**Report Title: Evaluation of Rating Curve Data – 2003-2005 Lower Athabasca River Habitat Surveys**

**Working Group: Surface Water Working Group (SWWG)**

**Final/Approved Report Date: 2007**

**Contract Number: 2005-0002**

# CEMA Disclaimer

**Contract Name: Evaluation of Rating Curve Data – 2003-2005 Lower Athabasca River Habitat Surveys**

**Consultant Name: Northwest Hydraulics Consultants**

This report was commissioned by the Instream Flow Needs Task Group of the Surface Water Working Group of the Cumulative Environmental Management Association (CEMA), in its tasks of developing a water management framework for the lower Athabasca River (LAR). Specifically, this report was intended to evaluate 2003-2005 rating curve data for the lower Athabasca River habitat surveys.

This report has been completed in accordance with the terms of reference issued by the Instream Flow Needs Task Group. The Surface Water Working Group has closed this project and considers this report final.

The Surface Water Working Group and its task groups does not fully endorse all of the contents of this report, nor does the report necessarily represent the views or opinions of CEMA or the Surface Water Working Group or any of its Task Groups Members.

The conclusions and recommendations contained within this report are those of the consultant, and have neither been accepted nor rejected by the Surface Water Working Group and its Task Groups.

Until such time as the Surface Water Working Group issues correspondence confirming acceptance, rejection, or non-consensus regarding the conclusions and recommendations contained in this report, they should be regarded as information only.

For more information please contact CEMA at 780-799-3947.

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Project Number: 1-6576
Contract Number: 2005-0002

March 31, 2006

Cumulative Environmental Management Association
Wood Buffalo Region
Box 5656
Fort McMurray, Alberta, T9H 3G6
Attention: Project Officer

Dear Sir or Madam:

**RE: Evaluation of Rating Curve Data, 2003-2005**
**Lower Athabasca River Habitat Surveys**

We have completed our rating curve measurements for the summer of 2005 as part of the Lower Athabasca River Fish Habitat Survey Program. These measurements were carried out at the upstream and downstream ends of each of the four study reaches established for the Program. The rating curves are required as boundary conditions for the flow simulations which will be carried out at these sites to evaluate fish habitat.

The following report describes the data collection methodology and summarizes the results of this survey and also provides an evaluation of all the summer and winter rating curve data collected from Dec, 2003 to Sept, 2005. A CD containing the data and simulations is also included.

If you have any questions or comments about this report, please call me at 780-436-5868.

Sincerely,

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# 1.0 INTRODUCTION

The Lower Athabasca River Fish Habitat Survey Program established four study reaches where two-dimensional flow simulations were to be carried out to evaluate fish habitat. Summer rating curves describing the relationship between river flow and water levels were required at the upstream and downstream cross sections of these study reaches to establish boundary conditions for the flow simulations. Water level measurements were carried out previously at these eight cross section sites during the summer of 2004 as well as during the winters of 2003-04 and 2004-05.

The following report describes the data collection methodology and rating curve data developed from the 2005 water level measurement program and compares the results with those from the 2004 summer rating curve surveys. Previous winter water level and ice thickness measurements are also evaluated in the report. The evaluation of the rating curves was carried out using a range of hydraulic modeling techniques to provide the appropriate hydraulic framework to extrapolate the rating curves outside the range of measurements.

# 2.0 SUMMER WATER LEVEL MEASUREMENTS

## 2.1 Summer Data Collection Methodology

The summer water level data was collected at the upstream and downstream cross section locations of each of the four survey reaches. Reach #2 is located near the Embarras Airstrip; Reach #3 is near the reserve land at Poplar Point; Reach #4 is near the Bitumount historical site; and Reach #5 is near the Northlands Sawmill (Figure 1).

Solinst Levelogger water level recorders were placed in the water at each cross section in the spring after breakup and then removed in the fall before freeze-up. Solinst Leveloggers were selected because they are self-contained which makes them easy to install and less susceptible to damage. The accuracy of the Levelogger water level recorders is typically within 0.01 m when the data is corrected to fluctuations in barometric pressure. Leveloggers measure water pressure so they must remain at a constant elevation to measure water level data fluctuations accurately. To provide stability, each Levelogger was attached to a 25 kg block of concrete placed on the river bed. This concrete block was anchored with a steel cable to a tree on the bank so that the Levelogger could be retrieved easily.

