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Determining Environmental Flows for the South Saskatchewan River Basin, Alberta, Canada

C. W. Koning,[1] A.G.H. Locke,[2] J.M. Mahoney[3]

[1] Alberta Environment, 2938 – 11 St NE, Calgary, AB, Canada T2E 7L7, wendell.koning@gov.ab.ca
[2] Alberta Sustainable Resource Development, 213 – 1 St W, Cochrane, AB
Canada T0L 0W0, allan.locke@gov.ab.ca
[3]Alberta Environment, 200 – 5 Ave S, Lethbridge, AB, Canada T1J 4L1, john.mahoney@gov.ab.ca

Abstract

The Province of Alberta, Canada recently introduced a Water Management Policy for the South Saskatchewan River Basin that called for determination of the maximum amount of water that can be allocated for irrigation and other uses in the various sub-basins of the South Saskatchewan River. Part of this process required determining the environmental flows (also called instream flow needs) according to the stated objective which was for the full protection of the aquatic environment. Environmental flow determinations were developed to reflect the seasonal pattern and general changes in magnitude, frequency, timing and duration of the natural flow hydrograph both within a year and between years. The intent was to provide flow values based on the ecological need for natural flow variation. To meet these expectations, four ecosystem components were chosen to represent the full extent of the aquatic ecosystem: water quality, fish habitat, riparian vegetation, and channel maintenance. The environmental flow values for each of the individual components were integrated to produce an ecosystem based value. The final flow values were generated for 27 reaches in the SSRB using a weekly time-step in a flow duration curve format (in total, 1404 discreet flow determinations).

Keywords

Environmental; instream; flows; fish; riparian; channel; water quality

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I. Introduction

Environmental flows (EFs) are river flows critical to maintain the aquatic health of a river. Also called "instream flow needs" (IFN), environmental flows maintain the healthy, diverse aquatic communities that would naturally be found in a specific watercourse. There is great interest in the determination of EFs because these flows frequently compete with the water volumes allocated to anthropogenic uses such as agriculture, industry, and domestic consumption. Increasingly, competing demands are threatening our willingness to maintain minimum environmental flows.

Traditionally, environmental flows have been based on single ecosystem needs such as fish habitat or water quality parameters. The case has been made that a single minimum flow determination does not result in the long-term maintenance of the resource that the minimum flow recommendation was intended to protect (Stalnaker 1994, Annear et al. 2004). Annear et al. (2004) conducted a detailed review of the most common methods for developing instream needs by EF (IFN) practitioners from across the United States and Canada and concluded that the predominance of single-flow recommendations has not succeeded in protecting the integrity of aquatic ecosystems. Annear et al. (2002) suggest that five interrelated riverine components should be considered in the setting of aquatic ecosystem objectives: hydrology, geomorphology, biology, water quality, and connectivity.

The natural variability of flows, both seasonally and from year to year, have shaped aquatic ecosystems over many thousands of years. The species associated with these dynamic systems have adapted to take advantage of this functional diversity (e.g. cottonwood tree recruitment, Mahoney and Rood 1998). The concept of basing an environmental flow determination on the ecological need for natural flow variation is commonly referred to as the "natural flow paradigm" (Poff et al. 1997; Annear et al. 2004; Richter et al. 1997). Although the acceptance of these ecological principles is wide spread and can be supported by a large body of knowledge (Poff et al. 1997), incorporating these ecosystem principles into river management practice is a difficult challenge (Richter et al. 1997).

The Province of Alberta recently introduced a Water Management Policy for the South Saskatchewan River Basin (SSRB). The South Saskatchewan River Basin is located in western Canada, originating in the eastern slopes of the Canadian Rockies and covering approximately 120 000 square kilometers in Alberta. The three major rivers are the Red Deer, Bow and Oldman rivers. Approximately 75 percent of the annual discharge originates from snow melt in the mountains, with 60 per cent of the flows occurring between early May and mid-July. Flows vary widely from year to year, and can range from as high as 3000 cubic meters per second, to less than 10 cubic meters per second at the confluence of the South Saskatchewan and Red Deer rivers.

