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.

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1.0 INTRODUCTION

Water is a renewable resource, but it is also a finite resource that is approaching the limit of sustainable development internationally. Often, in situations with high water demand, all the competing demands cannot be met (UNCSD 1999). As greater volumes of water are diverted for human use, the effect on surface and groundwater systems increases, causing a reduction in the quality of the water supply. The necessity of maintaining the health of aquatic resources is increasing though as Postel (2000) states, the

> *"opportunities to protect and restore natural freshwater systems will be limited without a concerted effort to reduce human demands for water."*

Postel (2000) further suggests that with the current trends in global population growth and ecosystem declines, society will need to double its water productivity during the next three decades. That is, we will need to get twice as much value from each unit of water removed from a river, lake, or aquifer.

In the early 1990s the Province of Alberta introduced a Water Management Policy for the South Saskatchewan River Basin (Alberta Environment 1990). Within this initiative, the policy called for determination of the maximum amount of water that could be allocated for irrigation in the Red Deer, Bow, Oldman, and South Saskatchewan River sub-basins, considering the requirements for all other uses, including instream uses.

In the late 1990s, the South Saskatchewan River Basin Water Management Plan (SSRB WMP) was initiated under the new *Alberta Water Act*. A Steering Committee was struck, with representation from several Government of Alberta departments. The Steering Committee appointed the Instream Flow Needs Technical Team (referred to hereafter as the Technical Team) to develop instream flow needs (IFN) determinations for the mainstem reaches of the South Saskatchewan River Basin.

The SSRB WMP provides an opportunity to improve aquatic biodiversity conservation. It will bring new scientific and technical understanding of flow requirements for riverine ecosystems into the water management decision arena in Alberta.

Maintaining the ecological integrity and biodiversity of riverine ecosystems is dependent on preserving the dynamic qualities of the flow regime of a river. The approach adopted by the Technical Team for the development of instream flow recommendations is based on the premise that an IFN determination should emulate the seasonal pattern and general magnitude of the natural flow hydrograph of a given water year. That is, intra- and inter-annual variability of flow must be maintained. The intent is to provide an instream determination relative to the ecological basis of the natural flow regime or to accommodate the natural flow paradigm (see Poff et al. 1997 and Annear et al. 2002 for a detailed discussion).

As directed by the Steering Committee for the SSRB WMP, the IFN recommendations are based on the latest scientific understanding of riverine ecosystems. The intrinsic values of natural habitats and organisms of rivers can only be maintained by preserving the processes and functions of the river ecosystem. Management of one riverine component, such as instream habitat for a single or limited number of species in isolation is typically not effective, because each hydrologic component is in continuous interaction with the other components (Winter et al. 1998). Thus the Technical Team incorporated four ecosystem components, water quality, fish habitat, riparian vegetation, and channel maintenance, to address the full spectrum of flows that occur within the natural flow regime.

Bringing the latest scientific and technical understanding of the biological implications of water resource management into the decision-making arena facilitates the development of more sensitive and sophisticated policies for meeting human needs while preserving natural ecosystems. An iterative process of communication between instream flow practitioners and decision-makers is essential if we are to apply what we have learned from the results of past water resource management in a way that positively influences future water management decisions. As Poff et al. (1997) state,

> *"Just as rivers have been incrementally modified, they can be incrementally restored, with resulting improvements to many physical and biological processes."*

This report documents how the Technical Team developed an integrated aquatic ecosystem IFN based on fish habitat, water quality, riparian vegetation, and channel maintenance. The integrated IFN determination is presented in a format suitable for input to the SSRB WMP water-balancing model, the Water Resources Management Model.

2.0 SOUTH SASKATCHEWAN RIVER BASIN WATER MANAGEMENT PLAN

In 1990, the Province of Alberta announced the Water Management Policy for the South Saskatchewan River Basin (Alberta Environment 1990). The policy called for determination of the maximum amount of water that could be allocated for irrigation in the Red Deer, Bow and Oldman River basins, and the South Saskatchewan River sub-basin, with due consideration of the requirements for all other uses, including instream uses.

In 1991, Alberta Environment worked with the Alberta Water Resources Commission and Alberta Agriculture to establish the sizes and locations of irrigation expansion that could be supported by the available water supply in the South Saskatchewan River Basin. These agencies discussed the determination of the expansion limits with the Irrigation Council, irrigation districts, private irrigators, Members of the Legislative Assembly and government committees. The result of these efforts was the irrigation expansion guidelines implemented in Alberta Regulation (307/91).

A commitment to review the irrigation expansion guidelines was made in the Water Management Policy for the South Saskatchewan River Basin (Alberta Environment 1990). It was recognized that the information available for decision-making was limited, particularly with regard to the determination of instream flow needs. Consequently, the policy committed the government to a review of the irrigation expansion guidelines in the year 2000.

Adequate and reliable water supplies are also essential to municipal and industrial water users, and indeed, all water users in the South Saskatchewan River Basin. Consequently, the commitment to review irrigation expansion guidelines necessitates a comprehensive examination and assessment of the needs of all water uses within the basin. The review of irrigation expansion guidelines is occurring in the context of an overall review of water management in the basin, referred to hereafter as the South Saskatchewan River Basin Water Management Plan (SSRB WMP).

Alberta Environment (AENV) is the lead agency responsible for water management and setting the water allocation limit. AENV also owns and operates a system of headworks in Alberta. Alberta Agriculture, Food and Rural Development (AAFRD) is responsible for agricultural issues, including irrigation farming and water distribution systems within irrigation districts.

The SSRB WMP will be consistent with the requirements of the *Alberta Water Act.* As directed by the *Water Act,* a Framework for Water Management Planning was produced in 2001 (Alberta Environment 2001a). The framework includes a Strategy for the Protection of the Aquatic Environment and promotes the establishment of Water Conservation Objectives that are defined in Section 1(1)(iii) of the *Water Act* as the amount and quality of water necessary for the:

- protection of a natural water body and its aquatic environment, in whole or in part;
- protection of tourism and recreation, transportation, or waste assimilation uses of water; and
- management of fish and wildlife.

The *Water Act* also sets requirements for:

- public involvement;

- attention to cumulative environmental effects; and
- authorization for water transfers, including provisions for withholding up to 10% to protect the aquatic environment.

The process that will be followed for the SSRB WMP will be to review the limit on maximum water allocation for all water uses. Protecting the aquatic environment will be accomplished by:

- determining instream needs;
- identifying the amount of water potentially available for allocation, (including examination of risks to consumptive and instream uses);
- setting recommendations for Water Conservation Objectives (WCO); and
- determining the maximum amount of water available for allocation.

The SSRB WMP is guided by a Steering Committee with representation from Alberta Environment, Alberta Sustainable Resource Development and Alberta Agriculture, Food and Rural Development. The Steering Committee instructed the Technical Team to develop IFNs using existing information.

2.1 Instream Flow Needs Technical Team

The Steering Committee appointed the Instream Flow Needs Technical Team to prepare instream flow needs (IFN) values as input to the SSRB WMP. The objective of the Technical Team is:

> *"To develop science-based IFN determinations for the protection of the aquatic environment for the mainstem reaches within the SSRB. The IFN values to protect the aquatic environment are based on the integration of flows required to maintain water quality, fish habitat, riparian vegetation and channel maintenance."*

The goal of the Technical Team is to provide a flow determination that will vary with the season of year (intra-annually), and with the water supply (inter-annually). IFN values are generated for each reach on a weekly time-step in a duration curve format. A weekly time-step is appropriate for an ecosystem-based IFN because a monthly time-step is too coarse and would not account for some of the seasonal biological issues to be addressed. A daily time-step is too detailed and unnecessarily large for the current planning level study. The weekly duration format of the IFN is also compatible with the format required for the Water Resources Management Model (WRMM) that will be used during the SSRB WMP process.

The aquatic environment is vastly complex and determining an IFN for every potential component would be enormously difficult. For the SSRB WMP, the Technical Team used surrogate measures to represent the aquatic environment: water quality, fish habitat, riparian vegetation, and channel maintenance processes. The water quality IFN is based on flows required to protect against high instream temperatures and occasionally, high ammonia levels, and to ensure minimum dissolved oxygen values for the protection of fish species are maintained. The fish habitat IFN is based on flows required to protect physical fish habitat. The riparian IFN is based on flows required to sustain the growth and recruitment processes of poplar forests. The channel maintenance IFN is based on flows that would ensure substrate flushing and channel forming processes continue. Although the methods for determining instream flow needs for each of these components are described separately in this report, all components must be considered in the context of the other components. Each ecosystem component is interconnected with the other ecosystem components. In isolation, one component cannot protect the aquatic ecosystem in and of itself.

2.2 Purpose of the SSRB IFN Report

This report provides instream flow needs recommendations to the SSRB WMP Steering Committee designed to protect the aquatic ecosystem. The report:

- Provides an overview of the aquatic ecosystem resources in the SSRB.
- Presents the current scientific knowledge of the flows necessary to protect the aquatic ecosystem by recognizing the interconnectivity of different ecosystem components.
- Outlines the specific methods used by the Technical Team to develop an IFN determination for each riverine component: channel maintenance, riparian vegetation, fish habitat, and water quality.
- Describes the method used to integrate the various ecosystem components into a single IFN determination for the protection of the aquatic ecosystem.
- Provides the ecosystem IFN determination flows for each reach, on a weekly time-step based on the 1912 - 1995 flow record provided by Alberta Environment (2001b).
- Concludes that, with an accompanying adaptive management approach to managing flows, an ecosystem-based IFN determination will provide for the protection or restoration of riverine resources in the SSRB.

Fundamentally, the approach taken acknowledges that fish, wildlife, and riparian vegetation communities evolved and adapted to the fluvial processes and habitat characteristics of the pre-disturbance rivers within the South Saskatchewan River Basin. Protecting, maintaining or restoring the aquatic ecosystem must be founded on rehabilitating and managing fluvial processes that create and maintain habitat vital to fish, wildlife, and riparian species.

The Technical Team was assigned the task of determining the flow regime needed to provide protection for the aquatic ecosystem. However, the Technical Team also recognizes that historic land use and water management practices have altered the current landscape. Although the existing condition must be considered in deciding the potential for ecosystem restoration, determining a restoration strategy with due consideration of the current social, legal and structural limitations is beyond the scope of the Technical Team mandate at this stage. The Technical Team provides a recommendation that incorporates the natural variability of flow that would have occurred, without the water management and land-use practices currently in place.

Regardless of flow management decisions, it should be mandatory to validate the predictions of the models used in this report. Any major change in current water management, as a result of implementing the IFN determinations, will require additional investigation to evaluate the impacts on the existing channel regime, aquatic biota, and the potential for flood-related property damage.

3.0 OVERVIEW OF THE SSRB AQUATIC RESOURCES

Detailed descriptions of the aquatic resources of the major river sub-basins within the SSRB are available elsewhere (Brayshaw 1965, Kellerhals et al. 1972, Longmore and Stenton 1981, Shaw and Kellerhals 1982, Environmental Management Associates [EMA] 1983, Fernet and Matkowski 1986, Martin J Paetz Enterprises 1986, Rood et al. 1986, EMA 1989, Alberta Environmental Protection 1996, R.L. & L. 1996, R.L. & L. 1997). The complete Fisheries Management Objectives for the SSRB are included in Appendix A. Details of existing water management within the SSRB are also provided in more detail elsewhere (Alberta Environment 1984, BRWQTF 1991, BRWQTF 1994, Alberta Environment 2001a, Alberta Environment 2002). The following section provides an overview of water management and the aquatic ecosystems within the study area of the SSRB WMP.

3.1 Study Area

There are large onstream water management structures on each of the major tributaries within the SSRB (Figure 3.1). For the purpose of the SSRB WMP, instream needs were defined for reaches downstream of these structures. The study area included reaches on the Red Deer River downstream of the Dickson Dam, the Bow River downstream of the Western Irrigation District (WID) 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 (Figure 3.2).

The Technical Team, in consultation with Alberta Environment flow modelling staff, defined river reaches to be used for the SSRB evaluation. Reach boundaries had been set for existing fish habitat IFN studies, water quality studies, channel maintenance studies, and the Water Resources Management Model (WRMM). The Technical Team concluded it was critical to use a single set of reach boundaries for the development of integrated instream flows. Modifications were made to the original sets of reach boundaries to best accommodate every component without sacrificing detail. Each reach was then assigned either a single Water Survey of Canada (WSC) gauging station, a pair of WSC stations to be added together, or a calculated flow file provided by AENV (2001b) to provide the hydrologic data for conducting the IFN evaluations. Members of the Technical Team, in consultation with Alberta Environment flow modelling staff, selected representative gauging stations for each reach. The naturalized and recorded flow data were obtained from Alberta Environment (2001b). The reach boundary descriptions and associated hydrological data source are presented in Tables 3.1 through 3.5.

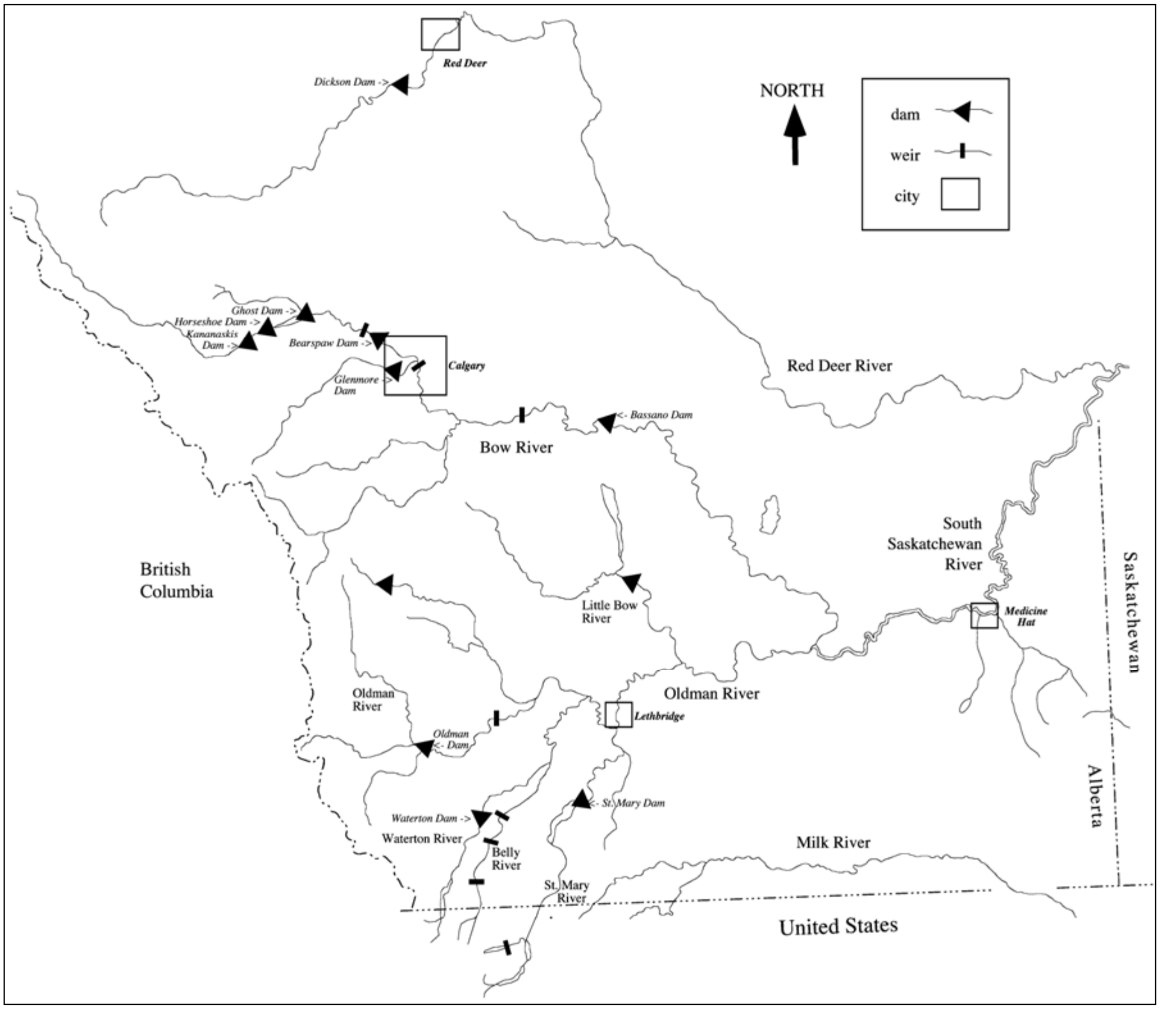


Figure 3.1. Major flow regulating structures on the mainstem reaches of the Red Deer, Bow, Oldman, St. Mary, Belly, and Waterton Rivers (after Gom and Mahoney 2002).

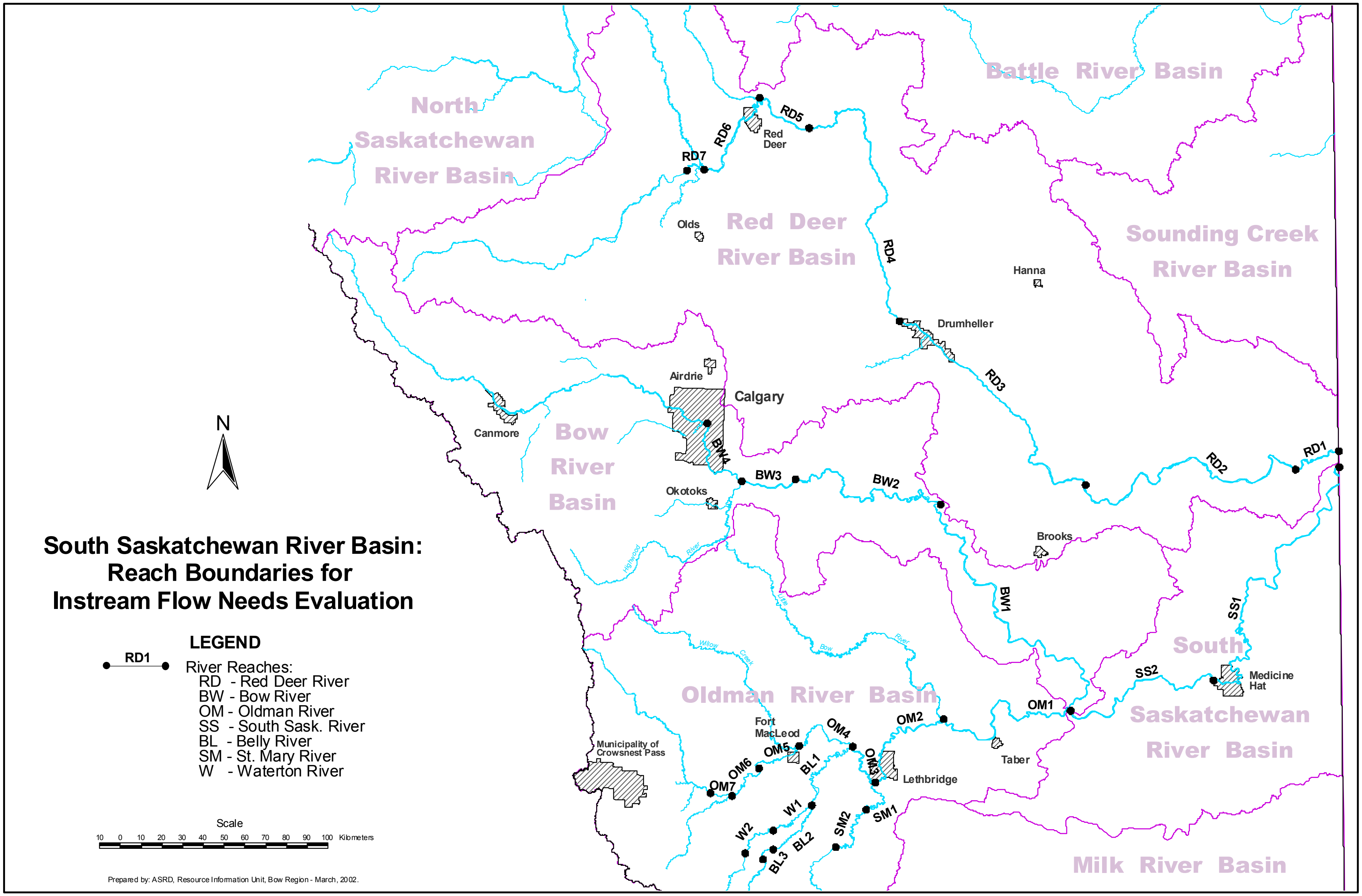


Figure 3.2. Location of the IFN reach boundaries for the Red Deer (RD), Bow (BW), Oldman (OM), St. Mary (SM), Belly (BL), Waterton (W) and South Saskatchewan (SS) Rivers.

Table 3.1. Red Deer River reach boundaries and gauging stations.

*Note: * indicates flow file was generated by AENV (2001b) and is not at a WSC gauge location.*

Reach Boundaries	Reach Code	WSC Gauge	Location
Saskatchewan/Alberta border upstream to Bindloss gauging station	RD1	05CK004	Near Bindloss
Bindloss upstream to the western boundary of Dinosaur Provincial Park	RD2	GRDJEN*	Near Jenner
Dinosaur Provincial Park upstream to the western boundary of Drumheller	RD3	05CE001	Near Drumheller
Drumheller upstream to the SAWSP diversion site	RD4	GRDBIG*	Near Big Valley
SAWSP diversion upstream to the Blindman River confluence	RD5	05CD004	Near Nevis
Blindman River confluence upstream to the Medicine River confluence	RD6	05CC002	Near Red Deer
Medicine River confluence upstream to the Dickson Dam	RD7	05CB007	Dickson Dam

Table 3.2. Bow River reach boundaries and gauging stations.

Reach Boundaries	Reach Code	WSC Gauge	Location
Grand Forks upstream to the Bassano Dam	BW1	05BM004	Below Bassano Dam
Bassano Dam upstream to the Carseland weir	BW2	05BM002	Below Carseland weir
Carseland weir upstream to the Highwood River confluence	BW3	05BM002	Below Carseland weir
Highwood River confluence upstream to the WID weir	BW4	GBOWID*	Below WID weir

Table 3.3. South Saskatchewan River reach boundaries and gauging stations.

Reach Boundaries	Reach Code	WSC Gauge	Location
Saskatchewan/Alberta border upstream to Medicine Hat	SS1	05AK001	Near Hwy 41
Medicine Hat upstream to the Grand Forks	SS2	05AJ001	Medicine Hat

Table 3.4. Oldman River reach boundaries and gauging stations.

*Note: * indicates flow file was generated by AENV (2001b) and is not at a WSC gauge location.*

Reach Boundaries	Reach Code	WSC Gauge	Location
Grand Forks upstream to the Little Bow River confluence	OM1	05AG006	Near Mouth
Little Bow River confluence upstream to the St. Mary River confluence	OM2	05AD007	Near Lethbridge
St. Mary River confluence upstream to the Belly River confluence	OM3	05AD019 + GBEMOU*	Monarch + Belly River
Belly River confluence upstream to the Willow Creek confluence	OM4	05AD019	Near Monarch
Willow Creek confluence upstream to the LNID weir	OM5	05AB007	Near Ft. MacLeod
LNID weir upstream to the Pincher Creek confluence	OM6	05AA024 + 05AA004	Brocket + Pincher Cr.
Pincher Creek confluence upstream to the Oldman Dam	OM7	05AA024	Near Brocket

Table 3.5. Belly, St. Mary and Waterton river reach boundaries and gauging stations.

Reach Boundaries	Reach Code	WSC Gauge	Location
Belly River			
Confluence with the Oldman River upstream to the Waterton River confluence	BL1	GBWCON*	Waterton River confluence
Waterton River confluence upstream to a point 5km downstream of St. Mary canal	BL2	05AD002	Near Standoff
5km downstream of the canal upstream to the St. Mary Canal	BL3	05AD041	Near Glenwood
St. Mary River			
Confluence with the Oldman River to 37km upstream	SM1	05AE006	Near Lethbridge
37km upstream of the Oldman River upstream to the St. Mary River Dam	SM2	GSTDAM*	St. Mary River Dam
Waterton River			
Confluence with the Belly River upstream to 25km downstream of the Waterton Reservoir	W1	05AD008	Near Standoff
25km downstream of the reservoir upstream to the Waterton Reservoir	W2	05AD026	Waterton Reservoir

3.2 Background of Water Management in the SSRB

Irrigation, hydroelectric power generation, industrial water uses, and municipal uses are the main uses of water that can alter the flow regime within the SSRB system. Irrigation is the largest consumer of water in the SSRB, accounting for more than 90% of the total allocated water in the Bow and Oldman systems and 25% in the Red Deer system.

Withdrawals for irrigation include water licensed to irrigation districts and to private irrigators, including First Nations' irrigation projects. There are 13 irrigation districts in the SSRB, the largest being the St. Mary River, Eastern, Bow River, Lethbridge Northern, and Western Irrigation Districts. These districts provide water to more than 450,000 hectares of farmland. At present, the amount of land that can be irrigated is limited by Alberta Regulation (307/91) and the Irrigation Districts Act (Chapter I-11, RSA 2000).

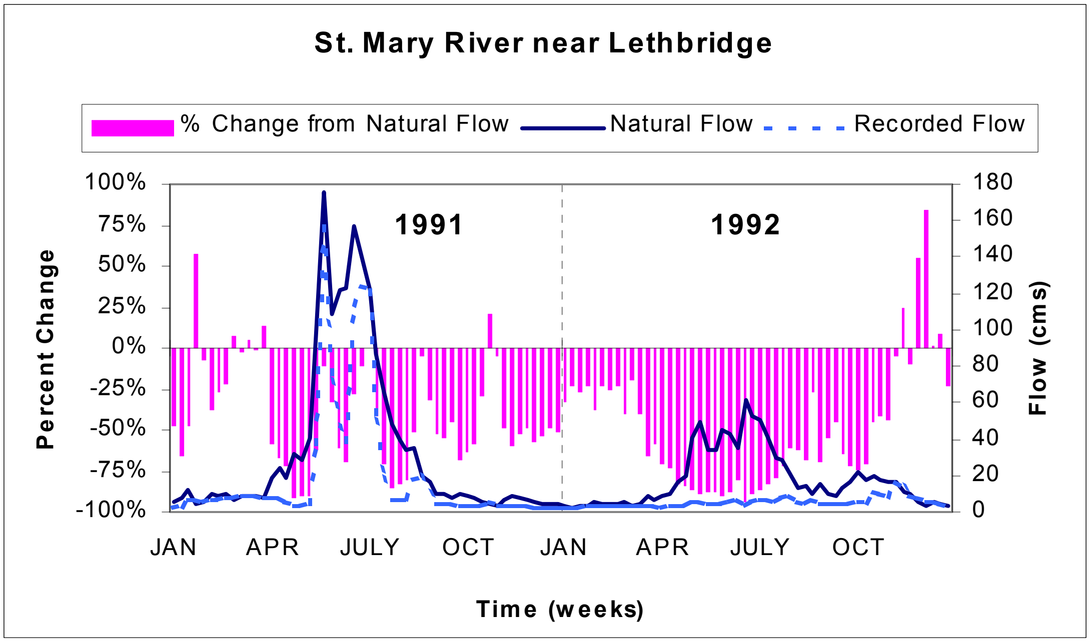
The pattern of water use in irrigated systems is dependent on the specifics of each storage or diversion license. However, most reservoirs are filled during spring runoff and drawn down for the remainder of the irrigation season. As illustrated in Figure 3.3 for the St. Mary River Dam and the Oldman River Dam, the capacity to store or divert water during the spring runoff will depend on antecedent conditions and the amount of natural flow in the system. During wetter years (1991), a higher proportion of the spring runoff remains in the river. In drier years (1992), almost all the spring runoff is stored (Figure 3.3). The pattern of water use from the Belly and Waterton Rivers is similar.

Hydro-electric power generation is not considered a consumptive use as virtually all water eventually makes its way downstream. However, hydroelectric dams can alter the timing of water delivery downstream. Typically, water is stored during spring runoff, resulting in decreased downstream flows. Water is released in the fall and winter, resulting in augmented flows. The flow regime in Calgary is, in large part, a result of TransAlta Utilities' operations and is shown in Figure 3.4. The Bow River system has the most extensive hydroelectric system, with three dams on the Bow River mainstem (Figure 3.1), and another eight dams on its tributaries upstream of Calgary, all owned and operated by TransAlta Utilities.

Water management structures on the Bow River system have a limited capacity to alter the flow regime during a wetter than average year, but do have a noticeable effect during a drier year (Figure 3.4). Once downstream of the City of Calgary, the flow regime of the Bow River becomes more influenced by irrigation diversions. Downstream of the Bassano Dam, the flow during some parts of the year is altered substantially from natural (Figure 3.4).

Municipal uses are prevalent in each of the sub-basins of the SSRB, with the City of Calgary on the Bow River being the largest municipal user within the SSRB. The major municipal users include Red Deer and Drumheller on the Red Deer River; Fort Macleod and Lethbridge on the Oldman River; and Medicine Hat on the South Saskatchewan River. A large percentage of the water withdrawn for municipal uses is returned to the river downstream of the diversion, after being treated at wastewater treatment facilities.

Major industrial uses of water in the SSRB include petrochemical plants, food processing operations, and thermal power generation plants. The Red Deer River has the highest percentage of water allocated to industrial uses. The Dickson Dam on the Red Deer River is the main water management structure used to alter the flow regime in the Red Deer River Basin (Figure 3.5). The major change to the flow pattern in the Red Deer River is augmentation of winter flows. The recorded flow during the rest of the year is much closer to the natural flow pattern when compared with the Bow and Oldman rivers.



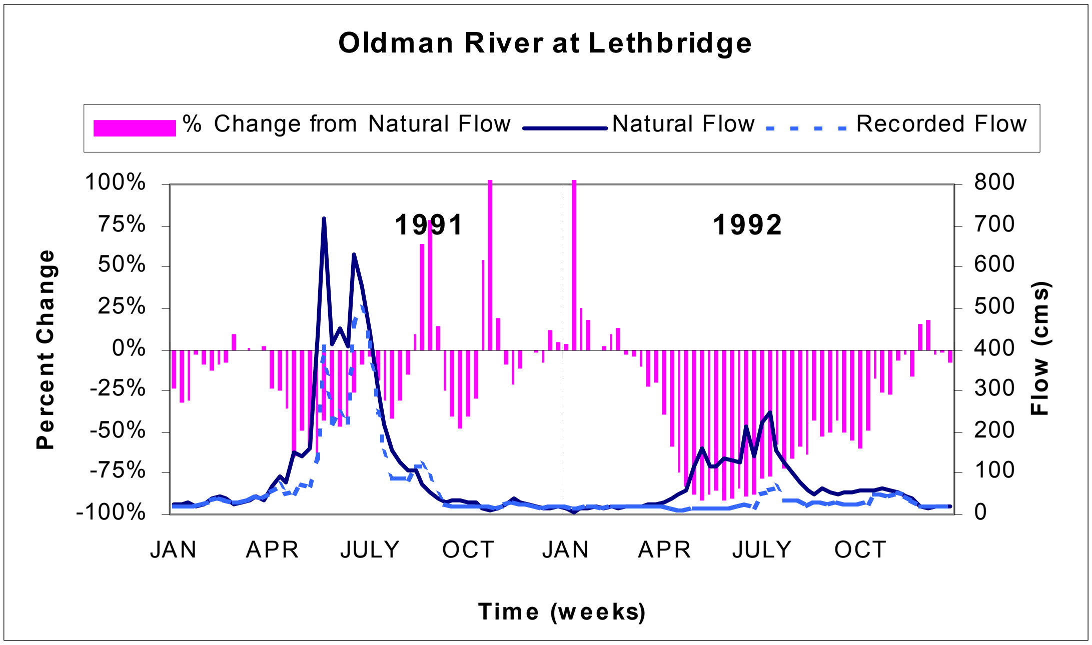
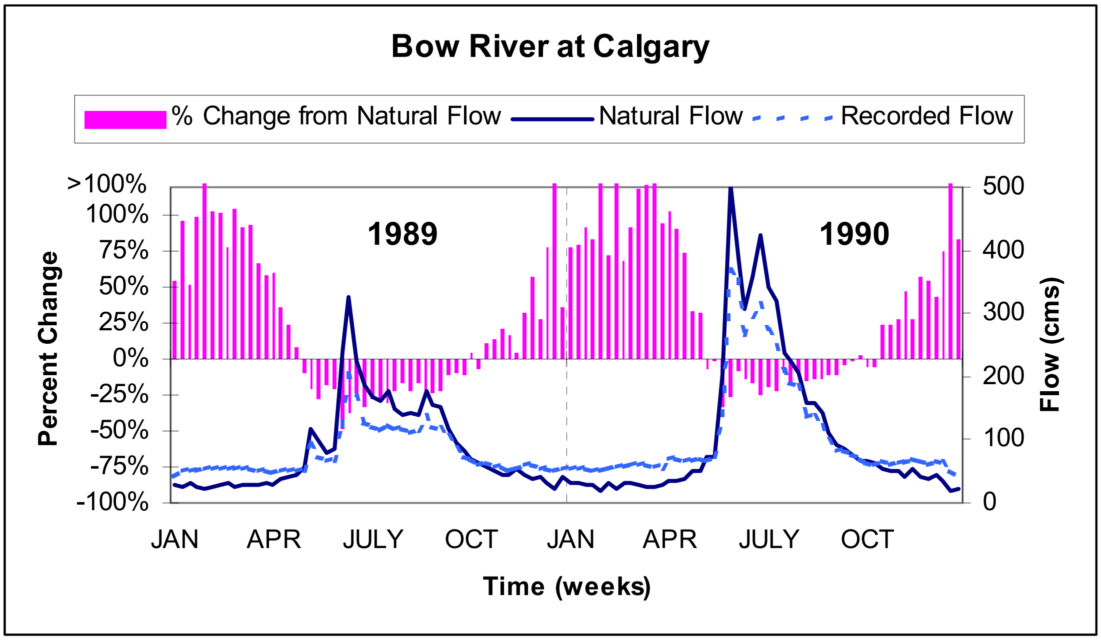


Figure 3.3. The natural and recorded flow downstream of the St. Mary River Dam (top) and the Oldman River at Lethbridge (bottom) showing the effects of current water management in a wet year (left) versus a dry year (right). The percent change in flow is the difference between the natural flow and the recorded flow.



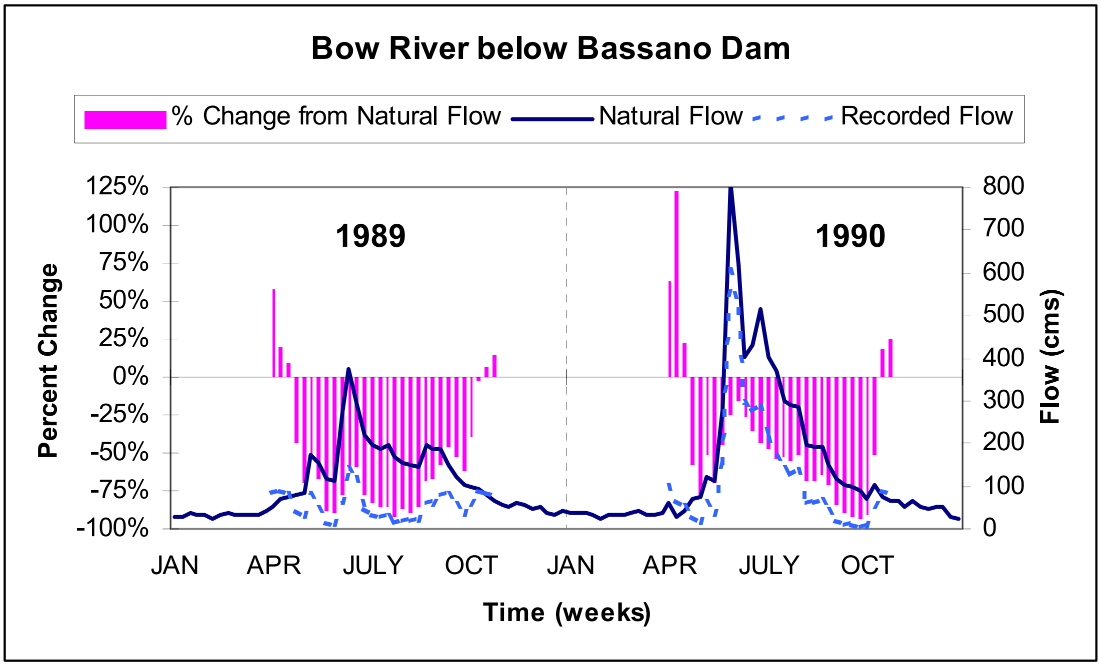


Figure 3.4. The natural and recorded flow for the Bow River at Calgary (top) and downstream of the Bassano Dam (bottom) showing the effects of current water management in a drier than average year (left) and a wetter than average year (right). The percent change in flow is the difference between the natural flow and the recorded flow. Recorded flow data for the winter season is not available below Bassano Dam.

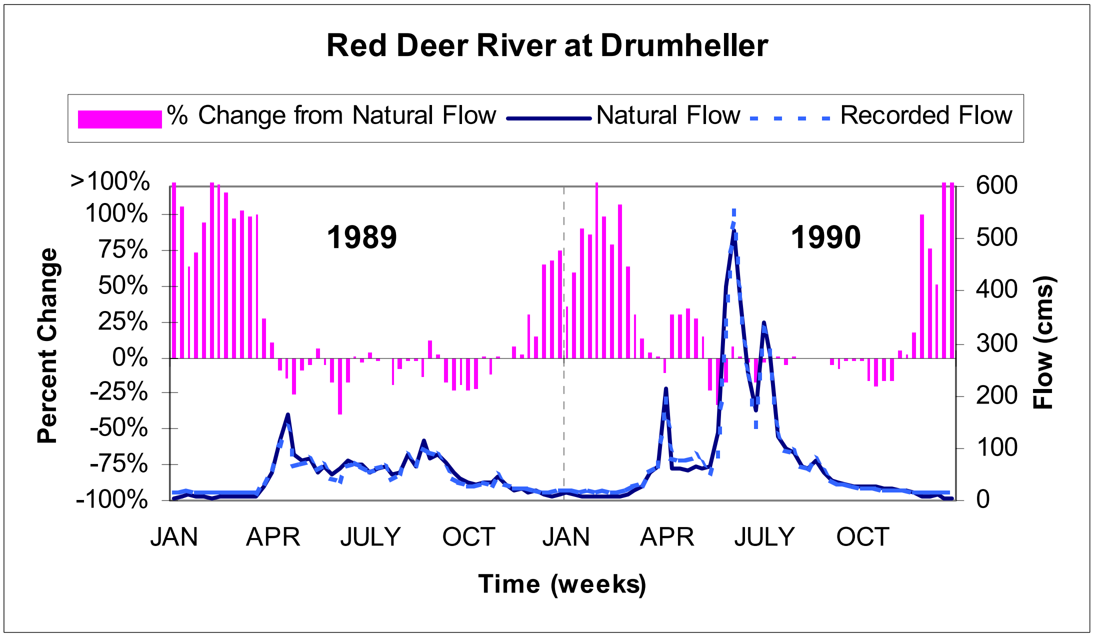


Figure 3.5. The natural and recorded flow downstream of the Dickson Dam for the Red Deer River at Drumheller, showing the effects of current water management in a drier than average year (left) and a wetter than average year (right). The percent change in flow is the difference between the natural flow and the recorded flow.

3.3 Red Deer River Basin

The Red Deer River is the most northerly of the three major tributaries of the South Saskatchewan River and flows for approximately 708 km, from its headwaters to the Alberta-Saskatchewan border. It is the largest sub-basin of the SSRB by area. However, it is the smallest basin by flow volume, contributing an average of 20% to the annual flow of the South Saskatchewan River. It originates in the Rocky Mountains within Banff National Park and flows north-easterly through foothills and parkland to the City of Red Deer. Near Nevis, the Red Deer River turns sharply to the south, flows through grassland to Dinosaur Provincial Park, then continues eastward toward the Alberta-Saskatchewan border and its confluence with the South Saskatchewan River. Except in the mountain and foothills regions, most land use in the Red Deer River Basin is agricultural. There are two cities along the river, Red Deer in the central part of the province, and Drumheller to the south and east.

The Red Deer River is the least regulated major tributary in the South Saskatchewan River Basin. The only major regulatory structure is the Dickson Dam, which is located on the mainstem of the Red Deer River upstream from the City of Red Deer. The Dickson Dam is a low capacity dam built for flow regulation. It has been in operation since 1983.

3.3.1 Fisheries Resources

The general fluvial characteristics of the Red Deer River are provided in Longmore and Stenton (1981). Prior to the construction of the Dickson Dam, the river below Red Deer supported mainly cool-water fish species and mountain whitefish, a cold-water species.

Upon completion of the Dickson Dam, an attempt was made to establish a tail-water fishery for rainbow trout. During the period 1985–1988, more than 250,000 rainbow trout were stocked below the dam. Although rainbow trout initially survived the stocking and were reported in angler's creels, successful reproduction was not adequate to establish and sustain a viable population. Brown trout that were already present in the Red Deer River Basin (Fallentimber Creek, Little Red Deer River and Raven River) were starting to increase in numbers below the Dickson Dam in the late 1980s. Stocking of adult brown trout was done in 1991 and 1992, to aid in the development of this fishery. These stocks of brown trout were successful in finding spawning habitat and recruitment was documented (Wieliczko et al. 1992). The future potential of this population of brown trout will be dependent on the spawning and early rearing habitats available within the Red Deer River system.

Warmer water temperatures, compared with upstream reaches, and additional nutrients contributed by the City of Red Deer, significantly increase biological productivity in the section of the river below Red Deer. Summer water temperatures frequently reach 24^0 C; maximum summer temperatures approach 27^0 C, occasionally exceeding the tolerance of mountain whitefish. Baker et al. (1982) noted that dissolved oxygen (DO) levels in the Red Deer River fall dangerously low during the winter months due to heavy loading of oxygen-demanding organic substances in the water, particularly during the period of ice-over. The operations of the Dickson Dam are designed to address the issues of low winter oxygen by sustaining a winter flow of approximately 16 m^3/s.

3.3.2 Riparian Resources

Two species of riparian cottonwoods occur in the Red Deer River Basin, the plains cottonwood (*Populus deltoides*) and the balsam poplar (*P. balsamifera*). The two species hybridize where their ranges overlap in the Drumheller area (Figure 3.6). The differences in the ranges of the two species appear related to differences in their regenerative strategies and temperature tolerances. Although both species are capable of producing seedlings, *P. balsamifera* is better able to reproduce clonally by suckering (Gom and Rood 1999). This clonal ability may be increasingly adaptive to the north and west, where conditions are less conducive for seedling establishment due to increasing stream gradients and coarser floodplain substrates.

The riparian forests along the Red Deer River tend to be dominated by mature and aging cottonwoods that were established as seedlings between the 1890s and 1930s (Marken 1993). This period of widespread recruitment was associated with a series of large floods that were of approximately 1-in-100 year magnitude (Cordes et al. 1997). A series of more moderate floods (greater than 1-in-10 year magnitude) occurred in the 1950s. Seedling recruitment was stimulated by these flows but was less widespread and occurred lower on the streambanks (Cordes et al. 1997). Comparisons of aerial photographs indicate there has been little change to overall riparian forest abundance along the Red Deer River since the 1950s (Table 3.6).

Since 1950, there have been no large floods and negligible channel migration (Marken 1993). Subsequently, there have been fewer opportunities for cottonwood seedling establishment. Terraces of the lower Red Deer River floodplain are now well above the 1-in-100 year flood level. Thus, the majority of the large cottonwood stands that were established there more than 50 years ago are not likely to be replaced until large floods, of greater than 1-in-50 year magnitude, occur again (Cordes et al. 1997). Currently the establishment of seedlings is limited to a narrow zone of barren, moistened substrates closely paralleling the active channel. This pattern of 'fringe' replenishment has become the dominant form of regeneration for cottonwoods along the Red Deer River.

