Instream Flow Needs Determinations for the South Saskatchewan River Basin, Alberta, Canada

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EXECUTIVE SUMMARY

The Province of Alberta introduced a Water Management Policy for the South Saskatchewan River Basin (SSRB) that called for determination of the maximum amount of water that can be allocated for irrigation in the Red Deer, Bow, Oldman, and South Saskatchewan River sub-basins. Implicit in this determination was the requirement to consider the needs for all other uses, including instream uses. To address this policy a Steering Committee with membership from several Government of Alberta departments was struck. This Steering Committee subsequently appointed a technical team to develop instream flow needs (IFN) determinations for all mainstem reaches in the SSRB. The Technical Team was comprised of staff from Alberta Environment and Alberta Sustainable Resource Development. They accessed expertise from within and outside the Government of Alberta when necessary to complete the tasks involved in developing the IFN determinations.

The study area included reaches on the Red Deer River downstream of the Dickson Dam to the Alberta-Saskatchewan border, the Bow River downstream of the Western Irrigation District weir, the Oldman River downstream of the Oldman River Dam, the St. Mary River downstream of the St. Mary River Dam, the Belly River downstream of the Belly River diversion weir, the Waterton River downstream of the Waterton Reservoir and the entire extent of the South Saskatchewan River to the Alberta-Saskatchewan border.

The approach developed by the Technical Team is based on the premise that an IFN determination should reflect the seasonal pattern and general changes in magnitude, frequency, timing and duration of the natural flow hydrograph so that both intra-annual (within a year) and inter-annual (between years) variability of flow is maintained. The intent was to provide an instream flow determination based on the ecological need for natural flow variation. This concept is commonly referred to as the natural flow paradigm. Furthermore, the Steering Committee directed that the IFN recommendations should be based on the latest scientific understanding of riverine ecosystems. Therefore, a holistic approach was required to preserve the processes and functions of the river ecosystem.

To meet these expectations, the Technical Team chose four ecosystem components to represent the full extent of the aquatic ecosystem: water quality, fish habitat, riparian vegetation, and channel maintenance. IFN flow values were generated for 27 reaches, on a weekly time-step, in a duration curve format. A weekly time-step was deemed appropriate from the perspective of biological, hydrological and water planning modelling.

The water quality IFN is based primarily on flows required to protect against high instream temperatures and, in some instances, high ammonia levels. It also ensures that minimum dissolved oxygen concentrations are maintained for the protection of fish species. The fish habitat IFN is based on flows required to protect physical fish habitat. The riparian IFN is based on flows required to provide adequate recruitment opportunities for riparian poplar forests and to promote tree growth between recruitment events. The channel structure IFN is based on flows required to maintain channel structure processes. These flows range from low flows necessary to flush fines from streambed substrates to higher flows that shape and form the channel within the river valley.

The Technical Team chose to use the natural flow regime as a benchmark condition in making instream flow needs descriptions based on the following objectives and principles:

- The primary objective of determining instream flow needs is to provide a description of flow requirements for achieving a high level of protection of

the riverine ecosystem to the extent that it can be achieved by instream flows alone.

- Provision of streamflows that provide habitat conditions similar to naturally occurring habitat conditions is considered to be sufficient to provide ecosystem protection, in the context of IFN analysis.
- In order to achieve ecosystem protection, an IFN determination must provide for protection of aquatic habitats in the short term and protection of the processes that maintain aquatic habitats in the long term.

Enhancement of habitat beyond what would occur naturally is considered to be distinct from a purely environmental protection objective. Therefore, what are referred to as instream flow needs for protection do not address enhancement of habitat. However, implementing a protective IFN may result in an improvement of habitat compared with existing conditions.

The goal of the Technical Team was to develop an IFN determination that ensured a high level of protection for the aquatic ecosystem. The integrated IFN determination specifies an environmental flow regime that maintains elements of the natural intra-and inter-annual flow variability. The Technical Team also considered flow magnitude, flow timing, and flow duration to be critical to the IFN determination.