A Solinst Barologger was installed at the downstream end on the Bitumount reach (Reach #2) to record barometric pressure while the Leveloggers were operating. This data was used to correct the Levelogger data at all the sites. Some variation in barometric pressure occurred over the length of the study reach; however, comparison of variations in the Bitumount data with variations in the Environment Canada data from Ft. McMurray Airport indicated that the differences were quite small, typically less than the equivalent of a change of 0.01 m in water surface elevation.

Water levels at each cross section were referenced to cross section pin elevations established from the bathymetric surveys using a survey level and rod. The water levels were referenced to the benchmarks at the time of installation and again when the recorders were removed. Additional water level elevations were also available when a bathymetric survey was carried out in the reach.

The elevations of the cross section pins used at each site are listed in Table 1. These elevations are only approximate geodetic elevations since they have not been referenced to independent geodetic benchmarks. Some elevations have also been adjusted from previously reported values to correct inconsistencies in the elevations discovered during the analysis of the rating curve data.

**Table 1 Summary of reference elevations for water level measurements**

| Reach | Location | Pin Number | Elevation[1] (m) |
|---|---|---|---|
| Embarras (Reach #2) | Upstream east bank | 01RB | 229.31 |
| | Downstream west bank | 12LB | 216.77 |
| | Reference elevation for reach | TEH 04-1 | 229.30 |
| Poplar Point (Reach #3) | Upstream east bank | 01RB | 217.39 |
| | Downstream east bank | 12RB | 217.64 |
| | Reference elevation for reach | TEH 04-3 | 216.19 |
| Bitumount (Reach #4) | Upstream east bank | 01RB | 232.90 |
| | Downstream east bank | 12RB | 234.90 |
| | Reference elevation for reach | TEH 03-1 | 235.08 |
| Northlands (Reach #5) | Upstream east bank | 01RB | 240.55 |
| | Downstream west bank | 12LB | 240.73 |
| | Reference elevation for reach | TEH 03-3 | 240.70 |

[1] Elevations not referenced to geodetic benchmarks

## 2.2 2005 Summer Water Level Survey

Levelogger water level recorders were installed at each of the eight locations during the period of May 10-11, 2005. The Leveloggers were set to record water levels at one-half hour intervals until the recorders were removed again on Oct 11-12, 2005.

Because the Leveloggers are self-contained, data cannot be obtained from them until they are removed from the water. The data from the Levelogger installed at the downstream section at Poplar Point (Reach #3) was not recovered because it could not be removed from the river bottom. The Levelogger had about 2.5 m of sand deposited over it during high flows the summer so it could not be pulled out. The data from this logger could not be retrieved but most of the data is likely affected by the presence of the sand so would not be useable in any case.

The water levels surveyed during installation and removal were also used as a check on the stability of the Leveloggers. If a surveyed difference in water level was not the same as the difference indicated by a Levelogger, the Levelogger was assumed to have moved. If differences were detected, the Levelogger data was compared to Levelogger data from the nearest location to determine when the deviation occurred. Typically, the deviation was found to be a rapid increase in depth as a Levelogger fell into a scour hole during high flow. Deviations of up to 0.82 m were found at four of the sites. However, when these rapid shifts in level were eliminated, the water level deviations were within 0.09 m of the surveyed levels at all the sites over the duration of the measurements.

## 2.3 2004 Summer Water Level Survey

The 2004 summer water level survey was carried out in the same manner as the 2005 water level survey. Solinst Levelogger water level recorders were installed at each of the eight locations during the period of May 18-20, 2004. The Leveloggers were set to record water levels at one-half hour intervals until the recorders were removed again on Oct 4-5, 2004.

Deviations in water level between Levelogger and level and rod surveys at the end of the data collection season of up to 0.34 m were found at three of the sites. However, when the rapid shifts in level were eliminated, the water level deviations were within 0.05 m of the surveyed levels at all the sites over the duration of the measurements.

## 2.4 Discharge Data

The discharges at the time of the water level measurements were determined from discharge measurements reported by Water Survey of Canada (WSC) for the Athabasca River below Fort McMurray (07DA001). Flows were adjusted for travel time and tributary inflows between this gauge and the survey reaches. Measured tributary discharges were prorated to the entire drainage area between Fort McMurray and the survey reaches. Data from four gauged tributaries were available: Steepbank Creek near Fort McMurray (07DA006); Mackay River at Fort Mackay (07DB001); Muskeg River at Fort Mackay (07DA008); and Firebag River at the mouth (07DC001).