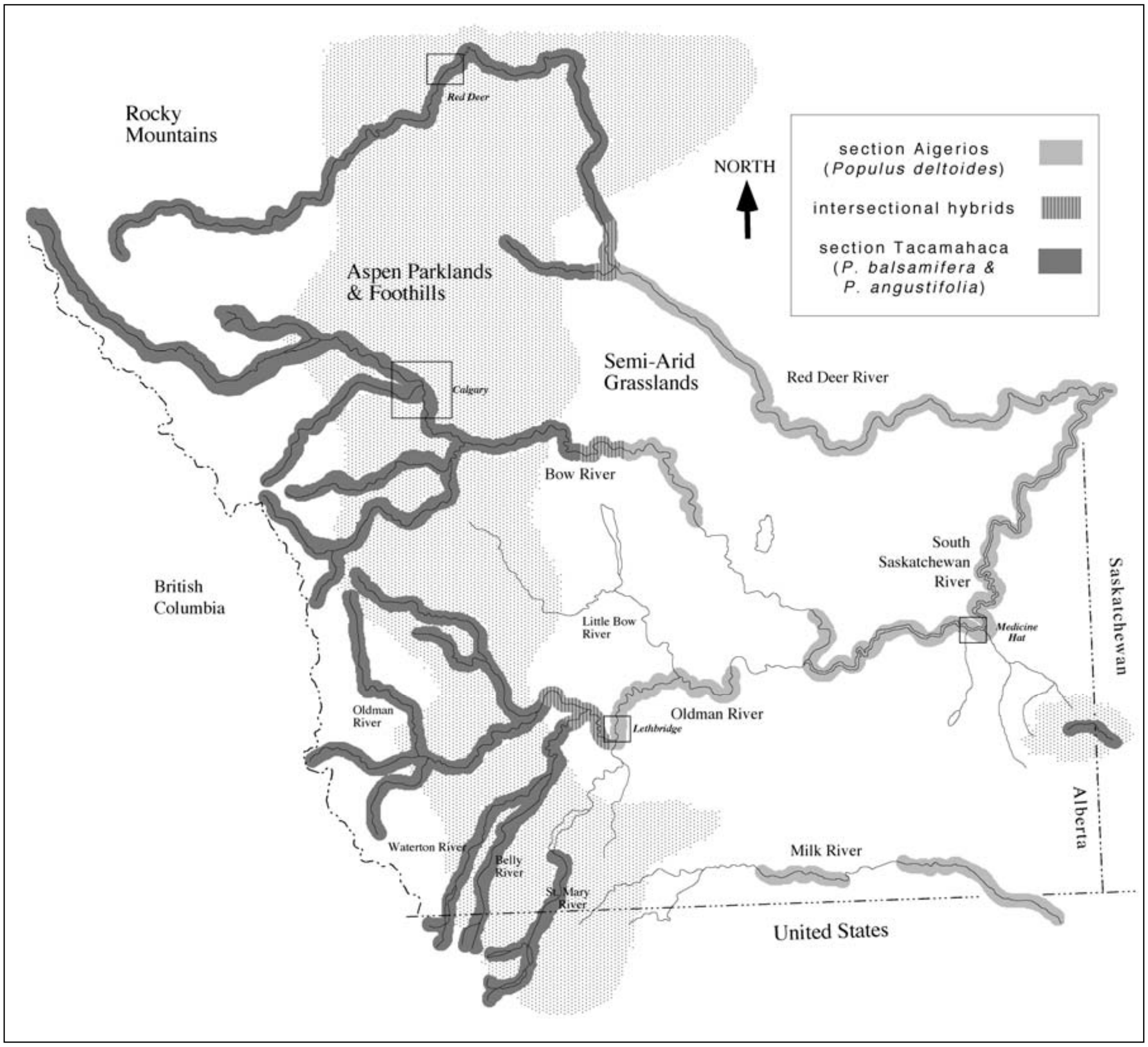


Figure 3.6. Geographic ranges of the cottonwood species that occur in the SSRB (after Gom and Mahoney 2002).

Table 3.6. Assessments of riparian forest abundances along the Red Deer River in the 1880s, 1950s, 1980s, and late 1990s using historic surveys and aerial photographs.

Current Study Reach Code	Reach:	-----------1980s----------- Length (km)	Floodplain Width (m)	Channel Type	Riparian Poplar Density: 1880s	1950s	1980s	1997-99	General Change 1880-1999
RD5	R1	22.86	200-300	CM		3	3	2	less dense
RD4	R2	32.06	300-400	CM		2	2	2	-
RD3	R3	32.13	200-400	CM-ST	1	3	3	3	more dense
RD3	R4	39.98	100	CM-ST	2	2	2	2	-
RD3	R5	16.48	300-500	CM	2	3	3	3	more dense
RD3	R6	78.23	500	CM	3 to 5	4	4	4	-
RD2	R7	37.14	200-300	CM-ST	1	3	3	3 to 4	more dense
RD2	R8	51.33	500-1300	CM-FM	2	3	4	3 to 4	more dense
RD2	R9	18.45	300-500	ST-CM		3	3	3	-
RD1	R10	37.99	1000-1500	FM-BR		3	3	3 to 4	-

(1880-1980 content adapted from Bradley et al. 1991)

Channel Type categories:
FM = freely meandering
ST = straight
CM = confined meandering
BR = braided

Density categories:
1 = none / negligible
2 = sparse
3 = moderate
4 = dense
5 = very dense

After the Dickson Dam became operational in 1983, mean monthly discharge during the spring and summer has been lowered (Marken 1993). By attenuating flood flows and reducing summer flows, the Dickson Dam may be exacerbating an already declining situation for cottonwoods along the Red Deer River; all but eliminating the rare opportunities for seedling establishment.

In addition to streamflow modifications, there are a variety of other activities that impact cottonwoods along the Red Deer River. In particular, livestock grazing has had moderate to severe impacts (Marken 1993), as browsing and trampling tends to destroy seedlings and degrade nursery sites. Additionally, expansion of settlements and other land uses continues to encroach on riparian areas, removing forests and increasing the demand for flood protection.

3.3.3 Water Quality

The Red Deer River is a well-buffered, relatively hard-water system, dominated by calcium and bicarbonate. Flow regulation has resulted in generally lower median levels of calcium, magnesium, sulphate, conductivity, and alkalinity in reaches between the Dickson Dam and the Alberta-Saskatchewan border. Suspended solids increase progressively as the river traverses the highly erodable substrates of the badlands in the lower basin.

Historically, the principal concern for the water quality of the Red Deer River has been low levels of dissolved oxygen (DO) during the winter, particularly in the lower reaches (Morrin Bridge at Highway 27 to the Alberta-Saskatchewan border). With the construction of the Dickson Dam, flow regulation has resulted in a significant increase in winter minimum DO levels in the lower river. However, concentrations of less than 5 mg/L (Alberta surface water quality acute guideline for the protection of aquatic life) still occur in some areas between the City of Red Deer and the Alberta-Saskatchewan border (Shaw and Anderson 1994).

Several point and non-point contributors of fecal coliforms include municipal discharges, irrigation return flows, tributaries, and direct access to the river for livestock watering. The cities of Red Deer and Drumheller, and some smaller municipalities such as Blackfalds, East Coulee, and Rosedale, discharge their wastewater effluent to the Red Deer River. The City of Red Deer has the largest municipal discharge to the Red Deer River; Blackfalds and Drumheller discharge about 10% of that city's volume. The Red Deer wastewater treatment plant is presently being upgraded to implement tertiary treatment. This upgrade will include nutrient (ammonia and phosphorus) removal, dissolved air flotation, and ultra-violet disinfection. The nutrient removal conversions have been operational since 2003. The disinfection component is slated for construction in 2006-2007.

Until 1997, chlorine treatment of effluent was a license requirement for Drumheller, East Coulee and Rosedale. Currently, these plants do not add chlorine. They use physical treatment by aeration with activated sludge and subsequent clarification. Other municipalities, such as Delia, Hanna, Duchess, Rosemary and Patricia, discharge their effluent intermittently (spring and fall) into tributaries of the Red Deer River. The town of Brooks has biannual discharges to One Tree Creek. In 1992, the sewage treatment plant at Dinosaur Provincial Park became operational. It treats wastewater produced by park visitors during the tourist season (June-September). Visitor numbers influence frequency and duration of discharges to the Red Deer River.

Populations of phytoplankton and attached algae are considerably higher immediately downstream of Dickson Dam than in reaches farther downstream. Increased algal growth is probably a result of the more stable temperature and flow regimes as well as the lower concentration of suspended sediments in water released from the reservoir. (The increased clarity allows greater penetration of light giving rise to greater algal growth.) Flow regulation has noticeably altered the zoo-benthic communities of the Red Deer River, particularly immediately downstream of the dam. The number of invertebrates has increased dramatically, whereas the diversity of zoo-benthic organisms has decreased. Aquatic earthworms and midges are numerous, and mayflies and stoneflies have declined. Changes in the Red Deer River zoo-benthos are attributed to alteration of the habitat and food base and to temperature and water quality changes caused by flow regulation (Shaw and Anderson 1994). Before construction of the Dickson Dam, insect larvae such as mayflies and stoneflies were more prevalent and more diverse in the erosional habitats (i.e., rocky substrate, swift water flow) that typified the upper reaches of the river. Burrowing organisms such as midges and worms were more numerous farther downstream in the silty, sandy substrates, and in areas of slow water flow. Studies have shown an increase in invertebrate numbers downstream of the City of Red Deer as a result of enrichment by treated wastewater discharges (Shaw and Anderson 1994).

There are significant changes in water quality in the Red Deer River between the Dickson Dam and Innisfail, and in the lower river reaches. These involve changes in bacteria, nutrients, odour and colour levels (Shaw and Anderson 1994, Anderson 1999). Variations in annual runoff conditions play an important role in the quality of water entering the river. Agricultural activities also contribute bacteria and nutrients to the Red Deer River and its tributaries that adversely affect water colour and odour.

Continued population growth in the basin will influence water withdrawals and effluent loading (e.g., nutrients, organic compounds, pesticides, and metals). Moreover, intensification of land use in the basin could result in increased loadings of contaminants such as nutrients and pesticides to the river. To maintain desired water quality in the Red Deer River in the future, reach-specific instream needs for water quality may need to be adjusted to account for increased loadings.

3.3.4 Geomorphology

Geomorphicly, the Red Deer River can be divided into two reaches; the upper Red Deer River (from its headwaters to Finnegan), and the lower Red Deer River (from Finnegan to the confluence with the South Saskatchewan River). The primary difference between these reaches is the bed material. The riverbed of the upper Red Deer River consists mainly of gravel. This changes in the vicinity of Finnegan to a mostly sand riverbed for the lower Red Deer River.

The Red Deer River channel in the upper reach is set in a broad valley and is frequently deflected by the valley walls and high terraces. The river exhibits a sinuous to irregular meander pattern, with frequent islands and mid-channel bars. The river profile features a regular sequence of shallow riffles and deep pools. The channel bed material is predominantly gravel with a D_{50} of approximately 38 mm. The banks are mostly alluvial, consisting of sands and gravel.

Prior to the operations of the Dickson Dam, the channel width at Red Deer averaged 89 m; at Drumheller it averaged 96 m. The river was shallower at Red Deer, with a mean depth of 0.8 m; at Drumheller the mean depth of the river was 1.0 m (Kellerhals et al. 1972).

The lower Red Deer River valley varies noticeably in both width and depth, though it is cut to a considerable depth below the surrounding arid prairie terrain throughout its run. In some places, several terrace levels are detectable between the top of the valley and the present floodplain. There are some areas of well-developed badland topography along the valley sides. The valley follows a sinuous course and the present river winds and meanders within it. The valley bottomland is generally flat, relatively fertile, and subject to occasional flooding. The region traversed by the river is sparsely populated and mostly used for cattle ranching. Much of the floodplain is unoccupied and covered with trees and brush, but towards the eastern end a considerable proportion is cultivated, generally with the aid of irrigation.

Little detailed work has been reported on the geology of the valley. The valley walls generally show the prairie till sheet at the top overlying sandstones and shales of the Upper Cretaceous series. The bottomlands appear to consist principally of alluvial deposits laid down by the river, fan deposits washed down from the decomposing valley walls, sand and gravel terraces presumably of glacial origin, and wind-blown sand.

The lower river exhibits many sand and mud-bars at low stage. At steady low discharges it may be relatively clear, but even small rises can cause it to become silty. High stages are generally due to ice-jams in the spring, or to upstream runoff in the summer. Variations in flow pattern from year to year are marked, but there is frequently a general rise in May and June, and a gradual decline through July and August. The sand bars and banks in many locations are subject to shifting. The geographic characteristics of the Red Deer River and the river valley are summarized in Table 3.7.

Table 3.7. Geographic characteristics of the Red Deer River and river valley.

Location	Red Deer River Geographic Features (from Kellerhals et al. 1972)									
	General Setting	Valley features			Channel features, environment and processes					Bankfull conditions (valley flat level)
(water survey of Canada Index Number)	Terrain surrounding valley	Description	Depth [ft]/ Top width [mi]/ Bottom width [mi]	Terraces	Description of valley flat/ Width [mi]	Channel pattern	Relation of channel to valley	Sinuosity/ Wave length/ Belt width [mi]	Lateral activity/ Lateral stability	Dschge (cfs)/ Stage (ft)/ Return Period (yrs)
Near Sundre 05CA001	Moderately forested foothills, no cultivation	Stream-cut valley in wide valley, forested valley walls.	150 1.00 0.20	Several continuous levels.	Indefinite and narrow; covered by shrubs. 0.02	Sinuous, tumbling flow; mid-channel bars.	Partly entrenched, confined; braided with broad valley flat downstream.	1.04 - -	Slightly unstable.	--
at Red Deer 05CC002	Mainly cultivated and partly built-up till plain.	Stream-cut valley with occasional slumping of forested valley walls.	100 1.50 0.50	Several continuous levels.	Fragmentary and narrow; covered with shrubs. 0.05	Irregular meanders with pool and riffle sequence, diagonal and mid-channel bars.	Partially entrenched and frequently confined.	1.40 1.40 0.50	Downstream progression. Slightly unstable	--
at Drumheller 05CE001	Mainly cultivated lacustrine and till plain.	Deep, stream-cut valley; badland topography.	400 1.50 0.30	Two levels, main low terrace and upper dissected terrace.	Fragmentary and narrow; covered with shrubs. 0.07	Sinuous with occasional islands; uniform rapids in reach; side bars.	Partly entrenched and confined.	1.10 - -	Downstream progression. Slightly unstable	36,000 13.9 10.5
Near Empress 05CK002 near Bindloss 05CK004	Grass vegetated hummocky till plain, mainly pasture, partly cultivated	Stream-cut valley, valley walls in grass or bare	250 2.00 1.00	Two continuous levels.	Fragmentary and narrow; covered with shrubs, not cultivated. 0.20	Sinuous with occasional islands; mid-channel bars and large dunes	Not obviously degrading or aggr., frequently confined.	1.06 - -	Downstream progression. Moderately unstable.	30,000 7.5 8

3.4 Bow River Basin

The Bow River flows for approximately 500 km, from its headwaters in the Rocky Mountains to its confluence with the Oldman River at the Grand Forks. The Bow is the largest contributor of water to the South Saskatchewan River system, providing an average of 43% of the annual flow to the South Saskatchewan. The Bow River begins its flows through the largely forested and undeveloped areas of Banff National Park. As it leaves the park, it flows through the foothills and becomes a prairie river by the time it reaches the City of Calgary. Approximately 50 km of the Bow River is contained within the city limits of Calgary, which has a population that is quickly approaching 1 million people. Downstream of the City of Calgary, the river slows as it winds through a wide prairie valley, bordered mostly by farmland. At the confluence of the Bow and Oldman, the rivers become the South Saskatchewan River.

The Bow River Basin is probably the most regulated river system in Alberta (Figure 3.1). Upstream of the City of Calgary, there are 11 hydroelectric dams operating on the Bow River and its tributaries. Major dams on the mainstem of the Bow River include the Kananaskis Dam (operating since 1914), Horseshoe Dam (1911), Ghost Dam (1929) and Bearspaw Dam (1954). These dams are operated to meet peak electricity demands and tend to moderate natural high and low flows, but they do not divert water away from the river. Further downstream, major flow diversions are made via the Western Irrigation District diversion weir (1912) at Calgary, the Carseland diversion weir (1918) for the Bow River Irrigation District, and the Eastern Irrigation District diversion at the Bassano Dam (1914). These diversions have the capacity to substantially de-water the river downstream (Rood and Bradley 1993, Rood et al. 1999).

The Bow River and its reservoirs are used extensively for fishing, rafting, canoeing, kayaking and power boating. The best-known and most heavily angled section of the Bow River is the 50 km reach from Calgary to Carseland, which supports an internationally renowned catch-and-release trout fishery.

Irrigation is the major consumptive use of Bow River water, using 96% of all water actually consumed in 1991. Three irrigation districts withdraw 98% of the diversions for irrigation between Calgary and Bassano: the Western Irrigation District (WID), the Bow River Irrigation District (BRID), and the Eastern Irrigation District (EID).

3.4.1 Fisheries Resources

The Bow River from the Banff Park boundary to the Carseland weir is cold-water aquatic habitat. Mountain whitefish are the most abundant sport fish species, although rainbow trout, brown trout and bull trout are common. Mountain whitefish and rainbow trout migrate seasonally from the Bow River to spawning habitat in the cold upper tributaries of the Sheep and Highwood Rivers.

Unlike rainbow trout, the distribution of brown trout tends to be restricted to the Bow River mainstem. Some brown trout are found in the Bow River downstream of the Carseland Weir, but they are generally limited to the upper part of the reach where the water temperatures are cooler. Major spawning areas for brown trout have been identified downstream of the Bearspaw Reservoir within the City of Calgary adjacent to the Inglewood Bird Sanctuary, in the side channel of St. George's Island, and along the length of the Elbow River between Glenmore Reservoir and the Bow River confluence (Courtney and Fernet 1990).

The mainstem of the Bow River from the Banff Park boundary to the Bearspaw Dam exhibits marked daily fluctuations in discharges as a result of variable water releases at hydroelectric dams. Habitat instability resulting from these regular fluctuations in discharge limits fish production. River flow is re-regulated at the Bearspaw Dam, and the amplitude of fluctuations is greatly moderated. More stable discharges, and the addition of treated wastewater at Calgary, increases biological and fish production in the river between Bearspaw Dam and the Carseland weir.

Between the Carseland weir and the Eastern Irrigation District dam at Bassano, the Bow River is gradually transformed from cold to cool water aquatic habitat. The diversion of up to 90% of the streamflow for irrigation at the EID dam at Bassano has drastically reduced discharge, and consequently the fish-producing capability of the remaining 167 km of the river. The Bow River between the Bassano Dam and the Grand Forks is cool water aquatic habitat, but water temperatures of up to 29^0C exceed the tolerance of even cool water fish species. During low discharges, aquatic plants in the warm, shallow river cause low dissolved oxygen concentrations and fluctuations in pH. These factors combine to stress and occasionally kill fish.

3.4.2 Riparian Resources

Two, and possibly three, species of riparian cottonwoods occur on the floodplains along the Bow River and its tributaries (Figure 3.6). *Populus balsamifera* is especially common and *P. deltoides* is common downstream from the Bassano Dam. *P. angustifolia* (narrowleaf cottonwood) has been reported to occur along the Highwood River (Michalsky et al. 1991). Abundant mature cottonwood groves occur in the river valleys across the region. The existing mature trees appear to be generally healthy, with little evidence of branch or crown die-back. Overall forest abundance has not changed appreciably in more than 100 years (Table 3.8). Thus, dams and diversions upstream have probably not produced appreciable drought stress in recent years (Rood and Bradley 1993). This finding is consistent with stabilized flows downstream of major water management structures (Rood and Mahoney 1995). However, a deficiency of younger trees suggests that rates of regeneration are insufficient to maintain the present extent of these forests.

The existing mature forests along the Bow River were probably established as seedlings during a few major recruitment events between 1915 and 1932 (Cordes 1991, Rood and Bradley 1993, Rood et al. 1999). Since then, flows have become more stabilized due to regulation and drier climatic conditions (Rood and Bradley 1993) and disproportionately fewer trees have been recruited (Cordes 1991, Rood et al. 1999). Some recruitment occurred after moderate flood flows along some reaches in 1990 and 1995 (Rood et al. 1999).

In addition to flood magnitude, the timing and pattern of the flood flows must also be conducive for seedling recruitment. Recent high flows that occurred at the beginning of July, toward the end of the period that seeds are available to germinate, were not conducive to seedling growth because the flows declined rapidly after the peak and drought stress killed any newly sprouted seedlings. Even when the magnitude and pattern of flood flows are suitable, as occurred in 1967, recruitment may still be limited by subsequent flow conditions. Flood flows in 1969 surpassed those in 1967, probably causing seedlings established in 1967 to be scoured away or buried by sediment (Rood et al. 1999).

If the deficient rate of recruitment that occurred between 1960 and 1990 continues, it is expected the area of cottonwood forest will diminish to zero in about 100 to 150 years (Cordes 1991). Asexual reproduction, which is becoming the dominant form of regeneration, may extend relict groves beyond this time frame. However, declines in forest abundance and genetic diversity are likely to continue unless seedling replenishment is restored (Rood and Bradley 1993). Impacts associated with grazing by livestock, harvesting by beaver, and disturbances by humans are also becoming increasingly severe and need to be reduced to improve long-term forest survival.

Table 3.8. Assessments of riparian forest abundances along the Bow River in the 1880s, 1950s, 1980s, and late 1990s using historic surveys and aerial photographs.

Current Study Reach Code	Reach:	Length (km)	Floodplain Width (m)	Channel Type	Riparian Poplar Density: 1880s	1950s	1980s	1997-99	General Change 1880-1999
		-----------1980s-----------							
BW3&BW4	B1	42.58	300-1500	FM-CM	3 to 5	3	3	3	less dense
BW2	B2	38.86	500-1500	FM-BR	3 to 5	4	4	4	
BW2	B3	48.14	500-2500	FM-BR	3 to 5	4	5	5	
BW2	B4	36.26	500-1000	FM	3 to 5	3	3	3	less dense
BW1	B5	60.38	200-500	ST	1	2	2	2	more dense
BW1	B6	55.79	200-500	ST	1	1	1	1	
BW1	B7	41.39	200-500	ST	1	1	1	1	
BW1	B8	23.22	200-500	ST	2	2	2	2	

(1880-1980 content adapted from Bradley et al. 1991)

Channel Type categories:
FM = freely meandering
CM = confined meandering
ST = straight
BR = braided

Density categories:
1 = none / negligible
2 = sparse
3 = moderate
4 = dense
5 = very dense

Downstream of the inflow of the relatively free-flowing Highwood River, there is a more continuous range of tree sizes, suggesting that ongoing recruitment has been more successful there (Rood and Bradley 1993, Rood et al. 1999). Restoration of seedling recruitment along the Bow River probably requires the implementation of high flows with more natural magnitude, timing and pattern. However, extensive urban and industrial developments on the floodplain of the Bow River complicate the re-introduction of over-bank flows. Minor changes to upstream dam operation might encourage some channel migration, bar formation and subsequent cottonwood seedling establishment (Rood and Bradley 1993).

3.4.3 Water Quality

Water quality is generally excellent upstream from Calgary. Water quality guidelines are occasionally not met in the Bow River downstream from Calgary due to impacts of municipal wastewater and runoff from rapidly expanding urban development. Water quality below Calgary has greatly improved since 1982 (BRWQTF 1991, Culp et al. 1992, BRWQTF 1994, Sosiak 2002) due to a series of improvements in wastewater treatment, including full UV disinfection in 1997. The Sierra Legal Defence Fund rated Calgary wastewater treatment the best of 21 urban centres in Canada in 1999 (Wristen 1999). To control the effects of urban runoff, a total loading limit for wastewater and runoff is now being developed.

Although 68 industries were licensed to withdraw water from the Bow River in 1991, only three currently discharge treated effluent directly to surface water in the basin. Their impacts on water quality are minor. Runoff from rural non-point sources requires further investigation.

3.4.4 Geomorphology

In the study area, the Bow River valley is generally stream-cut in a wide valley. The channel is partly entrenched and frequently confined. The valley depth varies from approximately 60 m in Calgary to approximately 35 m below Carseland. The valley top width varies from 1.9 km in Calgary to 1.6 km below Bassano.

The channel pattern varies from sinuous with mid-channel and diagonal bars and frequent islands, to an irregular channel with diagonal bars and occasional islands. The sinuosity is around 1.10. The bed material is predominantly gravel, with D_{50} varying between 40 mm and 32 mm. The channel banks are mostly sand and gravel.

The geographic and river valley features of the Bow River are summarized in Table 3.9.

3.5 Oldman River Basin

The Oldman River originates in the Rocky Mountains and flows for approximately 450 km to its confluence with the Bow River at the Grand Forks. From its headwaters, the Oldman River flows southwards through the Livingstone Range to join with the Crowsnest and Castle Rivers in the foothills. The location where these three rivers meet is now within the Oldman River Reservoir, completed in 1991. From the dam, the Oldman River flows eastwards through semi-arid grasslands to join with the Bow River near Grassy Lake where they form the South Saskatchewan River. Major regulatory structures within the basin include the Oldman River Dam (operating since 1992), Lethbridge Northern Irrigation District *d*iversion weir (since 1922), Waterton Dam (since 1964), Belly River diversion weir (since 1935), and St. Mary River Dam (since 1951) (Figure 3.1). These projects, together with more than a dozen other structures, supply water to 13 irrigation districts and to other water users in the Oldman River Basin.

Peak flows, fed by mountain snowmelt, occur in May and June. At other times of the year, flows can be very low. The Oldman River Dam evens out these highly variable flows by storing water when flows are naturally high, and releasing it when flows are lower. This ensures downstream water supplies for human consumption, irrigation, and the protection of the aquatic and riparian environments. Human activity in the Oldman River Basin includes forestry, recreation, agriculture, and oil and gas development. Much of the agriculture in this basin depends on irrigation, relying on water from the Oldman River and its major tributaries to support a variety of crops. This basin also supports a large number of confined livestock feeding operations, particularly north of Lethbridge.

3.5.1 Fisheries Resources

The operation of the Oldman River Dam has altered the historical flow regime of the Oldman River by affecting both discharge and temperature patterns. Water flow tends to be more stable and water temperatures are cooler in summer and warmer in winter (Hazewinkel and Saffran 2002). The altered flow regime will doubtless affect fish populations downstream of the dam; however, it is unclear how these changes will be manifested.

Table 3.9. Geographic characteristics of the Bow River and river valley.

Location	Bow River Geographic Features (from Kellerhals et al. 1972)									
	General Setting	Valley features			Channel features, environment and processes					Bankfull conditions (valley flat level)
(water survey of Canada Index Number)	Terrain surrounding valley	Description	Depth [ft]/ Top width [mi]/ Bottom width [mi]	Terraces	Description of valley flat/ Width [mi]	Channel pattern	Relation of channel to valley	Sinuosity/ Wave length/ Belt width [mi]	Lateral activity/ Lateral stability	Dschge (cfs)/ Stage (ft)/ Return Period (yrs)
at Lake Louise 05BA001	Mountainous area, moderately forested, no cultivation	Wide mountain valley.	- - 0.25	One fragmentary level.	Fragmentary and narrow; sparsely forested or grass-covered 0.06	Sinuous with occasional islands; tumbling flow; diagonal and side bars.	Partly entrenched and confined.	1.01 - -	Slightly unstable.	1,900 6.7 2
at Banff 05BB001	Mountainous area, no cultivation moderately forested and open areas.	Wide mountain valley.	- - 0.80	Old lake bottom.	Continuous and wide; uncultivated, shrubs shallow lakes and swamps. 0.70	Irregular, point bars.	Not obviously degrading or aggr., occasionally confined.	1.10 - -	Slightly unstable.	10,000 11.5 9
at Kananaskis 05BE003	Mountainous area, sparsely forested, no cultivation.	Wide mountain valley; reach lies at eastern edge of Rockies.	- - 0.25	One fragmentary level; corresponds to valley flat.	Fragmentary and narrow; moderately forested, no cultivation. 0.10	Sinuous with occasional islands; mid-channel bars.	Entrenched.	1.10 - -	Stable	--
Near Seebe 05BE004	Foothills, near large outwash plain, no cultivation	Stream-cut, gorge-like valley in wide valley, three lateral constrictions.	200 0.10 0.05	Several indefinite levels.	None.	Irregular, with bedrock and boulder rapids; mid-channel and diagonal bars.	Entrenched.	1.10 - -	Stable	--
Below Ghost Dam 05BE006	Foothills, open range and partly cultivated	Stream-cut valley in wide valley, one constriction; valley walls partly forested.	100 1.20 0.40	One fragmentary level.	Fragmentary and narrow; covered with shrubs 0.05	Sinuous with occasional islands; uniform flow, boils and irreg. side and mid-channel bars.	Partly entrenched and confined.	1.10 - -	Stable	--
at Calgary 05BH004	Urbanized plain	Stream-cut valley in wide valley.	200 0.10 0.05	Three continuous levels; lowest corresponds to valley flat.	Fragmentary and narrow; sparsely forested or in grass. 0.10	Sinuous with frequent islands; mid-channel bars and diagonal bars.	Partly entrenched and frequently confined.	1.10 - -	Slightly unstable.	84,000 14.7 >100
below Carseland Dam 05BM002	Mainly cultivated till plain.	Stream-cut valley with bare or sparsely forested valley walls.	120 0.80 0.65	One continuous level.	Continuous of moderate extent; sparsely forested, not cultivated, 0.20	Irregular, with occasional islands; diagonal bars; split D/S of reach.	Partly entrenched and frequently confined.	1.02 - -	Stable	38,000 10.3 11
Below Bassano Dam 05BM004	Till plain, partly cultivated, or open range.	Stream-cut valley with frequent slumps, almost bare valley walls.	130 1.0 0.4	One continuous level, fans on terrace.	No valley flat.	Sinuous, with occasional islands, side bars and mid-channel bars, boulder rapids.	Entrenched.	1.16 - -	Stable	--

Mitigation for the Oldman River Dam included an enhancement program on the Oldman River downstream of the dam. One project was designed to provide high quality habitat for adult brown trout, using boulders placed in existing deep water areas. It is anticipated the hatchery brown trout that were stocked during the 1992–1997 period will use these areas, thereby facilitating the development of a self-sustaining brown trout population downstream of the reservoir.

The fish community within the Oldman River system below the Oldman River Dam is influenced by a temperature gradient and the availability of different habitat types (R.L. & L. 2000a and 2000b). Rainbow trout and bull trout are confined to the cold water upper reach, immediately below the Oldman River Dam. In contrast, cool water species such as sauger and lake sturgeon are restricted to downstream areas. In the transition zone, northern pike, lake sturgeon and walleye (cool water species) are found in association with the cold water species.

Mountain whitefish provide a good example of a species that is influenced by the transition between cold and cool water habitats. This cold water species is present in all sections. However, catch per unit effort values decreased from upstream to downstream. Mountain whitefish dominate the fish community in the upper sections, exhibit reduced abundance indices in the mid sections, and are largely absent from the sample in the lower section (R.L. & L. 2000a and 2000b). In addition to the influence of temperature, changes in river gradient, flow velocities and bed substrates could impact the distribution of mountain whitefish.

3.5.2 Riparian Resources

Three riparian cottonwood species occur on floodplains in the Oldman River Basin (Brayshaw 1965). Each has slightly different life-history characteristics that suit it to its particular geographic range. *Populus deltoides* (plains cottonwood) occupies the eastern half of the Oldman River Basin, while *P. balsamifera* (balsam poplar) and *P. angustifolia* (narrowleaf cottonwood) occur to the west and south. All these species can interbreed to produce hybrids wherever their ranges overlap (Figure 3.6). An additional species, the black cottonwood (*P. trichocarpa*), is nearly indistinguishable from *P. balsamifera.* It usually occurs west of the continental divide, but is found in the headwaters of the Oldman River Basin. The riparian forests of the Oldman River and its southern tributaries are the most studied and best understood riparian forest systems in Alberta.

The Oldman River remains entrenched in mountain and foothills valleys with limited floodplains until it enters the Oldman River Reservoir near Pincher Creek. The floodplains of these upper reaches are generally forested with poplar and willow as described by Dawson in 1885 (Appendix B). Extraction of water upstream of the Oldman River Dam is minor and does not significantly affect the natural flow regime. Reduction in riparian forest quantity or quality is not extensive, being limited to sites used for agricultural purposes (grazing or cultivation), human habitation, natural cycling due to flood events, or beaver activity.

Downstream of the Oldman River Dam, the river is generally either freely meandering or confined meandering, with wide floodplains and moderate to very dense riparian forests (Table 3.10). The forests are naturally reduced downstream of Lethbridge and are negligible along the final reach before the confluence with the Bow River. The reach of the Oldman River between Pincher Creek and Lethbridge is generally recognized as significant on a national and international scale. This reach supports broad, dense stands of riparian poplars, including the narrowleaf cottonwood that has a restricted range in Canada. The hybrid poplars found along this reach are unique in Canada (Rood et al. 1986).

Table 3.10. Assessment of riparian forest abundance along the Oldman River in the 1880s, 1950s, 1980s, and late 1990s using historic surveys and aerial photographs.

Current Study Reach Code	Reach:	-----------1980s-----------			Riparian Poplar Density:				General Change 1880-1999
		Length (km)	**Floodplain Width (m)**	**Channel Type**	**1880s**	**1950s**	**1980s**	**1997-99**	
OM7	OM1	17.26	200-500	FM	3 to 5	2	2	2	**less dense**
OM6&OM5	OM2	98.82	1500-1700	BR-FM	3 to 5	5	5	5	**more dense**
OM4	OM3	21.28	200-1000	ST	3 to 5	2	2	2	**less dense**
OM3	OM4	61.93	500-2000	FM-CM	3 to 5	4	4	4	
OM2	OM5	78.64	300-2000	CM-FM	2	2	2	2 to 3	
OM1	OM6	62.08	300-700	ST-CM	2	1	1	1	**less dense**

(1880-1980 content adapted from Bradley et al. 1991)

Channel Type categories:

FM = freely meandering
ST = straight
CM = confined meandering
BR = braided

Density categories:

1 = none / negligible
2 = sparse
3 = moderate
4 = dense
5 = very dense

Bradley et al. (1991) report a slight decline in the abundance of riparian poplars along the Oldman River between 1880 and 1990. All reaches showing a change in forest abundance during that period exhibited the change between 1880 and 1950. Flow management along the mainstem of the Oldman River was minimal during this period, indicating that other factors must have caused the observed decline. Bradley et al. (1991) noted cultivation of floodplains was prevalent downstream from Fort Macleod.

Although flow regulation of the Oldman River began in the 1920s, with the construction of the Lethbridge Northern Irrigation District headworks, the downstream riparian forests were not significantly reduced during that period. The addition of larger reservoirs on the Waterton and St. Mary rivers has significantly altered the downstream hydrological regime and contributed to the reduction in abundance of riparian poplars along those rivers (Rood and Heinze-Milne 1989). The completion of the Oldman River Dam in 1991 means all major flow contributors to the Oldman River are controlled. This added control has improved the minimum flow condition for riparian poplars in the Oldman River, but has also reduced the frequency and magnitude of larger flows necessary for riparian poplar seedling recruitment.

3.5.3 Water Quality

The water entering and exiting the Oldman River Reservoir is generally of excellent quality. Levels of nutrients, bacteria, and pesticides are low, and levels of dissolved oxygen are high. The water is low in total dissolved solids and is relatively hard, with bicarbonate and calcium ions being the most abundant.

Water quality in the Oldman River changes as it leaves the foothills and flows through the prairies. Some of this change is the natural result of a fast flowing mountain stream becoming a slower, wider, meandering prairie river. The rest is due to human influence. Concentrations of nutrients, bacteria, and pesticides tend to increase with distance downstream from the dam, reaching a peak downstream of the City of Lethbridge.

There are eight wastewater treatment facilities in the basin that discharge effluent directly into the Oldman River. The largest of these, located in Lethbridge, was upgraded in 1999. This has significantly reduced the load of bacteria, nitrogen, and phosphorus contributed by the city to the river. Runoff from rural non-point sources requires further investigation.

Extensive monitoring of water temperatures and dissolved oxygen has occurred since the construction of the Oldman River Dam. Post-impoundment flows have resulted in an improvement in dissolved oxygen levels relative to historic conditions. Prior to impoundment, diel (24 hour) minima often fell to critically low levels between Monarch and the confluence of the Bow and Oldman rivers. Under the existing (post-impoundment) flow regime, the incidence of dissolved oxygen levels falling below the 5 mg/L Alberta Surface Water Quality Acute Guideline (Alberta Environment 1999) is far less frequent (Hazewinkel and Saffran 2002). Water quality within the Oldman River Reservoir is excellent and is suitable for all intended purposes (Mitchell 2001).

3.5.4 Geomorphology

The Oldman River is a gravel bed stream that flows through mountains, foothills and plains. At its confluence with the Bow in southern Alberta, the rivers become the South Saskatchewan. The Oldman River has an elevation of 3,300 m above sea level at its headwaters in the mountain ranges, dropping to about 700 m at the confluence with the Bow River.

The upper Oldman River basin, above Brocket, is comprised of four major physiographic units: the Rocky Mountain front range and border ranges (the mountains); the Southern Foothills; the Cardston Plain; and the Porcupine Hills Upland.

The lower Oldman River moves through mostly cultivated till plain. The Oldman River and its valley features are summarized in Table 3.11.

Table 3.11. Geographic characteristics of the Oldman River and river valley.

	Oldman River Geographic Features (from Kellerhals et al. 1972)									
Location	General Setting	Valley features			Channel features, environment and processes					Bankfull conditions (valley flat level)
(water survey of Canada Index Number)	Terrain surrounding valley	Description	Depth [ft]/ Top width [mi]/ Bottom width [mi]	Terraces	Description of valley flat/ Width [mi]	Channel pattern	Relation of channel to valley	Sinuosity/ Wave length/ Belt width [mi]	Lateral activity/ Lateral stability	Dschge (cfs)/ Stage (ft)/ Return Period (yrs)
near Waldron's Corner 05AA023	Foothills, partly cultivated or open range.	Stream-cut valley in wide valley, grass-covered valley walls.	100 0.60 0.40	Several continuous levels.	None	Irregular, with tumbling flows; diagonal bars; boulders.	Entrenched	1.30 - -	Entrenched loop development. Slightly unstable.	--
near Cowley 05AA001	Mainly cultivated foothills.	Stream-cut valley, valley walls grass-covered.	150 0.35 0.15	One continuous level. Valley flat might be low terrace.	Fragmentary and of mod. extent; grass-covered or sparsely for., no cult. 0.08	Irregular, with tumbling flows; diagonal and side bars.	Not obviously degrading or aggr., confined.	1.20 - -	Slightly unstable.	--
near Brocket 05AA024	Plain with lacustrine and till deposits, open range and partly cultivated.	Stream-cut valley, widening in reach. Valley walls shrub and grass-covered.	150 0.50 0.35	Several fragmentary levels.	Continuous and of moderate extent, sparsely forested or shrub-covered. 0.20	Sinuous, with occasional islands, pool and riffle sequence, mid-channel and diagonal bars.	Not obviously degrading or aggr., frequently confined.	1.30 - -	Slightly unstable.	18,000 8.4 8.6
near Fort MacLeod 05AB007	Mainly cultivated plain.	Stream-cut valley. Valley walls shrub or grass-covered.	50 0.70 0.35	Several continuous levels.	Continuous and of mod. extent, sparsely forested or shrub-covered. 0.20	Sinuous, with occasional islands, pool and riffle sequence; diagonal transverse and side bars.	Not obviously degrading or aggr., occasionally confined.	1.20 - -	Moderately unstable.	17,200 9.2 3.7
near Monarch	Mainly cultivated till plain.	Stream-cut valley with bare or grass-covered valley walls.	175 0.30 0.20	Several continuous levels.	None	Irregular with occasional islands; diagonal and mid-channel bars, long straights.	Entrenched	1.40 - -	Entrenched loop development. Stable.	--
Lethbridge 05AD007	Cultivated and urbanized plain.	Stream-cut valley, occasional slumps.	300 0.80 0.40	One fragmentary level.	Continuous and of moderate extent; sparsely forested, no cultivation. 0.25	Irregular with frequent islands; pool and riffle sequence; diagonal and side bars.	Not obviously degrading or aggr., confined.	1.40 - -	Slightly active.	61,000 17.1 9.1
Mouth 05AG006	Plain, partly cultivated or open range.	Stream-cut valley in wide valley, occasional slumps, valley walls grass-covered.	200 1.00 0.60	Several continuous levels; slip-off slopes.	None	Irregular meanders with occasional islands; pool and riffle sequence; mid-channel bars, boulders.	Entrenched	1.30 1.80 0.50	Entrenched loop development. Stable.	--

3.6 Southern Tributaries

The Belly, Waterton, and St. Mary rivers are commonly referred to as the Southern Tributaries of the Oldman River.

The Belly River flows for approximately 200 km, of which 181 km are in Canada. Of these, 170 km occur downstream of the Waterton Lakes National Park/Blood Timber Reserve boundary. The river flows through foothills and prairie to its confluence with the Oldman River. Over this distance, the physiography and ecology of the river change dramatically. A distinct transition from cold to cool-water aquatic habitat is apparent, and the Belly River therefore supports a diverse game fish population of both cold and cool-water species. The Belly River is a relatively small tributary of the Oldman River. Its peak weekly flow averages only about 40 m^3/s; less than half the flow of the Waterton or St. Mary rivers. Despite this disparity in magnitude of flow, the Belly River floodplain is at least as wide, or wider than those of the Waterton and St. Mary rivers (Table 3.14). Along most of its length, the channel of the Belly River freely meanders within its wide floodplain, whereas the Waterton and St. Mary river channels tend to be more constrained.

The Waterton River flows for approximately 100 km within Alberta. It is bordered by open rangeland in the foothills. Irrigated, cultivated fields surround the Waterton Reservoir and the river downstream of the dam. Upstream of the reservoir, the Waterton River is a clear, cold, fast-flowing, unregulated mountain stream. Downstream of the reservoir, the river is warmer and slower. Natural annual peak weekly flows for the Waterton River average about 80 m^3/s, about twice the magnitude of those along the nearby Belly River. However, the width of the Waterton River floodplain is approximately equivalent to that of the Belly (Table 3.12).

Discharges are regulated at the Waterton Dam (since 1964) to meet local irrigation demands and maximize the contribution to the SMRID farther east. Although the Waterton Dam does not substantially attenuate high peak flows, it has caused significant reductions to moderate and lower flows and abrupt reductions following high flood peaks. Flow patterns downstream from the Waterton Dam mainly resemble a diversion-affected flow regime, however, the operation of the Waterton Reservoir can supplement natural low flows later in the season.

The St. Mary River flows for approximately 163 km in Alberta. The river’s annual peak weekly flow of approximately 90 m^3/s is comparable to that of the Waterton and about twice that of the Belly River. The upper third of the St. Mary River channel (from the Canada/US border to the confluence of Lee Creek) is mostly freely-meandering, within a moderately wide floodplain comparable in dimensions with that of the Waterton and Belly rivers. The St. Mary’s flow regime has been regulated by small weirs since the turn of the century, but significantly more flow control was added in 1951 when the St. Mary River Dam became operational. The size of the St. Mary Reservoir allows it to store a considerable portion of the river's flow, but peak flood flows have not been dramatically altered (Rood et al. 1995). In contrast, the St. Mary River Dam causes significant flow reductions during average flow years, and extreme reductions during low flow years. Operation of the St. Mary River Dam has also caused abrupt reductions in flow immediately following peak flows.

3.6.1 Fisheries Resources

Belly River

Between the Belly River diversion weir and its confluence with the Oldman River, the Belly River is considered cool water aquatic habitat and supports a mixed warm and cold water fish population. Longmore and Stenton (1981) report that mountain whitefish are common in this portion of the Belly River, but other cold-water species, specifically trout species, are rare. Cool water species include northern pike, sauger, and lake whitefish. Pike are especially numerous in the lower reaches of the river, near the mouth. Although streamflow is somewhat greater through this lower portion of the Belly River than through upstream reaches, fish production is relatively low (Longmore and Stenton 1981).

Waterton River

The Waterton Dam, completed in 1964, is a permanent blockage to fish movements along the river. During periods when water is not spilled, all the streamflow passes through control valves. Regulated discharges to the Waterton River during the irrigation season are considerably less than natural streamflow. Irrigation water abstractions at individual pump sites along the river further reduce instream flows. Habitat available during these extremely low discharges is not adequate to maintain a productive fish population (Longmore and Stenton 1981).

Warmer water temperatures and slower flows in the Waterton River downstream of the reservoir result in a mixed warm and cold water species population. Mountain whitefish is the most abundant species, but northern pike and lake whitefish are also common. A few trout also inhabit this section of the river.

Water returned to the Waterton River from irrigated fields may carry significant amounts of silt eroded from unprotected earth irrigation canals. At times, infusion of this silty water during the irrigation season causes high turbidity in the river downstream of the reservoir (Longmore and Stenton 1981). As the silt gradually settles, it can negatively affect the fish populations if it covers food sources or spawning areas.

St. Mary River

Low water levels on the St. Mary River due to flow diversion greatly reduce fish living space, shelter areas, food sources, and spawning sites. The extensive loss of habitat lowers fish productivity accordingly. Low discharges also lessen the capability of the river to flush away accumulating silt, nutrients and pollutants. Furthermore, the St. Mary River Dam is a permanent blockage to upstream fish movements. During periods when water is not spilled, all the streamflow passes through control valves.

3.6.2 Riparian Resources

Belly River

Dawson (1885) reported moderate to very dense riparian woodlands along the upper part of the Belly River and scattered groves in the middle portion, upstream of the confluence with the Waterton River (Appendix B, Table 3.12). About 50 years later, in 1935, the Belly River diversion weir (BRDW) became operational. After more than 50 years of flow-regulation, downstream cottonwoods have remained relatively healthy and their abundance along previously sparse reaches has even increased (Table 3.13).

Table 3.12. Assessment of riparian forest abundance along the southern tributaries in the 1880s, 1950s, 1980s, and late 1990s using historic surveys and aerial photographs.