No new data were gathered for this study, although some new modelling was carried out using existing information. Previous modelling results were re-examined and improvements were made where possible. Although not every aspect of every component of the aquatic ecosystem was addressed in the current evaluation, the information used is believed to be comprehensive by today's standards. Methods for quantifying instream flow needs have evolved considerably since the original instream flow studies were carried out in the South Saskatchewan River Basin in the 1980s and early 1990s. Most of the original studies were based on the quantification of instream flows from the relatively narrow perspective of identifying flows for only a few select sport fish species and for water quality. It is now generally accepted that it is better to include as many riverine components as possible in making comprehensive IFN determinations.

Fish Habitat

The fish habitat IFN component determination is based on site-specific data and habitat modelling using the PHABSIM (**P**hysical **HAB**itat **SIM**ulation) group of models. Existing hydraulic data were re-calibrated using recent technology to update the hydraulic simulations. For the Habitat Suitability Criteria (HSC) curves, a workshop was held with experts from within and outside the government, where existing data were assessed to produce a set of basin-wide HSC curves. The fish habitat IFN determination process consisted of five basics steps:

Develop a series of constant-percent flow reductions from the natural flow in 5% increments;

- Calculate the Ecosystem Base Flow (EBF);
- Identify the flow range to conduct habitat time series analyses using site-specific Weighted Usable Area (WUA) curves as the assessment criteria;
- Conduct habitat time series analyses for the natural flow and each constant-percent flow reduction with the added constraint of the EBF; and,
- Review the habitat evaluation metrics to identify the fish habitat IFN.

The first step in the process was to prepare the flow files to be used in the time-series analysis. Starting from the natural flow, flow files were created with a constant five percent reduction from natural (i.e., 5%, 10%, 15% of natural, etc.).

For the second step, a threshold value, referred to as the Ecosystem Base Flow (EBF), was established. This was done to reduce the impact on habitat during naturally low-flow periods. The EBF is defined for each reach and is calculated on a weekly time-step (i.e., there is a different EBF value for each week). For certain times of the year, and for some reaches where site-specific data were not available, the Tessmann Method, adapted to a weekly time-step, was used to set the Ecosystem Base Flow (EBF).

The third step was to determine a range of flows on which to carry out the fish habitat time-series analysis. An upper limit (or threshold for flow) was set, beyond which the use of the fish habitat data becomes questionable. During the spring freshet for example, ecosystem tools, such as data on riparian vegetation and channel structure processes, are more suitable than WUA curves for fish.. Within the year, weeks with median flows beyond the evaluation range of a WUA curve were removed from the analysis.

The fourth step was to carry out standard habitat time-series analyses. Only habitat during the open-water season, defined as the period from the beginning of April to the end of October, was evaluated.

The fifth and final step for the fish-habitat component was to review the results using three evaluation metrics: the change in total average habitat (chronic), the maximum weekly loss in average habitat (intermediate chronic), and the maximum instantaneous habitat loss (acute). For these metrics, three specific habitat loss thresholds were defined:

- a 10% loss from natural in average habitat;
- a 15% maximum weekly loss from natural of average habitat; and
- a 25% maximum instantaneous habitat loss from natural.

The greatest flow reduction from natural that did not exceed any one of the three thresholds was chosen as the flow recommendation. The reduction in flow from natural throughout the 27 reaches varied from 15 to 55%.

Water Quality

Water quality variables include nutrients, major ions, metals, pesticides and bacteria. In most cases, these variables are best managed by source control, rather than by dilution and bio-assimilation. Water quality instream flows focus on water temperature and concentration of dissolved oxygen and ammonia because they are amenable to management by flow regulation. These are also critical water quality variables for fisheries protection in southern Alberta rivers.

High water temperatures have a negative effect on fish metabolism and can cause fish mortality. The acute temperature for most sport fish in Alberta is between 22 and 29°C. The seven-day chronic value is between 18 and 24°C. Instream flows were determined to prevent the occurrence of acute or chronic high temperature incidents from exceeding their natural frequency.

Oxygen becomes less soluble as water temperature increases, causing a reduction in dissolved oxygen (DO) levels. The Alberta guideline for dissolved oxygen for the protection of fish is 5 mg/L for acute occurrences. A seven-day average DO concentration of 6.5 mg/L is set for protection against chronic deficits. Instream flows that would prevent the occurrence of acute or chronic DO deficits from exceeding their natural frequency were determined.