The discharge estimating procedure was calibrated using discharge data collected by WSC at both Embarras and Fort McMurray from 1975 to 1984. The four gauged tributaries (Steepbank, Mackay, Muskeg, and Firebag) which flow into the Athabasca River between these two WSC gauges account for about 65% of the total drainage area between the two gauges. The measured flows per unit area from these tributaries were applied to the entire drainage area to determine the total inflow between the two gauges. These total inflows were then added to the previous day's discharge at the gauge to determine the next day's discharge at the Embarras gauge. The standard error in the estimates was about 6% during the period of record so this procedure is expected to provide a reasonable estimate of discharge within the reach.

## 2.5 Comparison of 2005 Rating Curve Data with 2004 Rating Curve Data

The variations of average daily water levels with river discharge at each location in 2005 are shown in Figures 2-5 along with the data collected in 2004. In general there is good agreement between the shapes of the rating curves measured in 2004 and 2005; however, there are some small differences in elevation between the two sets of rating curves. At Embarras (Reach #2) the upstream rating curve for 2005 is about 0.04 m higher that the 2004 rating curve and the downstream rating curve in 2005 is about 0.10 m higher that the 2004 rating curve. At Poplar Point (Reach #3) the 2005 upstream rating curve data is also about 0.10 m higher than the 2004 rating curve data. No 2005 data was available for the downstream rating curve at Poplar Point. At Bitumount (Reach #4), the upstream rating curve from 2005 is about 0.06 m higher than that from 2004 and the downstream rating curve from 2005 is about 0.13 m higher than the 2004 rating curve. At Northlands (Reach #5), the upstream rating curve from 2005 is about 0.11 m higher than the 2004 rating curve and the downstream rating curve from 2005 is 0.15 m higher than in 2004.

The general trend is that the 2005 rating curves are slightly higher than the 2004 rating curves. The cause of these shifts in unknown but the increased elevations may be due to sand dune movement at the higher flows in 2005. Significant changes in channel shape were observed in the river in 2005. The burial of a Levelogger at Poplar Point under 2.5 m of sand is one example of this sand movement.

# 3.0 WINTER BOTTOM-OF-ICE MEASUREMENTS

## 3.1 Winter Data Collection Methodology

The eight rating curve sites were visited three times over the course of the winter at approximately the same time as the WSC discharge measurements were carried out for the Ft. McMurray gauge. During each site visit 9 to 11 holes were drilled through the ice across the river so that depth, water level and ice thickness could be measured. Water depth and ice thickness were established to ±0.005 m accuracy by direct reading of a submerged survey rod. Depth of the submerged portion of the ice was also measured to establish the position of the ice relative to the water level.

After these measurements were completed, the elevation difference between the water level and a benchmark was established using a survey level and rod. The existing upstream (XS01) and downstream (XS12) cross section pins established during the summer reach surveys were used as benchmarks (Table 1).

Measured discharges from WSC were adopted as the discharge at the data collection sites. It was assumed that no significant inflows occurred during the measurement periods because tributary flows are not gauged during winter. The daily discharges reported for Ft. McMurray WSC gauge indicates that the discharge was quite steady during the measurement periods and that the discharge at the sites is expected to be within about 5% of the measured discharge.

## 3.2 Winter Bottom-of-Ice Data

The winter bottom-of-ice data has been summarized in a previous report (**nhc**, 2005). Data was collected during the winter measurement programs in 2003-04 and 2004-05. Additional data from other sources were also used where available. In 2004-05, ice thicknesses varied from 0.38 to 0.57 m during the first set of measurements but varied from 0.66 to 0.98 m by the third set of measurements. In 2003-04, ice thicknesses varied from 0.40 to 0.55 m during the first set of measurements and from 0.60 to 0.80 m by the third set of measurements. Bottom-of-ice elevations at the eight cross section locations are summarized in Table 2.

Bottom-of-ice elevations are used in the rating curve analysis because variations in these elevations are independent of the ice thickness. Bottom-of-ice rating curves for each of the sites are shown in Figures 2-5 along with the summer rating curves. The bottom-of-ice rating curves tend to be higher than the summer rating curves due to the additional resistance to flow provided by the underside of the ice.

# 4.0 SUMMER RATING CURVE SIMULATIONS

Summer rating curves were simulated using a number of different hydraulic modeling techniques ranging from uniform flow to two-dimensional flow modeling. Hydraulic modeling techniques were used instead of statistical curve fitting because the hydraulic models provided a theoretical framework for extrapolating the rating curves outside the range of measurements.