Current Study Reach Code	Reach:	-----------1980s-----------			Riparian Poplar Density:				General Change 1880-1999
		Length (km)	**Floodplain Width (m)**	**Channel Type**	**1880s**	**1950s**	**1980s**	**1997-99**	
N/A	SM1	25.4	300-700	FM	3 to 5		4	4	
SM1&SM2	SM2	115.51	200-(1000)	CM	2		1	1	**less dense**
N/A	BL1	28.82	300-500	FM	3 to 5		3	3	**less dense**
BL2&BL3	BL2	48.81	500-1200	FM	2		5	5	**more dense**
BL1	BL3	37.59	1000-1500	FM-BR	3 to 5		4	4	
BL1	BL4	34.74	700-1500	FM	3 to 5		3	3	**less dense**
W1&W2	W1	75.31	500-700	FM	3 to 5		3	3	**less dense**

(1880-1980 content adapted from Bradley et al. 1991)

Channel Type categories:
FM = freely meandering ST = straight
CM = confined meandering BR = braided

Density categories:
1 = none / negligible
2 = sparse 4 = dense
3 = moderate 5 = very dense

Diversion at the BRDW has caused reductions to downstream flows typical of diversion-affected flow regimes. Because the BRDW is a relatively small structure, compared with the major dams on the Waterton and St. Mary rivers, the weir has had relatively little effect on high springtime peak flows, such as occurred in 1975. However, the weir has had a relatively greater impact on moderate and low flows throughout the growing season.

It is not known when the sparsely forested reach reported by Dawson in the 1880s (Appendix B) became the relatively dense woodland observed in air photos taken since 1950 (Table 3.12). Therefore, one cannot ascribe the increase to BRDW operations. Research has concluded that woodlands along the upstream reach of the Belly River have remained generally unchanged since the 1950s (Rood and Heinze-Milne 1989, Rood et al. 1995). Along the downstream reach, Reid et al. (1992) examined differences in general canopy health and stand composition between 1951 and 1990. They reported that apparent woodland increases were due largely to the expansion of closed canopy communities (Figure 3.7). They also observed that up to 15% of the poplars along the downstream reach exhibited some crown dieback and were decidedly less healthy than those along the upstream reach.

The exact role flow-regulation has played in changing riparian woodland abundance and health downstream from the BRDW is not completely understood. The expansion of existing woodlands and the increase in closed-canopy type stands suggest that the magnitude of flow-reductions downstream from the BRDW has not caused acute or lethal drought stress. However, the widespread symptoms of branch dieback indicate a more chronic level of drought stress. Simultaneous observations of both expansion and drought-stress suggest the forest is becoming adjusted to the new, regulated pattern of streamflow. These adjustments might include root elongation by established poplars to reach a lowered water table, and sucker or seedling colonization of the floodplain substrates revealed by lowered flows.

Table 3.13. A) Changes to cottonwood abundance in the Oldman River Basin from the 1950s to the 1980s, along reaches upstream (upper) and downstream (lower) from the Belly River diversion weir, Waterton River Dam, and St. Mary River Dam. The standard error for lineal measures is approximately 5% and for area measures is about 20% (bolded values indicate highly significant changes). **B)** Summary of magnitude of changes in cottonwood abundance using ranked categories (>10% = +2, 10 to 5% = +1, 5 to -5% = 0, -5 to -10 = -1, -10 to -20 = -2, <-20% = -3).

A)	**Percent change in the abundance of cottonwoods**					
	non-regulated reaches			**regulated reaches**		
	UBEL	UWAT	USTM	LBEL	LWAT	LSTM
Rood & Heinze-Milne 1989						
- 2D area (1961 to 1981)	-4.6	-6.1	-4.7	-0.1	**-22.9**	**-47.8**
Reid et al. 1992						
- lineal distance (1951-1985)	-7.4	-5.8	-7.2	+0.4	-9.0	**-73.7**
- lineal distance (1961-1981)	-4.5	-8.0	-7.1	-0.9	**-20.4**	**-45.4**
- 2D area (1951 to 1990)	-13.1	+4.7	-4.8	**+21.2**	+2.6	**-40.0**
Rood et al. 1995						
- 2D area (1951 to 1985)	-9.1	+1.9	-0.5	**+52.2**	+3.5	**-61**
- lineal distance (1951 to 1985)					-9.0	**-68**

B)	**Ranked change in abundance:**					
	UBEL	UWAT	USTM	LBEL	LWAT	LSTM
lineal distance:	-1	-1	-1	0	-2	-3
2D area:	-1	0	-1	+2	-1	-3
absolute value of total:	2	1	2	2	3	6
extent of change:	moderate	slight	moderate	moderate	severe	extremely severe

UBEL = upper Belly River, LBEL = lower Belly River, UWAT = upper Waterton River, LWAT = lower Waterton River, USTM = upper St. Mary River, LSTM = lower St. Mary River.

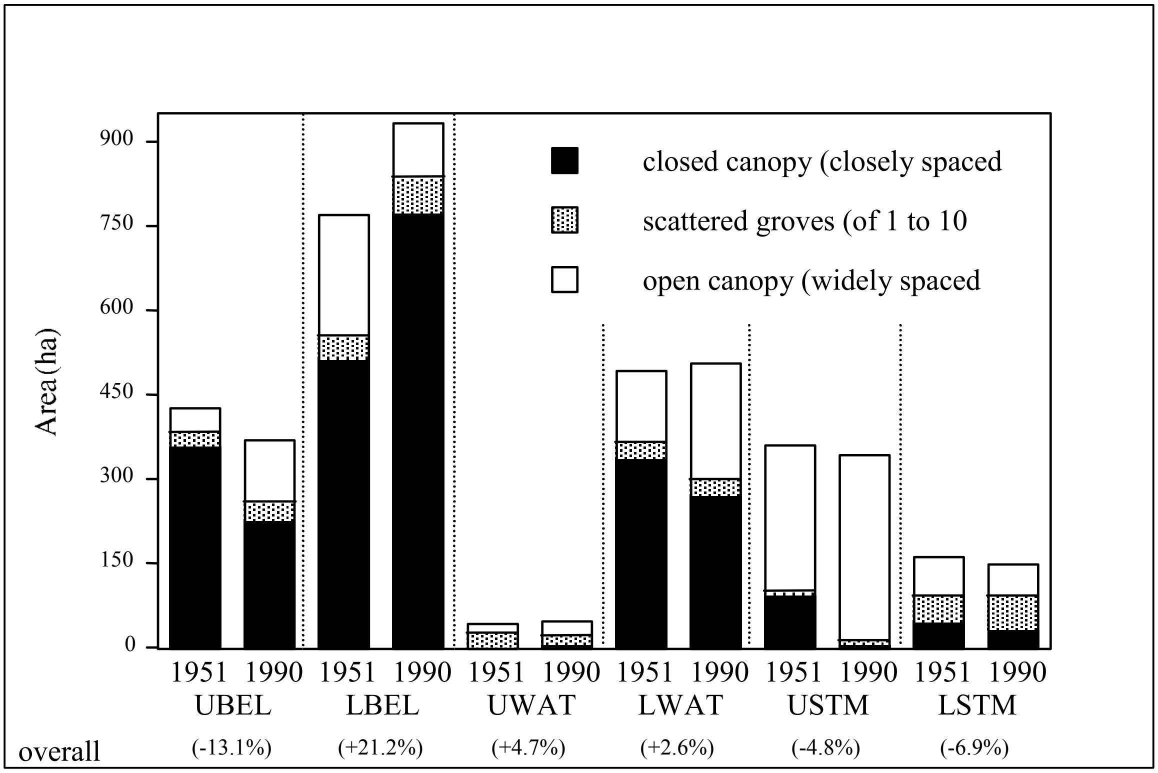


Figure 3.7. Changes in density of poplar communities from 1951 to 1990, as reported by Reid et al. (1992). (UBEL / LBEL = upper / lower Belly River, UWAT / LWAT = upper / lower Waterton River, USTM / LSTM = upper / lower St. Mary River).

Waterton River

In the 1880s, G.M. Dawson (1885) reported that riparian woodlands were present along the full length of the Waterton River (Appendix B). According to various researchers (Rood and Heinze-Milne 1989, Bradley et al. 1991, Reid et al. 1992, Rood et al. 1995), the extent and abundance of cottonwood forests has declined slightly upstream from the Waterton Dam and more severely downstream since that time (Table 3.12).

Reid et al. (1992) found that although the overall forested area remained relatively constant upstream and downstream of the reservoir from 1951 to 1990, the forest canopy downstream was becoming more open (Figure 3.7), suggesting gradual declines within established groves. They also reported that downstream poplars were generally less healthy, showing signs of both chronic and acute drought stress. Other field surveys made between 1988 and 1991 also reported considerable branch and crown die-back and numerous decrepit groves (Rood et al. 1995).

Based on these assessments, the regulated flow regime below the Waterton River Dam is believed to have had moderate negative impacts on the downstream cottonwood forest. Signs of chronic drought stress together with declines in canopy vigour suggest that flows have been inadequate during the cottonwood growing season. Signs of acute drought stress and general declines in forest abundance indicate that flow reductions during naturally dry years, such as 1977, have occasionally dropped streamflow below the minimum needed to support cottonwood survival.

In addition to affecting mature trees, regulated flows downstream from the Waterton Dam are also probably interfering with cottonwood regeneration processes. Although peak flows have not been substantially attenuated, the abrupt flow reductions following peak flows are not conducive to seedling establishment (Rood and Heinze-Milne 1989). Inadequate flows during the summer period are also likely to cause drought stress and mortality of any new seedlings. The long-term effects of reduced seedling-based replenishment, although not currently obvious, can significantly impact cottonwood forest populations.

St. Mary River

In the 1880s, G.M. Dawson (1885) reported that riparian woodlands occurred continuously along the upper part of the St. Mary River and along Lee Creek. However, they were scattered and sparse along the lower part of the St. Mary River, downstream from the inflow of Lee Creek and upstream from the inflow of Pothole Creek (Appendix B). These basic differences in woodland abundances are likely related to the geomorphic constraints of floodplain availability, but may also be accentuated by the increasingly semi-arid climate along the downstream reach (Figure 3.6). This would make the lower portion of the St. Mary River intrinsically less hospitable to riparian forests. Thus, this reach appears to be only marginally suitable for riparian forests, making these populations especially vulnerable to alterations of streamflow.

Reductions to riparian cottonwood forest abundance downstream from the St. Mary River Dam have been widely documented (Rood and Heinze-Milne 1989, Bradley et al. 1991, Reid et al. 1992, Rood et al. 1995). Forest declines ranging from 50% to more than 70% (Table 3.13) have occurred incrementally since 1951 (Rood et al. 1995). The progressive nature of this decline suggests that chronic drought stress is involved. Additionally, the rapid rate of decline, relative to the long lifespan (greater than 100 years) of cottonwoods, indicates that the severity of the drought stress has also been acute, causing accelerated mortality of mature trees. Combined chronic and acute drought stresses have probably resulted from excessive reductions to natural flow levels across the full range of exceedence. Because the moisture requirements for recruitment of seedlings and survival of saplings are even more stringent than for mature tree survival, it is reasonable to postulate that replenishment has also been minimal during this period (Rood et al. 1995).

3.6.3 Water Quality

Belly River

Agriculture, including the growing of cereal crops, grazing, and confined feeding operations, is the main human activity in the Belly River basin (WQA 1989). There are no major urban centres that discharge to the Belly River, however, the small municipality of Glenwood, discharges treated wastewater twice annually from their wastewater lagoon to the Belly River. The impact is not considered to be significant (Shaw 1994).

The water in the Belly River is moderately hard and clear. Water in the upper Belly at Highway 6 is dominated by calcium, bicarbonate, and to a lesser degree, magnesium ions. Near the confluence, the relative contribution of sulphate ions increases, which could indicate the presence of groundwater and tributary inflows or irrigation return flows (Shaw 1994).

Data from 1990 were used in water quality modelling. The maximum instream temperature for the Belly River at Highway 2 was 26.4° C; the maximum daily range was 4.69° C. In 1990, water temperature at this site exceeded the adult acute criteria for rainbow trout and mountain whitefish (24° C; Taylor and Barton 1992) on 23 days from July to mid August. The minimum

DO concentration was 6.01 mg/L and the maximum daily dissolved oxygen flux (diurnal variation) was 5.55 mg/L.

According to Shaw (1994), water quality in the Belly River is generally good. There are some exceedences of CCME water quality guidelines for Protection of Aquatic Life (CCME 2002), likely due to non-point source (NPS) surface runoff . More recent data, collected in 1998 to 2000 near the confluence with the Oldman River, suggests water quality is still generally good. For example, of more than 40 samples taken during that period, only two contained fecal coliform bacteria levels above the CCME Contact Recreation guideline of 200 CFU/100 ml. Nutrient and salt concentrations reported in recent data are generally low and do not significantly impact water quality in the Belly River, nor preclude any of the water uses for which guidelines are available: irrigation, stock watering, and protection of aquatic life.

Waterton River

Agriculture, including the growing of cereal crops, grazing, and confined feeding operations, is the main human activity in the Waterton Basin (WQA 1989). There are no major urban centres in this basin nor do any municipalities discharge treated wastewater into the Waterton River. The Shell-Waterton gas plant has a continuous discharge of treated process water and some surface runoff to Drywood Creek, a tributary to the Waterton River, but the impact of this to the Waterton River is rated as minimal (Shaw 1994).

The water in the Waterton River is moderately hard and clear. For example, water on the upper Waterton, at Highway 6, is dominated by calcium, bicarbonate, and to a lesser extent, magnesium ions.

Based on 1990 data, the maximum instream temperature reported in Shaw (1994) for the lower Waterton River, at Highway 810, was 23.1° C; the maximum daily range was 7.94 °C. Instream temperatures are partly affected by the extent of irrigation withdrawals during the open-water season. A gradual transition from cold to cool water aquatic habitat is apparent in the river downstream of the reservoir due to slower water velocities and the greater exposure to the sun. Near the dam, summer water temperatures averaged only 13.3^0 C in 1980, but near the confluence of the Waterton and Belly rivers, average summer water temperatures exceeded 16^0 C.

The minimum DO concentration recorded at the Highway 810 site in the summer of 1990 was 7.31 mg/L. The maximum daily dissolved oxygen flux (diurnal variation) was 4.34 mg/L (Shaw 1994). Dissolved oxygen levels usually vary more in rivers and river reaches subject to organic loadings from anthropogenic sources.

According to Shaw (1994) water quality in the Waterton River is generally good. There are some exceedences of CCME water quality guidelines for Protection of Aquatic Life (CCME 2002), likely due to non-point source runoff.

St. Mary River

Agriculture, including the growing of cereal crops, grazing, and confined feeding operations, is the main human activity in the St. Mary River Basin (WQA 1989). There are no major urban centres discharging to the St. Mary River. The towns of Magrath (lagoon, twice per year discharge) and Cardston (continuous discharge) discharge treated municipal effluent into the river, but with little impact (Shaw 1994).

The water in the St. Mary River is moderately hard and clear. It picks up salts along its course, some of which is a natural occurrence in all rivers. Water in the upper St. Mary, at the USA –

Alberta boundary, is dominated by calcium, bicarbonate and, to a lesser extent, magnesium ions. Near the confluence with the Oldman River, the relative contribution of sodium and sulphate ions increases, possibly indicating groundwater and tributary inflows or irrigation return flows (Shaw 1994).

Data from 1990 were used in water quality modelling. The maximum instream temperature for the St. Mary River, west of Raymond, was 27.37° C; the maximum daily range was 8.15 °C. In 1990, water temperature at this site exceeded the acute criteria for adult rainbow trout and mountain whitefish (24° C) on 29 days, from July to mid-August; and for brown trout (27° C) on one day in mid-July. The minimum DO concentration was 5.23 mg/L and the maximum daily dissolved oxygen flux (diurnal variation) was 5.86 mg/L. Instream temperatures are partly affected by the extent of irrigation withdrawals during the open-water season. Dissolved oxygen levels usually vary more in rivers subject to organic loadings from anthropogenic sources.

A review of the 1990 summer temperature and DO values in the southern tributaries showed that the highest temperatures, lowest DO values, and largest diurnal variation in temperature and DO occurred in the St. Mary River, followed by the Belly and Waterton rivers respectively. This suggests that of the three rivers, the St. Mary River is likely the most impacted by anthropogenic activities, in particular those related to flow management as this is the major activity affecting river flow. Based on temperature and DO data, the Waterton River is the least impacted of the three southern tributaries.

According to Shaw (1994), water quality in the St. Mary River, other than temperature and DO variables, is generally good. There are exceedences of CCME water quality guidelines for Protection of Aquatic Life (CCME 2002) for some metals, phenols and fecal coliform levels. These are likely due to non-point source runoff. NPS runoff is not well understood in the southern tributaries. It is not known if the impacts are due to human activities or to natural processes. The relationship between NPS runoff and river discharge is also not well defined (Shaw 1994).

More recent data (1998 to 2000) collected from the St. Mary River, near the confluence with the Oldman River, suggest water quality is still generally good. Similar to the data from near the mouth of the Belly River , fecal coliform bacteria levels were above the CCME Contact Recreation guideline of 200 CFU/100 ml only twice in more than 40 samples. Nutrient and salt concentrations in the recent data are generally low and do not significantly impact water quality in the St Mary River, nor preclude any of the water uses for which guidelines are available: irrigation, stock watering, and protection of aquatic life.

3.6.4 Geomorphology

Belly River

The Belly River, near Mountain View, is in foothills terrain with open range or moderately forested reaches. There is a general absence of cultivation in this area. The river's valley is stream-cut, with grass-covered valley walls. The valley depth is 15 m, with a top width of 400 m and a bottom valley width of 160 m. There are two continuous terraces in the valley.

In the vicinity of Standoff, the Belly River is in a lacustrine plain with open range and adjacent partly cultivated lands. The valley at this location is about 30 m deep, with a top width of 1.1 km and a bottom width of 0.90 km. Two continuous levels of terraces also exist at this location.

The Belly River changes from an irregular channel, with occasional islands through upstream reaches, to a more sinuous channel at Standoff. The channel bed is gravel throughout, although the channel bank changes from sand and gravel upstream of the Belly River diversion weir to sand and silt near Standoff. The channel slope varies from 0.0080 near Mountain View to 0.0017 at Standoff.

Waterton River

The Waterton River, near Waterton Lakes National Park, is set in the foothills with adjacent open range. The Waterton River, downstream of the dam, winds across the flat, arid prairie. Water flows slowly in pools and riffles through a broad, gravel-bottomed channel interspersed with occasional islands and bars. Near Standoff, the river valley cuts through a mainly cultivated lacustrine plain.

The river valley at both the park and Standoff is stream-cut in a wide valley, with a valley depth of approximately 15 m. The channel pattern is sinuous. The channel is entrenched near Waterton Lakes National Park and is frequently confined near Standoff. At both locations, the channel bed is predominantly gravel. The channel banks vary from gravel and sand along the upstream reach, to silt overlain by gravel near the confluence with the Belly River. The channel slope varies from 0.0019 to 0.0025 in the two reaches. Near its mouth, the Waterton River is approximately 67 m wide with a mean water depth of 0.8 m (Kellerhals et al. 1972).

St. Mary River

The reach of the St. Mary River near the international boundary is in foothills flowing through partially cultivated terrain. Near Lethbridge, the river is in the plains region, with adjacent open range and cultivated lands.

The river valley is stream cut, with grass or forest covered valley walls. It has several continuous terrace levels at both the international boundary and the mouth. Downstream of the St. Mary reservoir, the St. Mary River flows in broad loops through an entrenched valley 30 to 60 m deep, as it progresses across the flat, arid prairie to its confluence with the Oldman River. Occasional islands and side-bars intrude into the gravel-bottomed channel. The river averages 57 m in width near Lethbridge.

The riverbed is gravel throughout its length, and the riverbanks are sand and gravel. The channel slope varies from 0.0040 to 0.0020 near Lethbridge. Due to flow regulation and irrigation abstractions, mean water depth is only 0.6 m near Lethbridge (Kellerhals et al. 1972).

The geographic characteristics of the Belly, Waterton and St. Mary rivers and their valleys are provided in Table 3.14.

Table 3.14. Geographic characteristics of the southern tributaries of the Oldman River.

Location (water survey of Canada Index Number)	Southern Tributaries Geographic Features (from Kellerhals et al. 1972)									
	General Setting	Valley features			Channel features, environment and processes					Bankfull conditions (valley flat level)
	Terrain surrounding valley	Description	Depth [ft]/ Top width [mi]/ Bottom width [mi]	Terraces	Description of valley flat/ Width [mi]	Channel pattern	Relation of channel to valley	Sinuosity/ Wave length/ Belt width [mi]	Lateral activity/ Lateral stability	Dschge (cfs)/ Stage (ft)/ Return Period (yrs)
Belly River near Mountain View 05AD005	Foothills, open range or moderately forested, no cultivation.	Stream-cut valley, valley walls grass-covered.	100 0.25 0.10	Two continuous levels.	Fragmentary and narrow; covered with shrubs. 0.04	Irregular with occasional islands; tumbling flow; diagonal and mid-channel bars.	Entrenched and confined.	1.50 - -	Moderately unstable.	--
Belly River near Stand Off 05AD002	Lacustrine plain and prominent glacial spillway; open range and partly cultivated.	Stream-cut valley, grass-covered or bare valley walls.	100 0.70 0.55	Two continuous levels, lower one corresponds to valley flat.	Continuous and of moderate extent; mod. Forested or shrub-covered. 0.08	Sinuous, but almost tortuous beyond reach, pool and riffle sequence, diag. and point bars.	Not obviously degrading or aggr., occasionally confined.	1.20 - -	Mainly cut-offs. Moderately unstable.	6,300 8.3 59
Waterton River near Waterton Park 05AD003	Foothills, mainly open range.	Stream-cut valley in wide valley, valley walls shrub and grass-covered	- - 0.10	Several fragmentary levels, ill defined.	None	Sinuous with occasional islands; tumbling flow; boulders.	Entrenched.	1.20 -	Stable	--
Waterton River near Stand Off 05AD008	Large glacial spillway in lacustrine plain, mainly cultivated.	Stream-cut valley in wide valley.	50 0.20 0.10	Several indefinite levels, lowest corresponds to valley flat.	Continuous and of moderate extent; sparsely forested or shrub-covered. 0.10	Irregular, with occasional islands, pool and riffle sequence, diag. and point bars.	Not obviously degrading or aggr., frequently confined.	1.30 - -	Downstream progression. Moderately unstable.	--
St. Mary River at Cook's Ranch 05AE001 International Boundary 05AE027	Foothills, partly cultivated or open range.	Stream-cut valley, occasional slumps, valley walls grass or forest covered.	200 0.50 0.10	Several continuous levels.	Fragmentary and narrow; uncultivated and sparsely forested. 0.05	Irregular with occasional islands; pool and riffle sequence; diag. and mid-channel bars.	Partially entrenched and confined.	1.40 - -	Entrenched loop development. Moderately unstable.	--
St. Mary River Near Lethbridge 05AE006	Plain, partly cultivated or open range.	Stream-cut valley, occasional slumps, valley walls grass-covered or forested.	100 0.40 0.20	Several continuous levels.	Fragmentary and of moderate extent; uncultivated and grass vegetated. 0.08	Irregular meanders with occasional islands; pool and riffle sequence; diag and side bars.	Partly entrenched and confined.	1.80 1.00 0.40	Entrenched loop development. Slightly unstable.	17,300 10.1 >100

3.7 South Saskatchewan River Basin

The Bow and Oldman Rivers join at the Grand Forks, approximately 100 km upstream of Medicine Hat, to form a short section of the South Saskatchewan River in southeastern Alberta. The river flows in a wide, deep valley through prairie farmlands. Downstream of Medicine Hat, the river flows through the largest contiguous area of intact prairie grassland in western Canada, Canadian Forces Base (CFB) Suffield.

Human activities in the sub-basin include oil and gas development, a variety of industrial developments, mixed farming, and the military activities at CFB Suffield. Dense algae growth and low flow conditions have been recorded at the City of Medicine Hat.

3.7.1 Fisheries Resources

The South Saskatchewan River provides the major portion of the habitat for lake sturgeon in Alberta. The Grand Forks area is the only known lake sturgeon spawning area in the South Saskatchewan River (R.L. & L. 1994). Radio telemetry studies conducted with lake sturgeon have indicated major over-wintering habitats occur in the Rattlesnake and Boundary areas (R.L. & L. 1997). Other critical habitats may also occur within the portion of the river contained within the boundaries of the CFB. However, this area has not received sufficient sampling to date. Protection of nursery habitats for young-of-year sturgeon may be as important as protecting spawning sites. Information on the trans-boundary (Alberta/Saskatchewan) movements of all stages of the life cycle of lake sturgeon is required to complete management plans for this unique species.

Sauger and walleye utilize major over-wintering habitats in the South Saskatchewan River. During the spawning period, they move throughout the system; migrations into the lower sections of the Red Deer River and the Bow River have been recorded (R.L.& L. 1997).

3.7.2 Riparian Resources

The South Saskatchewan River supports a markedly different population of cottonwoods than portions of the Oldman and Bow rivers that occur immediately upstream. The plains cottonwood (*Populus deltoides*) dominates along the South Saskatchewan River, whereas the balsam poplar (*P. balsamifera*) and narrow leaf cottonwood (*P. angustifolia*) are found to the north and west. The plains cottonwood is a relatively fast-growing tree, with a short life span of 100-150 years (Cooper and VanHaverbeke 1990). Although Brayshaw (1965) reports the occurrence of poplar hybrids throughout the South Saskatchewan River, the frequency of hybrids is progressively reduced downstream from the confluence of the Oldman and Bow Rivers. Riparian forests are essentially pure *P. deltoides* from the City of Medicine Hat and downstream (Rood and Kalischuk 2003).

The riparian cottonwood ecosystem of the South Saskatchewan River is perhaps the least studied of all the reaches in the South Saskatchewan River Basin. Bradley et al. (1991) measured change in forest abundance from the 1880s to the 1980s for the reach between the Grand Forks and the City of Medicine Hat (SS1). Reid (1991) reported on the condition of perhaps the most extensive part of the forest, found at Police Point in the City of Medicine Hat. Usher and Strong (1994) completed detailed inventory work along the reach within CFB Suffield as part of the proposed Suffield National Wildlife Area. Most recently, an assessment of riparian forest condition and recruitment following the large flow event of 1995 was completed (Rood and Kalischuk 2003).

The riparian forest of the South Saskatchewan River has not changed substantially since first reported by Dawson (1885) (Gom and Mahoney 2002). In general, cottonwoods are sparse along the entire South Saskatchewan River with a few notable exceptions. Large groves of cottonwoods can be found at the confluence of the Bow and Oldman Rivers, Police Point Park in the City of Medicine Hat, and Sherwood Forest on CFB Suffield (Bradley et al. 1991, Usher and Strong 1994, Rood and Kalischuk 2003).

Despite the discontinuous nature of the forests, the trees that are present are in good condition, suggesting that current flow conditions are adequate to sustain the existing trees (Rood and Kalischuk 2003). However, there was a lack of significant seedling recruitment in the latter half of the 1900s until 1995. Seedling replenishment may be a naturally uncommon event along the South Saskatchewan River, with long-term occurrences only once in every 5-10 years (Braatne et al. 1996, Mahoney and Rood 1998). However, research indicates that significant diversion of streamflow can further reduce the occurrence of recruitment events (Rood and Mahoney 1990). The reduction of recruitment events will lead to the decline of forest abundance (Rood and Heinze-Milne 1989). Although free of significant water management diversions itself, the cumulative impact of water management programs in both the Oldman and Bow sub-basins appears to have contributed to a reduction in recent seedling recruitment opportunities along the South Saskatchewan River (Rood and Kalischuk 2003). Rood and Kalischuk (2003) also report the successful initial establishment of extensive cottonwood seedlings along the South Saskatchewan River following the high flow event of 1995 and subsequent high flow years of 1996 and 1997.

Plains cottonwood relies heavily on sexual (seedling) reproduction as the primary means of recruitment. The trees rarely reproduce by root suckering or by branch propagation, but may reproduce asexually by shoot suckering from stumps (coppice growth) (Bradley 1982, Gom and Rood 1999). The dependence of successful seedling recruitment on suitable streamflows (Mahoney and Rood 1998) can have serious implications on the long-term viability of the riparian forests along reaches with heavily altered flow regimes, such as the South Saskatchewan River. Even limited clonal propagation may be important in sustaining forest abundance until a more suitable flow regime is restored.

The substrates along the banks of the South Saskatchewan River are relatively fine, consisting of clay, silt and sand (Kellerhals et al. 1972). These substrates are ideal for supporting cottonwood seedling recruitment (Bradley and Smith 1986). The river follows a generally meandering pattern, but is often constrained within sandstone and shale canyons. These canyons limit floodplain size and the rate of meandering (Table 3.15). This results in a paucity of sites suitable for seedling recruitment on an ongoing basis and has probably contributed to the current sporadic riparian forest distribution.

Table 3.15. Assessments of riparian forest abundances along the South Saskatchewan River in the 1880s, 1950s, 1980s, and late 1990s using historic surveys and aerial photographs.

Current Study Reach Code	Reach:	-----------1980s-----------			Riparian Poplar Density:				General Change 1880-1999
		Length (km)	Floodplain Width (m)	Channel Type	1880s	1950s	1980s	1997-99	
SS1&SS2	S1	197.20	200-3000	ST-FM-CM	2	2	2	2	
SS1	S2	35.95	200	ST		1	1	1	
SS1	S3	54.89	200-750	ST-CM		1	2	1 to 2	denser

(1880-1980 content adapted from Bradley et al. 1991)

Channel Type categories:
FM = freely meandering
ST = straight
CM = confined meandering
BR = braided

Density categories:
1 = none / negligible
2 = sparse
3 = moderate
4 = dense
5 = very dense

3.7.3 Water Quality

Water quality in the South Saskatchewan River is generally good, depending primarily on the quality of the lower Bow and Oldman Rivers. Industrial and municipal discharges at Medicine Hat have relatively minor effects on the water quality of the South Saskatchewan River.

3.7.4 Geomorphology

The general setting of the South Saskatchewan River valley is in a mainly cultivated plain. Through the City of Medicine Hat, this plain is urbanized. Downstream from the Medicine Hat the river flows through a plain that is partly cultivated and partly open range. The river valley is stream-cut, with sparsely forested valley walls and with occasional slumps through Medicine Hat. It is approximately 90 m deep, and 2.9 km wide at the top and 1.9 km wide at the bottom. The river channel meanders irregularly, with occasional islands, mid-channel and point bars, and is partly entrenched and frequently confined. Downstream from Medicine Hat at Highway #41, the river is entrenched with a sinuous channel containing occasional islands and point bars. The river bed through Medicine Hat and downstream is sand and gravel. The bank materials are gravel over silt, silt and sand, or till.

4.0 ECOLOGICAL BASIS OF FLOW REGIMES FOR AQUATIC RESOURCES

4.1 The Aquatic Ecosystem and Biological Diversity

To place the IFN work in context, the ecological basis for the establishment of instream flows to provide suitable conditions for the protection and enhancement of aquatic species must be understood. Flowing aquatic ecosystems are complex. Even the simplest watershed is made up of many physical, biological and chemical components, and the interactions among these components are very intricate. Ecosystem degradation can occur when watersheds are disturbed by any of a variety of activities, including de-vegetation, agricultural activities, urbanization, or water management projects such as dams, weirs, water withdrawals, and stream channel modifications. These disturbances are potential threats to the biological diversity or ecological integrity of aquatic ecosystems.

Hughes and Noss (1992) defined biological diversity as “the variety of life and its processes.” This definition encompasses genetic, species, assemblage, ecosystem, and landscape levels of biological organization. It has structural, compositional, and functional components.

Goldstein (1999) states that ecological integrity

> *“includes a critical range of variability in biodiversity, ecological processes and structures, regional and historical context, and sustainable cultural practices.”*

Most definitions of diversity or integrity include elements at three levels: genetic, taxonomic and ecosystem. They also include structure, function, processes, and aspects of naturalness. There is a strong message in these definitions that there is a real need to address human impact on rivers and streams at a broader ecosystem level, rather than focusing solely on fish habitat or water quality.

Providing an instream flow needs determination to protect the aquatic ecosystem should be based on the Natural Flow Paradigm (Poff et al. 1997, Richter et al. 1997). The Technical Team used this approach to address as many components of the aquatic ecosystem as possible, within the constraints of the information available at the time of this report. The Natural Flow Paradigm does not imply that the natural flow is recommended at all times. It does indicate that the natural variability of flow in terms of magnitude, duration, frequency and timing is beneficial to the ecosystem.

4.2 Instream Flows in the Context of Riverine Ecology

River ecosystems create a temporally and spatially variable physical, chemical, and biological template within which fish and other aquatic resources can exist if they possess the proper suite of physiological, behavioural, and life history traits (Orth 1987, Poff and Ward 1990). This environmental template, in conjunction with species-specific life history traits, is often characterized as a multi-dimensional niche of environmental conditions (envelopes of depth, velocity, substrate, temperature) and resources (food, space) that describe the environmental necessities of species survival. Environmental conditions and resources must be available in suitable quantity, quality and timing to sustain a viable long-term population (Colwell and Futuyma 1971, May and MacArthur 1972, Pianka 1974, Statzner 1988).

Because a variety of factors and resources are required to meet the life history requirements of a species, the short- and long-term success of individuals, and ultimately populations, can be limited by a single factor or a combination of factors. In river systems, the suitability of environmental conditions for aquatic resources is directly related to the characteristics of the flow regime. Therefore, quantification of flow requirements that will provide for the long-term protection of the aquatic resources must be undertaken within an ecological framework and with an understanding of the flow-dependent environmental factors that may limit these resources.

In essence, an ecologically-based flow regime must incorporate the spatial and temporal flow conditions necessary to ensure long-term protection of the aquatic resources. The flow regime must maintain the linkages between the physical, chemical, and biological components of the river.

4.2.1 Ecological Principles

As a science, riverine ecology is relatively new. Many of the conceptual foundations of this new science were developed by studying highly regulated streams in Europe and North America (Ward et al. 2001). However, in recent years, the understanding of riverine ecology has expanded beyond the view of rivers as stable, single channel, longitudinal corridors that are often the result of regulation. The science now includes a more dynamic view of a natural stream channel that has complex interactions with its floodplain and groundwater zones (Ward et al. 2001). Despite the efforts of natural resource agencies to restore many regulated streams using mechanistic approaches, such as improving water quality, habitat mitigation, or the use of fish hatcheries, there continue to be widespread declines in fish populations, species diversity, and a host of other indicators of an aquatic ecosystem's sustainability (NRC 1992a, Independent Scientific Group 2000). It has been proposed that large-scale restoration of the biological integrity of an aquatic ecosystem cannot be achieved without restoring the functional integrity of a variable and dynamic flow regime (NRC 1992a, Independent Scientific Group 2000).

Poff et al. (1997) state that

> *"the natural flow regime of virtually all rivers is inherently variable and this variability is critical to ecosystem function and native biodiversity."*

During the past decade, the importance of preserving elements of the natural hydrograph as a means of protecting or restoring aquatic ecosystems has gained more attention in both the academic and natural resource management communities (Karr 1991, Hughes and Noss 1992, NRC 1992a, Stalnaker 1994, Castleberry et al. 1996, Frissell and Bayles 1996, Rasmussen 1996, Stanford et al. 1996, Poff et al. 1997, Richter et al. 1997, Bovee et al. 1998, Hardy 1998, Ward 1998, Goldstein 1999, Potyondy and Andrews 1999, Ward et al. 1999, Hughes et al. 2001, Ward and Tockner 2001, Annear et al. 2002, Bunn and Arthington 2002). The concept of the Natural Flow Paradigm is based on evidence suggesting that intra- and inter-annual flow variability, as related to the natural magnitude, timing, duration, frequency and rate of change of flows, is necessary for maintaining or restoring the native integrity of aquatic ecosystems (Richter et al. 1997). Richter et al. (1997) also conclude,

> *"if conservation of native biodiversity and ecosystem integrity are objectives of river management, then river management targets must accommodate the natural flow paradigm."*

This is not to say that the natural flow is best simply because it is natural; it is the pattern of flows that is important. Different components of the flow regime have distinct functions, and it is maintaining this functional diversity and interconnectivity that will result in both habitat diversity and species diversity (Ward and Tockner 2001). The natural variability of flows, both seasonally and from year to year, has shaped aquatic ecosystems for many thousands of years. The species associated with dynamic systems such as riparian cottonwoods have adapted to take advantage of this functional diversity (Mahoney and Rood 1998) .

Annear et al. (2002) conducted a detailed review of the most common methods for developing instream needs by 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. Although the acceptance of the ecological principles behind the Natural Flow Paradigm is widespread and can be supported by a large body of knowledge (Poff et al. 1997, Bunn and Arthington 2002), incorporating these ecosystem principles into river management practice is a challenge (Richter et al. 1997). 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.

Previous reviews (Poff et al. 1997, Richter et al. 1997, Annear et al. 2002, Bunn and Arthington 2002) have compiled numerous references from decades of research. These provide evidence of the effects of altering different components of the natural flow regime and clearly support the rationale behind the Natural Flow Paradigm. A similar level of detail will not be replicated for this report because comprehensive reviews are available in the scientific literature. The following section is included to provide a general overview of the different components of the Natural Flow Paradigm. The references provided are not exhaustive and are intended only to provide a few key examples of the main concepts.

4.2.2 Physical Processes

In recent years, increasing attention has focused on channel-forming, channel-maintaining, and flushing flows (Reiser et al. 1987, Wesche et al. 1987, Reiser et al. 1989a, Hill et al. 1991, Kondolf 1998, Milhous 1998, Whiting 1998). Channel forming flows are necessary to create and maintain the habitats that are used by river dwelling species (Hill et al. 1991, Whiting 1998). Flushing flows have a lower magnitude than channel maintenance flows, but are important for removing fine sediment from spawning gravel in years when channel maintenance flows do not occur (Milhous 1990). These flows tend to be much greater than flows that provide suitable microhabitat conditions for fish, but they are relatively infrequent events of short duration. Refuge areas are usually available, allowing the majority of the fish to survive.

A naturally-functioning alluvial stream channel will be in a state of dynamic equilibrium defined as a system where there is approximate sediment equilibrium (Dunne and Leopold 1978, Bovee et al. 1998). This occurs when sediment export equals sediment import on average, for a period of years (Carling 1995, US Forest Service 1997). This is not to say that the channel is static. Scouring and deposition will occur, point bars will be formed and will disappear, and the channel will meander. However, over time, the general channel pattern remains fairly consistent for the entire stream (Rosgen 1996, Bovee et al. 1998).

When magnitudes or frequencies of occurrence of discharges in the range of channel maintenance flows are altered with time, a channel can be put into disequilibrium. Some gravel-bed channels respond by altering one or many of their characteristics (width and depth, rate of lateral migration, streambed elevation, bed material composition, structural character, ratio of pools to riffles, composition of streamside vegetation, or water carrying capacity) until a new equilibrium is achieved (Williams and Wolman 1984, Rosgen et al. 1986, Hill et al. 1991). The time scales for a riverine system to respond to an impoundment and a regulated flow regime can be immediate, such as a change in hydrology, or decades, for the full effects on channel form, aquatic plants and invertebrates to be known (Petts 1987).

Maintenance of channel features cannot be obtained by a single threshold flow. A dynamic hydrograph of variable flows for continuation of processes that maintain stream channel and habitat characteristics is required (Gordon 1995, US Forest Service 1997, Trush and McBain 2000). Within the range of channel maintenance flows, bankfull flow is generally regarded as the type of flow that moves most sediment, that forms and removes bars, bends and meanders, and that results, over time, in the average morphologic characteristics of channels (Dunne and Leopold 1978, Andrews 1984). Although higher discharges move more sediment, they occur less frequently and during the long-term, move less bedload than more frequent, lesser discharges (Wolman and Miller 1960). It has been recommended (Andrews and Nankervis 1995) that a range of flows, as opposed to a single specified high flow, is needed for channel maintenance. Andrews and Nankervis (1995) found that 80% of the mean annual load was transported by flows that ranged between approximately 0.8 and 1.6 times the bankfull discharge.

Many different factors interact to define the structure of a channel. For example, riparian forests will stabilize the riverbanks and will reduce the sediment input that affects the structure of a channel (Osborne and Kovacic 1993). Defining a channel-maintenance flow regime based strictly on bedload movement is a necessary, though perhaps insufficient condition to maintain a channel (Andrews and Nankervis 1995).

Higher flows also import nutrients, particulate organic matter, and woody debris into the channel (Keller and Swanson 1979), thereby increasing habitat diversity and providing food sources for some species (Moore and Gregory 1988, Muth et al. 2000). Flood flows provide a critical interaction between a river channel and its associated side channels and floodplain (Ward et al. 2001). In these fluvial areas, flood flows ensure there is connectivity between the main channel, the side channels and the floodplain that can provide critical rearing and spawning habitats for some species of fish (Muth et al. 2000). High flows also recharge the floodplain water table, a critical process for the survival of many riparian species (Hughes et al. 2001).

4.2.3 Biological Processes

The physical processes described in the previous section deal mainly with flow magnitude and are responsible for providing the structural habitat characteristics necessary for many aquatic species. However, many species have adapted to be dependent on the seasonal timing of different flow magnitudes as well. Just as important as the timing of different flow events, the duration and rate of change of flow can be critical to certain species. Maintaining the natural pattern of flow variability as it relates to biological requirements and species life histories is discussed below.

The timing of high flow events or seasonal variation in flow is important to biological systems. Aquatic and riparian species are adapted to either avoid or exploit flows of variable magnitudes. Temporally variable flows create and maintain the dynamics of stream channel conditions and create the habitats that are essential to aquatic and riparian species (Hughes et al. 2001). The magnitude, timing, and frequency of occurrence of high flow events directly regulate numerous ecological processes, such as spawning cues and movement into and out of floodplain areas for some fish (Muth et al. 2000), or the recruitment and composition of riparian forests (Hughes et al. 2001, Mahoney and Rood 1998).

Seasonal sequences of flowering, seed dispersal, germination, and seedling growth are timed to natural flow events (Mahoney and Rood 1998). Seasonal seed release by cottonwoods is timed to coincide with the typical spring peak flows that build suitable sedimentation habitat sites for seed germination and seedling survival (Hughes et al. 2001). Peak flows that are not seasonally timed can result in high mortality rates of cottonwood seedlings (Hughes et al. 2001). Native riparian plants are well adapted to the natural pattern of flow. Alteration to the natural pattern of flow has been shown to favour the growth of exotic riparian species, compared with native species (Merrit and Cooper 2000, Shafroth et al. 2000, Levine and Stromberg 2001, Shafroth et al. 2002). See Section 7.0 of this report for a more in-depth discussion of the flow requirements of riparian poplar communities.

Seasonal access to floodplain wetlands for spawning and rearing is essential for the survival of certain riverine fishes (Muth et al. 2000). When access to floodplains is reduced due to the alteration of high flow events, such species may become endangered (Muth et al. 2000) or extirpated. Spring high flows create an increase in available riffle habitats that are necessary for some spring spawning fish species (Aadland 1993). In contrast, the life cycle of fall spawning fish has adapted to avoid high flows (Simonson and Swenson 1990). The stabilization of seasonal flow variation can result in the loss of native species diversity and favour introduced species that thrive in the compromised environment (Hawkins et al. 1997).

The thermal regime of a river can also be dependent on the timing and magnitude of high and low flows within a year. As with the flow regime, the thermal regime of a river has a seasonal pattern and the life history of many species are temperature-dependent. Changes in temperature regime can put native species of fish at a competitive disadvantage with introduced fish species (Reese and Harvey 2002). Changes to the thermal regime of a river can affect fish in many different ways, including the duration of egg incubation, timing of fry emergence, growth rates, maturation, spawning, and resistance to parasites, disease and pollution (Armour 1991).

The annual variability of flow magnitude is necessary to meet a range of biological needs. High annual peak flows scour the stream channel, prevent encroachment of riparian vegetation, and deposit the sediments that maintain a dynamic alternate bar morphology and a successionally diverse riparian vegetation community (Hughes et al. 2001, Trush and McBain 2000). Years with lower flows are as valuable as high flow years, as they enable successful establishment of riparian seedlings on bars deposited in immediately preceding wet years (Trush and McBain 2000).

The natural interaction of high and low flows is essential for normal riparian vegetation development. If only high flows were available, then annual scouring would occur, preventing riparian development. If only low flows were available, then encroachment by upland vegetation and reduction in stream channel size would occur. The pattern of riparian plant distribution is largely defined by the magnitude and frequency of flood events (Chapin et al. 2002). Plant communities adapted to frequent flooding, such as sedge dominated communities, are found at lower riverbank elevations. There is a gradual shift to plant communities that have adapted to less frequent flooding, such as the willow dominated communities found at higher elevations, and eventually to upland plant communities, such as the pine dominated communities that experience relatively infrequent, low duration flooding (Chapin et al. 2002).

Rapid flow increases in streams often serve as spawning cues for native species whose fast developing eggs are either broadcast into the water column (Taylor and Miller 1990) or attached to submerged structures as floodwaters recede. More gradual, seasonal rates of change in flow conditions also regulate the persistence of many aquatic and riparian species. In the case of cottonwoods, the rate of floodwater recession is critical to seedling germination, because seedling roots must remain connected to a receding water table as they grow (Rood and Mahoney 1990, Mahoney and Rood 1998, Hughes et al. 2001).

The duration of high flow events can also be ecologically important (Poff et al. 1997). Indigenous plants, aquatic invertebrates and fishes have different tolerances to prolonged flooding, allowing some species to persist in locations from which they may otherwise be displaced by dominant, but less flood-tolerant species (Chapin et al. 2002). Native species of fish are often better adapted to surviving naturally variable flow events. When flows become stabilized, non-native fish species begin to out-compete native species (Hawkins et al. 1997).