The Water Management Policy called for determination of the maximum amount of water that can be allocated for irrigation-based agriculture and other uses in the Red Deer, Bow, Oldman, and South Saskatchewan River sub-basins. Part of this process required the determination of environmental flows for each mainstem reach. Our goal was to develop an EF determination that ensured a high level of protection for the aquatic ecosystem. The approach we developed was based on the premise that an EF determination should reflect the general changes in magnitude, frequency, timing and duration of the natural flow pattern both within a year and between years.

II. Methods

A holistic approach was taken to preserve the processes and functions of the river ecosystem. Four ecosystem components were selected to represent the full extent of the aquatic ecosystem: water quality, fish habitat, riparian vegetation, and channel structure. Flow recommendations were prepared for 27 mainstem reaches in the study area for each ecosystem component. The recommendations were based on weekly time- step flow duration curves (exceedance curves) of the 1912 – 1995 naturalized flow record in the SSRB. A weekly time step was deemed suitable from each of a biological, hydrological and water planning and modelling perspective (Fig 1).

A. Fish habitat

The fish habitat EF component determination is based on site-specific data and habitat modelling using the PHABSIM (**P**hysical **HAB**itat **SIM**ulation) group of models. Fish habitat variables used were stream velocity, depth and substrate type.

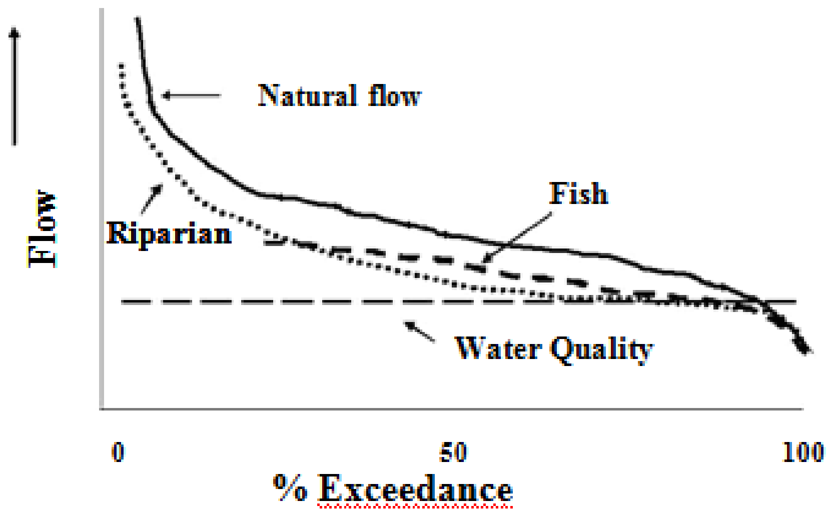


Figure 1. A sample weekly flow exceedance curve with riparian, fish and water quality flow needs identified.

The fish habitat EF determination process consisted of five basics steps:

1. Develop a series of constant percent flow reductions from the natural flow in 5% increments,
2. Calculate the Ecosystem Base Flow,
3. Identify the flow range to conduct habitat time series analyses using site-specific Weighted Usable Area (WUA) curves as the assessment criteria,
4. Conduct habitat time series analyses for the natural flow and each constant percent flow reduction with the added constraint of the ecosystem base flow,
5. Review the habitat evaluation metrics to identify the fish habitat EF, and
6. Only habitat during the open water season, defined as the period from the beginning of April to the end of October, was evaluated.

Three evaluation metrics formed the basis of acceptance of the fish habitat flow recommendation: 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, specific and acceptable habitat loss thresholds were defined as:

- a 10% loss in average habitat from natural,
- a 15% maximum weekly loss of average habitat from natural, 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 results throughout the 27 reaches varied ranging from a 15 to 55% reduction in flow from natural. For certain times of the year and for some reaches where site-specific data was not available, the Tessmann Method (Tessmann 1979) adapted to a weekly time-step was used to set the Ecosystem Base Flow.