## 4.1 Uniform Flow Simulations

The simplest model used was a uniform flow model using reach-averaged section characteristics. Average flow area and top width for a wide range of water levels were calculated from the 12 cross sections measured during the bathymetric surveys. The average water level slope measured during the bathymetric surveys for each reach was adopted for all flows. The average water level slope was quite consistent from reach to reach (Table 3), varying from 0.00012 at Embarras (Reach #2) to 0.00013 at Northlands (Reach #5).

The hydraulic roughness was adjusted so that the simulated rating curve fit the measured water level data at each location; however, a constant hydraulic roughness was not able to simulate the rating curve data at any of the locations. Instead, the roughness was found to increase with increasing mean depth at each of the sites. The adopted roughness relationships are summarized in Table 3 while the simulated rating curves are shown in Figures 6 to 9. In general, the change in roughness with mean depth was found to increase from downstream to upstream within the study area.

**Table 2 Summary of bottom-of-ice elevation measurements**

| Source | Date | Discharge ($m^3/s$) | Bottom-of-ice elevation | |
|---|---|---|---|---|
| | | | Upstream (m) | Downstream (m) |
| **Embarras (Reach #2)** | | | | |
| Winter rating curves | 2003-Dec-17 | 185 | 212.32 | 211.55 |
| Winter rating curves | 2004-Jan-19 | 141 | 211.26 | 210.51 |
| Winter rating curves | 2004-Mar-09 | 139 | 211.25 | 210.51 |
| Winter rating curves | 2004-Dec-14 | 184 | 211.93 | 211.42 |
| Winter rating curves | 2005-Feb-01 | 187 | 211.77 | 211.05 |
| Winter rating curves | 2005-Mar-09 | 200 | 211.86 | 211.05 |
| Winter surveys | 2005-Mar-13 | 222 | 212.04 | |
| Winter surveys | 2005-Mar-16 | 235 | 212.31 | |
| Winter surveys | 2005-Mar-17 | 235 | | 211.53 |
| **Poplar Point (Reach #3)** | | | | |
| Winter rating curves | 2003-Dec-17 | 185 | 213.68 | 212.14 |
| Winter rating curves | 2004-Jan-19 | 141 | 213.25 | |
| Winter rating curves | 2004-Mar-09 | 139 | 213.25 | 211.68 |
| Winter rating curves | 2005-Feb-02 | 187 | 213.54 | 212.60 |
| Winter rating curves | 2005-Mar-10 | 200 | 213.48 | 212.28 |
| **Bitumount (Reach #4)** | | | | |
| Winter mixing study | 2003-Mar-20 | 88 | 227.85 | |
| Winter rating curves | 2003-Dec-17 | 185 | 228.60 | 227.65 |
| Winter rating curves | 2004-Jan-19 | 141 | 228.44 | 227.34 |
| Winter surveys | 2004-Feb-23 | 132 | 228.35 | 227.41 |
| Winter surveys | 2004-Feb-24 | 132 | 228.37 | |
| Winter rating curves | 2004-Mar-09 | 139 | 228.27 | 227.34 |
| Winter surveys | 2004-Mar-19 | 146 | | 227.42 |
| Winter rating curves | 2004-Dec-16 | 184 | 228.78 | 227.96 |
| Winter rating curves | 2005-Mar-08 | 200 | 228.77 | 227.79 |
| **Northlands (Reach #5)** | | | | |
| Winter mixing study | 2003-Mar-27 | 93 | | 233.52 |
| Winter rating curves | 2003-Dec-17 | 185 | 235.20 | 233.99 |
| Winter rating curves | 2004-Jan-19 | 141 | 234.82 | |
| Winter rating curves | 2004-Mar-09 | 139 | 234.81 | 233.69 |
| Winter surveys | 2004-Mar-27 | 136 | 234.81 | 233.74 |
| Winter rating curves | 2004-Dec-15 | 184 | 235.11 | 233.90 |
| Winter rating curves | 2005-Feb-03 | 187 | | 233.88 |
| Winter rating curves | 2005-Mar-08 | 200 | 234.85 | 233.87 |

**Table 3 Summary of hydraulic characteristics for uniform flow rating curves**

| Reach | Location | Manning Roughness[1] n | Slope |
|---|---|---|---|
| #2 Embarras | Upstream and downstream | n = 0.020 + 0.0013 H | 0.00012 |
| #3 Poplar Point | Upstream and downstream | n = 0.021 + 0.0011 H | 0.00012 |
| #4 Bitumount | Upstream and downstream | n = 0.019 + 0.0020 H | 0.00013 |
| #5 Northlands | Downstream | n = 0.016 + 0.0025 H | 0.00013 |
| | Upstream | n = 0.013 + 0.0030 H | |