Stream invertebrates also respond to changes in the flow regime. Studies have shown that invertebrate species abundance and diversity is significantly reduced in streams where natural flows are reduced or regulated (Rader and Belish 1999, Growns and Growns 2001). High flows that recharge the water table are beneficial to invertebrates, because a large proportion of invertebrate biomass can be located deep below the river channel, and as far as 2 km laterally from the river channel, in what is called the hyporheic zone (Stanford and Ward 1993).

4.2.4 Interconnectivity of the Riverine Ecosystem

Continuous, seasonally-determined instream flows are essential for maintaining self-sustaining fish communities and the aquatic ecosystem in general. Prescribed instream flow needs must provide for the dynamic interaction of flowing water, sediment movement, and riparian vegetation development to maintain good quality habitats and populations of fish and other aquatic organisms (Poff et al. 1997, Annear et al. 2002). An effective instream flow need determination must, therefore, maintain the existing dynamic characteristics of the entire ecosystem. This means it is essential to maintain functional linkages between the stream channel, riparian corridor, and floodplain to perpetuate essential habitat structure and ecological function.

The Natural Flow Paradigm as outlined by Poff et al. (1997) has taken many individual research results from different fields and has concisely incorporated them into a unified ecological principle. However, the intricacies of whole ecosystems make them a difficult subject to study. While it is almost impossible to test a singular hypothesis, such as the Natural Flow Paradigm, on a complete ecosystem in a single field experiment, when the ecosystem is broken down into discrete components, the way each component is connected with the other components can be seen.

Healthy riparian ecosystems provide multiple benefits by supporting channel maintenance, adding to nutrient and energy cycles, and providing physical habitat for many aquatic species (Gregory et al. 1991, Koning 1999). The long-term sustainability of riparian ecosystems is in large part dependent on an appropriate flow regime (Hughes et al. 2001). Habitat structure used by aquatic species is also controlled by channel maintenance flows. Channel maintenance flows will move the bedload and create and maintain a pattern of habitats within the river, but the physical aquatic habitat is also dependent on factors such as bank stability (Andrews and Nankervis 1995), which is controlled in large part by the riparian ecosystem (Osborne and Kovacic 1993).

Fish habitat is dependent on channel maintenance and riparian flows. Similarly, channel maintenance flows and riparian flows are closely linked. Water quality is also dependent on both a healthy riparian zone, to filter runoff contaminants, and scouring flows, to prevent the establishment of permanent macrophyte beds. Even though the full complexity of an aquatic ecosystem is difficult to outline, and the connections between the different components of the ecosystem can be intricate, consideration of instream flows should focus on multiple components of the flow regime, to protect the interconnected functions of an ecosystem (Annear et al. 2002). Riverine values can be maintained only by preserving the processes and functions of the river ecosystem. Management for one element, such as the biology or status of a single species, is usually not effective, because the contributions needed from other ecosystem components to support that single species are not provided by a single component IFN (Winter et al. 1998).

4.3 Current Methods and Research for Ecosystem IFN Studies

Current quantification methods accommodate distinct flow components that define suitable flow regimes (Hill et al. 1991, Petts et al. 1995). These authors suggest fish habitat base flows, channel maintenance flows, riparian flows, and valley maintenance flows as four possible defining flow components. Annear et al. (2002) suggest that five interrelated components should be considered in the setting of aquatic ecosystem objectives: hydrology, geomorphology, biology, water quality, and connectivity. Although the specific quantification methods for each of these flow components may vary, all components are essential to maintain the ecological health of the stream system (Hill et al. 1991).

Research on instream flow requirements has resulted in the development and application of a number of evaluation methods during the past few decades. This research focused on instream flow assessment methods continues at an elevated rate today. Excellent reviews of many of the techniques developed and applied within the United States and elsewhere can be found in CDM (1986), EPRI (1986), Gore (1989), Reiser et al. (1989b), and Hardy (1998). Some of the research on instream flow assessments is focused on modification or extension of existing methods, while other efforts are being directed at the development and application of new tools. This is driven to some extent by the current ecosystem management objectives of resource agencies. It is also led by a growing consensus among researchers and practitioners that the basis upon which the fundamental science and analytical procedures are developed, validated, and applied will benefit from a broader ecological perspective (Stanford 1994, Orth 1995, Hardy1998, Annear et al. 2002).

Recent research has focused on the development and application of tools and assessment frameworks aimed at quantifying the factors controlling fisheries resources, rather than the continued application of tools for evaluation of a single target species from the limited perspective of physical habitat. Broadly, this includes research on trophic level dynamics, process oriented delineation of flow induced changes in the physical and biological components of the aquatic environment (USFWS and Hoopa Valley Tribe 1999); and in the development of ecological frameworks for the evaluation of impact assessments or restoration efforts in aquatic ecosystems (Addley 1993, Nehring and Anderson 1993, Hearne et al. 1994, Capra et al. 1995, Johnson and Law 1995, Johnson et al. 1995, Leclerc et al. 1995, Muhar et al. 1995).

Other pertinent research within the general arena of instream flows has focused on delineation of key life history characteristics leading to shifts in habitat use under natural and induced flow variability (Bardonnet and Gaudin 1990, Crisp and Hurley 1991, Bardonnet et al. 1993, Heland et al. 1995), the relationship between flow and macro-invertebrate community dynamics (Gore 1989, Weisberg et al. 1990, Jowett et al. 1991, Statzner et al. 1991, Lancaster and Hildrew 1993), and the importance of trophic level dependencies between macroinvertebrates and fish (Easton and Orth 1992, Weisberg and Burton 1993, Roell and Orth 1994, Filbert and Hawkins 1995, Bevelhimer 1996).

Efforts to use mechanistic, individual-based bioenergetics, physical habitat-based population models, and multi-variate statistical approaches have also produced encouraging results (Jowett 1992, Addley 1993, Hill and Grossman 1993, Jager et al. 1993, Bovee et al. 1994, Guensch et al. 2001). This has included linking community level distribution and abundance with spatially explicit delineations of the habitat mosaic at the meso-scale (Jowett 1992, Aadland 1993, Dibble and Killgore 1994, Bain 1995). A broader view of the river corridor as an integrated ecosystem has also provided excellent research on methods and frameworks for delineating the process driven linkages between flow, sediment transport, channel maintenance, and the riparian community (Hill et al. 1991, Nilsson et al. 1991, Stromberg et al. 1991, Rabeni and Jacobson 1993, Stromberg 1993, Goodwin and Hardy 1999).

Many of these techniques could be applied to the South Saskatchewan River Basin, for determining instream flow needs and restoration activities within an adaptive management framework, as part of long-term on-going management efforts.

4.3.1 Use of Natural Flow as a Benchmark Condition

In the 1990s, a growing body of research emerged, directed at managing river health, or the ecological integrity of riverine systems (Karr 1991, Frissell and Bayles 1996). Providing for a healthy aquatic ecosystem requires that the intra- and inter-annual patterns of flow variation in the natural flow regime be considered (Poff et al. 1997, Richter et al. 1997). Different species and different life stages of the same species have different requirements for instream flow needs. Variable conditions are important for maintaining species diversity by allowing all species and life stages not only to survive, but to thrive at different times.

The discussion presented in Section 4.2 provides the theory and a brief review of the evidence supporting the need for an IFN determination recommendation with a pattern of flow variability similar to the naturally occurring variability. Annear et al. (2002) have argued that single flow IFNs have largely failed in the past and a shift towards IFNs that consider multiple ecosystem components is needed. The American Fisheries Society passed a policy to encourage the restoration of natural riverine functions flow by restoring flows that more closely mimic natural hydrographs (Rasmussen 1996). This movement away from single flow IFNs to multi-flow component IFNs is reflected by several recent IFN determinations, including those on the:

- Southeast Australia (Arthington et al. 1991),
- River Babingley, England (Petss 1996),
- Trinity River, California (USFWS and Hoopa Valley Tribe 1999),
- Colorado River (Muth et al. 2000),
- Columbia River (Independent Scientific Group 2000),
- Nooksak River (Hardy 2000a),
- Klamath River Basin, California (Hardy and Addley 2001),
- Highwood River (Clipperton et al. 2002),
- Mokelumme River, California (McGurk and Paulson 2002), and
- South Africa (Brown and King 2002).

Many of these studies based the need to develop a variable flow IFN on long-term field studies of different components of the aquatic ecosystem.

The Trinity River flow evaluation, for example, was prepared by an independent panel of experts that incorporated the findings from several long-term studies, to bring the best available science forward to the decision makers (USFWS and Hoopa Valley Tribe 1999). The final flow recommendation incorporated the natural variability of inter-annual and intra-annual flows based on evaluations of fish habitat, temperature regimes, channel geomorphology, and riparian requirements. The authors of the report state:

> *"Variability is a keystone to the management strategy because no single annual flow regime can be expected to perform all functions needed to maintain an alluvial river system and restore the fishery resources."*

On the Green River in the Colorado River Basin, it was also concluded that no single flow could achieve protection and that variable flow conditions among and within years was required to benefit the entire ecosystem (Muth et al. 2000). This conclusion was based on multiple years of field studies on the biology of endangered fish species, as well as the hydrology and geomorphology of the Green River. As a result of these studies, the operation of the Flaming Gorge dam has been modified to better reflect the natural flow variability of the system in an attempt to recover the endangered species of the Green River (Muth et al. 2000).

A federally-reserved water right for the Virgin River, through Zion National Park in Utah, was established that protects the full range of flow variability based on detailed studies outlining the different flow requirements for native fish, riparian vegetation, channel maintenance, and recreational activities (National Park Service 2001).

The American National Research Council (NRC 1992a) has called for a national restoration strategy that focuses on restoring the natural processes of aquatic ecosystems relative to a pre-existing condition. After many years of research and management efforts to restore Pacific salmon stocks in the Columbia River drainage, the Independent Scientific Group (2000) recommended that any future restoration must include the re-establishment of the ecological and biophysical attributes that are typical of a natural river.

Although these examples focus on river restoration, the concepts of providing conditions that reflect the natural flow variability are equally important for protecting an aquatic ecosystem with little or no flow regulation.

Natural resource agencies from South Africa and Australia have adopted a holistic approach that considers all ecosystem components and draws upon components of the natural flow regime, as determined by daily flow records, for determining instream flows (Arthington et al. 1991, Brown and King 2002).

The current understanding of available scientific data and application of that data in recent IFN studies indicate that a variable flow regime is necessary to protect alluvial systems. The South Saskatchewan River Basin (SSRB) Technical Team chose to use the natural flow regime as a benchmark condition in conducting instream flow needs analyses, based on the following objectives and principles:

1. 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 can be achieved by instream flows alone.

2. Provision of streamflows that provide habitat conditions similar to the naturally occurring habitat conditions is considered sufficient to provide ecosystem protection, in the context of instream flow needs analysis.
3. In order to achieve ecosystem protection, an IFN determination must provide for both protection of aquatic habitats in the short term, and protection of the processes that maintain aquatic habitats for the long term.
4. Enhancement of habitat beyond what would occur naturally is considered to be an objective that is distinct from a purely environmental protection objective. What are referred to as instream flow needs for protection therefore do not address enhancement of habitat, but the protective IFN may result in an improvement compared with existing conditions.

Comparisons with the natural flow regime are made during the analysis of instream flow needs to assist in identifying flow regime conditions that will achieve the high level of protection objective. Use of the natural flow regime as the benchmark condition is necessary to confirm that an instream flow need determination does, in fact, provide variable streamflow conditions with the timing, magnitude, duration, and frequency of occurrence necessary to protect aquatic habitats, ecosystem structure, and physical and biological processes.

4.4 Technical Team Approach to Defining an Aquatic Ecosystem IFN

The Technical Team was formed to include members with expertise in channel morphology, fish habitat, riparian vegetation, and water quality. This interdisciplinary team was tasked with developing an ecosystem-based IFN determination using the best available scientific understanding of the riverine environment. The Technical Team recognizes that the practice of defining single value minimum flows is no longer considered to be suitable to provide long term protection for the aquatic ecosystem (Annear et al. 2002). The shift towards developing variable flow IFN determinations to protect the natural range and variability of flows is a much more promising approach to determining effective IFNs, and is occurring across North America, Europe, Australia, and South Africa (Petts and Maddock 1996, Annear et al. 2002, Bunn and Arthington 2002, Brown and King 2002).

In Alberta, IFN determinations were historically developed using only fish habitat data, with water quality requirements incorporated as a separate component. The fish rule curve approach (Locke 1989) provided a variable flow recommendation, and was a definite improvement compared with the single value, minimum flow approach that was common throughout most of North America at the time. However, an IFN determination based solely on an evaluation of fish habitat or water quality is no longer considered sufficient to provide for full ecosystem protection. A shift in method occurred starting with the Highwood River IFN re-evaluation (Clipperton et al. 2002), as an attempt to directly incorporate the latest scientific understanding for the protection of the aquatic ecosystem. A cornerstone to the shift in scientific understanding is summarized by the concept of the Natural Flow Paradigm as discussed previously. What was lacking in the Highwood River process was representation by experts in fields beyond fish habitat at the Working Group level. This shortcoming was recognized and a surrogate approach was adopted to protect the natural flow variability (Clipperton et al. 2002).

The SSRB IFN study was developed with expertise from multiple disciplines. Although channel morphology, fish habitat, riparian vegetation, and water quality are not the entire extent of knowledge required to completely describe all the interactions and flow requirements of the aquatic ecosystem, they cover a broad range of ecological functions for a wide range of flows.

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 provides a flow regime that maintains elements of the natural inter- and intra-annual flow variability. The Technical Team also considered flow magnitude, flow timing, and flow duration to be critical to the integrated IFN. The final integrated IFN method and results are presented in Section 9. The integrated IFN relied upon information from four ecosystem components: water quality, fish habitat, riparian vegetation, and channel maintenance. The detailed methods for evaluating the four ecosystem components are provided in sections 5 though 8 of this report. Because this was the first attempt at conducting this level of analysis in Alberta, each component was developed separately and then combined at the end to create the integrated IFN. In developing the integrated IFN, the Technical Team, in essence, followed a process very similar to the Instream Flow Incremental Methodology (IFIM) (Bovee et al. 1998).

The IFIM, developed by the U.S. Fish and Wildlife Service, is a decision-making process grounded on ecological principles. It has been suggested (Gorman and Karr 1978; Karr et al. 1986) that human-induced impacts to river systems fall into five major categories: flow regime, habitat structure, water quality, food source, and biotic interactions. The IFIM approach is consistent with this view (Bovee et al. 1998). The Technical Team relied on specific information on water quality, fish habitat, riparian vegetation, and channel maintenance to address these ecosystem components.

IFIM is often incorrectly thought to refer only to the Physical Habitat Simulation (PHABSIM) group of models. However, IFIM is a process, rather than just a group of models, and the approach the Technical Team followed relied on a multidisciplinary assessment framework that, in essence, parallels the IFIM. This framework is illustrated in Figure 4.1 and outlines the integrated nature of the physical, chemical and biological processes, and the specific technical assessment components required to address instream flows in the South Saskatchewan River Basin. The boxes on the left side of Figure 4.1 indicate the steps that were normally taken if no data were available and a new study was being designed. The reliance of the SSRB process on available data means all of these steps were not directly incorporated at this phase of the project. Many steps were considered in the study planning done to collect the original data for each component.

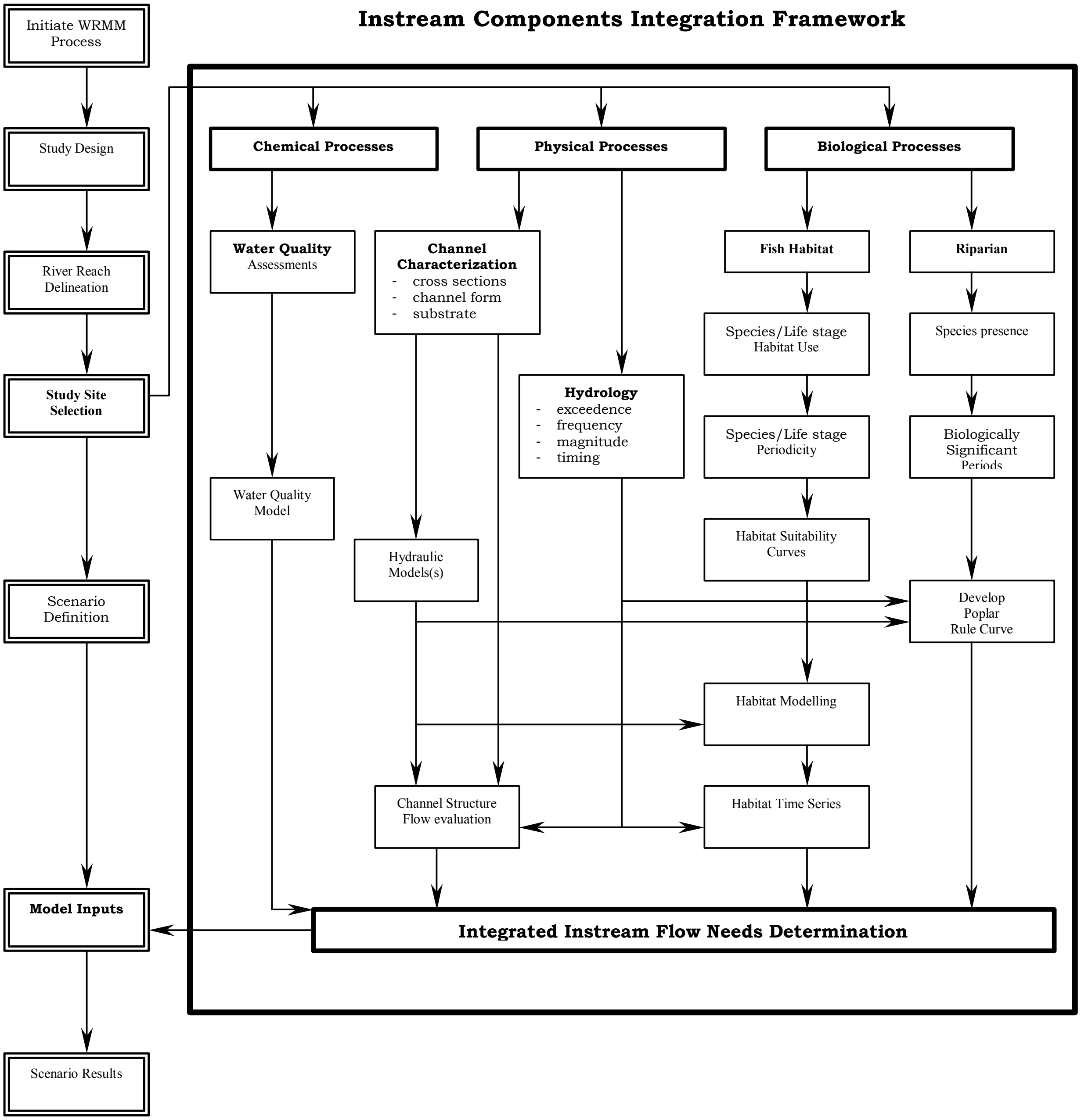


Figure 4.1. Multi-disciplinary assessment framework applied for the SSRB WMP, to determine the ecosystem IFN (adapted from Hardy and Addley 2001).

5.0 FISH HABITAT INSTREAM FLOW NEEDS

5.1 General Process

This section of the report provides an overview of the process used to make instream flow needs (IFN) determinations based on fish habitat modelling. A considerable amount of fish habitat modelling data already existed in the SSRB from previous PHABSIM studies (**P**hysical **HAB**itat **SIM**ulation system developed by the U.S. Fish and Wildlife Service). It was decided to review this information with the purpose of determining whether it met current habitat modelling criteria, standards, protocols, and objectives for the SSRB study. This was considered to be the most cost efficient approach for ensuring existing data were up to current standards and were in the most suitable format for the SSRB evaluation. Collecting new PHABSIM data at locations for which data did not exist required considerably more resources than were available for this study.

It should be noted that the PHABSIM group of models are widely used, and often, equally widely criticized. The criticisms usually cite:

- The representativeness of transects used to calculate habitat (Williams 1996);
- The underlying assumptions about the interpretation of weighted useable area (WUA) curves for fish species (EPRI 2000, Railsback et al. *in press*); and
- The explicit narrowness of the modelled biological responses. The pros and cons of PHABSIM are widely discussed in the scientific literature (Wesche and Rechard 1980, EPRI 1986, Annear et al. 2002).

Notwithstanding these criticisms, the use of the PHABSIM models, as presented in this report, is believed to be reasonable and to adequately describe the flow requirements for fish for the appropriate time of year and range of flows. As with the use of any model, extreme care and caution must be used and the true test is to monitor the response of the fish populations to the flow regime that is ultimately selected.

The PHABSIM models were used to develop fish habitat versus flow relationships, or WUA curves for each reach of each river where site-specific data were available. Where site-specific data were not available, office based techniques were used. The WUA curves were used to conduct time-series analysis for evaluating different flow regimes, created as constant-percent flow reductions from natural, to produce IFN determinations for fish habitat. The fish habitat-derived flow determinations were subsequently integrated with the flow recommendations for the other aquatic ecosystem components (i.e., channel maintenance, riparian vegetation and water quality,) to form one integrated instream flow need recommendation.

The primary objective for the fish habitat-modelling component was to develop a science based IFN determination using the available field data, current modelling techniques, and the best available evaluation protocols. This effort was focused on the use of physical habitat modelling as a central element.

5.1.1 Physical Habitat Modelling

In habitat modelling, a hydraulic model is used to determine characteristics of the stream, in terms of depth and velocity, as a function of discharge. This information is integrated with habitat suitability criteria curves to produce a measurement for available habitat as a function of discharge.

The general assumption underlying habitat modelling is that aquatic species will react to changes in the hydraulic environment. This assumption is rooted in ecological principles and has been demonstrated to be valid in applied research (Jowett 1992, Jager et al. 1993, Nehring and Anderson 1993, Railsback et al. 1993, Bovee et al. 1994, Stalnaker et al. 1995, Studley et al. 1995). These changes in hydraulic properties are simulated for each computational cell within each cross section, throughout the study reach. The stream reach simulation takes the form of a multi-dimensional matrix of the calculated surface areas of a stream, having different combinations of hydraulic parameters (i.e., depth, velocity, and channel index), as illustrated in Figure 5.1. This figure shows the generalized representation of a segment of river for a series of transects that define a grid of habitat cells with their associated attributes of depth, velocity, and channel index (i.e., substrate and cover). These cells represent the basic computational elements used by the habitat programs to derive relevant indices of available habitat. Depth and velocity attributes for each computational cell vary with simulated changes in discharge. These variations in discharge can result in changes in the amount and quality of available habitat.

Habitat Suitability Criteria (HSC) are used to describe the adequacy of various combinations of depth, velocity and channel index conditions in each habitat computational cell to produce an estimate of the quantity and/or quality of habitat in terms of surface area. This measure is referred to as the weighted usable area (WUA) and is expressed in terms of units of area per linear length of stream (traditionally square feet per 1000 linear feet of stream). WUA is computed within the reach, at a specific discharge, by the following equation:

$$WUA = \frac{\sum_{i=1}^{n} A_i C_i}{\text{Reach Length (1000's feet)}}$$

Equation 5.1

Where:

Ai = Surface area of cell i,

Ci = Combined suitability of cell i (i.e., composite of individual depth, velocity and channel index suitabilities).

The combined or composite suitability of the cell is derived from the aggregation of the individual suitabilities for depth, velocity, and channel index based on the simulated depth, velocity and channel index attributes within a habitat computational cell. The individual suitabilities for depth, velocity and channel index are obtained from the corresponding species and life stage HSC. This is illustrated in Figure 5.2.

Composite suitabilities can be computed by a number of methods. The most common are the multiplicative, geometric mean, or limiting value approaches. The specific habitat modelling approaches used in these studies are detailed in the following sections.

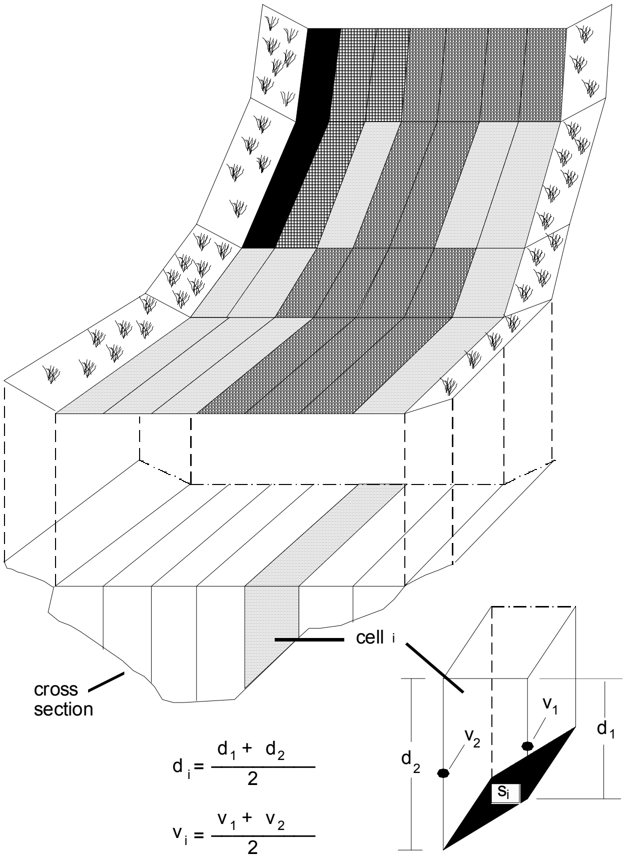


Figure 5.1. Conceptual representation of a stream reach by computational cells, with attributes of depth, velocity, and channel index, used in habitat modelling (from Hardy and Addley 2001).

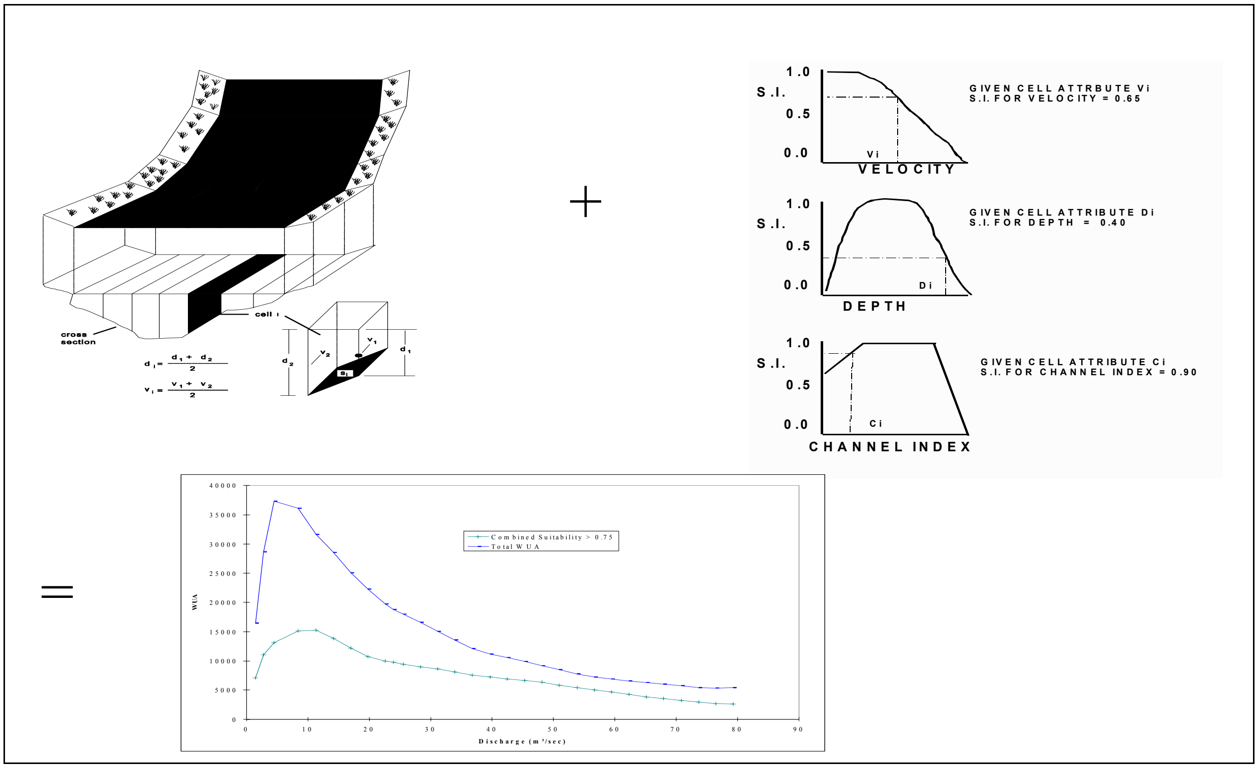


Figure 5.2. Calculation of component suitability index values for the depth, velocity and channel index that generates the WUA versus discharge function for a species and life stage (from Hardy and Addley 2001)

5.2 Site-specific Fish Habitat IFN Data for the SSRB

5.2.1 River Reach Delineation

River reaches had been defined for the Red Deer, Bow, Oldman, Belly, Waterton, and St. Mary rivers from previous IFN studies. The rivers were delineated according to the standard procedures outlined by the US Fish and Wildlife Service (Bovee 1982). Details of the specific procedures that were used are found in the reports that describe the original instream flow needs studies carried out on the Red Deer, Bow, Oldman, Waterton, Belly and St. Mary rivers (Fernet et al. 1990, EMA 1994, Golder & WER 1994, Golder 1999). The decision process for delineating the river into reaches was reviewed by the Technical Team, in consultation with fisheries biologists in Alberta Sustainable Resource Development (SRD). Based on this review, the original reach delineation was deemed acceptable.

The final river reaches selected for the SSRB review were based largely on the reaches defined by previous fish habitat IFN studies (Figure 3.2). Some minor modifications were made to the original reach delineations, to better accommodate the reach boundaries defined for the other ecosystem components and the reaches defined for the Water Resource Management Model (WRMM). Since the IFN values will be incorporated into the WRMM, it was decided by the Technical Team to try to accommodate the WRMM reaches as much as possible. Additional reach breaks were identified for the Red Deer River, particularly in the downstream reaches. The original fish habitat IFN here identified two reaches, whereas the WRMM uses four reaches. In these situations, the single PHABSIM site was used to calculate a single set of WUA curves that were then evaluated using the reach specific hydrology data.

Several reaches were also adjusted on the Oldman River to overlap the WRMM reach breaks. One major change to the Oldman reaches involved moving the reach boundary to start at the confluence of Pincher Creek and Willow Creek (see Reaches OM7 And OM5 in Figure 3.2). The St. Mary River was originally divided into four different reaches for the fish habitat IFN study. However, because only two study sites were measured, and there are only two different gauging stations, it was decided to reduce the number of reaches to two. The downstream reach boundary remained unchanged and the upper three reaches were combined into a single reach for the purpose of this review process.

5.2.2 Study Site Selection

Discussions on study site selection procedures for the original studies are found in the detailed IFN reports for each river (Fernet et al. 1990, EMA 1994, Golder & WER 1994, Golder 1999). Every PHABSIM study site defined within the SSRB applies the representative reach method, in which all the variability in habitat types present in the larger reach is represented within the selected study site (Bovee et al. 1998). Members of the Technical Team, in consultation with fisheries biologists of SRD, reviewed the study site selection process for these studies. Based on this review, the original selection of study sites was deemed acceptable for this study.

A total of 19 PHABSIM study sites were available from previous studies within the SSRB WMP study boundaries. These included:

- 4 study sites on the Red Deer River,
- 3 study sites on the Bow River,

- 6 study sites on the Oldman River, and
- 2 study sites on each of the St. Mary, Belly, and Waterton rivers.

The location of the study sites can be found in the original study reports (Fernet et al. 1990, EMA 1994, Golder & WER 1994, Golder 1999).

5.2.3 Hydraulic Modelling

All the original data collection and hydraulic modelling procedures were done according to standard PHABSIM protocols (Bovee 1982, Milhous et al. 1989) and are presented in the original IFN reports for each river (Fernet et al. 1990, EMA 1994, Golder & WER 1994, Golder 1999). The original calibration data files and model production data files were all available electronically as output files from the DOS-based PHABSIM computer models.

The original hydraulic data were sent to Utah State University (USU) for evaluation. This was done as a check on whether there were any errors in the original data decks and to use the latest hydraulic modelling techniques, procedures and practices to improve the calibration if and where necessary. The hydraulic data from the original IFN studies, which was a DOS-based format, were converted into the USU Windows version of PHABSIM, for ease of use in subsequent model runs. The Windows-based software allows the user to conduct the water surface elevation, velocity, and habitat modelling within the same interface and have the data stored in a single Microsoft® Access® database file. The software provides quicker model calibration, allows for graphical evaluations of the model outputs, and simplifies the data management requirements of PHABSIM modelling. The specific model calibration procedures are detailed below.

Water Surface Modelling

The determination of the relationship between the water surface (stage) and the discharge is the first step in hydraulic calibration and simulation phases of PHABSIM. The stage is used in the simulations to derive depth distributions for each cross section and to identify the location of the free surface to establish boundaries (i.e. wetted cell locations) for some of the equations that describe velocity distributions. If stage and bed elevation are known, depth may be determined at any location on the cross section by subtracting the bed elevation from the stage.

Several approaches may be used in the prediction of stage-discharge relationships. In PHABSIM this includes:

- linear regression techniques based on multiple measurements of stage and discharge (Stage-Q or IFG4);
- use of Manning's equation (MANSQ); and
- calculation of water surface profiles (WSP) using standard step backwater computations.

These three approaches represent the three main hydraulic modelling options within PHABSIM for water surface predictions.

Water surface modelling at each study site followed recognized guidelines for calibration and simulation of water surface elevations for the application of PHABSIM, as outlined in Bovee et al. (1998) and Hardy (2000b). In general, the calibration and simulation of water surface elevations for specific cross sections employed one or more of the following three models:

Stage-Q The Stage-Q model uses a stage-discharge relationship (rating curve) to calculate water surface elevations at each cross section. Implicit in this approach is analyzing each cross section independently of all others in the study reach. The basic computational procedure is conducted by performing a log-linear regression between observed stage and discharge pairs at each cross section. The resulting regression equation is then utilized to simulate water surface elevations at all flows of interest.

MANSQ The MANSQ program uses Manning's equation to calculate water surface elevations on a cross-section by cross-section basis. It therefore treats each cross-section independently. Model calibration is accomplished by a trial and error procedure to select a β coefficient that minimizes the error between observed and simulated water surface elevations at all measured discharge and water surface elevation pairs.

WSP The Water Surface Profile (WSP) program uses a standard step backwater method to determine water surface elevations at each cross section. The WSP program requires that all cross sections being analyzed in a given model run be dependent. That is, each cross section's hydraulic characteristics in terms of bed geometry and water surface elevations are measured from a common survey datum (bench mark). The model is initially calibrated to a measured longitudinal profile of the water surface elevations by adjusting Manning's roughness at each cross section, such that predicted and observed water surface elevations are acceptable. The model is then further calibrated by adjustment of roughness modifiers used within the model to other observed longitudinal profiles associated with other calibration discharges.

The specific equations for each of these models and their application to water surface modelling in PHABSIM can be found in Bovee et al. (1998) and Hardy (2000b).

The selection of a particular model(s) (i.e., Stage-Q, MANSQ, or WSP) for specific cross sections for specific flow ranges at each study site was based on a comparative evaluation of calibration and simulation results among the three models. This evaluation included a comparison of simulated and observed water surface elevations at each calibration flow and the behaviour of simulated water surface elevations at all simulated discharges to ensure that model outputs were rational (i.e., water flowed downhill between successive cross sections within the hydraulic modelling study site).

Calibration and simulation results for water surface elevations at each study site for each cross section were considered to meet acceptable standards of practice for the application of PHABSIM (see, Bovee et al. 1998, Hardy 2000b). The final water surface model definitions and calibration results for water surface elevations are reported in Hardy (2003) and are provided in Appendix C.

Velocity Modelling

The second major step in hydraulic modelling within PHABSIM involves the determination of velocity profiles at each cross section within the river. PHABSIM models velocities at one cross section at a time and, as such, treats the cross sections independently regardless of the model employed to generate the water surface elevations. Within PHABSIM, the IFG4 model is used for all velocity predictions. These are subsequently used in the habitat modelling components of the system. The specific equations and different approaches for velocity modelling and their application to simulation of velocity profiles in PHABSIM can be found in Bovee et al. (1998), and Hardy (2000b).

Velocity modelling at each study site followed recognized guidelines for calibration and simulation of PHABSIM data sets as outlined in Bovee et al. (1998), and Hardy (2000b). The specific IFG4 computational options (velocity calibration sets, use of cell specific Manning's n, Manning's n minimum/maximums) for individual cross sections for specific flow ranges was based on model predictions compared with calibration data. It also included reviews of the simulated model results of velocity predictions for the full range of simulated discharges.

The calibrations involved a comparison of simulated and observed velocities at each vertical for all cross sections, at all calibration flows. This included use of single and multiple velocity calibration sets (different velocity models) for each cross section. The calibrations used adjustments to individual cell Manning's n values, where poor simulation results at specific locations within a cross section were initially obtained. Once an adequate fit between observed and simulated velocity profiles at the calibration flows was obtained, the behaviour of the model predictions for the full range of simulated discharges was examined. The behaviour of the velocities in each cell of each cross section, for all simulated ranges of discharges, were examined to ensure model outputs were rational (i.e. velocity magnitudes in edge cells were within realistic ranges for computed cell depths).

Calibration and simulation results for velocities at each study site for each cross section were considered to meet acceptable standards of practice for the application of PHABSIM (Bovee et al. 1998, Hardy 2000b). Calibration and simulation results for velocities are reported in Hardy (2003) and are provided in Appendix C.

5.2.4 Selection of Target Species and Life Stages

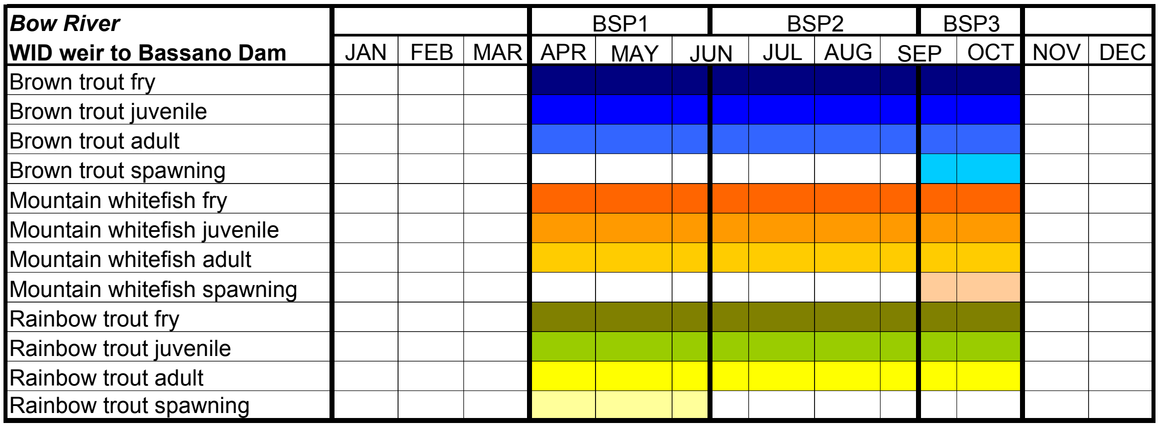
For the original studies, the list of species and life stages were derived from existing knowledge and through extensive discussions with regional fisheries biologists (Fernet et al. 1990, EMA 1994, Golder & WER 1994, Golder 1999). The selection of species for this study was based on the information contained in the previous reports and through examination of more recent knowledge and current discussions with regional fisheries staff.

Selecting a few sport fish species and life stages to represent all aquatic species is a concern with using these types of habitat models. Given quantification of the selected management species and life stages, consideration of other species and life stage life history needs, and professional judgment, it is assumed that flow protection for non-modelled species and life stages (e.g., sturgeon in the case of the South Saskatchewan and Oldman rivers, and other sport fish and non-sport fish species) will be met. This assumption has frequently been employed under similar circumstances in applied instream flow assessments, where specific species and life stages are used to represent indicator species or guilds for multi-species aquatic communities (Hardy 2000a).

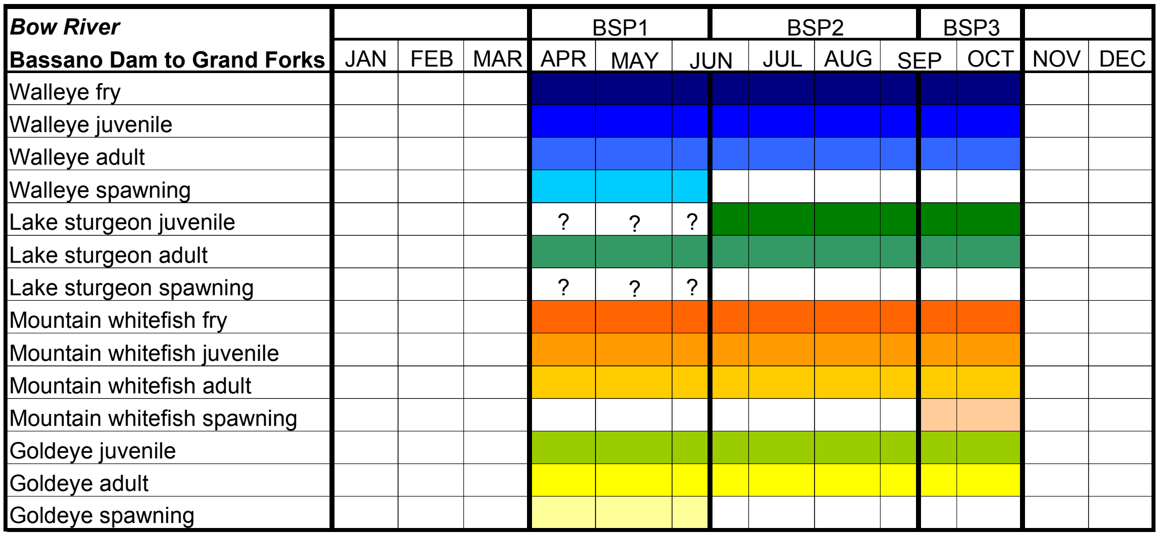
This assumption is particularly problematic for sturgeon, since it is a much larger fish, with unique habitat requirements compared with the largest species for which data were collected such as rainbow trout. Without the ability to collect data on sturgeon, we simply had to rely on a much broader assumption that the integrated IFN would meet the life history requirements of the species. In the future, the specific habitat suitability criteria data for this species should be collected and directly factored into the fish habitat IFN requirement component.

5.2.5 Species and Life Stage Periodicities

Species and life stage periodicity for the fish species within the South Saskatchewan River Basin were discussed with regional fisheries biologists at the time of the original studies and again for this study. All available existing fisheries data from the South Saskatchewan River Basin and additional literature on known species distributions and life stage periodicities were reviewed. The review included consideration of potential longitudinal and seasonal variation within the mainstem rivers in the South Saskatchewan River Basin. The species and life stage periodicity used in the assessment of instream flows is provided in Figures 5.3 through 5.6. A time period that has a common set of life stages present is referred to as a Biologically Significant Period (BSP) (Geer 1983). Winter or ice-covered months were not included in the analysis in any of the original IFN studies. As a result, the species periodicity tables only represent the open-water period. This in no way implies that some species and life stages are not present or do not over-winter in any of the reaches. It is, however, a reflection on the lack of a suitable tool to evaluate ice-covered conditions using standard IFN hydraulic modelling tools and a lack of under-ice habitat suitability data. As no new data were collected for the current evaluation, the ice-covered period was once again not included in the fish habitat portion of the analysis. For this study, as is the case with many other PHABSIM studies, only the sport fish of concern were modelled. Implicit in this is the assumption that sport fish serve as a surrogate for all fish species, including forage fish. In the future, data should be collected to verify this assumption.