B. Riparian Vegetation

EFs were developed for riparian poplar trees (*Populus* Sp.) native to the SSRB. They were designed to provide the full range of flows required to both support the health of existing trees in a condition comparable to that expected under natural conditions; and to maintain the frequency of seedling recruitment events so that the long term viability of the riparian forest is sustained.

The determination of poplar instream flow needs addresses the pattern of flow required to provide moisture for poplars during the growing season. The natural degree of streamflow variability was incorporated to sustaining the channel processes that poplars depend on for recruitment events. Riparian poplar EFs were based on the exceedance curves of naturalized flows and are defined by a composite of three weekly time step exceedance-based curves and bankfull discharge.

The determination of poplar instream needs was based on four rules. These rules dictate; 1) there be no reductions to flows with natural exceedances of 90% or greater, 2) flows above the 90% exceedance flow may not be reduced below the 90% exceedance level, 3) reduction of up to 35% of the natural flow is acceptable provided that the resulting RI (return interval) shift is not greater than 50%, and 4) the highest flows may be reduced to 125% of bankfull.

C. Channel structure

Channel structure flows cover the range of flows that have been commonly referred to as flushing flows, channel maintenance flows, or valley maintenance and forming flows. Although the importance of these flows is well understood, the method of implementing them for EF determinations is only just emerging. There are several sediment transport models that can be used to determine channel structure flows. Most of these methods are data intensive beyond the extent of data available for the present work.

Channel structure flow recommendations were developed using an incipient motion method based on the Shields entrainment function that incorporates sediment grain size and channel slope in the estimation of flushing flows (Shields 1936). The Shields Equation generates a flow magnitude needed to generate transport of the channel bed material and 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 EF values in a duration curve format for channel structure. Instead, a comparative analysis was done to ensure the EF determinations based on the riparian vegetation needs at the higher discharges were adequate to provide the frequency and duration of flows for channel maintenance. The channel structure flow recommendations are preliminary.

D. Water quality

Water quality instream flows focused on water temperature, and concentration of dissolved oxygen and ammonia because these three variables are amenable to management by flow regulation. These variables 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 were determined to prevent the occurrence of acute or chronic DO deficits from exceeding their natural frequency.

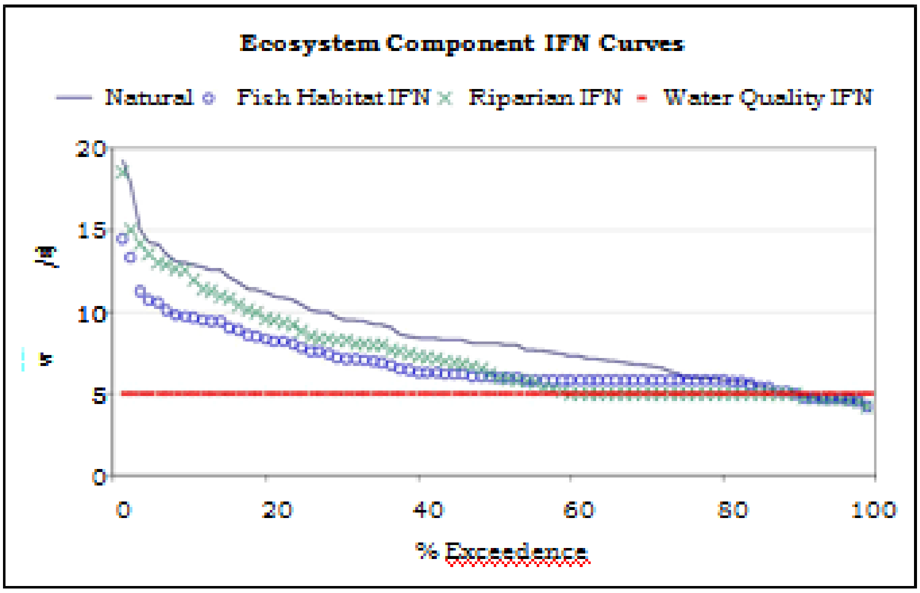
Scouring flows are the high flows that typically occur in late spring and early summer due to snowmelt. The scouring or flushing flows dislodge organic-laden sediments that accumulate on and within the riverbed and carry them downstream. This action reduces existing aquatic vegetation and impedes the establishment of new plants. Removing the accumulating sediments and aquatic vegetation limits the oxygen demand that would otherwise be produced. 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 EF. The scouring flows determined within other components, such as the riparian EF, fulfill this need.