[1] Roughness was found to vary with mean depth, **H**

### 4.2 HEC-RAS Simulations

The cross sections obtained from the bathymetric surveys were also used to construct HEC-RAS models of each reach. HEC-RAS is a one-dimensional gradually varied flow model developed by the Hydraulic Engineering Center of the US Army Corp of Engineers (HEC, 2002) and is considered the standard model for this type of hydraulic modeling. The model, however, requires a downstream boundary condition to be specified, usually a known water level or uniform flow rating curve, so it cannot be used directly to establish the downstream rating curve at each site. For this study it was assumed that the 12 cross sections surveyed in each reach provided a reasonable representation of the average conditions downstream of the reach so an additional set of the 12 cross sections was input downstream of each study reach and adjusted for slope to provide hydraulic data downstream of the study reach. This method was found to provide reasonable simulations of both the upstream and downstream rating curves using the same roughness characteristics.

The rating curves obtained from the HEC-RAS simulations are shown in Figures 6-9 along with the uniform flow simulations. The roughness values required to simulate the measured rating curves in HEC-RAS were found to increase with increasing flow depth in a similar manner to the uniform flow simulations. One difference, however, between the HEC-RAS rating curves and the uniform flow rating curves is that typically the HEC-RAS curves predict slightly higher water levels at extreme low flow conditions. At an extreme low flow of 100 $m^3/s$, the HEC-RAS model predicts water levels ranging from -0.01 m to 0.24 m higher than the uniform flow model, except at Poplar Point (Reach #3) where the water levels were 0.58 m higher.

### 4.3 River2D Simulations

The upstream rating curve for each reach was also simulated using River2D, a two-dimensional flow model developed at the University of Alberta (Steffler and Blackburn, 2001), using the downstream rating curve as the downstream boundary condition for the model. For ease of use, the uniform flow simulations were adopted as the rating curves for three of the reaches; however, at Poplar Point (Reach #3) the HEC-RAS rating curves were adopted due to the large differences between the HEC-RAS and the uniform flow simulations at low flows in this reach.

The results of the River2D rating curve simulations are shown in Figures 6-9 along with the other rating curve simulations. The River2D rating curves were found to be consistent with the other rating curves at medium and high flows but at low flows the water levels simulated by River2D were consistently higher than those predicted by the other methods even though the roughness height was reduced significantly. The River2D model uses bed roughness height to establish hydraulic roughness rather than Manning roughness. Manning roughness is proportional to the sixth root of roughness height, but typically includes some form roughness which is not required by the two-dimensional flow model.

## 4.4 Comparison of Hydraulic Modeling Techniques

The variations in roughness height with discharge for all three hydraulic models are shown in Figures 10-13. The roughness heights used in River2D were typically lower than the equivalent roughness heights from the uniform flow and HEC-RAS models, although the River2D and HEC-RAS roughness heights were similar at the higher flows. The higher roughness heights at the higher flows are likely due to the formation of ripples on the sand surface at higher flows. At low flows, however, even when roughness heights smaller than the sand grain roughness estimated to be about 1 mm were used, the water levels simulated by River2D were higher than the water levels simulated by the other two hydraulic models.

It is difficult to determine which model provides the more accurate results since all three models are extrapolated to low flows from the measured values. The uniform flow model may slightly under-predict water levels at low flow because it uses average section characteristics rather than the riffle section characteristics which control the water level. The HEC-RAS and River2D models simulate the effects of the control sections but do not account for the effects of a mobile bed where local high velocities in riffles may cause the riffles to erode even at relatively low flows. This may cause lower than predicted water levels in some local areas where water level is controlled by a riffle. The actual low flow water levels are likely within the range of simulated values. A two-dimensional mobile bed model of the reach would provide better prediction of actual low flow water levels; however, this type of modeling is not feasible at the present time due to limitations in the available technology.

# 5.0 WINTER RATING CURVE SIMULATIONS

In winter, the water levels change in response to changes in ice thickness as well as changes in discharge. Rating curves in winter must, therefore, account for the growth in ice thickness over time in order to be valid for periods other than the measurement period. The bottom-of-ice elevation is independent of the ice thickness; and, thus is a better parameter than water level for developing winter rating curves. Actual water levels can then be determined by adding a given submerged ice thickness to the bottom-of-ice elevation.