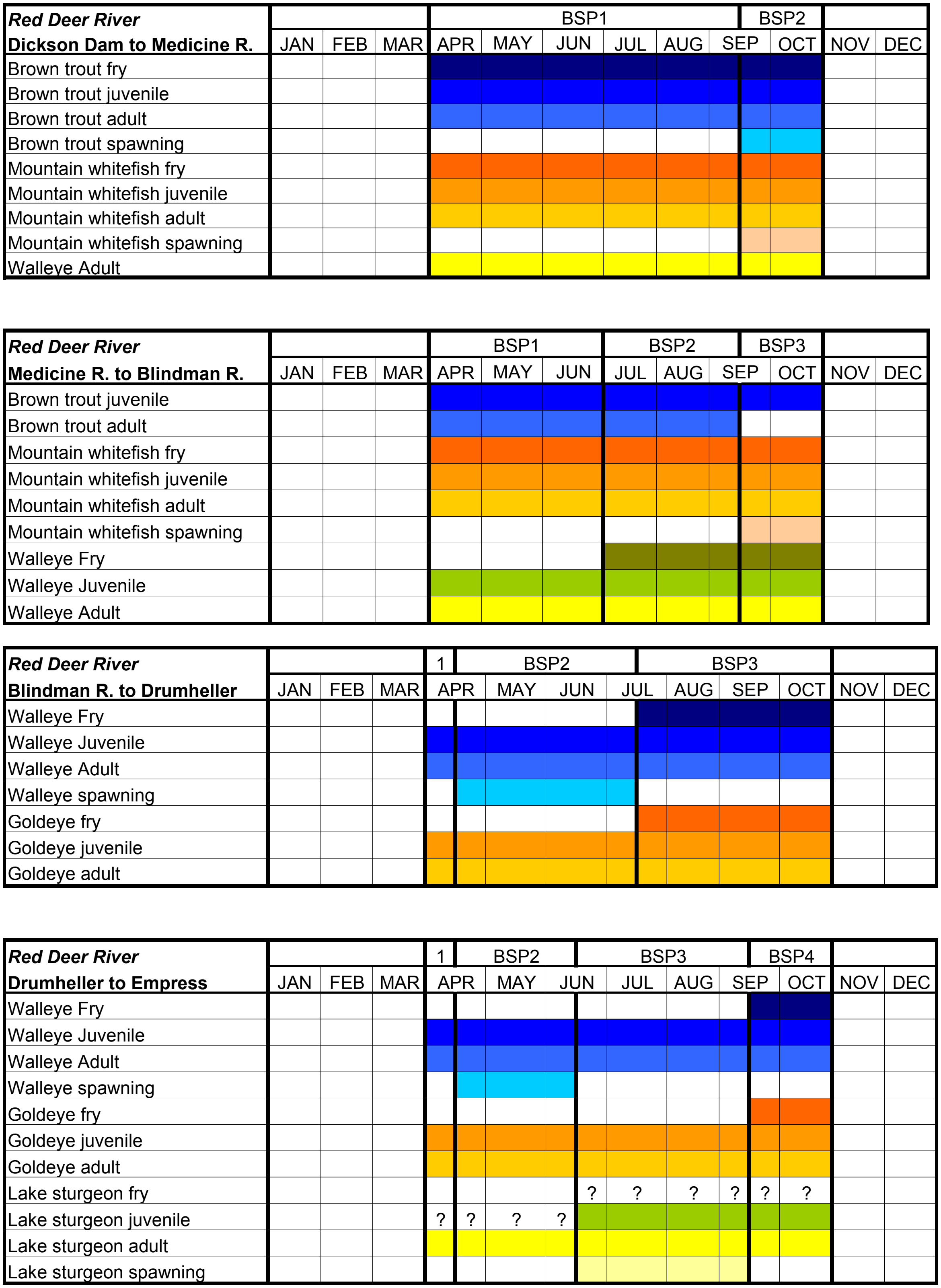


Bow River **WID weir to Bassano Dam**	JAN	FEB	MAR	BSP1 APR MAY JUN	BSP2 JUL AUG SEP	BSP3 SEP OCT	NOV	DEC
Brown trout fry				■	■	■		
Brown trout juvenile				■	■	■		
Brown trout adult				■	■	■		
Brown trout spawning						■		
Mountain whitefish fry				■	■	■		
Mountain whitefish juvenile				■	■	■		
Mountain whitefish adult				■	■	■		
Mountain whitefish spawning						■		
Rainbow trout fry				■	■	■		
Rainbow trout juvenile				■	■	■		
Rainbow trout adult				■	■	■		
Rainbow trout spawning				■				



Bow River **Bassano Dam to Grand Forks**	JAN	FEB	MAR	BSP1 APR MAY JUN	BSP2 JUL AUG SEP	BSP3 SEP OCT	NOV	DEC
Walleye fry				■	■	■		
Walleye juvenile				■	■	■		
Walleye adult				■	■	■		
Walleye spawning				■				
Lake sturgeon juvenile				? ? ?	■	■		
Lake sturgeon adult				■	■	■		
Lake sturgeon spawning				? ? ?				
Mountain whitefish fry				■	■	■		
Mountain whitefish juvenile				■	■	■		
Mountain whitefish adult				■	■	■		
Mountain whitefish spawning						■		
Goldeye juvenile				■	■	■		
Goldeye adult				■	■	■		
Goldeye spawning				■				

Figure 5.3. Species periodicity charts for the Bow River. *Note: "?" identifies a data gap.*



Red Deer River				BSP1						BSP2			
Dickson Dam to Medicine R.	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP		OCT	NOV	DEC
Brown trout fry				■	■	■	■	■	■	■	■		
Brown trout juvenile				■	■	■	■	■	■	■	■		
Brown trout adult				■	■	■	■	■	■	■	■		
Brown trout spawning										■	■		
Mountain whitefish fry				■	■	■	■	■	■	■	■		
Mountain whitefish juvenile				■	■	■	■	■	■	■	■		
Mountain whitefish adult				■	■	■	■	■	■	■	■		
Mountain whitefish spawning										■	■		
Walleye Adult				■	■	■	■	■	■	■	■		

Red Deer River				BSP1			BSP2			BSP3			
Medicine R. to Blindman R.	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP		OCT	NOV	DEC
Brown trout juvenile				■	■	■	■	■	■	■	■		
Brown trout adult				■	■	■	■	■	■				
Mountain whitefish fry				■	■	■	■	■	■	■	■		
Mountain whitefish juvenile				■	■	■	■	■	■	■	■		
Mountain whitefish adult				■	■	■	■	■	■	■	■		
Mountain whitefish spawning										■	■		
Walleye Fry							■	■	■	■	■		
Walleye Juvenile				■	■	■	■	■	■	■	■		
Walleye Adult				■	■	■	■	■	■	■	■		

Red Deer River				1	BSP2				BSP3					
Blindman R. to Drumheller	JAN	FEB	MAR	APR		MAY	JUN	JUL		AUG	SEP	OCT	NOV	DEC
Walleye Fry									■	■	■	■		
Walleye Juvenile				■	■	■	■	■	■	■	■	■		
Walleye Adult				■	■	■	■	■	■	■	■	■		
Walleye spawning					■	■	■	■						
Goldeye fry									■	■	■	■		
Goldeye juvenile				■	■	■	■	■	■	■	■	■		
Goldeye adult				■	■	■	■	■	■	■	■	■		

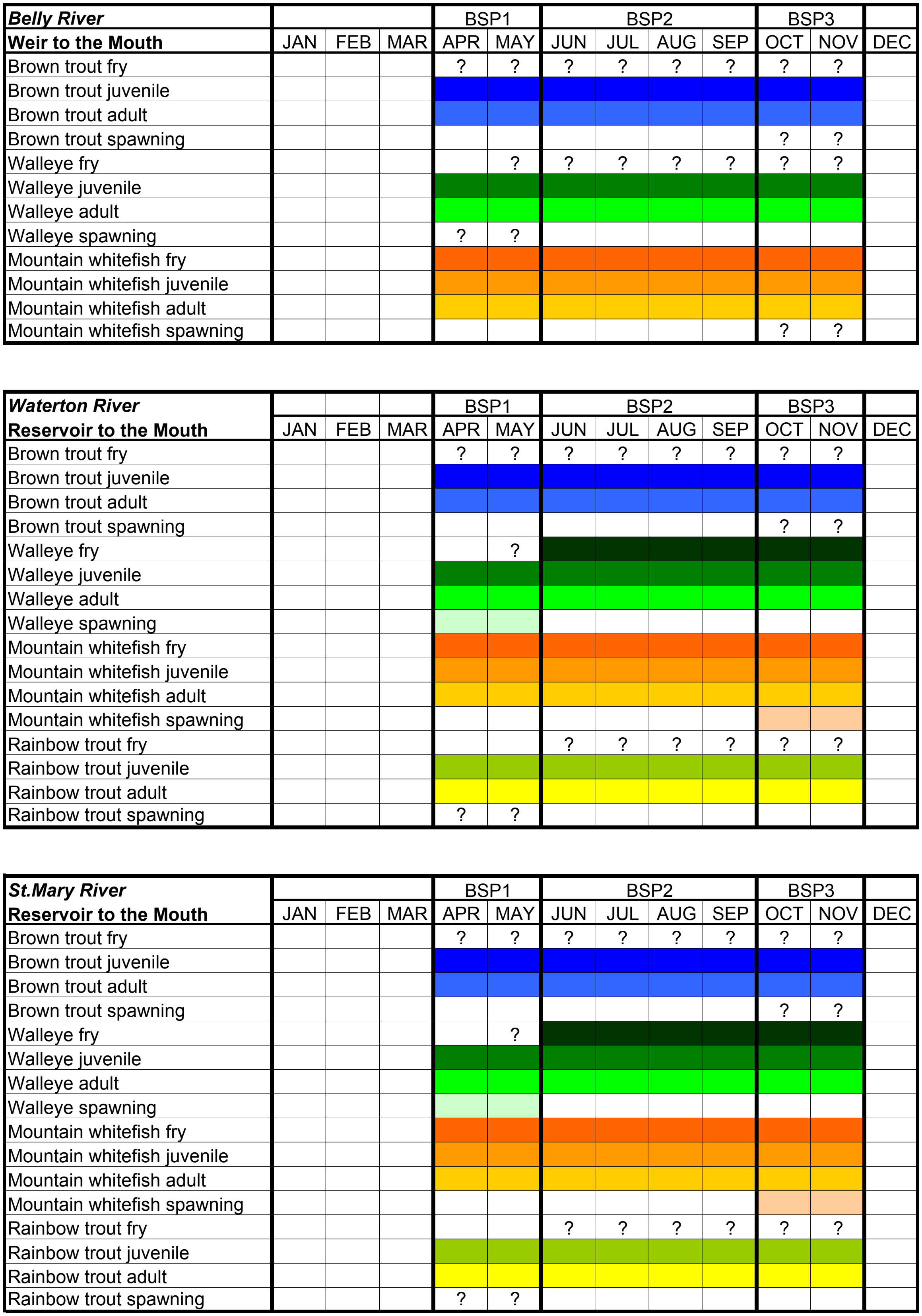
Red Deer River				1	BSP2			BSP3				BSP4			
Drumheller to Empress	JAN	FEB	MAR	APR		MAY	JUN		JUL	AUG	SEP		OCT	NOV	DEC
Walleye Fry												■	■		
Walleye Juvenile				■	■	■	■	■	■	■	■	■	■		
Walleye Adult				■	■	■	■	■	■	■	■	■	■		
Walleye spawning					■	■	■								
Goldeye fry												■	■		
Goldeye juvenile				■	■	■	■	■	■	■	■	■	■		
Goldeye adult				■	■	■	■	■	■	■	■	■	■		
Lake sturgeon fry								?	?	?	?	?	?		
Lake sturgeon juvenile				?	?	?	?	■	■	■	■	■	■		
Lake sturgeon adult				■	■	■	■	■	■	■	■	■	■		
Lake sturgeon spawning								■	■	■	■				

Figure 5.4. Species periodicity charts for the Red Deer River. *Note: "?" identifies a data gap.*

Oldman River				BSP1		BSP2				BSP3		
Oldman Dam to Willow Creek	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Brown trout fry				🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	
Brown trout juvenile				🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	
Brown trout adult				🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	
Brown trout spawning										🟦	🟦	
Mountain whitefish fry				🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	
Mountain whitefish juvenile				🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	
Mountain whitefish adult				🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	
Mountain whitefish spawning										🟧	🟧	
Rainbow trout fry						🟫	🟫	🟫	🟫	🟫	🟫	
Rainbow trout juvenile				🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	
Rainbow trout adult				🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	
Rainbow trout spawning				🟨	🟨							

Oldman River				BSP1		BSP2				BSP3		
Willow Creek to Grand Forks	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Brown trout fry				🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	
Brown trout juvenile				🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	
Brown trout adult				🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	
Brown trout spawning										🟦	🟦	
Walleye/ Sauger fry					?	🟩	🟩	🟩	🟩	🟩	🟩	
Walleye/ Sauger juvenile				🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	
Walleye/ Sauger adult				🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	
Walleye/ Sauger spawning				🟩	🟩							
Mountain whitefish fry				🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	
Mountain whitefish juvenile				🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	
Mountain whitefish adult				🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	
Mountain whitefish spawning										🟧	🟧	
Lake sturgeon juvenile				?	?	🟩	🟩	🟩	🟩	🟩	🟩	
Lake sturgeon adult				🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	
Lake sturgeon spawning						?	?	?	?			

Figure 5.5. Species periodicity charts for the Oldman River. *Note: "?" identifies a data gap.*



Belly River				BSP1		BSP2				BSP3		
Weir to the Mouth	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Brown trout fry				?	?	?	?	?	?	?	?	
Brown trout juvenile				🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	
Brown trout adult				🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	
Brown trout spawning										?	?	
Walleye fry					?	?	?	?	?	?	?	
Walleye juvenile				🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	
Walleye adult				🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	
Walleye spawning				?	?							
Mountain whitefish fry				🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	
Mountain whitefish juvenile				🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	
Mountain whitefish adult				🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	
Mountain whitefish spawning										?	?	

Waterton River				BSP1		BSP2				BSP3		
Reservoir to the Mouth	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Brown trout fry				?	?	?	?	?	?	?	?	
Brown trout juvenile				🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	
Brown trout adult				🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	
Brown trout spawning										?	?	
Walleye fry					?	🟩	🟩	🟩	🟩	🟩	🟩	
Walleye juvenile				🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	
Walleye adult				🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	
Walleye spawning				🟩	🟩							
Mountain whitefish fry				🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	
Mountain whitefish juvenile				🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	
Mountain whitefish adult				🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	
Mountain whitefish spawning										🟧	🟧	
Rainbow trout fry						?	?	?	?	?	?	
Rainbow trout juvenile				🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	
Rainbow trout adult				🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	
Rainbow trout spawning				?	?							

St.Mary River				BSP1		BSP2				BSP3		
Reservoir to the Mouth	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Brown trout fry				?	?	?	?	?	?	?	?	
Brown trout juvenile				🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	
Brown trout adult				🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	
Brown trout spawning										?	?	
Walleye fry					?	🟩	🟩	🟩	🟩	🟩	🟩	
Walleye juvenile				🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	
Walleye adult				🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	
Walleye spawning				🟩	🟩							
Mountain whitefish fry				🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	
Mountain whitefish juvenile				🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	
Mountain whitefish adult				🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	
Mountain whitefish spawning										🟧	🟧	
Rainbow trout fry						?	?	?	?	?	?	
Rainbow trout juvenile				🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	
Rainbow trout adult				🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	
Rainbow trout spawning				?	?							

Figure 5.6. Species periodicity charts for the St. Mary, Belly, and Waterton Rivers. *Note: "?" identifies a data gap.*

5.2.6 Habitat Suitability Criteria

Physical habitat modelling component assessments require that relationships between hydraulic properties and biological responses of target species and life stages be quantified. The common approach to defining these relationships is to develop Habitat Suitability Criteria. HSC represent how suitable the gradient of a factor (depth, velocity, substrate, or cover) is to a target species and life stage. HSC typically represent the suitability of a factor on a scale between 0.0 and 1.0. A suitability value of 0.0 represents a condition that is wholly unsuitable, while a 1.0 indicates a condition that is 'ideally' suitable.

In general, it is commonly considered most appropriate to develop site-specific HSC data from the river in which the instream flow assessment is undertaken. However, many factors, such as presence of predators, presence of introduced species, modified hydrology, or modified habitat, can make development of HSC from the target stream system both infeasible and/or undesirable. Poor field conditions, such as low water visibility or dangerously high flows, can also make collection of HSC data infeasible in many river systems on a seasonal basis.

When site-specific HSC cannot be developed, an alternate procedure is to assess the applicability of HSC from another river. This requires observational data for the target species and life stages in the stream under study, in order to attempt a validation or transferability test of the HSC. Existing methods for testing transferability of HSC (Thomas and Bovee 1993) are not generally accepted and are known to produce inconsistent results (Dunbar and Ibbotson 2001). In the South Saskatchewan River Basin, attempts at validating transferability of HSC curves has resulted in less than satisfactory results (Bjornson and Fernet 1989, Fernet et al. 1990, Fernet et al. 1992, Golder 1994, Golder 1999). In the absence of site-specific or transferable HSC data, a workshop, attended by fisheries biologists with expertise in the target species, is often held to review literature-based curves and any site-specific habitat use data from the region of interest and to set the HSC using professional judgment. This is perhaps the most commonly applied technique for HSC development for instream flow assessments in Canada, the United States, and elsewhere.

Hardy (2000a, 2001) provides an extensive discussion of the different types of HSC, different methods for their development, and practical implications of their use in physical habitat modelling. Specific details on how the HSC curves were derived for this study and details of the expert workshop process are provided in a separate report (Addley et al. 2003). The report contains an in-depth discussion that lays an objective foundation, from an ecological perspective, for the assessment of the techniques used to develop the HSC curves that were used in this study. The report also provides a detailed account on the history of HSC curve development in Alberta, the previous use of expert workshops in Alberta, and the underpinnings of the use of 'envelope' HSC curves in the context of ecological niche theory and applied science. The final HSC curves used in this study are presented in Addley et al. (2003).

Today, it is common practice when using the PHABSIM habitat suitability models to validate the model output by comparing model suitability values predicted for each simulated habitat cell in a modelled reach with empirical field observations of fish presence or absence. The validation procedure runs the model at the same discharges as when the fish observations were made. The model should predict good habitat, where fish were observed, and poor habitat, where fish were not observed. Because the exact locations of the fish observations were not recorded in the original studies, this type of validation is not possible using the existing data. Although a validation process was not possible for this study, the habitat suitability criteria were developed using a large pool of site specific data collected across southern Alberta. The data were reviewed by an expert panel of fish biologists with many years of regional experience to reflect the best available knowledge of the habitat that each species and life stage uses (Addley et al. 2003).

The majority of fish habitat use observations conducted for IFN studies in the SSRB have been collected by underwater observations. However, there are several common conditions that will result in underwater observations providing unsatisfactory results. In the Red Deer River, turbidity prevented efficient and accurate underwater observations. As well, life stages that hide in cover, particularly fry that often bury themselves amongst cobbles, are also difficult to observe directly. In both these cases, electro-fishing is often necessary to collect habitat use data. Golder (1999) used boat electro-fishing to collect the majority of habitat use data on the Red Deer River.

5.2.7 WUA Results for Each Reach

Physical habitat availability was calculated for each reach where an existing PHABSIM study site was available. The species and life stages used for each reach are identified in Figures 5.3 through 5.6. For all life stages except spawning, substrate or cover was not included in the calculation of fish habitat availability. The reason for this was two-fold:

- The original hydraulic decks used for recalibration were not consistent in the coding of substrate or cover and did not allow for an equal evaluation of habitat for every reach. Time did not permit the re-coding of each hydraulic data set using the original field notes to apply a consistent code for each reach.
- For a recent study carried out on the Highwood River IFN (Clipperton et al. 2002), a sensitivity analysis was conducted that compared the results of an analysis with and without the substrate code. Although the magnitude of the WUA curves may change, it was discovered that when the curves are normalized, which is a standard procedure, the shape of the WUA curves were virtually identical.

The channel index code (either substrate or cover) for each habitat unit remains as a constant within the PHABSIM models. This means that the channel index value does not change as different flows are modelled and the useable habitat calculation is then driven by the suitability of the depth and velocity at each flow modelled. The only apparent exception to this rule is when the channel index code contains a suitability criterion of zero preference for a certain range of substrate or cover. This is the case for spawning life stages that select suitable habitat based largely on suitable substrate and that avoid unsuitable substrate types. For all spawning life stages, a binary substrate code was used that indicated a preference of 1.0 for gravel (and for some species, small cobble.) All other substrate types were coded with a preference of 0.0.

Other life stages may be more typically associated with a certain type of substrate or cover type, but in general it has been the observation in the SSRB that older life stages of the target fish did not avoid suitable depth and velocity conditions based solely on substrate or cover. This issue has been discussed at recent HSC workshops (Courtney and Walder 1999, Clipperton et al. 2002, Addley et al. 2003), and although a range of suitability values could be assigned, it was believed that a suitability of zero, indicating absolute avoidance, was never warranted for substrate or cover. This rationale then did not justify the additional effort required to re-code all of the data files for a parameter that would have a minimal effect on the final result. However, it is recognized that other studies have shown that proximity to substrate/cover can be acritical habitat feature for fish (e.g. Orth 1987, EPRI 2000), and that juvenile fish may show some preference for cover to avoid predation. It is believed that the cover requirements of the older life stages of the target fish in the SSRB are not critical. If, in the future, cover is indeed found to be an important factor, then the necessary data should be collected.

Another common pattern observed time and again is the indication of peak habitat for fry life stages at very low flow. On occasion, the peak habitat is at a flow that is lower than historical low flows. The reason can be attributed to suitability criteria for fry life stages. Typically, fry inhabit shallow, slow habitats that can be found on the stream margins under normal flow conditions. In the habitat model, however, the largest area of habitat that meets the shallow and slow criteria will often occur at a very low flow, when the entire centre of the river channel is identified as suitable habitat. However, for many other reasons, such as the potential for high water temperatures, and fry having to share this habitat with larger fish, making them susceptible to heavy predation, the habitat at these lower flows is not likely ideal.

Within PHABSIM, there is the potential to develop conditional habitat suitability criteria in an attempt to create a more realistic picture within the models. Such criteria might indicate suitability for a range of depths and velocities if a certain cover type is present. They might also indicate suitability for a different range of depths and velocities when cover is absent. Another type of conditional curve that can be used in PHABSIM includes the evaluation of habitats in relation to adjacent conditions, such as distance from shore, distance from cover, or distance from holding habitats to feeding habitats. However, the information to create these types of curves was not collected in the original studies. Developing these curves would require additional field data collection. As indicated earlier in the report, the constraints of the project did not allow for collection of new data, and conditional curves were not created for this project. It is recommended that in the future, conditional criteria data be collected to develop HSC curves that better reflect habitat descriptors, such as distance from shore or cover, that are biologically relevant to the species and life stages of concern.

Using the re-calibrated hydraulic data (Section 5.2.3) and the HSC curves developed at the expert workshop (Section 5.2.6), WUA curves were developed for every life stage present in each different reach in the SSRB. Habitat computations were derived using a computer program based on the original PHABSIM models developed by the US Fish and Wildlife Service (see Sections 5.1.2 and 5.2.3 for descriptions of PHABSIM). The resulting WUA curves for each reach are presented in Appendix D. A sample set of WUA curves from the Oldman River is provided in Figure 5.7.

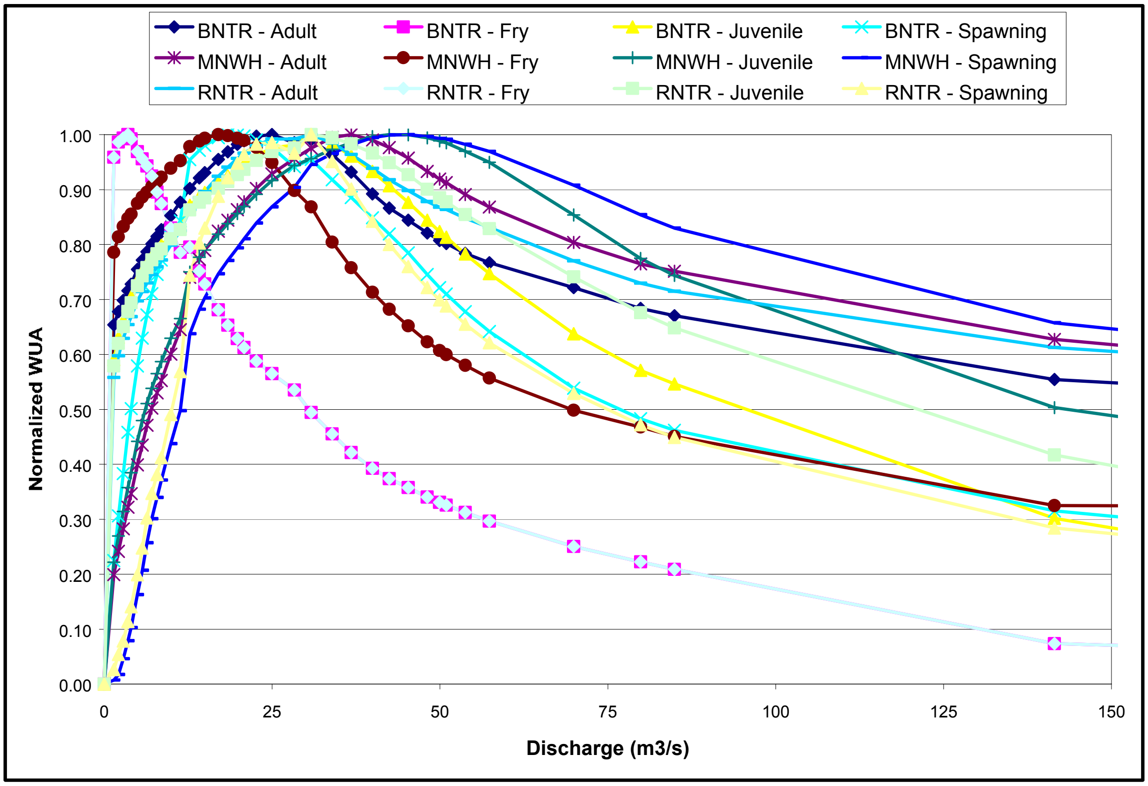


Figure 5.7. Oldman River Reach 6 (OM6) WUA curves for all target management species and life stages.

5.3 Fish Habitat IFN Determination Method

5.3.1 Background

In a recent study, a working group consisting of IFN experts was formed to develop an IFN determination for the Highwood River based on current scientific understanding and protocols, as directed by the Natural Resources Conservation Board (Clipperton et al. 2002). Despite the practical necessity of making IFN determinations throughout the world, there is no general agreement within the scientific community on a single method for making those determinations. It is important to note, however, that there is general agreement that a single flow determination will not protect nor is best for an ecosystem, nor is optimal for the full suite of organisms in an aquatic ecosystem.

As stated by Bovee (1982):

- A flow that is beneficial to one life stage may be detrimental to another life stage.
- A flow that is beneficial to one species may be detrimental to another.
- Various life stages and species may require different amounts of water at different times of the year.

- A flow that maximizes usable habitat in one part of the stream may not provide very much usable habitat in another part of the same stream.
- More water does not necessarily mean more habitat.

As part of the Highwood River IFN re-evaluation, Clipperton et al. (2002) reviewed several methods for developing an IFN determination, including the Fish Rule Curve. The Highwood River IFN Working Group adopted an ecosystem approach to recommending instream flow needs. This was deemed to be essential not only to protect long-term fisheries productivity, but also to ensure the sustainability of the ecosystem. It was decided by Clipperton et al. (2002) that a new evaluation protocol should be developed that better reflected the variable flow concepts of the Natural Flow Paradigm as described by Poff et al. (1997) and others (see discussion in Section 4.0).

A growing number of jurisdictions and agencies in the United States and throughout the world are adopting approaches that provide a variable flow recommendation that generally follows the concepts of the Natural Flow Paradigm. The specific methods and final format of the recommendations used in different jurisdictions varies, depending on site-specific water management issues. However, each has stressed the ecological necessity to establish a variable flow regime based on the natural range of hydrological variability. Some examples include:

- Southeast Australia (Arthington et al. 1991),
- River Babingley, England (Petss 1996),
- Trinity River, California (USFWS and Hoopa Valley Tribe 1999),
- Colorado River (Muth et al. 2000),
- Columbia River (Independent Scientific Group 2000),
- Nooksak River (Hardy 2000a),
- Klamath River Basin, California (Hardy and Addley 2001),
- Mokelumme River, California (McGurk and Paulson 2002), and
- South Africa (Brown and King 2002).

There is also widespread understanding in the scientific community that uncertainty is inherent in any IFN process. Decisions and assumptions at certain points in the process must be made based on professional judgment. Such assumptions and decisions are largely unavoidable, but an effort should be made to reduce the number of steps within a protocol that rely entirely on professional judgment. The approach developed by the Highwood River IFN Working Group was based, in part, on the desire to minimize arbitrary decisions and to provide an IFN description that could confidently be considered highly protective (Clipperton et al. 2002). The protocol that was developed for the Highwood River was adopted for the current SSRB IFN evaluations.

The basic concept of the Highwood River IFN Working Group protocol is to compare a series of constant-percent reductions from natural flow to the naturalized flow regime, and to evaluate each in terms of habitat losses relative to natural conditions. The protocol consists of five basics steps:

- Develop a series of constant-percent flow reductions from the naturalized flow, in 5% increments;
- Calculate the Ecosystem Base Flow (EBF);
- Identify high flow weeks to remove from the analysis;

- Conduct habitat time-series analyses for the natural flow and for each constant-percent flow reduction with the added constraint of the EBF; and
- Review the habitat evaluation metrics to identify the fish habitat IFN.

Instream flow needs are then defined in a weekly time-step and are presented in a flow exceedence curve format. The exceedence curve format provides an instream flow needs description that includes elements of flow variability similar to the natural intra- and inter-annual variations in flow. The weekly time-step accounts for the variability of the regional hydrology. In previous studies, the monthly time-step was found to be too coarse for the water mass balancing procedures that are typically done with the Water Resources Management Model (WRMM), as part of the water management planning process in this region.

5.3.2 Step 1: Percent Reduction in Flow from Natural

The first step in defining the full protection of the aquatic environment flow is to select a method for reducing flows from natural levels. There are a number of ways this could be done. One approach would be to vary the reduction of natural flow by season. However, this would add a level of complexity to the evaluation that is not necessary for a planning level study. For this study, the natural flow was reduced in even 5% increments, starting with a 5% reduction (i.e. 5%, 10%, 15%). A constant-percent flow departure from natural will maintain the pattern of natural flow variability both within and between years. In addition to retaining elements of temporal flow variability, this approach eliminates the relatively large changes in an IFN recommendation that can occur for relatively small changes in the natural flow when other approaches are used.

The natural flow data were obtained from Alberta Environment (2001b). The flow files used for each reach were confirmed with Alberta Environment to ensure compatibility with the flow files used in the WRMM.

5.3.3 Step 2: Defining The Ecosystem Base Flow

Another element the analysis approach addressed was the impact on habitat during naturally low flow periods. The Highwood River IFN Working Group believed that a constant-percent reduction from natural flows, if applied during periods when flows are naturally low (e.g., late summer, early fall), would likely result in significant negative impacts to habitat availability during those periods (Clipperton et al. 2002). The rationale provided by the Highwood River IFN Working Group for this is based on the observation that in many east slope streams in Alberta these low flow periods create potentially limiting habitat conditions, even under the natural flow regime. Based on this premise, a highly protective ecosystem IFN should not result in an increase in the frequency, duration, or magnitude of naturally limiting habitat conditions.

To address instream needs at low flows, a threshold flow value was defined below which the instream flow need was the natural flow. This threshold value was referred to as the Ecosystem Base Flow (EBF). The EBF was defined for each reach and was calculated on a weekly time-step so that the EBF value varies from week to week. Site-specific WUA curves and site-specific hydrology are required to calculate the weekly EBF values. Sale et al. (1981) proposed using habitat duration curves instead of flow duration curves to select an estimated instream flow need. A habitat duration analysis approach was incorporated into the Highwood River process to define the EBF (Clipperton et al. 2002).

The 80% habitat exceedence value represents a relatively limited habitat condition. Increasing the frequency of occurrence of limited habitat conditions is not desired in defining an IFN. The discharge corresponding to the 80% habitat exceedence value is defined as the EBF (Figure 5.8). The species life stage with the highest flow requirement, as determined by the site-specific WUA curves, was used to calculate the 80% habitat exceedence value. Habitat duration curves were then calculated for each week, using the natural flow data for each reach. Because the WUA curve typically has low habitat values associated with both high and low discharges, the actual 80% habitat exceedence value may be due to a high or low discharge in the period of record, depending on the week. The lowest discharge that corresponds with the 80% habitat exceedence value was selected as the EBF.

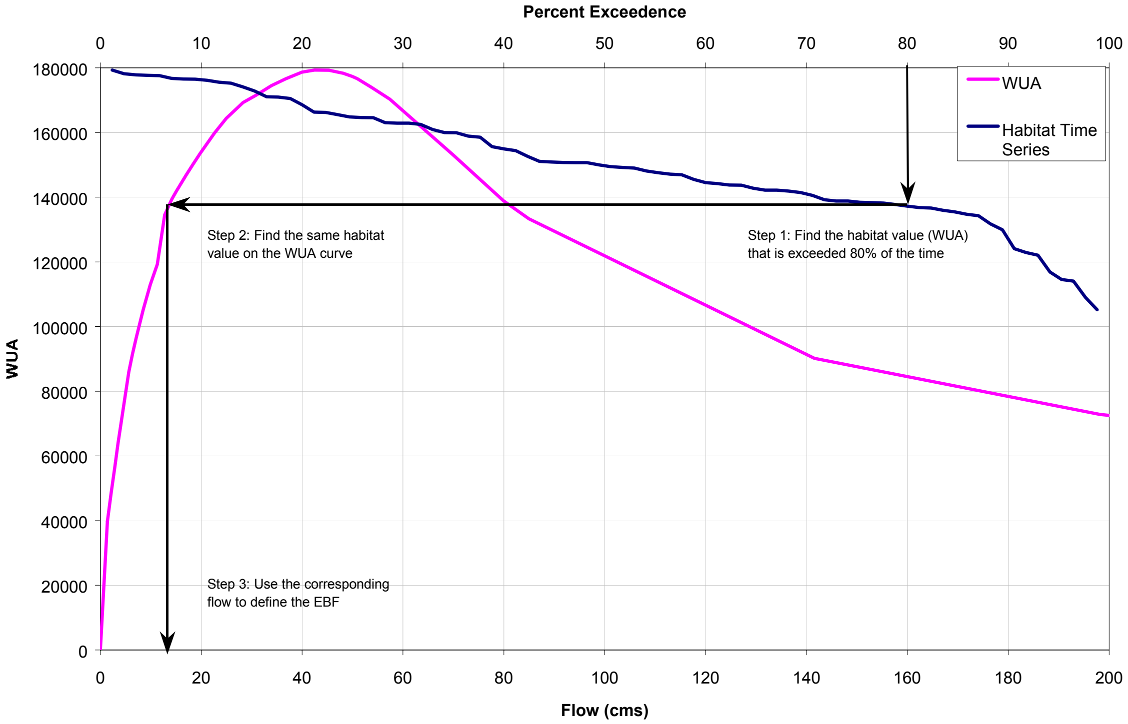


Figure 5.8. Example of the 80% habitat exceedence procedure for defining the EBF using the Week 33 habitat exceedence curve and the mountain whitefish juvenile WUA curve from the Oldman River Reach OM6. The EBF in this example is 13.6 m^3/s.

The Highwood River IFN Working Group also defined a method for protecting the seasonality of flows by modifying the EBF during the freshet period (Clipperton et al. 2002). To achieve protection during these weeks, the 95% flow exceedence value was calculated and the EBF was defined as either the weekly 95% flow exceedence discharge or the discharge corresponding to the 80% habitat exceedence value, whichever was greater.

This protocol was critical in the Highwood River process because additional information regarding riparian and channel maintenance flow requirements were not known. However, because riparian and channel maintenance flows were included in the SSRB WMP process, and are expected to meet fisheries needs during the freshet, the fish habitat analysis was removed from that period. The EBF for the weeks where fish habitat was included in the analysis was largely based on the discharge corresponding with the 80% habitat exceedence value.

5.3.4 Step 3: Determining Flows for Fish Habitat-Time Series Analysis

High flows often pose a problem in evaluating physical habitat for fish. There is an upper limit of flow where the validity of the fish habitat-based flow information (WUA curves) becomes questionable. WUA curves are based on two pieces of information, hydraulics and biology. The hydraulic data that are used have a limited range of extrapolation either above or below a measured or calibrated flow. More importantly, the information that is used to generate the HSC curves comes primarily from direct observations of fish. Fish habitat use at very high flows has rarely been sampled due to the physical limitations and safety considerations of collecting field data under high flow conditions.

In the higher flow ranges, normally from the beginning to the end of the spring freshet, other ecosystem tools should be used instead of WUA curves for fish. For example, it would be better to evaluate flows required for riparian vegetation needs, channel maintenance processes and other ecosystem processes dependent on high flows such as sediment transport, fish habitat forming processes, riparian seed dispersal, or invertebrate requirements. When considering flow ranges that are relevant for any of the ecosystem components there will always be some overlap.

Another limitation is that WUA curves are typically bell-shaped indicating the highest available habitat occurs at a specific flow and reduced habitat is present at both lower and higher flows. Higher flows can cause reduced habitat availability for fish due to high velocities. However, extremely high flows are typically short in duration and lower velocity habitat refugia are likely available to allow for survival in the short term. At extremely high flows, very large reductions from the natural flow can show an increase in fish habitat availability. Because riparian and channel maintenance flows are being evaluated as part of the SSRB process, it was decided to use only the fish habitat information for an appropriate flow range, as determined by the site-specific WUA curves and hydrology at each reach.

Following the method developed by the Highwood River IFN Working Group, an upper limit to the flow range for the habitat-time series analysis was defined (Clipperton et al. 2002). This was accomplished by removing weeks within the year that are beyond the evaluation range of a WUA curve. The criterion adopted by Clipperton et al. (2002) was to remove any week where the median flow was greater than the flow corresponding to the WUA peak that occurs at the highest flow for all of the life stages from the time series analysis. This step effectively removed the spring freshet from the fish habitat analysis. This does not mean that every individual flow datum point above the peak of the highest flow WUA curve was removed from the analysis. This approach removes only weeks where the majority of flows are beyond the limits of the WUA curves. Many individual flow records that are above the peaks of all of the WUA curves remain in the analysis.

5.3.5 Step 4: Conducting Habitat Time Series

Habitat time series for the constant-percent departure from natural flows were evaluated by examining the percent reduction in habitat availability. Time series evaluations are a highly recommended component of the instream flow incremental methodology (IFIM) as described by Bovee et al. (1998). The two basic requirements to conduct a habitat time series are WUA curves and stream discharge data.

The habitat suitability curves developed by a workshop process (Addley et al. 2003) and the recalibrated hydraulic models (see Section 5.2.3) were used to create new WUA curves for each reach in the SSRB where an existing PHABSIM study site was located (Section 5.2.7). The new

WUA curves were used to calculate the habitat time series for natural flow and for each constant-percent departure from the natural flow, for the period of record. Habitat time series were calculated, based on updated fisheries management objectives, for each management species and life stage identified for each reach.

A habitat time series is based on calculation of the available habitat for every discharge record used in the evaluation. For each discharge, a habitat value was calculated by linear interpolation between the two adjacent discharges represented in the WUA curve. The discharge records evaluated were based on mean weekly, naturalized flows from 1912 to 1995 (Alberta Environment 2001b). Only open-water season habitat was evaluated. This was defined as the period from Week 14 through Week 44 (approximately from the beginning of April to the end of October). Although there may be site-specific and seasonal differences in the duration and timing of the open-water season, a consistent period of evaluation was deemed suitable for the planning stage. Weeks at high flow conditions, as defined in Section 5.3.4, were also excluded from evaluation.

5.3.6 Step 5: Reviewing Evaluation Metrics

The overall strategy for determining instream flow needs for moderate and low flow periods was to identify an instream flow regime that would limit fish habitat reductions to amounts that would be generally be accepted as small, relative to the natural flow regime. The rationale is simply that if habitat reductions are limited to small amounts, it can reasonably be assumed a high level of protection has been provided by the IFN. Fish habitat is assumed to be an appropriate surrogate for providing ecosystem protection at low to moderate flows.

Several metrics were used to evaluate the effects of change in discharge relative to natural conditions. Each metric can be used to examine different effects of changes in flow, such as chronic (long-term) impacts, intermediate, or acute (short-term) impacts. The following metrics were calculated for each species and life stage at each reach:

1. **The change in total average habitat from natural.** The total average habitat was calculated for the naturalized flow regime and then compared against each incremental percent-reduction-from-natural-flow time series. The averages were computed from data for all weeks and all years, except for weeks removed as described in Section 5.3.4.
2. **Maximum weekly loss in average habitat.** The habitat averages for each week were calculated for all years (1912-1995) for the naturalized flow and then calculated for a 5%, 10%, 15% and so on departure from natural. The greatest percent loss from natural was reported.
3. **Maximum instantaneous habitat loss.** This was the greatest single percentage habitat loss recorded for all weeks in all years.
4. **Percent changes in average habitat.** These were calculated separately for the 50-90%, 10-50%, and 10-90% habitat exceedence ranges.
5. **Maximum weekly loss in average habitat.** This was calculated separately for the 50-90%, 10-50%, and 10-90% habitat exceedence ranges.
6. **Maximum yearly habitat loss.** This was calculated as the yearly average habitat loss, compared with natural, for the single worst year on record.

Although all habitat metrics were reviewed, the change in total average habitat, the maximum weekly loss in average habitat, and the maximum instantaneous habitat loss (metrics 1, 2, and 3 respectively), were viewed as the most useful metrics for making comparisons.

The difference in total average habitat (metric 1) was viewed as an indicator of chronic effects of flow reduction on both habitat availability and the aquatic ecosystem over the long term. This metric included data pooled across all weeks (except for weeks removed as described in Section 5.3.4) and for the entire period of record from 1912-1995. It was considered that a reduction in total average habitat of less than 10% could be considered small in the context of the magnitude of uncertainties inherent in the habitat calculations. A high level of protection would be provided with overall average habitat losses of less than 10%.

The maximum weekly loss in average habitat (metric 2) was considered to be an indicator of intermediate chronic effects of flow reduction on habitat availability and the aquatic ecosystem over an intermediate length of time. Many of the data points for some of the weeks included in the analysis of total average habitat loss will indicate a habitat gain with reduced flows relative to natural. To ensure that habitat gains in some weeks were not masking major habitat losses in other weeks, the maximum weekly loss in average habitat was used as an evaluation metric. This metric would detect problems with specific times of the year. A threshold value slightly higher than that used for the average habitat metric was used, given the shorter period of time represented by this metric. A threshold value of 15% was adopted for the maximum weekly loss in average habitat.

The final key evaluation metric chosen was the maximum instantaneous habitat loss (metric 3). This metric is based on the habitat available for the natural flow, during each individual week for the period of record and for each of the constant-percent flow departures from natural. Although the term instantaneous is used, the habitat values being evaluated are actually weekly averages, because a weekly time-step was used for all of the modelling. The maximum instantaneous habitat loss represents acute effects on habitat availability and the aquatic ecosystem. Because the other two evaluation metrics were based on averaged data, a check was needed to ensure that large habitat losses were not being masked in the longer-term evaluations. The rationale for including this metric was that an instantaneous habitat loss, if of sufficient magnitude, might result in significant changes to the ecosystem that could persist over a much longer time period than the duration of the acute habitat reduction. The threshold value for this metric was defined as an instantaneous habitat loss of 25%. This higher threshold is considered appropriate because the habitat reduction is expected to be short-term. Because the habitat values used are based on weekly modelling, the actual instantaneous loss for a single day, or for hours within a day, could be higher than 25%.

No single habitat evaluation metric can adequately assess the change in habitat from natural. Impacts of the same habitat loss are greater if it is long-term rather than short-term. By using all three metrics, we have a measure of impacts on habitat that are long-term chronic (difference in average habitat), seasonal or short-term chronic (maximum weekly loss in average habitat), and acute (maximum instantaneous habitat loss).

Each species and life stage identified for each reach was included in the final analysis and evaluation metrics were calculated for each life stage. The life stage negatively-impacted the most dictated whether habitat loss criteria were exceeded, because all other life stages would have had smaller habitat losses or habitat gains. The rationale for this approach is that by protecting the highest flow requirements and the life stage with greatest sensitivity to habitat loss, all life stages with lower flow requirements will also be protected within a variable flow regime.

5.3.7 Summary of the Final Approach

The final approach developed by Clipperton et al. (2002) has many advantages compared with the other methods available. The approach utilizes site-specific habitat data that are available, the concept and implementation is straightforward relative to the other methods, it considers chronic and acute impacts to the ecosystem, and it follows the Natural Flow Paradigm. The following summary outlines the steps in the application of this analysis approach.

1. Flow time series were created as a constant-percent reduction from natural, in even 5% increments, based on naturalized weekly average flows. Using a constant-percent departure from the natural flow regime as an IFN recommendation ensures the integrity of the natural flow regime is preserved.
2. In the reaches where site-specific fish habitat data did not exist, the hydrological flow statistic was used to determine the EBF. In the reaches with habitat data, selecting the greater of the 95% exceedence flow or the 80% habitat retention flow was used. In some instances, using only the 80% habitat retention value did not adequately account for the hydrographic transition from spring runoff to late season base flow. While there are no precedents for this approach, our goal was to make every attempt to ensure the intra-annual variability of flow, relative to the natural flow regime, was maintained. Further biological grounding regarding the setting of the EBF is critical and it is recommended this work be carried out in the future.
3. A flow range, based on an evaluation of site-specific WUA curves for all life stages, was determined for conducting the habitat time series analysis. All weeks with a median flow greater than the flow corresponding to the WUA peak that occurs at highest flow were removed from the habitat time series analysis. This effectively removed the spring freshet from the habitat time series analysis. The rationale for this step in the analysis is provided in Section 5.3.4.
4. A habitat time series was constructed for the naturalized-flow time series and for each percent-reduction from natural flow time series. Evaluation metrics were calculated for each biologically significant period (BSP) and for the entire open-water season (excluding weeks removed in step 3) for all life stages present in each reach. The available habitat for each of the percent-reduction from natural flow time series, with the added constraint of the EBF, was compared against the habitat available under the natural flow by using several evaluation metrics. The key evaluation metrics and thresholds are:
    - a 10% loss in total average habitat from natural;
    - a 15% maximum weekly loss of average habitat from natural; and
    - a 25% maximum instantaneous habitat loss from natural.
5. Starting with the 5% departure from the natural-flow time series, each metric was checked to see if it met or exceeded the defined thresholds. If the criteria were met, then the 10% departure from the natural flow regime was evaluated through a similar time series analysis. This was repeated for each flow-reduction time series, in 5% increments, until at least one of the three evaluation criteria was exceeded. The fish habitat IFN was then initially defined as the preceding flow reduction time series where all of the evaluation criteria are met.