E. Making One Ecosystem EF Determination Using the Four Riverine Components

The four ecosystem component EFs were integrated into a flow duration curve format. For the most part, water quality EF determinations are provided as a single value for each week of the year for each reach. The fish habitat EF determination is a variable flow curve that is applied seasonally for each week in the open water season excluding the spring freshet. Fish habitat data is not available for the winter weeks, and therefore values were derived using the Tessmann method (Tessman, 1979). The riparian EF determination is also a variable flow curve applied only during the growing season in the spring and summer. The channel structure EF determination was not readily incorporated into a weekly duration format. Instead, a check was conducted to ensure the EF determination at the higher discharges was adequate to also provide the necessary flows for channel maintenance.

The integrated EF is determined by comparing the EF 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 amongst the components. When this occurs, the component with the highest flow requirement becomes the primary determinant of the integrated, EF. Situations arose where not all three EF components are represented. In these cases the component with the highest flow requirement was still used to define the integrated EF. If EFs are only available for one component, the integrated EF is based solely on that component.

The integrated flows are then sorted into weekly flow duration curves. In the simplest case, when all ecosystem components had EF numbers available, the ecosystem component with the highest flow requirement defines the integrated EF at that point (Figure 2).



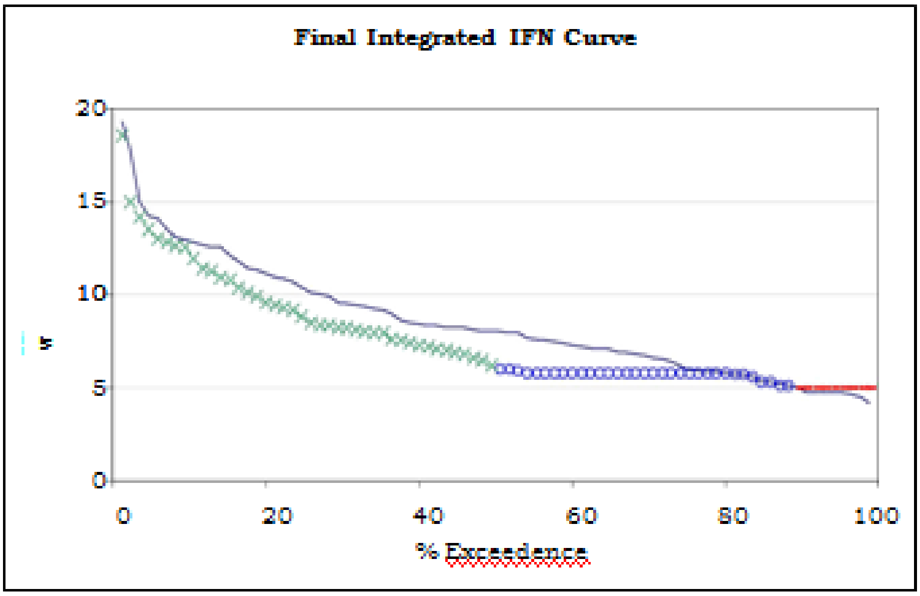


Fig. 2. Illustration of how each ecosystem component was integrated into the final ecosystem EF (IFN) curve for Week 33 on the Belly River (a tributary to the Oldman River) near Standoff.