The variations of bottom-of-ice elevations with discharge are shown for each reach in Figures 14-17 along with the winter rating curves obtained from the hydraulic models. There are some significant deviations in the data relative to the rating curves at some of the sites. These deviations are not related to survey error since the bed elevations are consistent for measurements on different dates in the same winter. The deviations may be due to changes in roughness of the bottom of the ice or to differences in discharge between the WSC measurements and the actual local discharge.

Winter bathymetric surveys were only completed at two of the reaches, Bitumount (Reach #4) and Northlands (Reach #5). Hydraulic simulations could be carried out using winter cross sections in these reaches but at the other two reaches only summer cross sections could be used to carry out the winter simulations. However, comparison of HEC-RAS results using summer and winter cross section data at Bitumount (Reach #4) and Northlands (Reach #5) indicate that differences in water levels simulated with the two data sets were less than 0.2 m.

For both the uniform flow and HEC-RAS rating curve simulations the bed roughness established from the summer rating curve analysis was adopted for the winter bed roughness. The ice roughness was then adjusted to fit the measured bottom-of-ice elevations. For the uniform flow simulations, the Manning roughness of the ice varied from 0.013 at Northlands (Reach #5) to 0.032 at Poplar Point (Reach #3). For the HEC-RAS simulations the Manning roughness of the ice was typically between 0.023 and 0.025, except at Embarras (Reach #2) where a higher roughness of 0.032 was required.

The rating curves adopted for boundary conditions in the River2D two-dimensional flow at Bitumount (Reach #4) and Northlands (Reach #5) were simulated using the uniform flow model. These adopted rating curves were found to provide reasonable estimates of bottom-of-ice elevations for the range of measured discharges; however, the trends indicated by the data are somewhat steeper than the trends indicated by the rating curves. The upstream rating curves obtained from River2D were found to be slightly higher than the adopted rating curves at extreme low lows, even when bed roughness heights were reduced to sand grain roughness heights. The adopted ice roughness height at Bitumount (Reach #4) was 10 mm while at Northlands (reach #5) a roughness height of 100 mm was required to fit the data. This difference in roughness height was consistent with observations of the ice surface roughness in these reaches. These values are also consistent with the equivalent ice roughness heights of 40 to 70 mm used in the HEC-RAS modeling.

The one-dimensional flow model used to develop the rating curves was calibrated assuming no bed movement and using a constant ice roughness; however, bed elevation or ice roughness may vary with discharge. Bottom-of-ice measurements over a wider range of discharges are required before these effects can be incorporated into the one-dimensional flow model. The measurements are limited to discharges ranging from 139 to 200 $m^3$/s (except for one site where data was available at a discharge of 88 $m^3$/s) while the rating curve is used for discharges ranging from 50 to 600 $m^3$/s. Further measurements are required during higher and lower flow winters to extend the data range; however, the range of measurements is constrained by the flows which occur over the winter.

## 6.0 CONCLUSIONS AND RECOMMENDATIONS

Comparison of the summer rating curve data collected in 2004 and 2005 indicated that the 2005 water levels tended to be slightly higher than the 2004 water levels; however, the reason for this difference was not apparent. The data also indicates that the rating curves developed from the one-dimensional flow model and the HEC-RAS model provide reasonable estimates of both summer water levels and winter bottom-of-ice levels, but these estimates may be less reliable at very low flows. Further data collection is recommended to collect summer water levels and winter bottom-of-ice elevations at low flows should they occur in the future.

The adopted summer and winter rating curve values used as boundary conditions for the two-dimensional flow modeling are listed in Tables 4 and 5. The values were obtained from the uniform flow simulations, except at Poplar Point (Reach #3) where the HEC-RAS results were used, so low flow water and bottom-of-ice levels may be slightly over-predicted at Poplar Point and slightly under-predicted in the other reaches.

The water levels simulated at the upstream cross sections by the River2D model were consistent with the simulations from the uniform flow and HEC-RAS models for medium and high flows but at low flows the River2D water levels were consistently higher even though very low roughness heights were selected. A two-dimensional mobile bed model of the reach would provide better prediction of actual low flow water levels; however, this type of modeling is not feasible at the present time due to limitations in the available technology.

## 7.0 REFERENCES

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Steffler and Blackburn, 2001. River2D – Two-dimensional depth averaged model of river hydrodynamics and fish habitat – Introduction to depth averaged modeling and users manual. University of Alberta, Edmonton, Alberta.