All the evaluation metrics, for each life stage and each BSP, were reviewed for outliers. The results were also reviewed to determine if all of the metrics were following a consistent pattern of habitat loss. Based on this review, the final fish habitat IFN was either left unadjusted as determined by the evaluation metric thresholds, or it was defined as a different constant-percent flow reduction using professional judgment. Each reach was evaluated on a case-by-case basis in this manner.

5.3.8 Modification for the South Saskatchewan River Basin

At the onset of the fish habitat evaluations, the protocol as defined in the Highwood River IFN process (Clipperton et al. 2002) was to be applied without modification. However, due to the larger number and different types of reaches being evaluated relative to the Highwood River, several modifications to the method were required in the process of developing the fish habitat IFN.

As described above, the high flow weeks identified for removal from the fish habitat analysis were not included in the final fish habitat IFN because riparian and channel maintenance IFN information were available during those weeks of the year. In the Highwood River IFN process, the fish habitat recommendation was extrapolated to the higher flow weeks as a surrogate for these other ecological processes that were not directly measured (Clipperton et al. 2002). In some instances, all weeks (from week 14 – 44) had median flows higher than the flow at the peak of the furthest right WUA curve. In these situations, the evaluation proceeded with weeks 16 – 36 removed from the analysis. The reason for selecting these weeks is that they provide a one-week overlap with the riparian evaluation (week 15 in the spring and week 37 in the fall) for the integration process.

The WUA curve that peaks at the highest flow was used to calculate the 80% habitat exceedence flow, to define the EBF for the Highwood River. However, in some reaches of the SSRB, two or more WUA curves peaked at the same flow, and occasionally a spawning life stage had a WUA curve that peaked at the highest flow. If two life stages had the same or similar peaks, the life stage with the fastest rate of habitat loss as flows were reduced was chosen. In cases where a spawning life stage had the highest WUA curve peak, one of two steps was taken. Initially, a life stage that is present year-round was used to define the ecosystem base flow (EBF) and to identify the high flow weeks. When reviewing the evaluation metrics, for Reaches RD4 and RD5 on the Red Deer River, the spawning life stage was showing very large habitat losses. In this case the EBF was calculated using the spawning life stage for the spawning weeks, in combination with the initial EBF defined using the life stage present year round for the remaining weeks.

A spawning life stage was often the first life stage to exceed one or more of the key evaluation metrics at the lowest constant-percent reduction from the natural flow. The IFN method defined for the Highwood River process used a single flow reduction and applied it across all the different BSPs (Clipperton et al. 2002). This was an acceptable practice when the most habitat limiting life stage is present year-round. Because spawning life stages are only present during a specific period within the year, it would be difficult to justify an IFN for the entire year defined solely on the spawning life stage. To balance the IFN across the entire year, while maintaining the original method of using a single flow reduction for the entire open-water season, the spawning life stages were occasionally allowed to exceed the defined thresholds. Caution was used in this approach, because there is the potential danger of creating a bottleneck by limiting the amount of spawning habitat. A future approach could be to adjust the fish habitat recommendation on more of a seasonal basis. However, a method to conduct this type of evaluation has not been developed, and hence was not applied for the SSRB.

The Highwood River IFN Working Group determined that commonly occurring low flows during the latter portion of the open-water season were very likely limiting, even under natural conditions (Clipperton et al. 2002). As such, the EBF value from week 33 was extended for all remaining weeks in the open-water season and replaced the 80% habitat duration flow calculated for those weeks. The rationale and method for modifying the EBF calculation for the Highwood River were consensus-based decisions made by the Working Group (Clipperton et al. 2002). For the SSRB evaluation, the final EBF was left unadjusted as the weekly 80% habitat exceedence flow, since replicating the consensus process used for the Highwood River was not possible at this stage in the planning process. Leaving the EBF unmodified does not mean habitat is not naturally limiting at low flow periods for some reaches throughout the SSRB. Additional information is required to identify reaches where frequent low flow conditions are naturally limiting. Adjustments to the EBF could be made, if required, when an IFN is to be implemented.

The largest adjustment to the Highwood River protocols required for their use in the present project was in the interpretation of the habitat evaluation metrics. In an ideal situation, all the evaluation metrics would show a similar pattern of habitat loss and all would exceed the defined thresholds at approximately the same flow reduction. This was generally the pattern for the Highwood River. (Clipperton et al. 2002) acknowledged that an adjustment to the IFN could be made after reviewing the more detailed evaluation output, if any alarming results were found. However, no method or protocol was developed for evaluating the other metrics or for determining an appropriate IFN when the three key metrics showed an inconsistent pattern of habitat loss.

Some patterns of habitat loss that arose in the SSRB did not follow the ideal pattern. These were likely due to a combination of site-specific hydraulics, channel geometry, and the WUA curves of the reach being evaluated. In some cases, large maximum instantaneous losses were found, while many of the other metrics showed very small habitat losses or even habitat gains. This occurred, for example, when a reach contained an island and maximum instantaneous habitat losses were observed in the high flow range, due to bimodal WUA curves. Sharp changes in the slope of the WUA curve as a result of combining low- and high-flow habitat models can also produce results with high maximum instantaneous losses and limited average and weekly habitat losses. A final situation where this pattern was common occurred if life stages, such as rainbow trout and walleye spawning, were only present during higher flow weeks.

Although these maximum instantaneous habitat losses are occurring, it is not necessarily indicative of a general pattern of habitat loss. The maximum instantaneous habitat loss is a telling metric of acute habitat conditions. However, it must be considered in context of the other metrics that evaluate intermediate and chronic habitat conditions. These results should not be ignored. The level of risk at which these large maximum instantaneous habitat losses may cause ecological problems is unknown but it may be more appropriate to deal with isolated maximum habitat losses at an operational level, rather than at the current planning study level. To overcome this problem, expert judgment was used to develop an instream flow need that was reflective of acute and chronic habitat losses for all species, at all times of the year. Balancing and compromising between yearly habitat losses and losses within specific BSPs was required. Future development of the fish habitat evaluation method could potentially resolve some of these shortfalls. However, due to the constraints of the planning phase, adjustments to the existing method were not possible. The evaluations provided in this report are considered to be valid and suitable for the current planning exercise.

5.4 Fish Habitat IFN Results and Discussion

The following section summarizes the fish habitat IFN results for each reach evaluated in the SSRB. Site-specific fish habitat results were developed for the open-water season only. To remain consistent for the SSRB evaluation, the open-water season was defined as week 14 through week 44 (beginning of May to the beginning of November) for every reach.

The results for each reach are expressed as a percent reduction from the natural flow, with an associated EBF. A summary table is provided with the key habitat evaluation metrics, showing the species that triggered the IFN. The detailed results showing all the habitat evaluation metrics for each reach, for all species and life stages, are located in Appendix E. The results from this section are subsequently incorporated with the other ecosystem components to create the final integrated ecosystem IFN (Section 9.0).

Each species and life stage that was identified as a management priority within a reach and that had HSC curves available was evaluated. The only exception to this was for the evaluation of lake sturgeon. Habitat use data for lake sturgeon in Alberta are unavailable. Some general habitat descriptions and swimming speed information were available to generate draft HSC curves during the HSC workshop (see Section 5.2.6). However, workshop participants had little or no experience with lake sturgeon. As a compounding factor, the site selection for the original IFN studies did not consider lake sturgeon as a target management species. As such, the location of the study sites may not be representative of the specialized habitat of lake sturgeon. Although lake sturgeon remains an important management species for some reaches within the SSRB, they were not included in the IFN determination at this stage in the process. The habitat requirements for lake sturgeon need to be more fully addressed in reaches where they have been identified as target management species when defining the IFN.

Reach balancing is another issue that has not been addressed in the results presented in this section. The IFN determinations may not follow the natural pattern of increasing flows from upstream to downstream. This variation has been observed and accounted for in other IFN studies in Alberta (Fernet et al. 1990, Golder 1999,) and elsewhere (H. Beecher and T. Annear, 2003, personal communication). The fish habitat results for this study were left unmodified for inclusion in the integrated IFN.

Figure 5.9 shows the reaches where site-specific PHABSIM study sites were available to develop the fish habitat IFN results. Reaches defined as having good site-specific data are indicative of locations where the hydraulic and habitat modelling results provide good quality data, over a wide range of flows, that require a minimal level of adjustment prior to analysis. Reaches defined as having acceptable site-specific data are indicative of locations where the hydraulic and habitat modelling results are good, but either a limited flow range was modelled or there was a poor transition between high and low flows. This can result in WUA curves with multiple peaks or WUA curves that do not mesh neatly in the transition from low to high flows. WUA can be adjusted prior to use in the habitat evaluation to mitigate inconsistencies. In cases that indicate poor site-specific data, the hydraulic calibration was determined to be unsuitable for further analysis. In locations that indicate no site-specific data, a PHABSIM study site was not available.

In reaches with either poor or no site-specific data, the Tessmann method (Tessmann 1979) was used in lieu of a site-specific habitat evaluation. The Tessmann method is the current office-based standard applied in Alberta for determining IFN at locations with no site-specific data available. It is a hydrology method that is derived from the Tennant method (Montana method) commonly used throughout North America (Tennant 1976). A monthly flow recommendation is calculated based on an evaluation of the mean annual flow and mean monthly flow. The recommendation is then transformed into a weekly recommendation for application in Alberta.

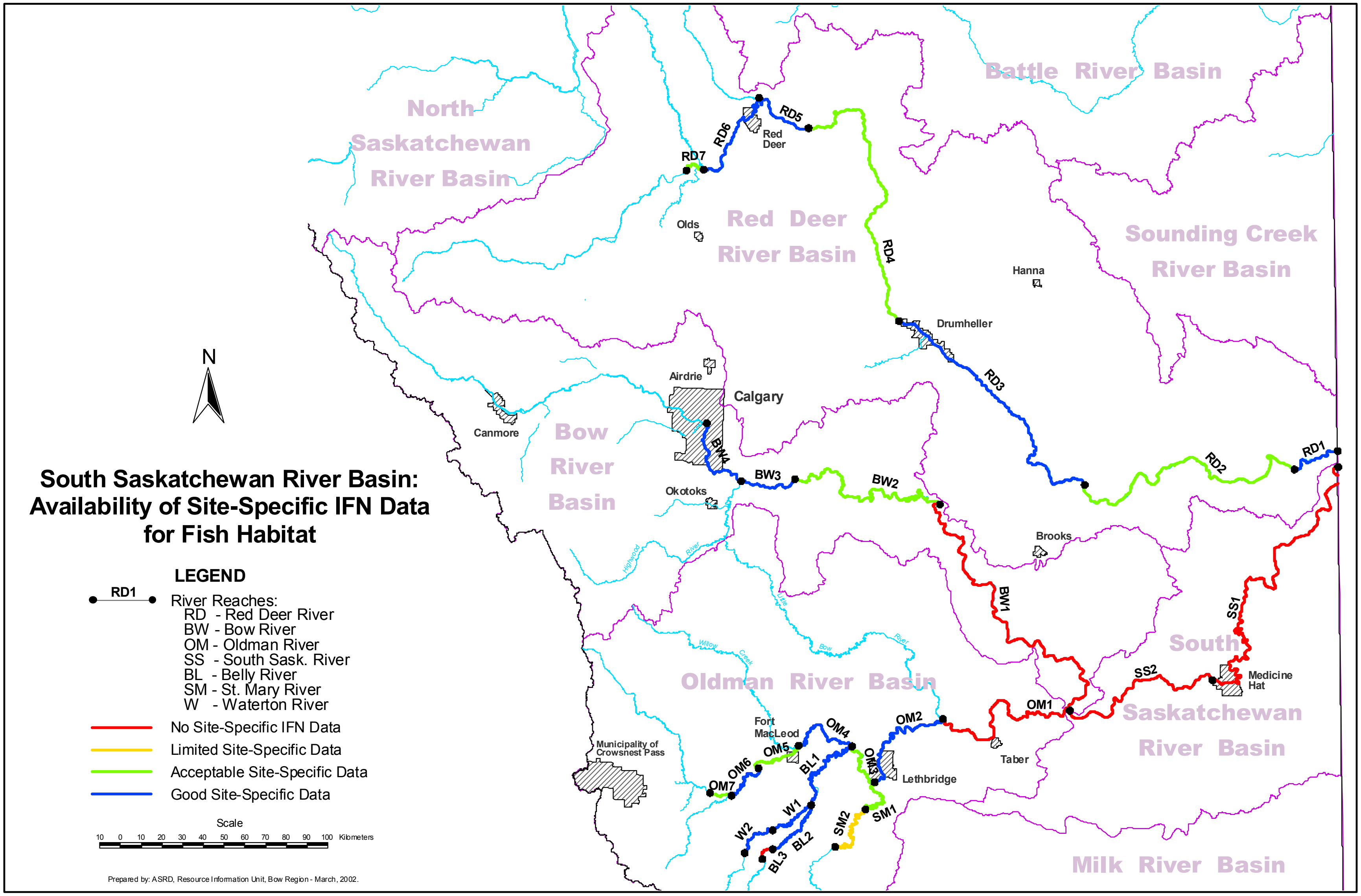


Figure 5.9. Availability of site-specific fish habitat IFN (PHABSIM) study sites used to develop the fish habitat IFN determination for the SSRB WMP.

5.4.1 Winter Ice-Covered IFN for Fish Habitat

For the purpose of this evaluation, the winter ice-covered period was defined to be from week 45 through week 13, (i.e. November – March) for every reach. The scope of this project did not allow for individual consideration of the average timing of the ice-covered period on a reach-by-reach basis. Therefore the same weeks were used for every reach. There is a growing body of knowledge that under-ice habitat is just as critical, and potentially even more critical, as habitat during the open-water times of the year (Power et al. 1993, Cunjak 1996, Cunjak 1996, Tesaker 2000, Prowse 2001, Alfredsen and Tesaker 2002). Tesaker (2000) noted that the formation and presence of ice strongly influences many variables. He stressed that "modification of geometry of flow may change the winter habitat to the better or worse."

Many scientists now understand that ice formation and break-up processes can significantly affect a variety of biological, hydrological and geomorphological processes (Beltaos 1995). The manner of formation and the type of ice present can affect (1) migration of fish under ice, (2) variation of velocity during ice formation and break-up, (3) long-term influence of ice on local fish populations and types of fish, (4) available physical winter habitat, and (5) bedload scour and sediment transport. Consequently, instream flow studies and recommendations based solely on the needs of aquatic organisms and habitat characteristics observed in the open-water period provide only a partial understanding of important ecological processes (Maki-Petays et al. 1999; Whalen et al. 1999). At this time, there are no known tools available to better define the instream flow recommendations for under-ice conditions. The province of Alberta and the Department of Fisheries and Oceans (Canada) are currently investigating the development of tools for the ice-covered time of year. Until better tools are available, the calculated Tessmann values will be recommended for the winter period for the SSRB WMP.

5.4.2 Red Deer River Fish Habitat IFN Results

Red Deer River Reach 1 (RD1)

The fish habitat IFN determination for RD1 is a 20% reduction from the natural flow, with the added weekly constraint of the EBF. The habitat-limiting life stages in this reach are walleye spawning and goldeye adults (Table 5.1). The key evaluation metrics that approach the defined thresholds in this reach are the maximum instantaneous habitat losses and the maximum weekly habitat losses. Although not defined as a primary metric, the maximum yearly habitat losses also show that, in some years, habitat losses are becoming large for some life stages. All the evaluation metrics show a trend of increasing habitat losses with continued reductions from the natural flow. The maximum weekly habitat loss for walleye spawning exceeds the defined threshold by a fraction of a percent in the IFN. However, all other metrics remained below the thresholds. Therefore, the results for a 20% flow reduction shown in Table 5.1 are considered to be protective of fish habitat in this reach.

The goldeye adult Weighted Useable Area curve peaks at a flow of 92.21 m^3/s. It is used to define the EBF (Figure 5.10) and to identify the wet weeks to be removed from the analysis. Weeks 23-28 have weekly median flows that are greater than the peak of the goldeye adult WUA curve and are removed from the analysis of the total mean habitat loss. The walleye spawning WUA curve peaks at a flow of 119.51 m^3/s, but was not used to define a portion of the EBF because the habitat losses for spawning were considered to be protected using the goldeye adult values for the entire year.

Table 5.1. Red Deer River Reach 1 (RD1) from the Saskatchewan Border upstream to near Bindloss. Habitat evaluation metrics for a 20% reduction from the natural flow with the added constraint of the EBF.

Species	Total Mean (Weeks 14-22: 29-44)	Maximum Weekly	Maximum Instantaneous	BSP2 Total Mean (Weeks 16-23)	Maximum Yearly
WALL-S	N/A	**-15.36%**	**-23.44%**	-6.21%	-20.16%
GOLD-A	-6.02%	-12.02%	**-22.54%**		-11.56%

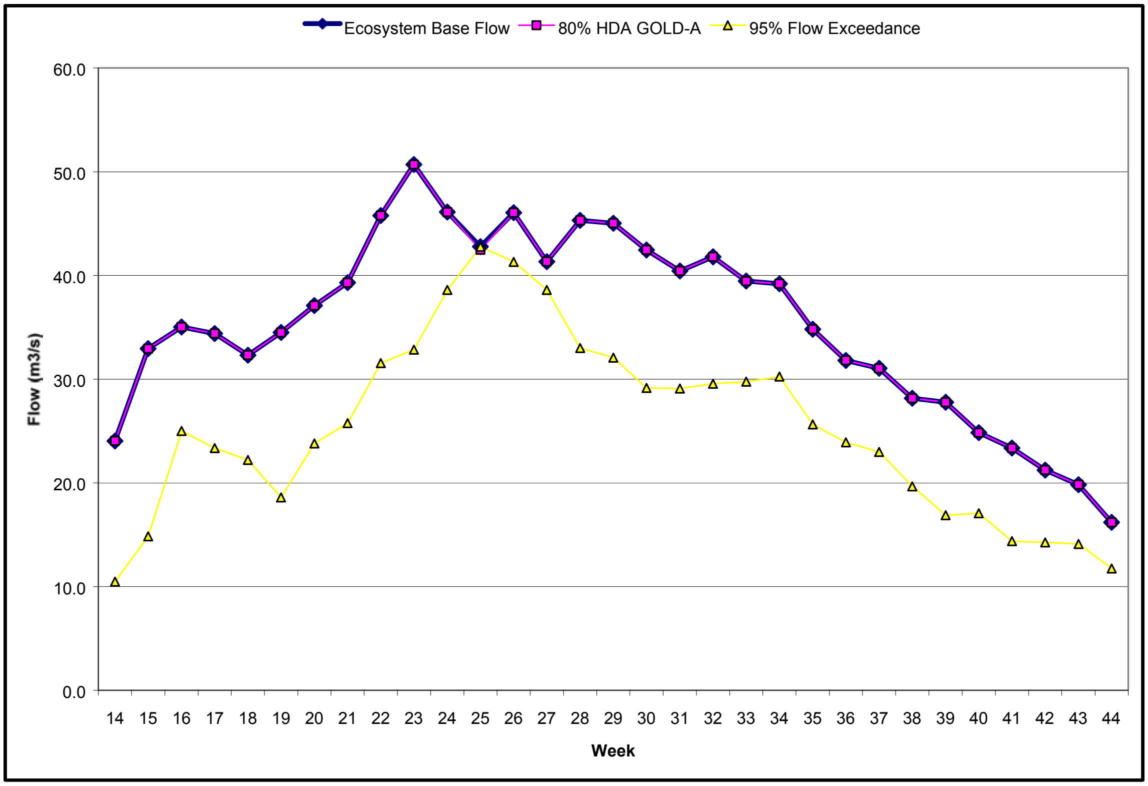


Figure 5.10. The weekly Ecosystem Base Flows for the Red Deer River Reach 1 (RD1), using the maximum value between the 80% habitat duration analysis for goldeye adult and the 95% flow exceedence.

Red Deer River Reach 2 (RD2)

In the current evaluation, reach boundaries were adjusted to overlap with the reaches used in the WRMM model. The reach boundaries defined in the initial fish habitat IFN study (Golder 1999) identified a single reach that contains the current reaches RD1 through RD3. The flow differences between Reaches RD1 and RD2 are minor. Since a separate study site to evaluate fish habitat was not available, the results from RD1 were applied directly to this reach.

Red Deer River Reach 3 (RD3)

The same study site used for the RD1 evaluation was also used for the RD3 evaluation, because Reach RD3 was contained wholly within a single reach as defined in the initial fish habitat IFN study (Golder 1999). All the WUA curves for RD3 are identical to those for RD1 because the study site is the same for both reaches. The only difference in the evaluation between RD3 and RD1 is the hydrology used for the time series evaluation.

The fish habitat IFN determination for RD3 is a 20% reduction from the natural flow, with the added weekly constraint of the EBF. The habitat limiting life stages in this reach are walleye spawning and goldeye adults (Table 5.2). The key evaluation metrics that approach the defined thresholds in this reach are the maximum instantaneous habitat losses and the maximum weekly habitat losses. The maximum weekly habitat loss for walleye spawning marginally exceeded the 15% habitat loss threshold. However, because the other key metrics for walleye spawning were still below the thresholds, and the weekly metric only exceeded the threshold by a fraction of a percent, the 20% flow reduction from natural was considered to be highly protective. All the evaluation metrics for every life stage show a trend of increasing habitat losses with continued reductions from the natural flow.

Table 5.2. Red Deer River Reach 3 (RD3) from Dinosaur Provincial Park upstream to Drumheller. Habitat evaluation metrics for a 20% reduction from the natural flow with the added constraint of the EBF.

Species	Total Mean (Weeks 14-22: 28-44)	Maximum Weekly	Maximum Instantaneous	BSP2 Total Mean (Weeks 16-23)	Maximum Yearly
WALL-S	N/A	**-15.17%**	**-23.42%**	-7.41%	-20.96%
GOLD-A	-6.22%	-11.24%	**-22.52%**		-10.99%

The goldeye adult WUA curve peaks at a flow of 92.21 m^3/s and is used to define the EBF (Figure 5.11) and to identify the wet weeks to be removed from the analysis. Weeks 23-27 have weekly median flows that are greater than the peak of the goldeye adult WUA curve and are removed from the analysis of the total mean habitat loss. The walleye spawning WUA curve peaks at a flow of 119.51 m^3/s, but was not used to define a portion of the EBF since the habitat losses for spawning were protected using the goldeye adult values for the entire year.

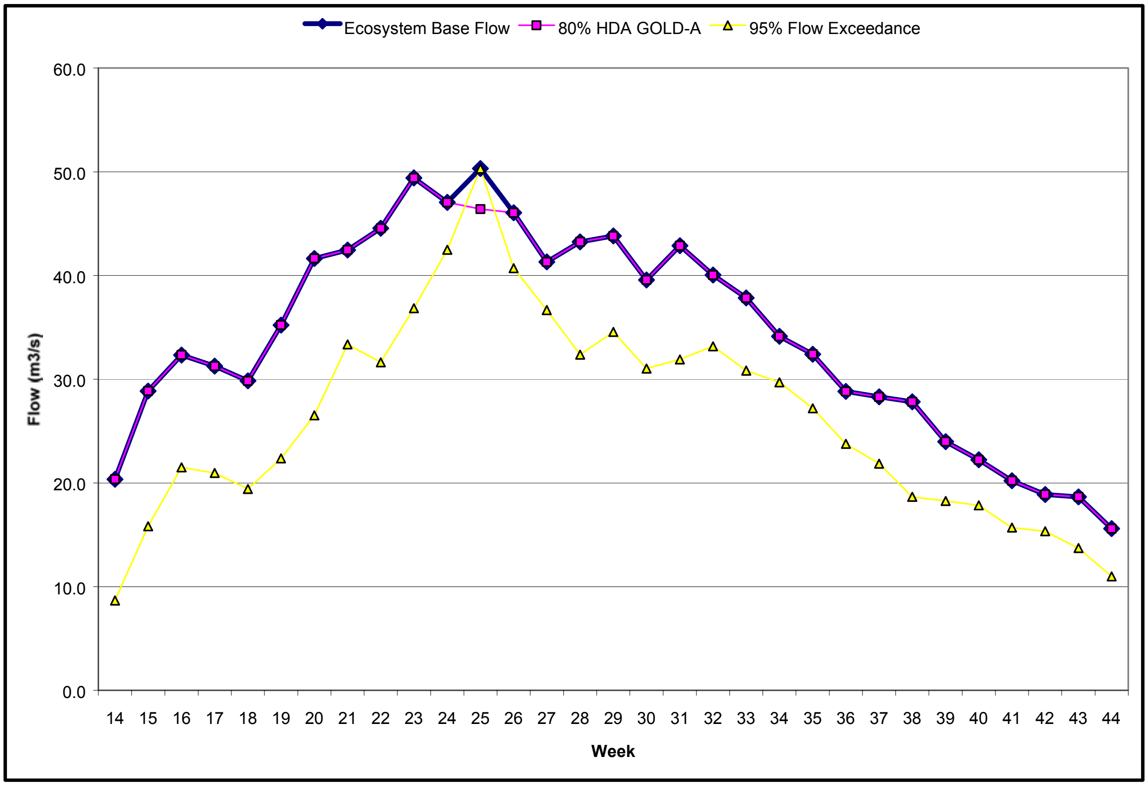


Figure 5.11. The weekly Ecosystem Base Flows for the Red Deer River Reach 3 (RD3) using the maximum value between the 80% habitat duration analysis for goldeye adult and the 95% flow exceedence.

Red Deer River Reach 4 (RD4)

Reaches RD4 and RD5 were identified as a single reach in the original fish habitat IFN study (Golder 1999). As such, a fish habitat evaluation was only conducted for RD5, and the results from RD5 were directly applied to RD4.

Red Deer River Reach 5 (RD5)

The fish habitat IFN determination for RD5 is a 25% reduction from the natural flow, with the added weekly constraint of the EBF. The habitat limiting life stages in this reach are walleye spawning, walleye adults, and goldeye adults. The key evaluation metric that approached the defined threshold in this reach is the maximum instantaneous habitat loss.

The results from this reach did not show a clear pattern of habitat loss across all the different metrics. As seen in Table 5.3 with walleye adult, although there was a large maximum instantaneous loss, the other metrics indicated habitat gains at the defined IFN. This can be caused by having WUA curves that peak at a relatively low flow compared with the typical hydrology of the site. In contrast, the goldeye adult results show a consistent pattern of habitat loss, but the values are well below the defined thresholds.

Table 5.3. Red Deer River Reach 5 (RD5) from the SAWSP diversion site upstream to the Blindman River confluence. Habitat evaluation metrics for a 25% reduction from the natural flow with the added constraint of the EBF.

Species	**Total Mean (Weeks 14:35-44)**	**Maximum Weekly**	**Maximum Instantaneous**	**BSP2 Total Mean (Weeks 16-28)**	**Maximum Yearly**
WALL-A	+4.72%	+0.11%	-18.37%		+2.34%
WALL-S	N/A	-5.74%	**-32.82%**	+4.88%	-13.16%
GOLD-A	-2.55%	-5.65%	-10.59%		-4.96%

The maximum instantaneous loss for walleye spawning exceeded the defined threshold criteria. However, the other metrics indicate a less definitive pattern of habitat loss. Continued reductions from the natural flow resulted in very large maximum instantaneous habitat losses for walleye spawning, and a steady increase in the maximum yearly loss. Several other life stages evaluated showed habitat losses below the thresholds, but did increase with continued reductions from natural flow. Other life stages showed habitat gains for most metrics other than the maximum instantaneous habitat loss metric. The resulting fish habitat IFN determination was judged to be the best balance of habitat reductions between all of the life stages.

The goldeye adult WUA curve peaks at a flow of 49.55 m^3/s and the walleye spawning WUA curve peaks at a flow of 77.83 m^3/s. Both curves are used to define the EBF (Figure 5.12), with the walleye spawning curve used for weeks 16-28 and the goldeye adult used for all remaining weeks. The goldeye adult curve was used to identify the wet weeks to be removed from the analysis. Weeks 15-34 have weekly median flows that are greater than the peak of the goldeye adult WUA curve. However, weeks 16-34 were removed from the analysis of the total mean habitat loss to provide a one-week overlap with the riparian descriptions and to ensure a smooth transition between these components in the spring.

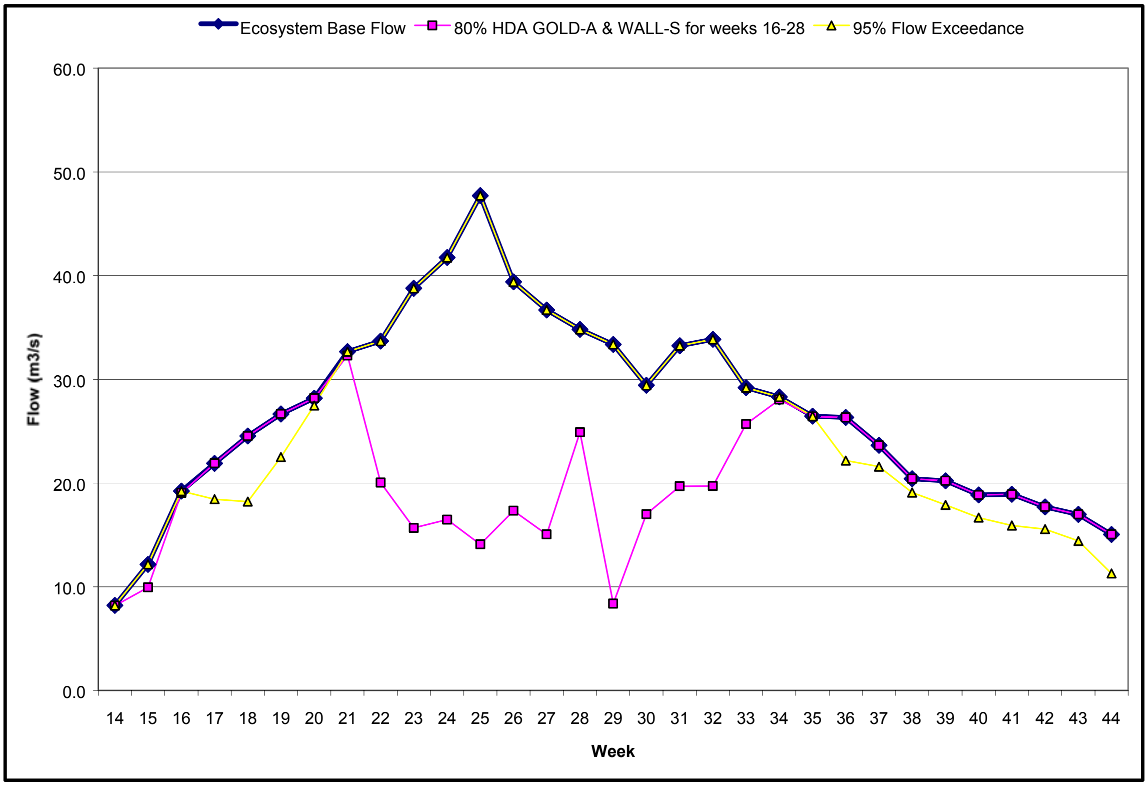


Figure 5.12. The weekly Ecosystem Base Flows for the Red Deer River Reach 5 (RD5) using the maximum value between the 80% habitat duration analysis for goldeye adult and walleye spawning and the 95% flow exceedence.

Red Deer River Reach 6 (RD6)

The fish habitat IFN determination for RD6 is a 20% reduction from the natural flow, with the added weekly constraint of the EBF. The habitat limiting life stage in this reach is mountain whitefish spawning (Table 5.4). The key evaluation metrics that approach the defined thresholds in this reach are the maximum instantaneous habitat losses and the maximum weekly habitat losses. The total mean habitat loss for BSP3, the time of year when mountain whitefish spawning occurs, also shows a large habitat loss. Most of the evaluation metrics, for most of the life stages, show a trend of increasing habitat losses with continued reductions from the natural flow.

Although the evaluation metrics for mountain whitefish spawning are exceeded at a 20% reduction in flow from natural, a 15% reduction from natural met all of the defined criteria. However, because mountain whitefish spawning only occurs in BSP3, the IFN determined for the entire year was deemed to be a compromise between the results for the spawning life stage and the remaining life stages that are present year round. Continued reductions in flow result in very rapid declines in habitat for mountain whitefish spawning and a steadily increasing trend of habitat loss across all of the metrics for most of the other life stages.

The mountain whitefish adult WUA curve peaks at a flow of 113.2 m^3/s and is used to define the EBF (Figure 5.13) and to identify the wet weeks to be removed from the analysis. There are no weeks that have a weekly median flow greater than the peak of the mountain whitefish adult WUA curve. As a surrogate for the analysis, the typically wettest weeks, from mid-May to mid-July (weeks 20-29), are removed from the analysis of the total mean habitat loss.

Table 5.4. Red Deer River Reach 6 (RD6) from the Blindman River confluence upstream to the Medicine River confluence. Habitat evaluation metrics for a 20% reduction from the natural flow with the added constraint of the EBF.

Species	**Total Mean (Weeks 14-19: 30-44)**	**Maximum Weekly**	**Maximum Instantaneous**	**Total Mean BSP3**	**Maximum Yearly**
MNWH-A	-5.03%	-9.92%	-14.66%	-8.13%	-7.12%
MNWH-S	N/A	**-18.47%**	**-30.57%**	**-13.59%**	-24.53%

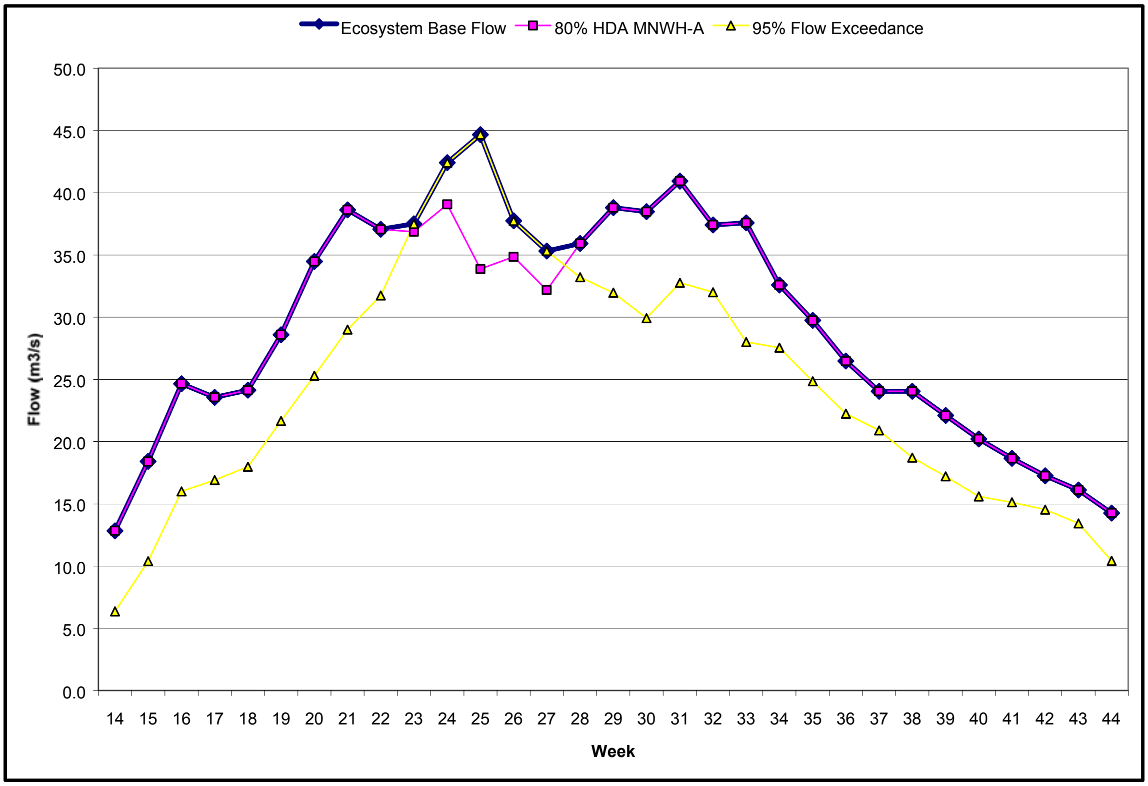


Figure 5.13. The weekly Ecosystem Base Flows for the Red Deer River Reach 6 (RD6) using the maximum value between the 80% habitat duration analysis for mountain whitefish and the 95% flow exceedence.

Red Deer River Reach 7 (RD7)

The fish habitat IFN determination for RD7 is a 25% reduction from the natural flow, with the added weekly constraint of the EBF. The habitat limiting life stage in this reach is walleye adult (Table 5.5). The key evaluation metrics that approach the defined thresholds in this reach are the maximum instantaneous habitat losses and maximum weekly habitat losses. The maximum instantaneous habitat loss for walleye was allowed to exceed the threshold criteria, while the maximum weekly habitat loss is very close to the defined threshold. However, the total mean habitat loss metric for walleye adult is fairly low, and the 25% flow reduction IFN selected is believed to provide a balance between acute and chronic habitat losses. All the other life stages show a trend of increasing habitat losses with continued reductions from the natural flow.

Table 5.5. Red Deer River Reach 7 (RD7) from the Medicine River confluence upstream to the Dickson Dam. Habitat evaluation metrics for a 25% reduction from the natural flow with the added constraint of the EBF.

Species	**Total Mean (Weeks 14-19: 30-44)**	**Maximum Weekly**	**Maximum Instantaneous**
WALL-A	-1.01%	**-12.82%**	**-27.45%**
BNTR-A	-2.47%	-8.49%	-20.09%
MNWH-J	-5.49%	-7.91%	-14.29%

The mountain whitefish juvenile WUA curve peaks at a flow of 226.4 m³/s and is used to define the EBF (Figure 5.14) and to identify the wet weeks to be removed from the analysis. There are no weeks that have a weekly median flow greater than the peak of the mountain whitefish juvenile WUA curve. As a surrogate for the analysis, the typically wettest weeks, from mid-May to mid-July (weeks 20-29), are removed from the analysis of the total mean habitat loss.

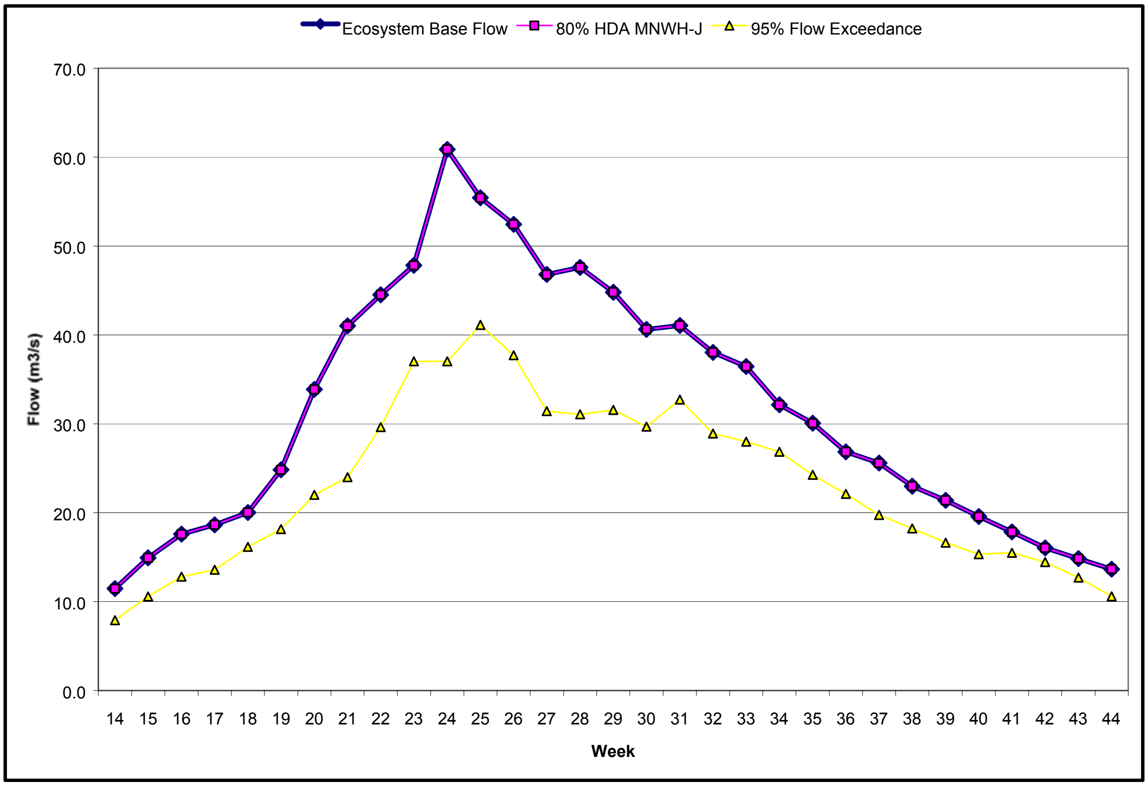


Figure 5.14. The weekly Ecosystem Base Flows for the Red Deer River Reach 7 (RD7) using the maximum value between the 80% habitat duration analysis for mountain whitefish juvenile and the 95% flow exceedence.

5.4.3 Bow River Fish Habitat IFN Results

Bow River Reach 1 (BW1)

Reach-specific PHABSIM data are not available for the Bow River from the Grand Forks (the confluence with the Oldman River) upstream to the Bassano Dam. The species composition for this reach of the Bow River also differs from the immediate upstream reach, which does not allow for a transfer of results to this reach. The EBF for fish habitat was developed using the Tessmann calculation for the entire year (Figure 5.15). These values must be combined with the other components to develop the ecosystem IFN.

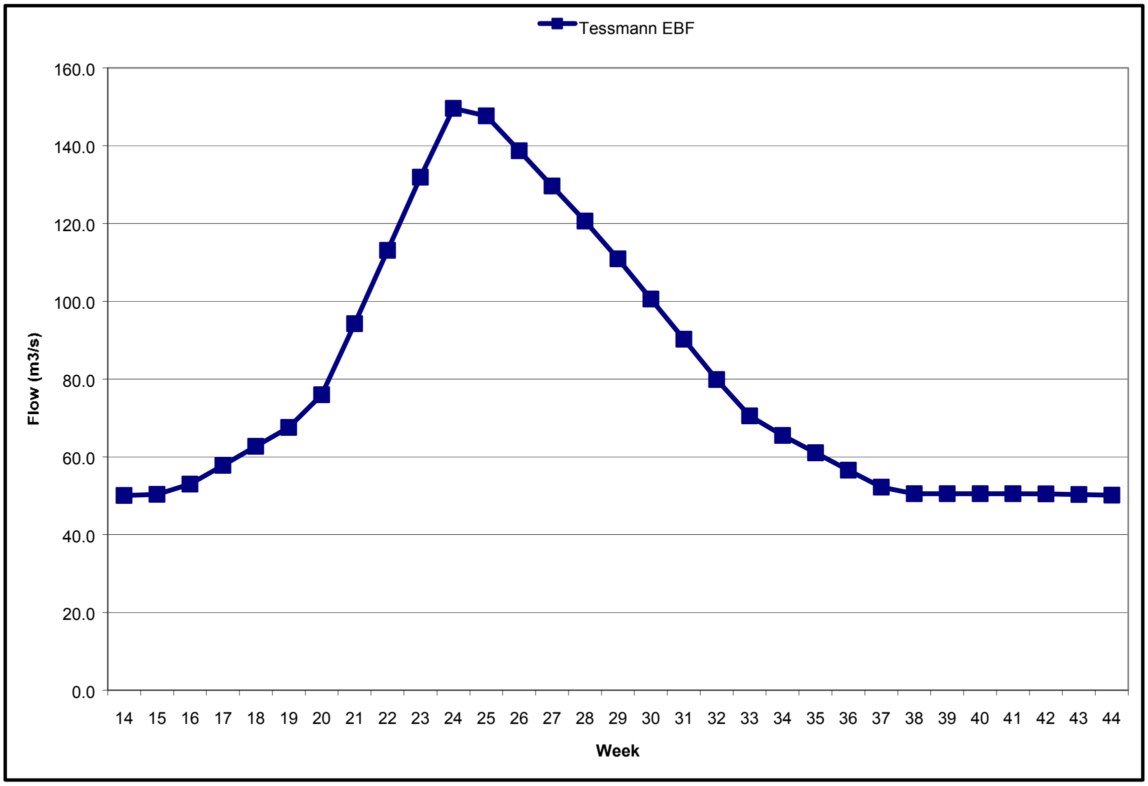


Figure 5.15. The weekly Ecosystem Base Flows for the Bow River Reach 1 (BW1) using the Tessmann calculation.

Bow River Reach 2 (BW2)

The fish habitat IFN determination for BW2 is a 25% reduction from the natural flow, with the added weekly constraint of the EBF. The habitat limiting life stages in this reach are brown trout and rainbow trout adults and brown trout fry (Table 5.6). The key evaluation metrics that approach the defined thresholds in this reach are the maximum instantaneous habitat losses and maximum weekly habitat losses. The total mean habitat loss for BSP2, which covers most of the year, is also provided to illustrate chronic habitat losses.