Instream flows that dilute waste discharges and allow for biological breakdown of organic wastes are required to protect the aquatic environment. These waste assimilation flows are calculated to ensure that dissolved oxygen and ammonia levels remain within provincial guidelines for the protection of aquatic life. River flows for waste assimilation are a consumptive use of our waterways because such use limits the volume of water that can be applied to other purposes. The need for these flows are greatest downstream of municipal wastewater treatment plant outfalls.

Scouring flows are an important element of water-quality based instream needs. These are the high flows that typically occur in late spring and early summer due to snowmelt. The scouring or flushing flows dislodge organic-laden sediments that accumulate on and within the riverbed and carry them downstream. This action reduces existing aquatic vegetation and impedes the establishment of new plants. Removing the accumulating sediments and aquatic vegetation limits the oxygen demand that would otherwise occur in the river. High oxygen demand lowers dissolved oxygen levels and can contribute to fish kills. Scouring flows are not specified within the water quality component of the integrated IFN. The scouring flows determined within other components, such as the riparian and channel maintenance IFN, fulfill this need.

The water-quality based IFN determination is presented as a series of weekly exceedence curves for the critical summer and winter low flow periods in most reaches in the project study area. Where possible, IFN values were determined for all four seasons.

Riparian Vegetation

The instream flow recommendations for riparian poplars are designed to provide the full range of flows required to help preserve and restore riparian forest ecosystems in the South Saskatchewan River Basin. The calculated instream flows are expected to sustain the health of existing trees in a condition comparable to that expected under natural conditions, and to maintain the frequency of seedling recruitment events to sustain the long-term viability of the riparian forest.

The determination of poplar instream flow needs addresses the pattern of flow required to meet the varied moisture requirements of the poplars during the growing season. The natural degree of streamflow variability was incorporated in the design of flow regimes for sustaining riparian cottonwoods and the fluvial processes they depend on. Riparian poplar IFNs were based on the exceedence curves of naturalized flows and were defined by a composite of three weekly time-step exceedence-based curves and bankfull discharge.

The first limit defined by the Poplar Rule Curve (PRC) sets the minimum streamflow required for long-term cottonwood survival and maintenance as the 90% exceedence flow. Lower flows will occur naturally, but cottonwoods should be able to tolerate acute level events, provided the frequency and magnitude of these events is not increased beyond natural flows. Thus, natural flows that are less than the 90% exceedence flow are not altered. Natural flows that are greater than the 90% exceedence flow are not reduced below the 90% exceedence flow level. Moderate to high PRC flows are defined by the greater of either 65% of naturalized flow or the flow that corresponds to a 50% increase in the return interval (RI). These two values bridge the minimum flow requirements for cottonwood survival to the higher flows needed for seedling establishment.

The maximum flow required to meet IFN for cottonwoods has been set at 125% of bankfull discharge. This includes flows critical for continuing the sediment transport processes necessary to create nursery sites essential for poplar seedling establishment.

The determination of poplar instream needs can be simplified into four rules. These rules dictate that:

- there be no reductions to flows with natural exceedences of 90% or greater;
- flows above the 90% exceedence flow not be reduced below the 90% exceedence level;
- reduction of up to 35% of the natural flow is acceptable provided the resulting RI shift is not greater than 50%; and
- the highest flows maybe reduced to 125% of bankfull.

A complete IFN recommendation for riparian poplars is composed of a series of natural weekly exceedence curves adjusted according to the decision criteria described above for the poplar-growing season.

Comparisons between calculated PRC flows and actual flow regimes along selected test reaches in the South Saskatchewan River Basin support the validity of the PRC for sustaining riparian cottonwood populations. A detailed validation of the PRC was completed through the assessment of each of the five decision criteria that form the basis of the final PRC. The only part of the PRC that could not be adequately evaluated based on comparisons with test reaches is the reduction of peak flows that exceed 125% bankfull. This is because none of the flow regimes along the test reaches have been modified in this way.

Trends observed along the test reaches show only minor revisions could be made to any of the criteria used in calculating the overall PRC without initiating changes in riparian vegetation communities.

Channel Maintenance

Channel maintenance flows cover the range of flows commonly referred to as flushing flows, bed mobilization flows, channel structure flows, or channel forming flows. Although the importance of these flows to the aquatic ecosystem is well understood, methods to describe these flows in the context of developing IFN determinations are only just emerging. As with most IFN methods, detailed data are required, along with the use of predictive models. The Technical Team reviewed several well-documented sediment transport models that can be used to determine channel maintenance flows. As expected, it was found that most of these methods are data intensive. Because no new data was collected for this study, such methods could not be used.