III. Results and conclusions

A typical annual hydrograph showing the timing of each of the ecosystem components and the resulting integrated ecosystem EF is illustrated in Figure 3. It can be seen in Figure 3 that the ecosystem component EF determinations have a seasonal distribution as well as a flow magnitude distribution as was illustrated in Figure 2.

A total of 1 404 discreet EF values were generated for 27 reaches in the SSRB using a weekly time-step in a flow duration curve format (Fig 2). Although not every aspect of every component of the aquatic ecosystem was addressed in the evaluation, the information used in this process is comprehensive by today's standards. The ecosystem EF is comprised of four riverine components that address a broad range of natural flows in terms of magnitude, frequency and duration. The inter-annual and intra-annual flow variability of the EF incorporated the pattern of natural flow variations in a consistent manner for every week.

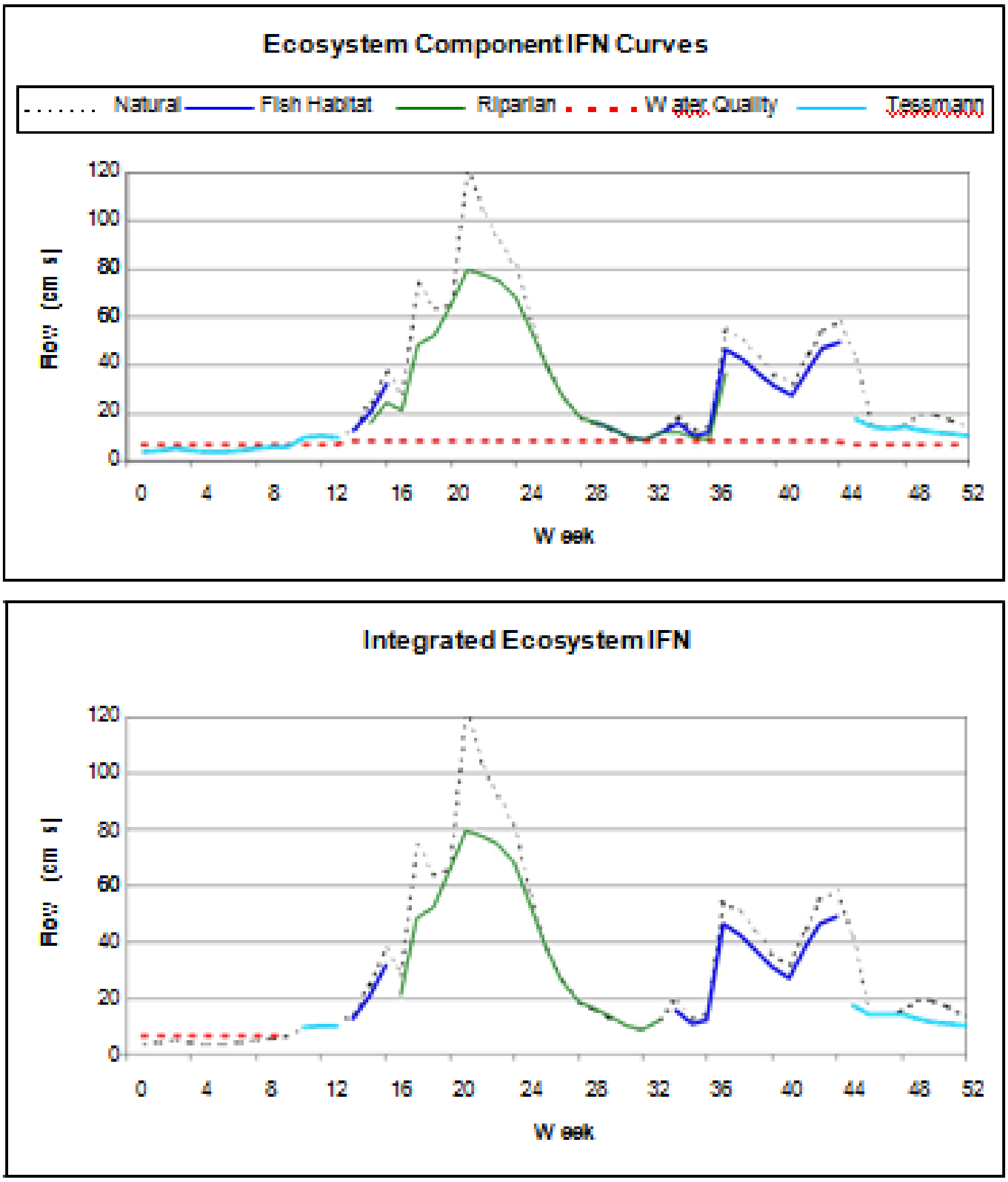


Fig. 3. Illustration of the seasonality of each ecosystem component (top graph) for 1985, a drier than average water year (based on the mean annual flow) and the resulting integrated ecosystem EF (IFN) (bottom graph). The Oldman River near Monarch

An ongoing challenge is to evaluate the aquatic impact of river flows that are less than the recommended EF. In general, flow values that are lower than the EF determinations, will likely result in the ecosystem not being protected over the long term. The ecosystem will not be able to provide all of the natural functions and services that it used to, over time. The further below the actual flow regime is from the EF recommendation, the greater the risk the ecosystem will not be protected compared to a flow regime that is closer to the EF recommendation.

