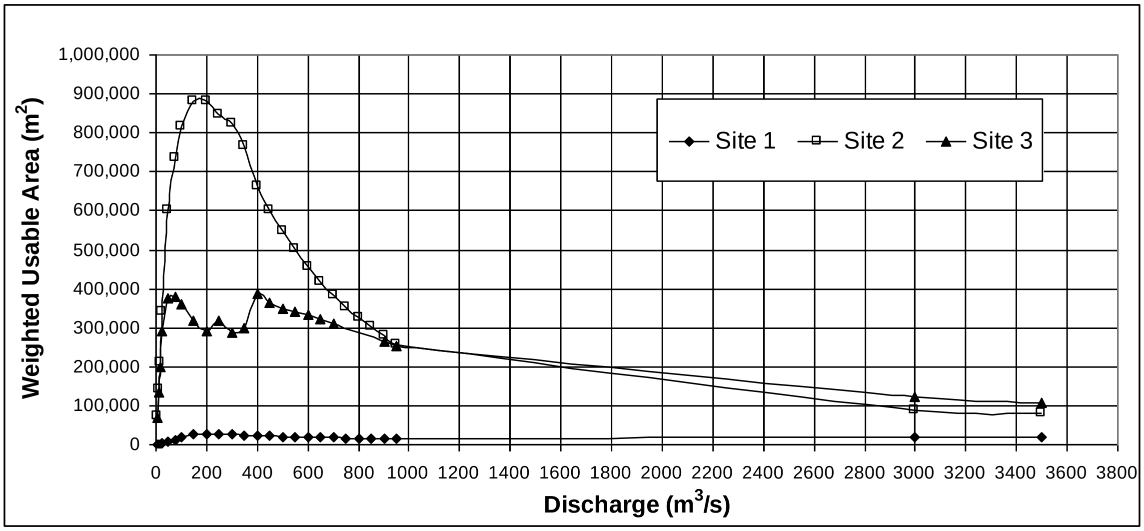


Figure A2.22. Weighted Useable Area calculations using habitat suitability criteria from the HSC workshop for Northern Pike at Sites 1, 2, and 3 with data collected during BSP 4 in 2005 and 2006.

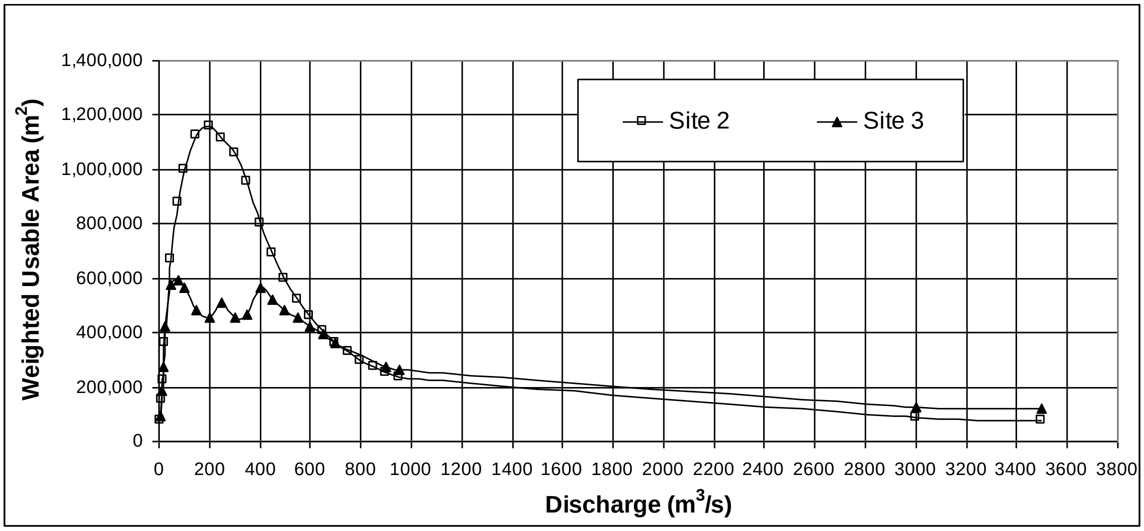


Figure A2.23. Weighted Useable Area calculations using habitat suitability criteria from the HSC workshop for Silver Redhorse at Sites 2, and 3 with data collected during BSP 4 in 2005 and 2006.