Channel maintenance flow recommendations were developed using an incipient motion method based on the Shields entrainment function. This incorporates sediment grain size and channel slope in the estimation of flushing and bed mobilization flows. The Shields Equation predicts a flow magnitude needed to initiate transport of the channel bed material and, as a long-term consequence, to sustain the natural configuration of the channel. It does not stipulate the timing or duration of the needed flow. It was therefore not possible to generate IFN values in a duration curve format for channel maintenance, as was done for riparian vegetation, fish habitat and water quality. Instead, following integration of the other three components, a comparative analysis was done to ensure the IFN determinations were adequate to provide the necessary flows for channel maintenance.

The channel maintenance flow recommendations are, at best, preliminary. More work is necessary to understand the changes in sediment regime that may occur, before any decisions are contemplated regarding implementation of these flows. It is possible that changes to the current high flow regime could have unexpected effects on the present channel structure.

One Ecosystem IFN Determination from Four Riverine Components

There is widespread acceptance by IFN practitioners of the need to consider all elements of the aquatic ecosystem in defining instream flow needs. However, there is no broadly accepted method for combining the different ecosystem components to develop an integrated flow recommendation. For this study, the Technical Team developed a method to integrate the four ecosystem-component IFNs into a flow duration curve format using a weekly time-step.

For the most part, water quality IFN determinations are provided as a single value for each week of the year for each reach. The fish habitat IFN determination is a variable flow curve applied seasonally for each week in the open-water season, excluding the spring freshet. Fish habitat data are not available for the winter weeks; therefore values were derived using the Tessmann method. The riparian IFN determination is also a variable flow curve and is applied only during the growing season in the spring and summer. The channel maintenance IFN determination was not readily incorporated into a weekly duration format. Instead, a check was conducted to ensure the IFN determination at the higher discharges was adequate to provide the necessary flows to maintain channel configuration and processes.

The integrated IFN is determined by comparing the IFN value for each of three components, on a week-by-week basis, for every data point in the period of record. Usually, but not always, there is some overlap among the components. When this occurs, the component with the highest flow requirement becomes the primary determinant of the integrated, or ecosystem, IFN. Situations arise where all three IFN components are not represented. In these cases, the component with the highest flow requirement is still used to define the integrated IFN. If IFNs are only available for one component, the integrated IFN is based solely on that component, for that reach, in that week.

Both the fish habitat and riparian IFN determinations identified a base flow below which no reduction in flow is recommended. In situations when the natural flow is below the base flow determination, the final integrated ecosystem IFN will usually be the same as the natural flow. The exception to this rule occurs when augmented flows are required to meet the water quality IFN determination, based on the current loadings in the system. In determining the water quality IFN, it is considered unrealistic to factor out current loadings from various sources.

For this study, all IFN determinations were made on a reach-by-reach basis. Ensuring the IFN determinations increase incrementally from upstream to downstream (reach balancing) is a task that needs to be done. This is a necessary refinement step normally completed during the running of the water balance model.

It is the opinion of the Technical Team that the instream flow needs determinations contained in this report represent an improvement compared with earlier IFN analyses. This is due to a number of reasons:

- The ecosystem IFN is comprised of four riverine components, water quality, fish habitat, riparian vegetation and channel maintenance. These address a broad range of natural flows in terms of magnitude, frequency and duration.
- The inter-annual and intra-annual flow variability of the IFN better incorporates the pattern of natural flow variations in a consistent manner for every week.
- There have been improvements to the determination of IFN requirements for each of the individual IFN components.
- The current IFN has a comprehensive EBF, defined for every week.

As is the case with any instream flow needs study, there is uncertainty. However, in the absence of data, assumptions must be made. The Technical Team reduced the uncertainty as much as possible and in those instances where arbitrary decisions had to be made, the decisions were documented and made through consensus of the Technical Team.

The IFN determination contained in this report is based on the best available knowledge at the time of publication. However, predictive models are inherently uncertain. Regardless of future flow management decisions, it is highly recommended that an adaptive environmental assessment and management program be established to validate the predictions of the models used.