A preliminary estimate of the impacts of actual flows being well below the identified EF was made based on model output and professional judgment. For the Red Deer River, one of the major tributaries in the SSRB, flows in the future will be reduced to approximately 50% of natural flow (due to abstraction for human uses). This is well below our EF determinations, and therefore we estimate significant negative impacts to the fish, cottonwood trees and associated communities. Future work is required to define impacts of flows less than the determined EF.

References

Annear, T., I. Chisholm, H. Beecher, A. Locke, and 12 other authors. 2004. Instream Flows for Riverine Resource Stewardship, revised edition. Instream Flow Council, Cheyenne, WY.

Koning, CW, K.A. Saffran, J.L. Little and L. Fent. 2006. Water Quality Monitoring: the Basis for Watershed Management in the Oldman River Basin, Canada. Water, Science and Technology 53(10) 153-161.

Mahoney, J.M. and S.B. Rood 1998. Streamflow requirements for cottonwood seedling recruitment: an integrative model. Wetlands 8(4):634-645.

Poff, N.L., J.D. Allan, M.B. Bain, J.R. Karr, K.L. Pretegaard, B.D. Richter, R.E. Sparks and J.C. Stromberg. 1997. The natural flow regime: a paradigm for river conservation and restoration. BioScience 47(11):769-784. http://lamar.colostate.edu/~poff/natflow.html

Richter, B.D., J.V. Baumgartner, R. Wigington and D.P. Braun. 1997. How much water does a river need? Freshwater Biology 37: 231-249.

Shields, A. 1936. Application of similarity principles and turbulence research to bed-load movement. Mitteilungen der preussischen Versuchsanstalt fur Wassen brau und Schiffbaur. W.P. Ott and J.C. Unchelen (trans.), California Institute of Technology, Pasadena. Rep. No. 167.

Stalnaker, C.B. 1994. Evolution of instream flow modelling. Pages 276-286 in P. Calow and G.E. Petts, editors. River Handbook. Volume II. Blackwell Scientific Publications, Oxford.

Tennant, D.L. 1976. Instream flow regimens for fish, wildlife, recreation, and related environmental resources. Fisheries 1(4):6-10.

Tessmann, S.A. 1979. Environmental assessment. *in:* Reconnaissance Elements of The Western Dakotas Region of South Dakota Study, Technical Appendix E. Water Resources Research Institute, South Dakota University.