The WUA curves for most life stages in this reach indicated two distinct habitat peaks, one at a low flow and a second at a moderate to high flow. This pattern appears to be a result of side channels that become inundated at higher flows and begin to form useable habitat. Due to the bimodal nature of the WUA curves, the pattern of habitat loss with some of the different metrics was not consistent and several metrics indicate habitat gains with increased flow reductions. As an example, the brown trout fry results for maximum instantaneous habitat loss exceed the defined criteria, while the more chronic measure of habitat loss shown for BSP2 indicates a habitat gain. The weekly habitat loss for brown trout adults exceeds the defined threshold by a very small margin, while all other metrics meet the threshold criteria. The defined IFN of a 25% flow reduction is judged to be protective and provide a suitable balance between acute and chronic habitat losses.

Table 5.6. Bow River Reach 2 (BW2) from the Bassano dam upstream to the Carseland weir. Habitat evaluation metrics for a 25% reduction from the natural flow with the added constraint of the EBF.

Species	**BSP2 Total Mean (Weeks 23-39)**	**Maximum Weekly**	**Maximum Instantaneous**
BNTR-F	+7.98	**-13.75%**	**-26.30%**
BNTR-A	-6.45	**-15.58%**	**-23.92%**
RNTR-A	-6.46	**-14.68%**	**-23.48%**

The mountain whitefish juvenile WUA curve peaks at a flow of 42.5 m^3/s and is used to define the EBF (Figure 5.16) and to identify the wet weeks to be removed from the analysis. Every week has a weekly median flow greater than the peak of the mountain whitefish juvenile WUA curve. Thus, a calculation of total mean habitat for the entire year was not available. The change in the mean habitat was still calculated for each BSP and provides some indication of longer-term habitat changes from natural. The habitat changes for BSP2, which spans a majority of the open-water season, is presented in Table 5.6. For the purpose of integrating the fish habitat results with the other components, weeks 14-15 and 37-44 were used. This allows for a one-week overlap with the riparian descriptions and ensures a smooth transition between these components in the spring and the fall.

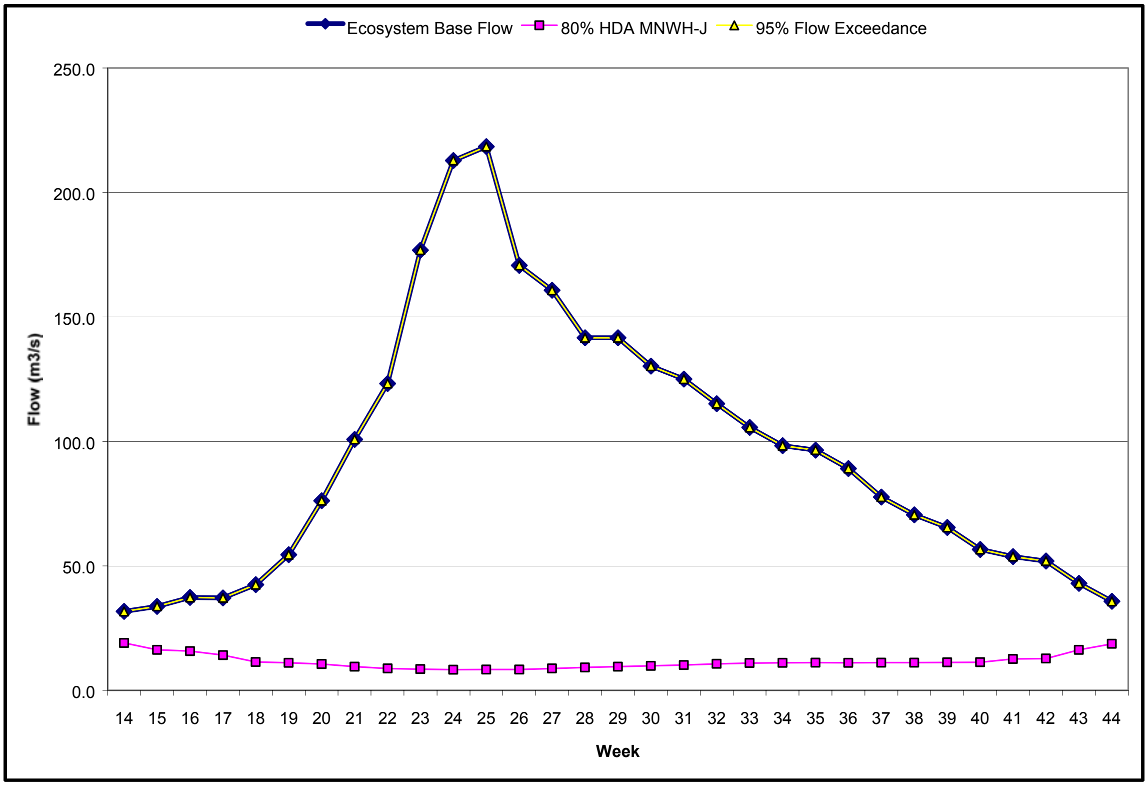


Figure 5.16. The weekly Ecosystem Base Flows for the Bow River Reach 2 (BW2) using the maximum value between the 80% habitat duration analysis for mountain whitefish juvenile and the 95% flow exceedence.

Bow River Reach 3 (BW3)

The fish habitat IFN determination for BW3 is constrained only by the EBF. All reductions in flow, until the flow is entirely limited by the EBF, meet all the defined threshold criteria except for the maximum instantaneous habitat loss for rainbow trout spawning (Table 5.7). Although the maximum habitat loss criterion was exceeded for rainbow trout spawning, all other metrics were below the identified thresholds. Some metrics indicated habitat gains relative to natural. Minimal habitat losses were shown for mountain whitefish adults and juveniles, for the longer-term metrics.

Table 5.7. Bow River Reach 3 (BW3) from the Carseland weir upstream to the Highwood River confluence. Habitat evaluation metrics for flows constrained only by the EBF.

Species	Total Mean (Weeks 14-19: 37-44)	Maximum Weekly	Maximum Instantaneous	Maximum Yearly
MNWH-A	-1.30%	-9.95%	**-21.11%**	0.17%
MNWH-J	-4.02%	-9.81%	**-20.69%**	-0.81%
MNWH-S	N/A	-9.37%	**-20.63%**	-12.99%
RNTR-S	N/A	**-14.45%**	**-27.76%**	-3.02%

The EBF for this reach provided suitable protection of the hydraulic habitat for all species and life stages. The WUA curves indicate suitable habitat at flows that are relatively low for most times of the year for this reach. A potential explanation for this result is that the Bow River in this reach has a relatively wide, single channel. As flows are reduced, the habitat suitability in terms of both depth and velocity remain fairly constant. As a result, the WUA curves in this reach peak at a relatively low flow. The peak of the WUA curves is also very broad and is not very sensitive to changes in flow. In order to meet the goal of intra- and inter-annual flow variability, it is even more critical that these results be incorporated with the riparian IFN determination.

The mountain whitefish juvenile WUA curve peaks at a flow of 113.2 m^3/s and is used to define the EBF (Figure 5.17) and to identify the wet weeks to be removed from the analysis. Weeks 20-36 have weekly median flows that are greater than the peak of the mountain whitefish juvenile WUA curve and are removed from the analysis of the total mean habitat loss.

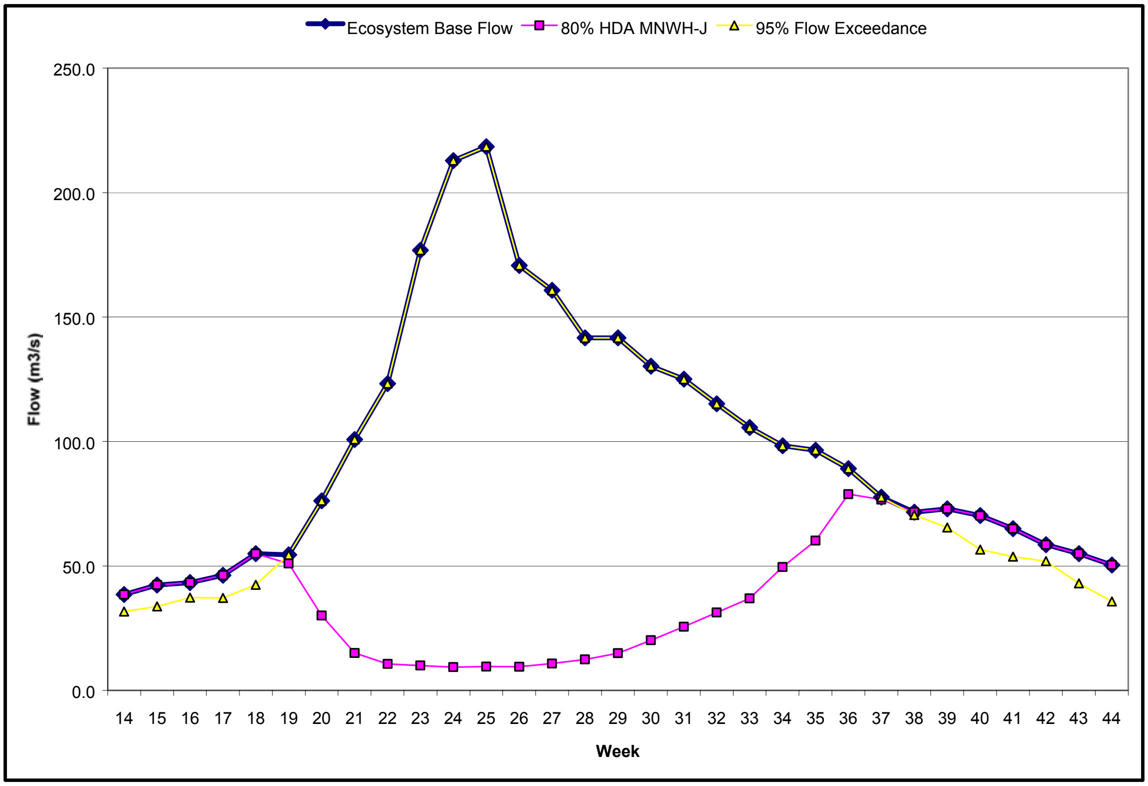


Figure 5.17. The weekly Ecosystem Base Flows for the Bow River Reach 3 (BW3) using the maximum value between the 80% habitat duration analysis for mountain whitefish juvenile and the 95% flow exceedence.

Bow River Reach 4 (BW4)

The fish habitat IFN determination for BW4 is a 55% reduction from the natural flow, with the added weekly constraint of the Ecosystem Base Flow. The habitat limiting life stage in this reach is mountain whitefish adult (Table 5.8). The key evaluation metrics that approach the defined thresholds in this reach are the maximum instantaneous habitat losses and maximum weekly habitat losses. The habitat reductions begin to flatten off with continued reductions from the natural flow, which again indicates that the EBF is in large part providing much of the habitat protection for this reach. The WUA curves in Reach BW4 peak at a relatively low flow compared with the natural hydrology. The WUA curve peaks are also very broad and are therefore not very sensitive to changes in flow. In order to meet the goal of intra- and inter-annual flow variability, it is even more critical that these results be incorporated with the riparian IFN determination.

Table 5.8. Bow River Reach 4 (BW4) from the Highwood River confluence upstream to the WID weir. Habitat evaluation metrics for a 55% reduction from the natural flow with the added constraint of the EBF.

Species	**Total Mean (Weeks 14-17:43-44)**	**Maximum Weekly**	**Maximum Instantaneous**
MNWH-A	-7.73%	**-14.63%**	**-22.47%**
RNTR-A	-4.41%	-12.10%	-20.25%

The mountain whitefish adult WUA curve peaks at a flow of 59.4 m^3/s and is used to define the EBF (Figure 5.18) and to identify the wet weeks to be removed from the analysis. Weeks 18-42 have weekly median flows that are greater than the peak of the mountain whitefish juvenile WUA curve and are removed from the analysis of the total mean habitat loss. For the purpose of integrating the fish habitat results with the other components, weeks 14-17 and 37-44 were used. This allows for a one-week overlap with the riparian descriptions and ensures a smooth transition between these components in the fall.

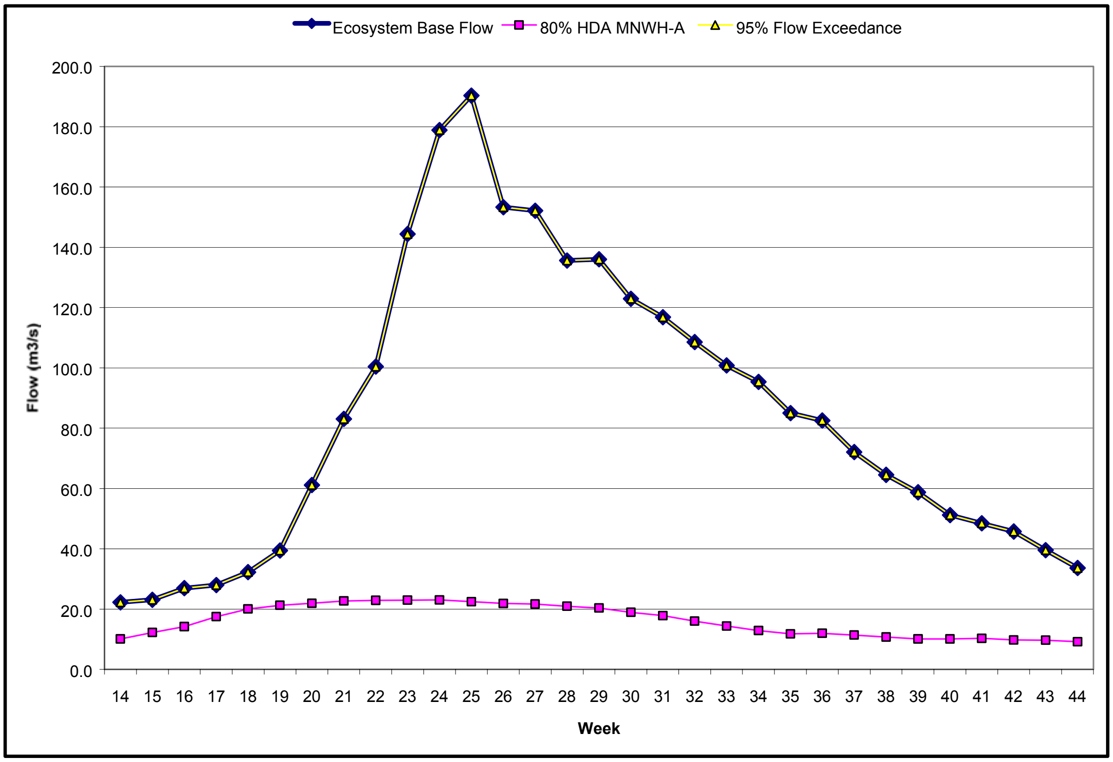


Figure 5.18. The weekly Ecosystem Base Flows for the Bow River Reach 4 (BW4) using the maximum value between the 80% habitat duration analysis for mountain whitefish adult and the 95% flow exceedence.

5.4.4 Oldman River Fish Habitat IFN Results

Oldman River Reach 1 (OM1)

Site-specific PHABSIM data are not available for the Oldman River from the Grand Forks upstream to the confluence of the Little Bow River. The EBF for fish habitat was developed using the Tessmann calculation for the entire year (Figure 5.19). These values must be combined with the other components to develop the ecosystem IFN.

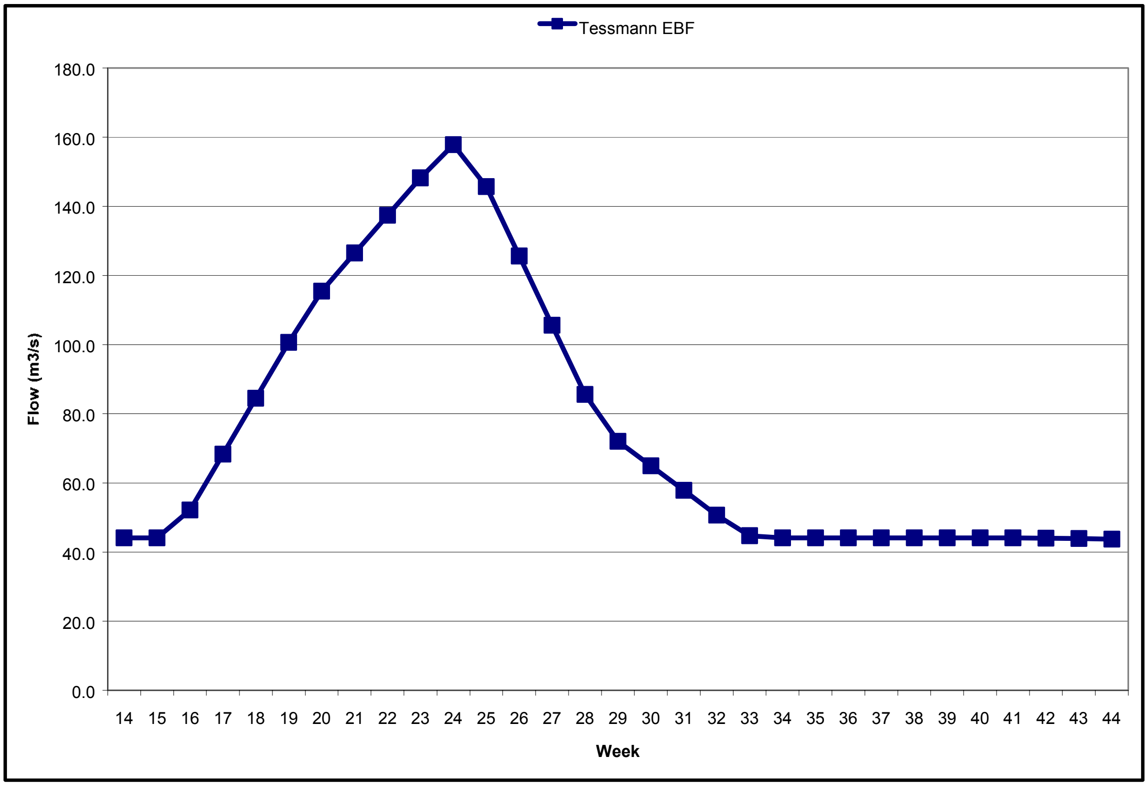


Figure 5.19. The weekly Ecosystem Base Flows for the Oldman River Reach 1 (OM1) using the Tessmann calculation.

Oldman River Reach 2 (OM2)

The fish habitat IFN determination for OM2 is a 40% reduction from the natural flow, with the added weekly constraint of the EBF. The habitat limiting life stages in this reach are mountain whitefish spawning and adult, and walleye spawning (Table 5.9). The key evaluation metrics that approach the defined thresholds in this reach are the maximum instantaneous habitat losses and maximum weekly habitat losses. The maximum instantaneous habitat losses for the spawning life stages were allowed to exceed the defined threshold. All metrics show a steady pattern of increased habitat loss with continued flow reductions and approach the defined thresholds.

This reach of the Oldman River was difficult to evaluate because many of the longer-term habitat metrics indicated habitat gains. For BSP1, the shorter-term evaluation metrics indicate high habitat losses for walleye spawning, whereas overall habitat gains are shown for BSP1 when walleye spawning occurs. A sensitivity analysis was conducted to assist in the interpretation of the maximum instantaneous habitat losses. For walleye spawning, a maximum instantaneous habitat loss greater than 20% occurred 17.5% of the time. Habitat losses greater than 25% remained relatively high, occurring 14.8% of the time. In comparison, greater than 20% maximum instantaneous habitat losses for mountain whitefish spawning occurred 26.7% of the time, whereas habitat losses greater than 25% occurred only 5.5% of the time. This, along with the other metrics, indicates the habitat losses for mountain whitefish spawning show a more consistent pattern with increased flow reductions. On the other hand, there appear to be a few critical low-flow situations for walleye spawning habitat that result in large maximum instantaneous habitat losses that are not indicative of the majority of the flows evaluated. Large maximum instantaneous habitat losses typically occur at low flows and are usually moderated by the EBF. The results for this reach suggest the EBF could be adjusted for the first few weeks of walleye spawning, to reduce the maximum instantaneous habitat losses. This adjustment has not been made for the current planning level evaluation, but should be examined prior to any IFN implementation. The mountain whitefish adult WUA curve peaks at a flow of 68.0 m^3/s and is used to define the EBF (Figure 5.20) and to identify the wet weeks to be removed from the analysis. Weeks 16-32 have weekly median flows greater than the peak of the mountain whitefish adult WUA curve and are removed from the analysis of the total mean habitat loss.

Table 5.9. Oldman River Reach 2 (OM2) from the Little Bow River confluence upstream to the St. Mary River. Habitat evaluation metrics for a 40% reduction from the natural flow with the added constraint of the EBF.

Species	**Total Mean (Weeks 14-15: 33-44)**	**Maximum Weekly**	**Maximum Instantaneous**	**Total Mean BSP1**	**Total Mean BSP3**
MNWH-A	-4.98%	-6.70%	-19.08%	+19.34%	-6.03%
MNWH-S	N/A	-11.45%	**-26.89%**	N/A	-11.03%
WALL-S	N/A	-10.23%	**-40.49%**	+23.98%	N/A

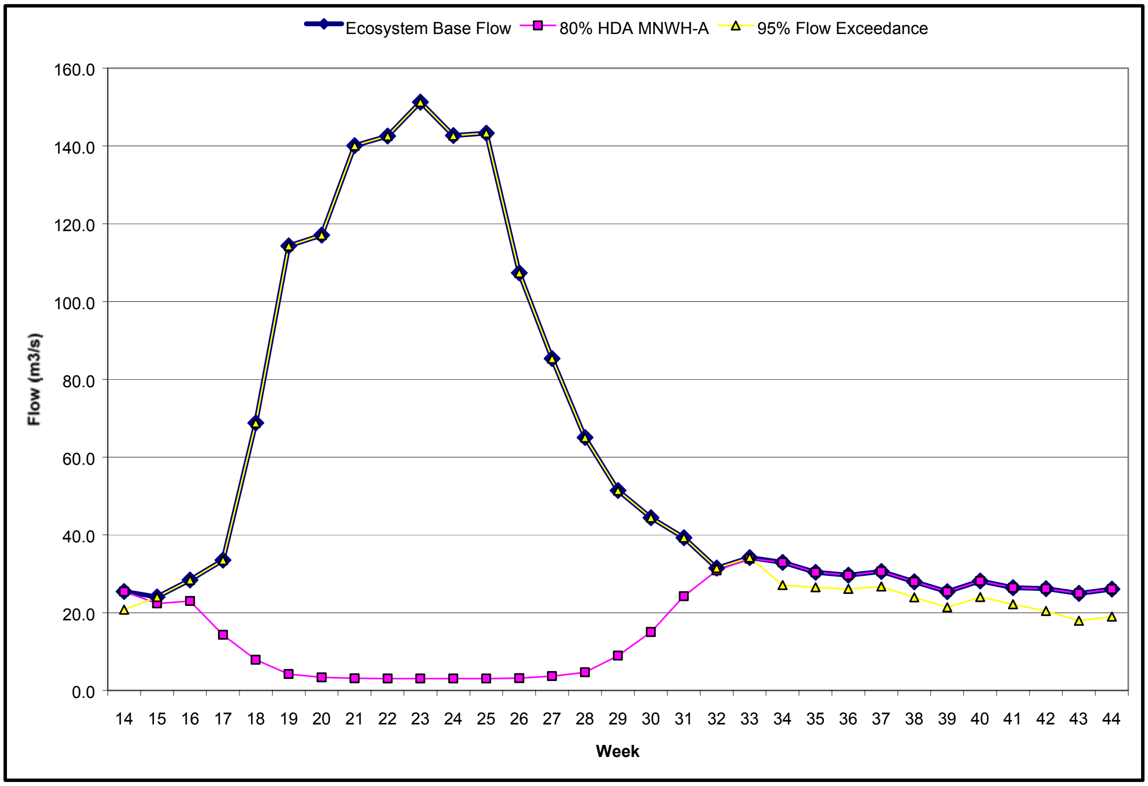


Figure 5.20. The weekly Ecosystem Base Flows for the Oldman River Reach 2 (OM2) using the maximum value between the 80% habitat duration analysis for mountain whitefish adult and the 95% flow exceedence.

Oldman River Reach 3 (OM3)

The fish habitat IFN determination for OM3 is a 30% reduction from the natural flow, with the added weekly constraint of the EBF. The habitat limiting life stages are mountain whitefish adult and spawning, and brown trout adult (Table 5.10). The key evaluation metrics that approach the defined thresholds in this reach are the maximum instantaneous habitat losses and maximum weekly habitat losses.

Table 5.10. Oldman River Reach 3 (OM3) from the St. Mary River confluence upstream to the Belly River confluence. Habitat evaluation metrics for a 30% reduction from the natural flow with the added constraint of the EBF.

Species	**Total Mean (Weeks 14-19: 27-44)**	**Maximum Weekly**	**Maximum Instantaneous**	**BSP3 Mean (Weeks 40-44)**	**Maximum Yearly**
MNWH-A	-8.38%	-10.81%	**-21.70%**	-10.03	-10.49%
MNWH-S	N/A	-11.55%	**-23.51%**	**-10.83**	-21.84%
BNTR-A	-6.48%	-9.16%	**-21.47%**	-6.48	-9.20%

The hydraulic modelling results from this reach could only be extended to 169.8 m^3/s, corresponding to the peak of several WUA curves. To complete the time series analysis, an arbitrary habitat value was assigned at a flow of 1870 m^3/s, the highest flow being evaluated. This resulted in a straight-line habitat relationship between 169.8 m^3/s and 1870 m^3/s, representing a gradual habitat decline for that range. The habitat value for all flows greater than 169.8 m^3/s was based on this criterium. The WUA results for flows less than 169.8 m^3/s displayed an irregular pattern for some life stages. However, the results were determined to be suitable for the current planning exercise and the Ecosystem Base Flows are considered to be accurate. Results from this reach should be evaluated carefully, based on the results from both upstream and downstream reaches, to validate the decisions made.

The mountain whitefish adult WUA curve peaks at a flow of 169.8 m^3/s and is used to define the EBF (Figure 5.21) and to identify the wet weeks to be removed from the analysis. Weeks 20-26 have weekly median flows greater than the peak of the mountain whitefish juvenile WUA curve and are removed from the analysis of the total mean habitat loss.

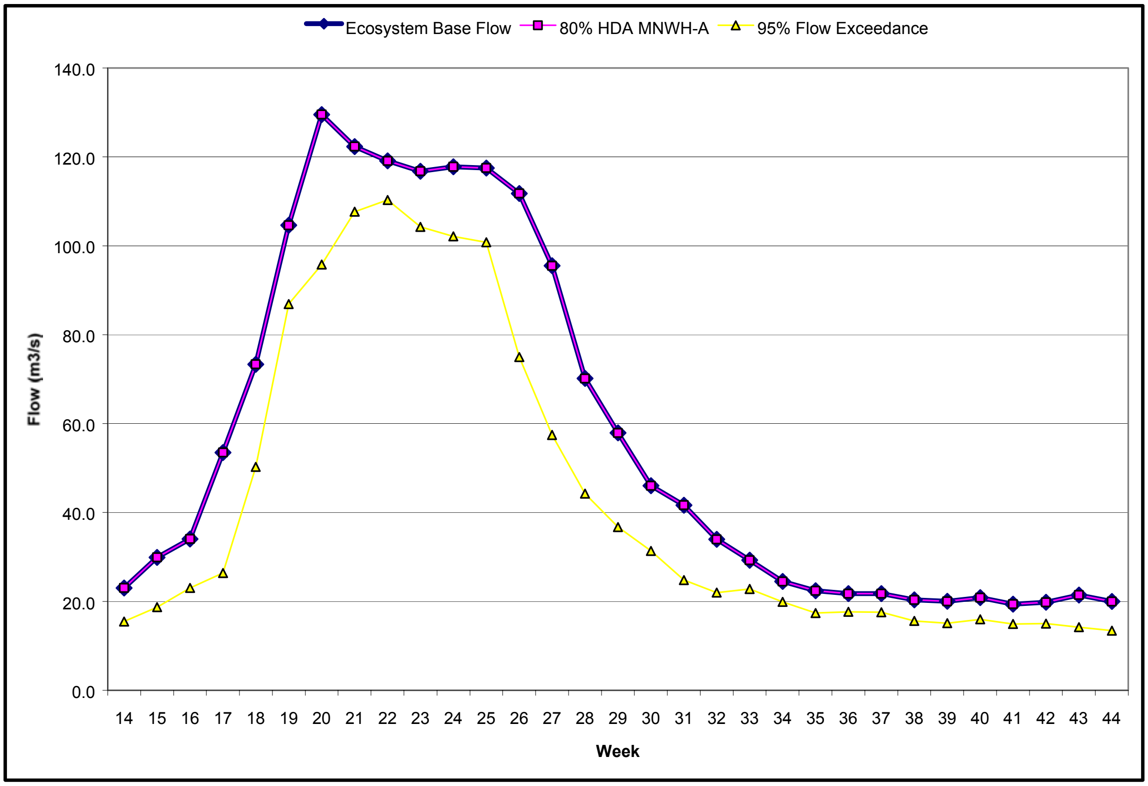


Figure 5.21. The weekly Ecosystem Base Flows for the Oldman River Reach 3 (OM3) using the maximum value between the 80% habitat duration analysis for mountain whitefish adult and the 95% flow exceedence.

Oldman River Reach 4 (OM4)

In a few reaches, as in this case Oldman River Reach 4, the 80% habitat retention curve does not follow an expected pattern. The specifics of why this occurred were not investigated in this study, but it seems reasonable to suggest it is due to a combination of the stream hydraulics and hydrology. The results of the 80% habitat evaluation do not necessarily scale in proportion with the hydrology from upstream to downstream. It is recommended that these anomalies be investigated.

The fish habitat IFN determination for OM4 is a 15% reduction from the natural flow, with the added weekly constraint of the EBF. The habitat limiting life stages in this reach are mountain whitefish and walleye spawning (Table 5.11). The key evaluation metrics that approach the defined thresholds in this reach are the maximum instantaneous habitat losses and maximum weekly habitat losses. The maximum instantaneous habitat loss for walleye spawning exceeds the defined threshold. However, the maximum weekly habitat loss and the total mean habitat loss for BSP1 indicate that the acute habitat losses are not indicative of chronic habitat losses. Flow reductions beyond 15% of natural result in a very rapid decline in habitat for both mountain whitefish and walleye spawning. Although the habitat limiting species are both spawning life stages, life stages present year-round, such as mountain whitefish adults, also show a steady trend of habitat loss with continued flow reductions.

The mountain whitefish adult WUA curve peaks at a flow of 49.5 m^3/s and is used to define the EBF (Figure 5.22) and to identify the wet weeks to be removed from the analysis. Weeks 17-28 have weekly median flows greater than the peak of the mountain whitefish adult WUA curve and are removed from the analysis of the total mean habitat loss.

Table 5.11. Oldman River Reach 4 (OM4) from the Belly River confluence upstream to the Willow Creek confluence. Habitat evaluation metrics for a 15% reduction from the natural flow with the added constraint of the EBF.

Species	**Total Mean (Weeks 14-16:29-44)**	**Maximum Weekly**	**Maximum Instantaneous**	**Total Mean BSP1**
MNWH-A	-4.53%	-6.60%	-11.74%	
MNWH-S	N/A	-10.59%	**-21.74%**	N/A
WALL-S	N/A	-9.90%	**-29.63%**	+5.07%

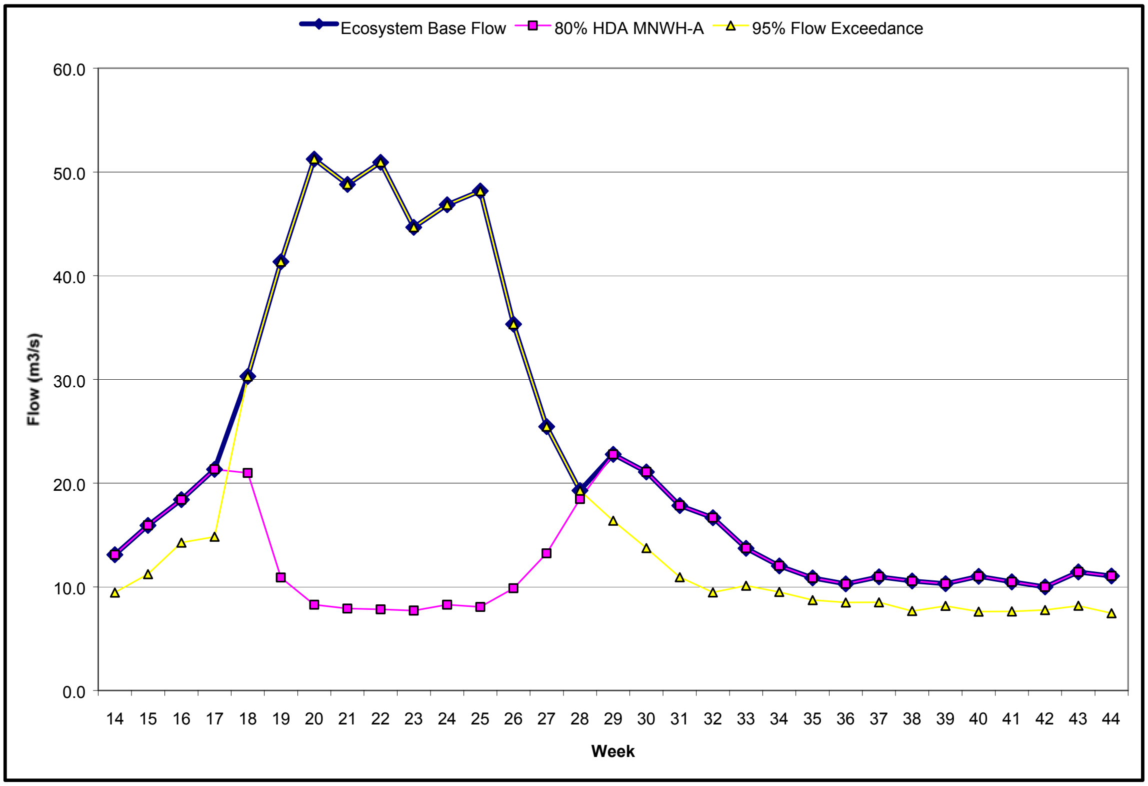


Figure 5.22. The weekly Ecosystem Base Flows for the Oldman River Reach 4 (OM4) using the maximum value between the 80% habitat duration analysis for mountain whitefish adult and the 95% flow exceedence.

Oldman River Reach 5 (OM5)

The fish habitat IFN determination for OM5 is a 30% reduction from the natural flow, with the added weekly constraint of the EBF. The habitat limiting life stages in this reach are mountain whitefish adult and spawning, and rainbow trout spawning (Table 5.12). The key evaluation metrics that approach the defined thresholds in this reach are the maximum instantaneous habitat losses and maximum weekly habitat losses. The rainbow trout spawning life stage has a very high maximum instantaneous habitat loss value. However, the other key habitat metrics were not consistent with this pattern and the maximum instantaneous threshold was allowed to exceed the threshold to this extent. All other species and life stages showed consistent habitat losses with continued flow reductions. The results for a 30% flow reduction are judged to provide a balance between all life stages throughout the year.

Table 5.12. Oldman River Reach 5 (OM5) from the Willow Creek confluence upstream to the LNID weir. Habitat evaluation metrics for a 30% reduction from the natural flow with the added constraint of the EBF.

Species	**Total Mean (Weeks 14-16: 29-44)**	**Maximum Weekly**	**Maximum Instantaneous**	**Total Mean BSP1**	**Maximum Yearly**
MNWH-A	-7.24%	-11.02%	-19.98%		-6.30%
MNWH-S	N/A	**-12.65%**	**-23.39%**	N/A	-22.14%
RNTR-S	N/A	-2.57%	**-46.17%**	+16.20%	-4.70%

The mountain whitefish juvenile WUA curve peaks at a flow of 42.5 m^3/s and is used to define the EBF (Figure 5.23) and to identify the wet weeks to be removed from the analysis. Weeks 17-28 have weekly median flows greater than the peak of the mountain whitefish juvenile WUA curve and are removed from the analysis of the total mean habitat loss.

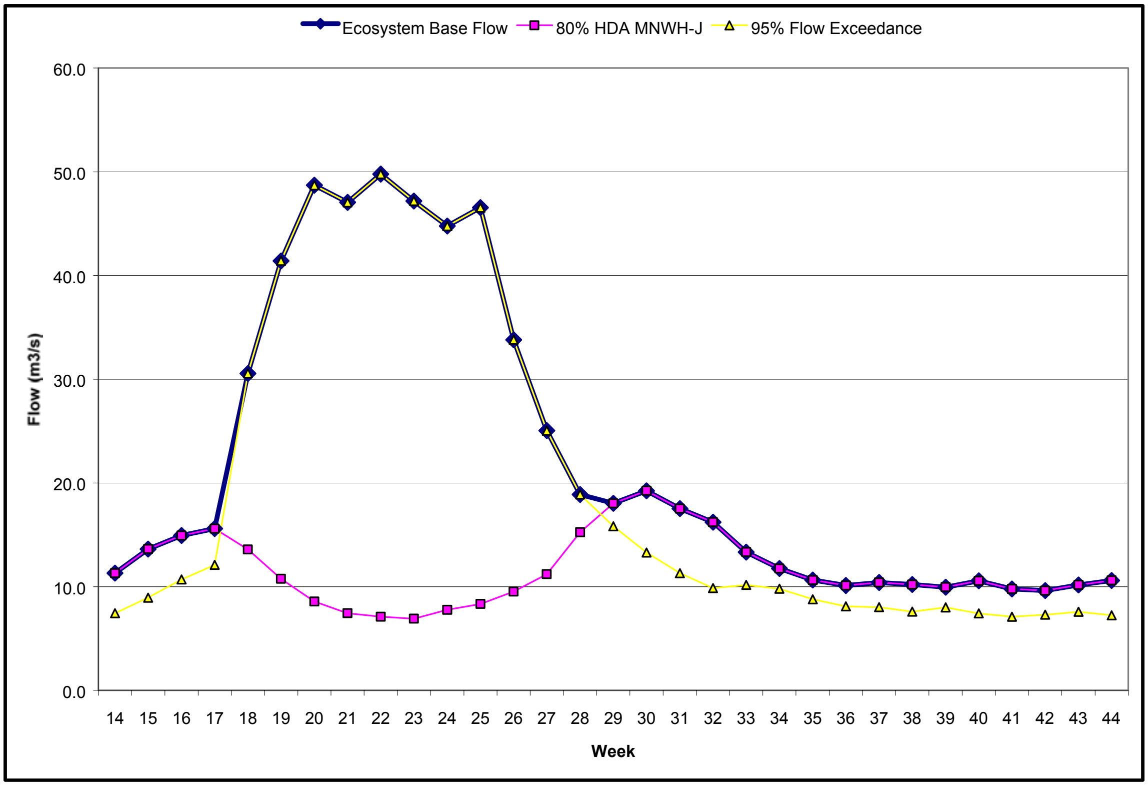


Figure 5.23. The weekly Ecosystem Base Flows for the Oldman River Reach 5 (OM5) using the maximum value between the 80% habitat duration analysis for mountain whitefish juvenile and the 95% flow exceedence.

Oldman River Reach 6 (OM6)

The fish habitat IFN determination for OM6 is a 20% reduction from the natural flow, with the added weekly constraint of the EBF. The habitat limiting life stages in this reach are mountain whitefish adult and spawning, and rainbow trout spawning (Table 5.13). The key evaluation metrics that approach the defined thresholds in this reach are the maximum instantaneous habitat losses and maximum weekly habitat losses. The maximum instantaneous habitat losses exceed the defined threshold for both spawning life stages. The rainbow trout results do not indicate that the acute habitat losses are indicative of chronic habitat losses. The mountain whitefish spawning habitat losses show a more consistent pattern of habitat loss. The habitat evaluation metrics show a consistent pattern of habitat loss with continued flow reductions in all of the life stages present year-round in the reach. The results for a 20% flow reduction are judged to provide a balance between all life stages throughout the year.

A flow reduction of 20% is judged to be the best balance of habitat reductions between all the life stages. The results for this reach suggest the EBF could be adjusted in the spring and fall to reduce the maximum instantaneous habitat losses for the spawning life stages. This adjustment has not been made for the current planning level evaluation, but should be examined prior to any IFN implementation.

Table 5.13. Oldman River Reach 6 (OM6) from the LNID weir upstream to the Pincher Creek confluence. Habitat evaluation metrics for a 20% reduction from the natural flow with the added constraint of the EBF.

Species	Total Mean (Weeks 14-16: 29-44)	Maximum Weekly	Maximum Instantaneous	Total Mean BSP1	Total Mean BSP3
MNWH-A	-4.24%	-7.23%	-17.68%		
MNWH-S	N/A	-10.63%	**-29.12%**	N/A	**-10.14%**
RNTR-S	N/A	-5.60%	**-31.60%**	+7.80%	N/A

The mountain whitefish juvenile WUA curve peaks at a flow of 42.5 m^3/s and is used to define the EBF (Figure 5.24) and to identify the wet weeks to be removed from the analysis. Weeks 17-28 have weekly median flows that are greater than the peak of the mountain whitefish juvenile WUA curve and are removed from the analysis of the total mean habitat loss.

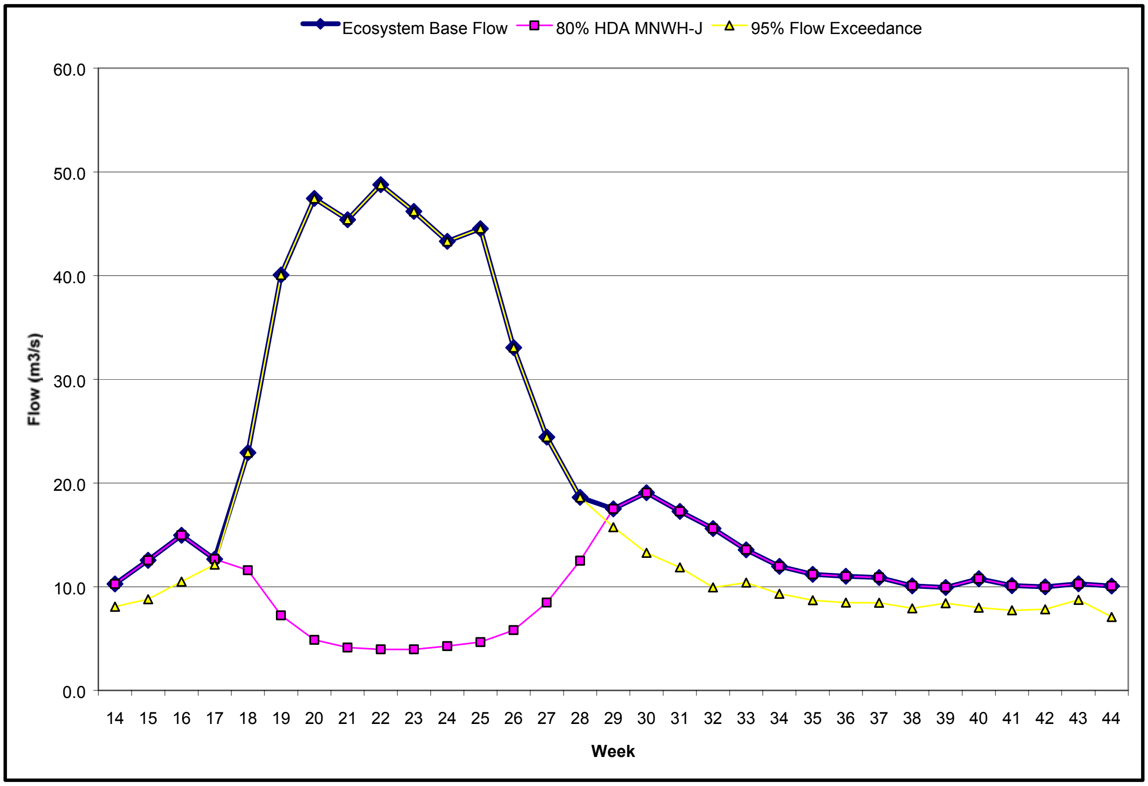


Figure 5.24. The weekly Ecosystem Base Flows for the Oldman River Reach 6 (OM6) using the maximum value between the 80% habitat duration analysis for mountain whitefish juvenile and the 95% flow exceedence.

Oldman River Reach 7 (OM7)

The fish habitat IFN determination for OM7 is a 20% reduction from the natural flow, with the added weekly constraint of the EBF. The habitat limiting life stages in this reach are mountain whitefish and rainbow trout spawning (Table 5.14). The key evaluation metric that approaches the defined threshold in this reach is the maximum instantaneous habitat loss. The maximum instantaneous habitat loss for rainbow trout spawning exceeds the defined threshold. However, the results for a 20% flow reduction are judged to provide a balance between all life stages throughout the year. A threshold for maximum yearly habitat loss was not defined, although some of the results were judged to be large enough to prevent further reductions in flow. Although spawning life stages triggered the IFN, both the spring and fall seasons contributed to the IFN determination. Mountain whitefish juveniles are present year-round and also showed a consistent pattern of habitat loss that approached the threshold values at the defined fish habitat IFN.

Table 5.14. Oldman River Reach 7 (OM7) from the Pincher Creek confluence upstream to the Oldman Dam. Habitat evaluation metrics for a 20% reduction from the natural flow with the added constraint of the EBF.

Species	**Total Mean (Weeks 14-17: 31-44)**	**Maximum Weekly**	**Maximum Instantaneous**	**Maximum Yearly**
MNWH-S	N/A	-7.92%	**-23.46%**	-22.68%
RNTR-S	N/A	-1.98%	**-27.27%**	-7.82%
MNWH-J	-2.93%	-4.57%	-16.52%	-3.70%

The mountain whitefish juvenile WUA curve peaks at a flow of 26.9 m^3/s and is used to define the EBF (Figure 5.25) and to identify the wet weeks to be removed from the analysis. Weeks 16-30 have weekly median flows greater than the peak of the mountain whitefish juvenile WUA curve and are removed from the analysis of the total mean habitat loss.

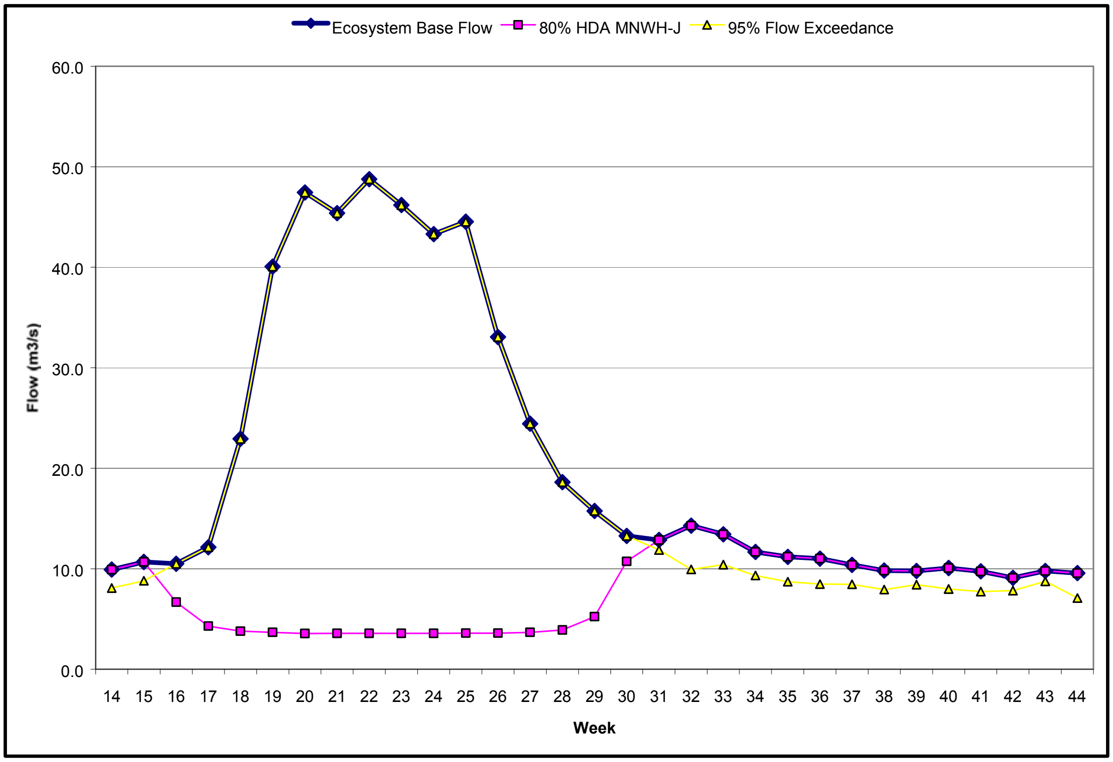


Figure 5.25. The weekly Ecosystem Base Flows for the Oldman River Reach 7 (OM7) using the maximum value between the 80% habitat duration analysis for mountain whitefish juvenile and the 95% flow exceedence.

5.4.5 Southern Tributaries Fish Habitat IFN Results

Belly River Reach 1 (BL1)

The fish habitat IFN determination for BL1 is a 30% reduction from the natural flow, with the added weekly constraint of the EBF. The habitat limiting life stage in this reach is mountain whitefish adult (Table 5.15), that had a consistent pattern of habitat loss across all of the key metrics. The key evaluation metrics that approach the defined thresholds are the maximum instantaneous habitat loss and the maximum weekly habitat loss. However, the total mean habitat loss was also very near the threshold criteria.

The mountain whitefish adult WUA curve peaks at a flow of 48.1 m^3/s and is used to define the EBF (Figure 5.26) and to identify the wet weeks to be removed from the analysis. Weeks 19-28 have weekly median flows greater than the peak of the mountain whitefish adult WUA curve and are removed from the analysis of the total mean habitat loss.

Table 5.15. Belly River Reach 1 (BL1) from the Oldman River upstream to the Waterton River confluence. Habitat evaluation metrics for a 30% reduction from the natural flow with the added constraint of the EBF.

Species	**Total Mean (Weeks 14-18:29-44)**	**Maximum Weekly**	**Maximum Instantaneous**
MNWH-A	-7.03%	**-12.78%**	**-24.06%**
MNWH-J	-4.26%	-8.33%	-18.86%
BNTR-A	-3.27%	-7.46%	-14.53%

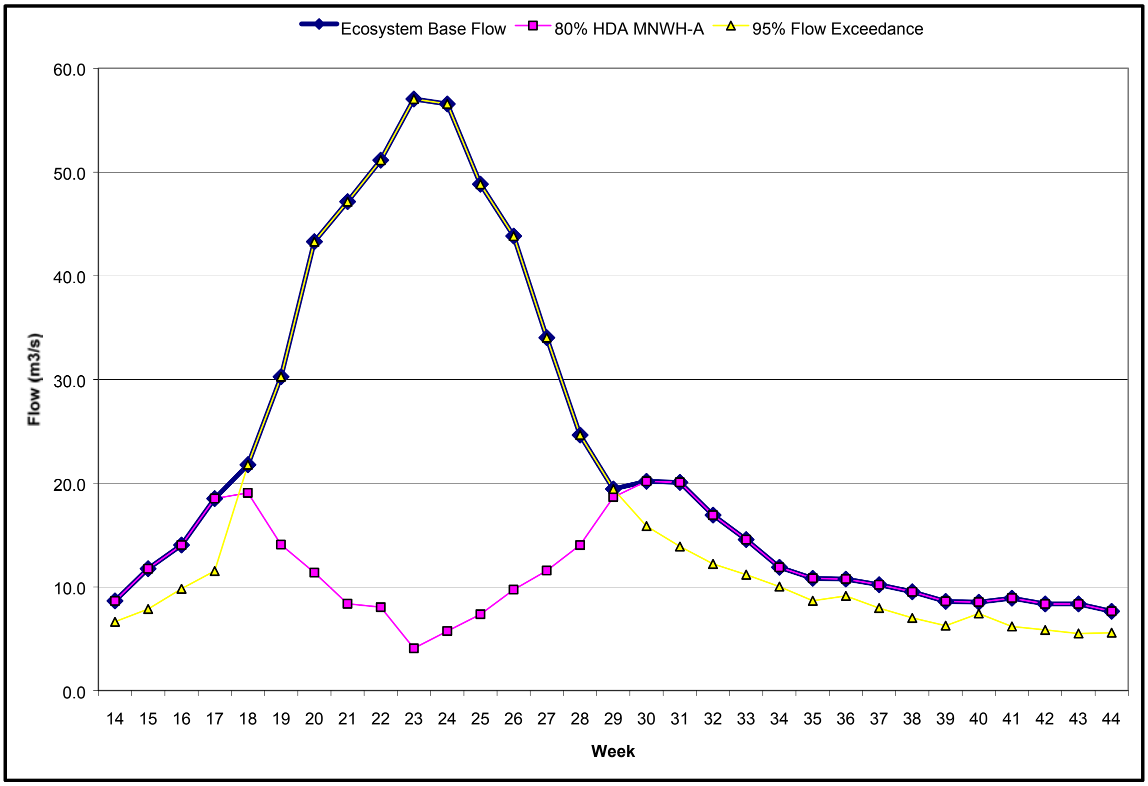


Figure 5.26. The weekly Ecosystem Base Flows for the Belly River Reach 1 (BL1) using the maximum value between the 80% habitat duration analysis for mountain whitefish adult and the 95% flow exceedence.

Belly River Reach 2 (BL2)

The fish habitat IFN determination for BL2 is a 20% reduction from the natural flow, with the added weekly constraint of the EBF. The habitat limiting life stages in this reach are mountain whitefish adult and juvenile (Table 5.16). All the key evaluation metrics showed a consistent pattern of habitat loss and approached the threshold values for the defined IFN. Although the maximum instantaneous habitat loss value exceeds the defined threshold for mountain whitefish adult and walleye adult by a very small margin, the other key metrics remained below the thresholds. This determination is therefore expected to be highly protective for all life stages.

The mountain whitefish juvenile WUA curve peaks at a flow of 14.2 m^3/s and is used to define the EBF (Figure 5.27) and to identify the wet weeks to be removed from the analysis. Weeks 19-29 have weekly median flows greater than the peak of the mountain whitefish juvenile WUA curve and are removed from the analysis of the total mean habitat loss.

Table 5.16. Belly River Reach 2 (BL2) from the Waterton River confluence upstream to the point 125 river kilometres upstream of the Oldman River. Habitat evaluation metrics for a 20% reduction from the natural flow with the added constraint of the EBF.

Species	**Total Mean (Weeks 14-18:30-44)**	**Maximum Weekly**	**Maximum Instantaneous**
MNWH-A	-6.00%	-9.88%	**-25.86%**
MNWH-J	-6.36%	-9.06%	-20.35%
BNTR-A	-1.27%	-4.97%	-21.24%
WALL-A	+5.31%	+2.11%	**-25.92%**

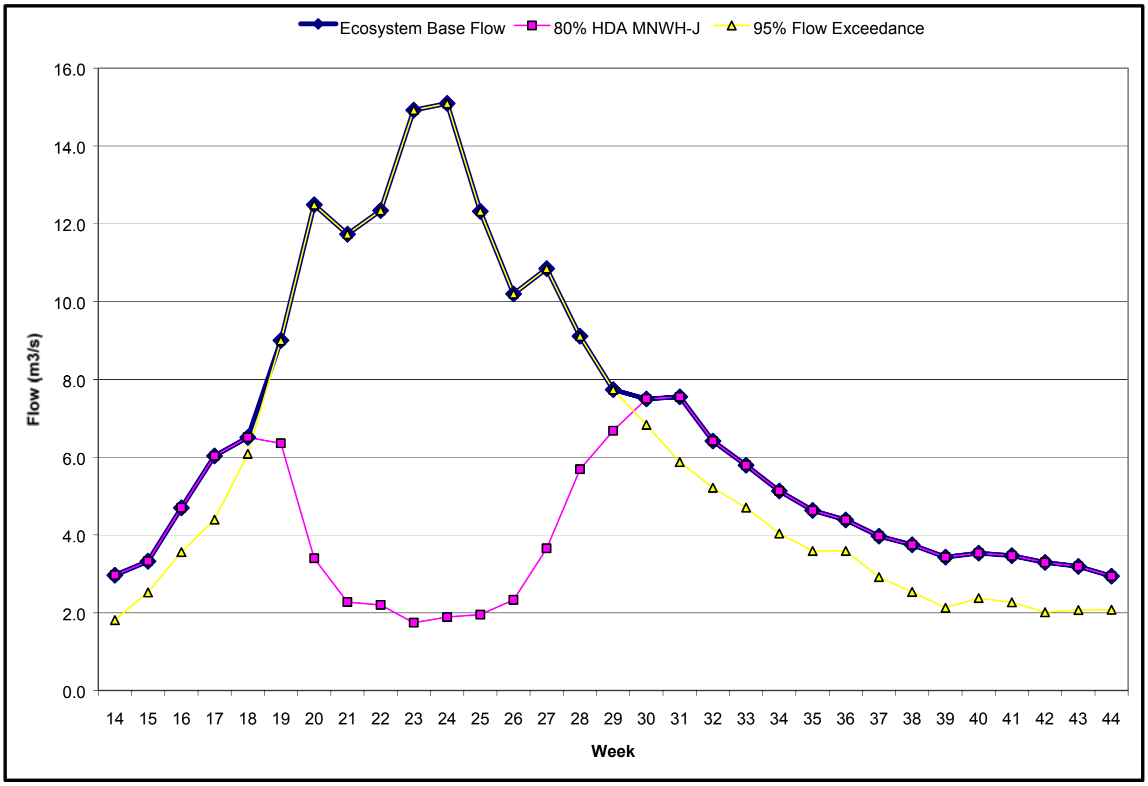


Figure 5.27. The weekly Ecosystem Base Flows for the Belly River Reach 2 (BL2) using the maximum value between the 80% habitat duration analysis for mountain whitefish juvenile and the 95% flow exceedence.

Belly River Reach 3 (BL3)

Reach-specific PHABSIM data are not available for the BL3 reach of the Belly River. Therefore, the final fish habitat IFN determination was developed using the Tessmann (1979) calculation for the entire year (Figure 5.28). These values must be combined with the other components to develop the ecosystem IFN.

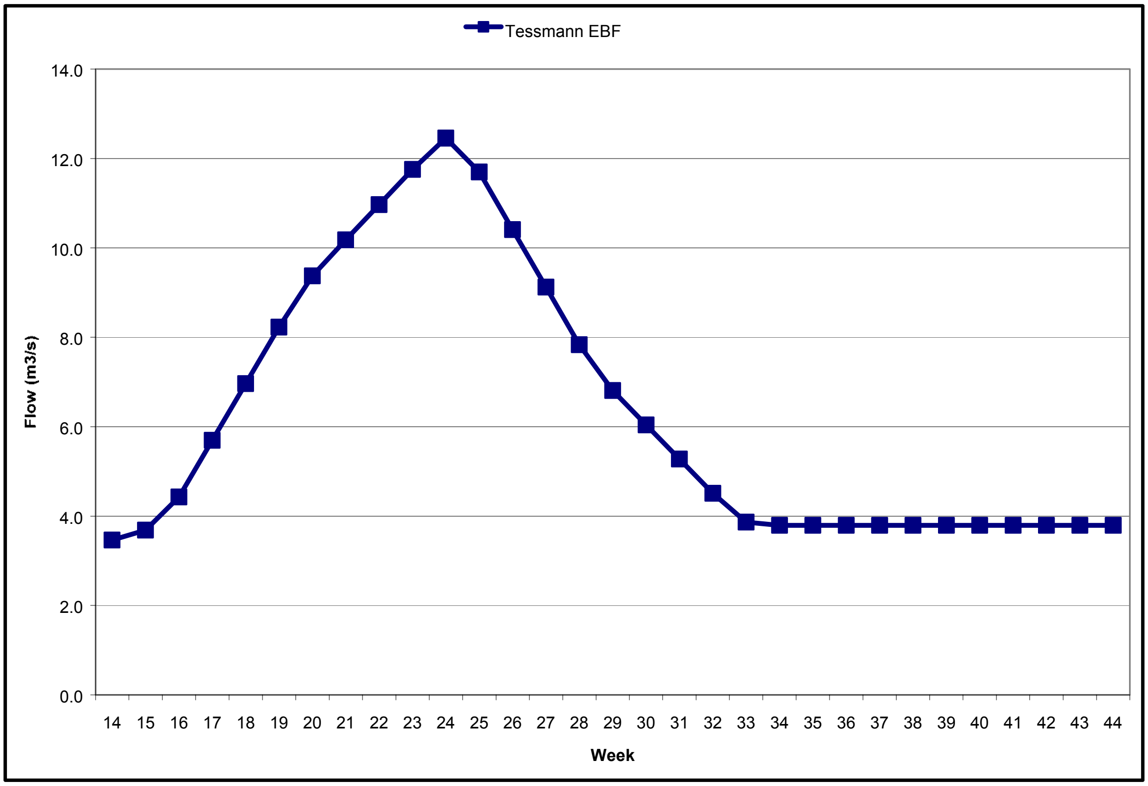


Figure 5.28. The weekly Ecosystem Base Flows for the Belly River Reach 3 (BL3) using the Tessmann calculation.

St. Mary River Reach 1 (SM1)

The fish habitat IFN determination for SM1 is a 40% reduction from the natural flow, with the added weekly constraint of the EBF. The habitat limiting life stages in this reach are mountain whitefish and walleye spawning (Table 5.17). The key evaluation metrics that approach the defined thresholds in this reach are the maximum instantaneous habitat losses and maximum weekly habitat losses. Although the walleye spawning maximum instantaneous habitat loss is very large, the weekly habitat loss is at the threshold, and the total mean habitat loss in BSP1 shows a large habitat gain. These results suggest that adjustments to the EBF during a few weeks in the spring could reduce the maximum instantaneous habitat losses. These adjustments have not been made at this time. All other life stages present year-round show a consistent pattern of habitat loss with continued reductions in flow.

The mountain whitefish juvenile WUA curve peaks at a flow of 34.0 m^3/s and is used to define the EBF (Figure 5.29) and to identify the wet weeks to be removed from the analysis. Weeks 18-30 have weekly median flows greater than the peak of the mountain whitefish juvenile WUA curve and are removed from the analysis of the total mean habitat loss.

Table 5.17. St. Mary River Reach 1 (SM1) from the Oldman River to 37 river kilometres upstream. Habitat evaluation metrics for a 40% reduction from the natural flow with the added constraint of the EBF.

Species	Total Mean (Weeks 14-17: 31-44)	Maximum Weekly	Maximum Instantaneous	Total Mean BSP1
MNWH-A	-4.56%	-8.32%	-17.33%	
WALL-S	N/A	-15.54%	-41.42%	+21.73
MNWH-S	N/A	-13.05%	-24.48%	

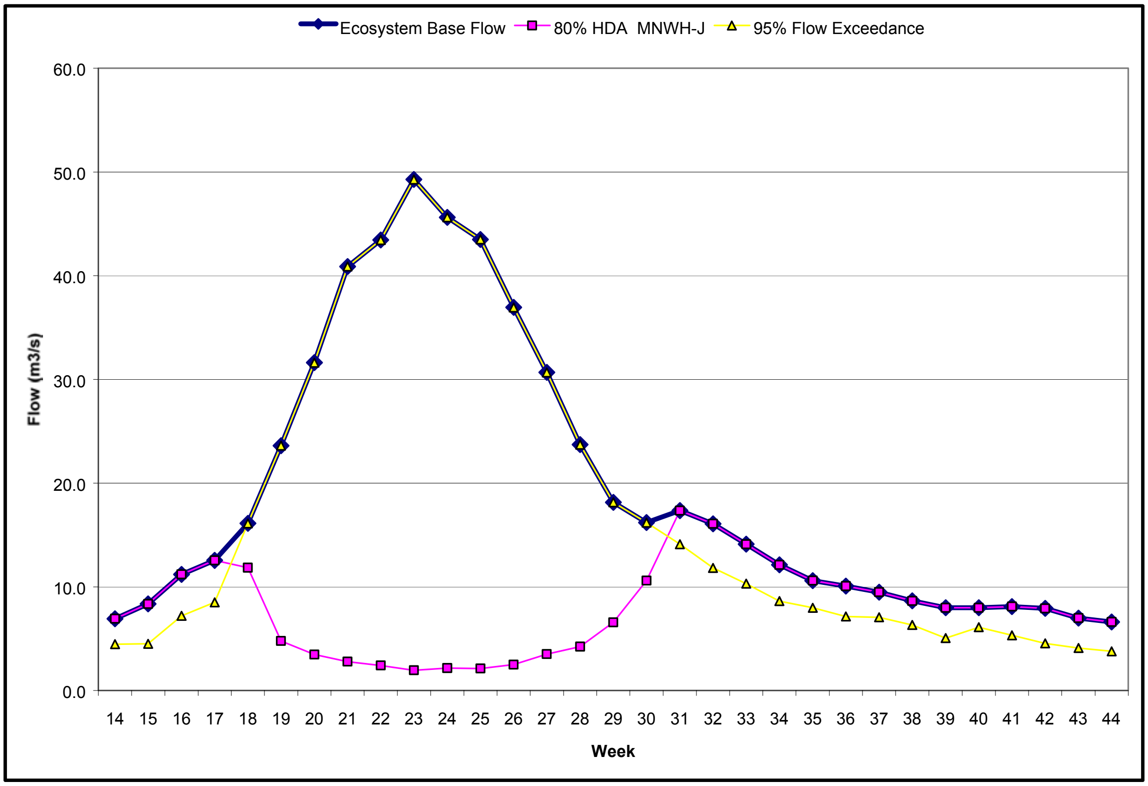


Figure 5.29. The weekly Ecosystem Base Flows for the St. Mary River Reach 1 (SM1) using the maximum value between the 80% habitat duration analysis for mountain whitefish juvenile and the 95% flow exceedence.

St. Mary River Reach 2 (SM2)

In the original IFN study, SM2 was defined as three separate reaches (Bjornson and Fernet 1989). The reach definitions were largely based on geomorphology, since there are no major tributaries present within this reach. Although three reaches were defined, only one study site was developed. The availability of a single study site, and a single flow dataset within SM2, made it necessary to treat SM2 as a single reach for the purpose of the fish habitat analysis for this phase of the SSRB WMP.

The hydraulic calibration for this reach produced poor results. The models could only be calibrated for a very limited range of low flows. It was decided that the modelling for this reach was not producing suitable results for the purpose of evaluating fish habitat. Therefore, the final fish habitat IFN determination was developed using the Tessmann (1979) calculation for the entire year (Figure 5.30). These values must be combined with the other components to develop the ecosystem IFN.

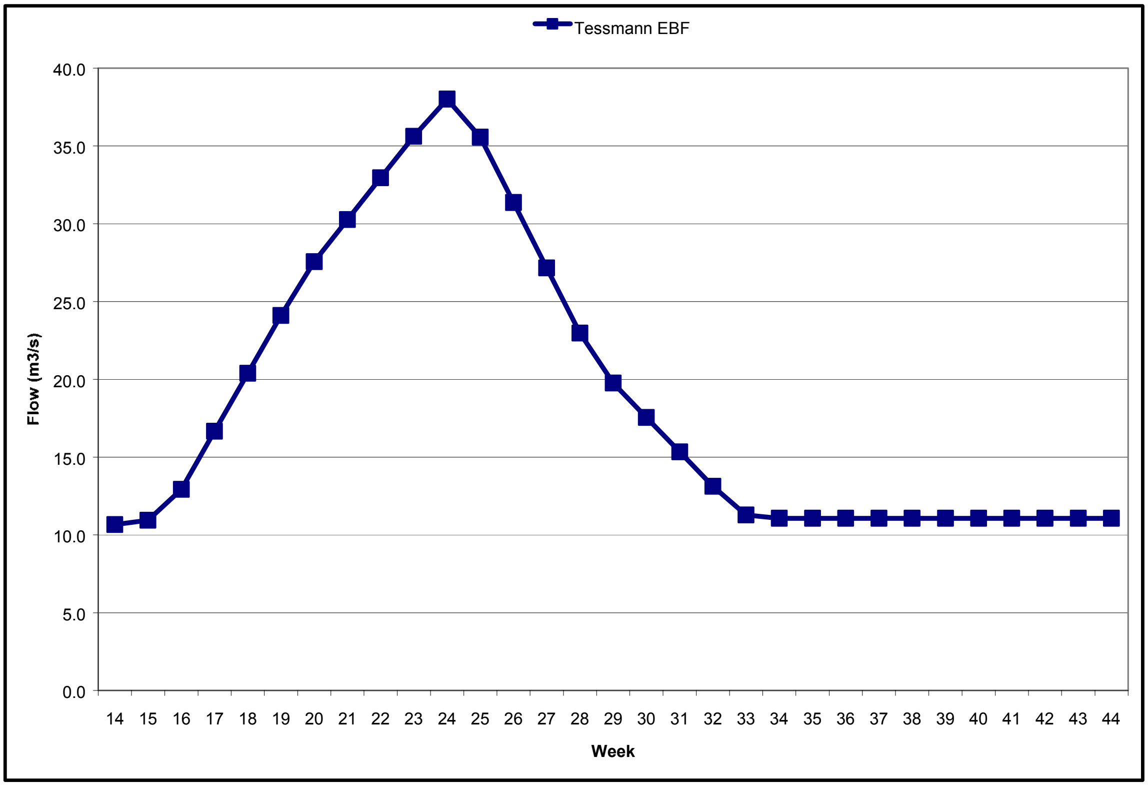


Figure 5.30. The weekly Ecosystem Base Flows for the St. Mary River Reach 2 (SM2) using the Tessmann calculation.

Waterton River Reach 1 (W1)

The fish habitat IFN determination for W1 is a 25% reduction from the natural flow with the added weekly constraint of the EBF. The habitat limiting life stages are mountain whitefish spawning and adult (Table 5.18). The key evaluation metrics that approach the defined thresholds in this reach are the maximum instantaneous habitat losses and maximum weekly habitat losses. With continued reductions in flow, the habitat metrics presented a consistent pattern of habitat loss for all metrics and for most of the life stages present in this reach.

The mountain whitefish adult WUA curve peaks at a flow of 29.0 m^3/s and is used to define the EBF (Figure 5.31) and to identify the wet weeks to be removed from the analysis. Weeks 18-28 have weekly median flows greater than the peak of the mountain whitefish juvenile WUA curve and are removed from the analysis of the total mean habitat loss.

Table 5.18. Waterton River Reach 1 (W1) from the Belly River to 45 river kilometres upstream. Habitat evaluation metrics for a 25% reduction from the natural flow with the added constraint of the EBF.

Species	Total Mean (Weeks 14-17: 29-44)	Maximum Weekly	Maximum Instantaneous
MNWH-A	-8.09%	**-12.51%**	**-21.67%**
RNTR-A	-6.78%	-10.57%	-18.58%
MNWH-S	N/A	**-14.34%**	**-25.97%**

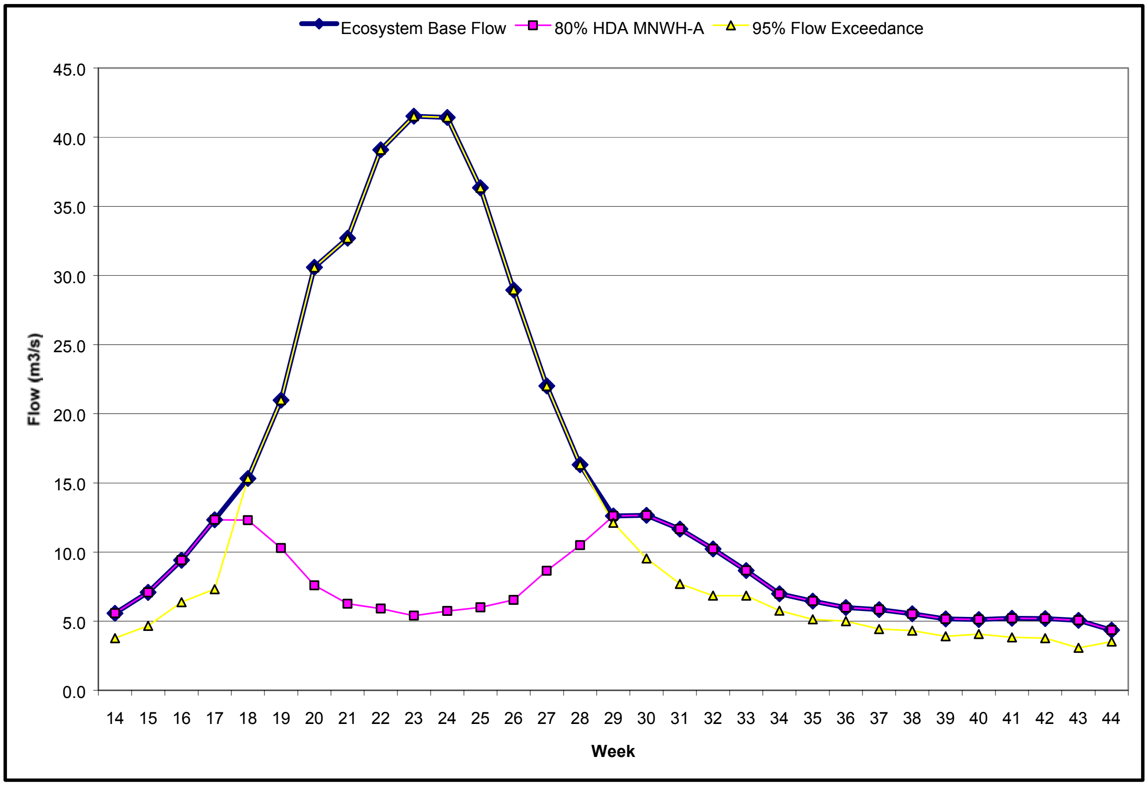


Figure 5.31. The weekly Ecosystem Base Flows for the Waterton River Reach 1 (W1) using the maximum value between the 80% habitat duration analysis for mountain whitefish adult and the 95% flow exceedence.

Waterton River Reach 2 (W2)

The fish habitat IFN determination for W2 is a 20% reduction from the natural flow, with the added weekly constraint of the EBF. The habitat limiting life stages in this reach are mountain whitefish spawning and adult, and rainbow trout spawning (Table 5.19). The key evaluation metrics that approach the defined thresholds in this reach are the maximum instantaneous habitat losses and maximum weekly habitat losses. Although the maximum instantaneous habitat losses have exceeded the defined threshold for the spawning life stages, the other evaluation metrics were below the threshold criteria. The results for a 20% flow reduction are judged to provide a balance between all life stages throughout the year. Continued flow reductions resulted in the other metrics approaching or exceeding the thresholds, with the maximum instantaneous habitat losses becoming exceedingly large.

The mountain whitefish adult WUA curve peaks at a flow of 19.8 m^3/s and is used to define the EBF (Figure) and to identify the wet weeks to be removed from the analysis. Weeks 18-29 have weekly median flows greater than the peak of the mountain whitefish juvenile WUA curve and are removed from the analysis of the total mean habitat loss.

Table 5.19. Waterton River Reach 2 (W2) from 45 river kilometres upstream of the Belly River upstream to the Waterton Reservoir. Habitat evaluation metrics for a 20% reduction from the natural flow with the added constraint of the EBF.

Species	**Total Mean (Weeks 14-17: 30-44)**	**Maximum Weekly**	**Maximum Instantaneous**	**Maximum Yearly**
MNWH-A	-4.98%	-8.85%	**-23.13%**	-4.33%
MNWH-S	N/A	-10.66%	**-28.55%**	**-26.77%**
RNTR-S	N/A	-6.44%	**-32.47%**	-5.42%

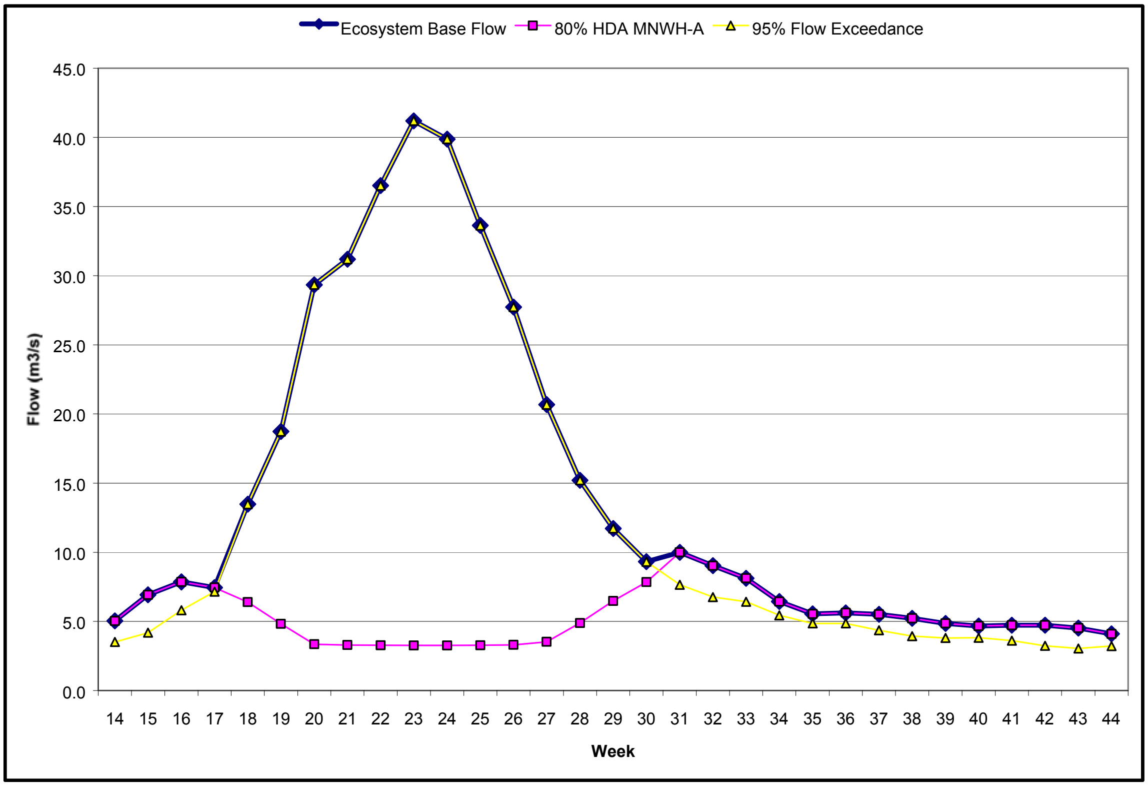


Figure 5.32. The weekly Ecosystem Base Flows for the Waterton River Reach 2 (W2) using the maximum value between the 80% habitat duration analysis for mountain whitefish adult and the 95% flow exceedence.

5.4.6 South Saskatchewan River

South Saskatchewan River Reach 1 (SS1)

Reach-specific fish habitat data are not currently available for the South Saskatchewan River from the Saskatchewan border upstream to Highway 41. Habitat information is also not available for lake sturgeon, a key management species for this reach of the river. Therefore, the current evaluation for fish habitat used the Tessmann (1979) calculation to define the EBF (Figure 5.33). These values must be combined with the other components to develop the ecosystem IFN.

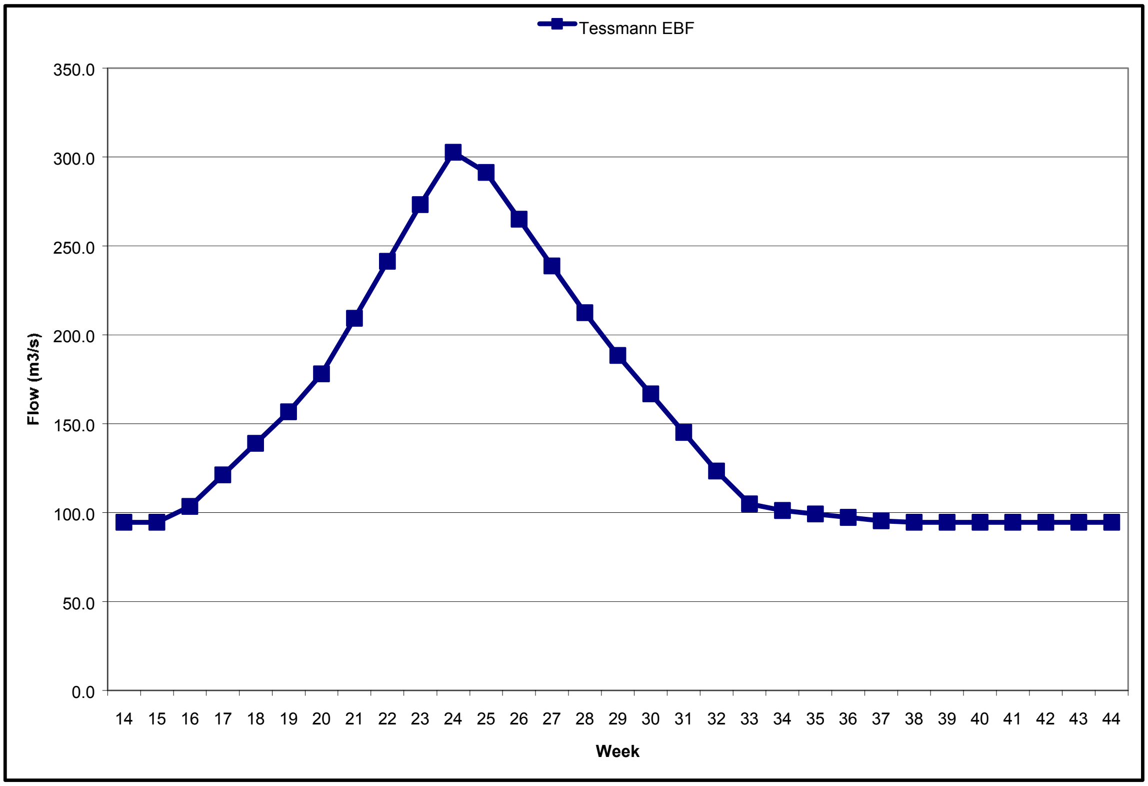


Figure 5.33. The weekly Ecosystem Base Flows for the South Saskatchewan River Reach 1 (SS1) using the Tessmann calculation.

South Saskatchewan River Reach 2 (SS2)

Reach-specific fish habitat data are not currently available for the South Saskatchewan River from Highway 41 upstream to the Grand Forks. Habitat information is also not available for lake sturgeon, a key management species for this reach of the river. Therefore, the current evaluation for fish habitat used the Tessmann (1979) calculation to define the EBF (Figure 5.34). These values must be combined with the other components to develop the ecosystem IFN.

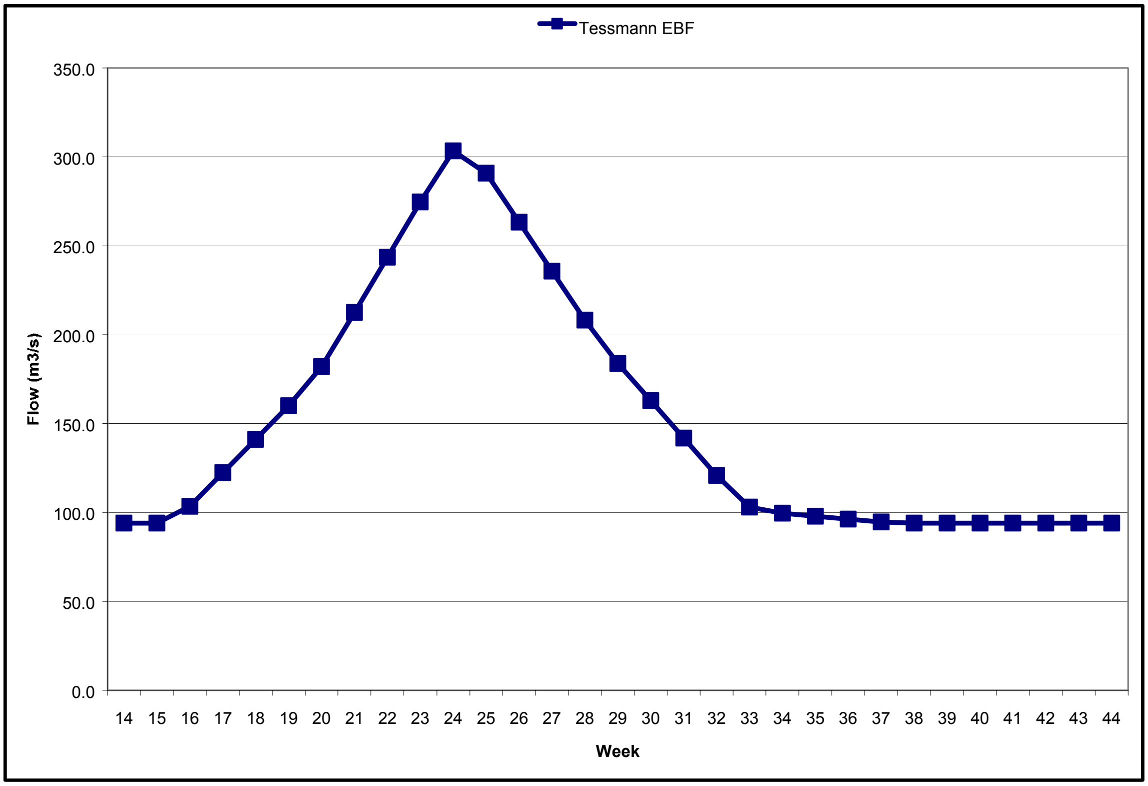


Figure 5.34. The weekly Ecosystem Base Flows for the South Saskatchewan River Reach 2 (SS2) using the Tessmann calculation.

5.4.7 Summary of Fish Habitat Results

The fish habitat results for each reach are presented in Table 5.20. The fish habitat IFN determination has two distinct components that act together to protect fish habitat for a range of flow conditions. The first component is the EBF, to protect naturally limiting habitat under low flow conditions. When natural flows are above the EBF, the fish habitat IFN determination indicates that reductions in the flow should not fall below the EBF. When natural flows are below the EBF, the fish habitat determination indicates no reductions in flow should occur.

The second component of the fish habitat IFN determination is a constant-percent flow reduction from the natural flow regime. The purpose of this component of the fish habitat recommendation is to protect a range of habitat conditions that vary within the year and between years. Providing a variable flow recommendation ensures there will be some years with good habitat conditions for every life stage present, as opposed to managing for a single life stage and providing a single flow IFN that can be detrimental to other life stages. With a variable flow IFN as provided by the constant-percent flow reduction, some years will have a flow regime that may be very well suited to adult life stages, while other years provide better spawning or rearing habitat.

Most of the results presented in Table 5.20 indicate a constant-percent flow reduction from natural in the 15% to 30% range. There are four reaches, however, with results that differ from the majority. Two reaches on the Bow River, BW3 and BW4, indicate very large flow reductions. The habitat results from Reach BW3 did not respond with continued percent reductions from the natural flow. The natural flow could be reduced entirely to the EBF across all flow ranges and still meet the habitat metric criteria. As a result, the flow recommendation for fish habitat at reach BW3 was just the EBF flows and no percent reduction rule was applied. At reach BW4, the habitat units were also unresponsive to reductions in flow resulting in a final flow reduction of 55% from natural with the added constraint of the EBF. In both cases, the WUA curves peak at a relatively low flow compared with the hydrology of the reach. Curve peaks are broad and are not sensitive to flow reductions. This is also the case for Reach OM2 and Reach SM1, where 40% flow reductions are indicated. Although the integration process with the other ecosystem components as detailed in section 9 will alleviate some of these large reductions in flow for many weeks of the year, the results should be interpreted and applied with caution. A reach balancing process, normally carried out during the running of the water balance model, is required to ensure results increase incrementally from upstream to downstream and make good biological sense.

Table 5.20. Summary of fish habitat IFN determinations to be incorporated into the ecosystem IFN.

River Reach	% Reduction from Natural Flow	Method for Defining the Ecosystem Base Flow	Weeks Included for Integrated IFN
RD1	20%	80% HDA – GOLD Adult	14-22 : 29-44
RD2	20%	Used RD1 Values	14-22 : 29-44
RD3	20%	80% HDA – GOLD Adult	14-22 : 28-44
RD4	25%	Used RD5 values	14-15 : 34-44
RD5	25%	80% HDA – GOLD Adult & WALL Spawning	14-15 : 34-44
RD6	20%	80% HDA – MNWH Adult	14-19 : 30-44
RD7	25%	80% HDA – MNWH Juvenile	14-19 : 30-44
BW1	N/A	Tessmann	All
BW2	25%	80% HDA – MNWH Juvenile	14-15 : 37-44
BW3	N/A	80% HDA – MNWH Juvenile	14-19 : 37-44
BW4	55%	80% HDA – MNWH Adult	14-17 : 37-44
OM1	N/A	Tessmann	All
OM2	40%	80% HDA – MNWH Adult	14-15 : 33-44
OM3	30%	80% HDA – MNWH Adult	14-19 : 27-44
OM4	15%	80% HDA – MNWH Adult	14-16 : 29-44
OM5	30%	80% HDA – MNWH Juvenile	14-16 : 29-44
OM6	20%	80% HDA – MNWH Juvenile	14-16 : 29-44
OM7	20%	80% HDA – MNWH Juvenile	14-15 : 31-44
BL1	30%	80% HDA – MNWH Adult	14-18 : 29-44
BL2	20%	80% HDA – MNWH Juvenile	14-19 : 30-44
BL3	N/A	Tessmann	All
SM1	40%	80% HDA – MNWH Juvenile	14-17 : 31-44
SM2	N/A	Tessmann	All
W1	25%	80% HDA – MNWH Adult	14-17 : 29-44
W2	20%	80% HDA – MNWH Adult	14-17 : 30-44
SS1	N/A	Tessmann	All
SS2	N/A	Tessmann	All

Notes – GOLD = Goldeye, MNWH = Mountain Whitefish, WALL = Walleye, HDA = Habitat Duration Analysis.

6.0 WATER QUALITY INSTREAM FLOW NEEDS

6.1 Background

A wide range of water quality variables are monitored within Alberta rivers. Starting in 1980, monthly data have been collected at long-term river network sites (LTRN sites) operated by Alberta Environment. LTRN sites on the Red Deer River are located at Highway 2 (upstream of Red Deer), at Nevis (downstream of Red Deer), and at Morrin Bridge (Highway 27). LTRN sites on the Bow River are at Cochrane, Carseland and the Ronalane Bridge, and on the Elbow River in Calgary at the 9th Avenue SE bridge. Monthly monitoring has more recently been initiated at Exshaw, Cluny and Bow City. There are three long-term sites on the Oldman River: at Brocket, at Highway 3 in Lethbridge, and farther downstream at Highway 36. A more extensive list of tributary, mainstem, and effluent sites (up to 40 sites) are currently being monitored as part of AENV's contribution to the Oldman River Basin Water Quality Initiative (OMRWQI 2000, 2001). There are two long-term monitoring sites on the South Saskatchewan River: one upstream of Medicine Hat, and the other (jointly funded by AENV and the Prairie Provinces Water Board) at the Alberta-Saskatchewan border.

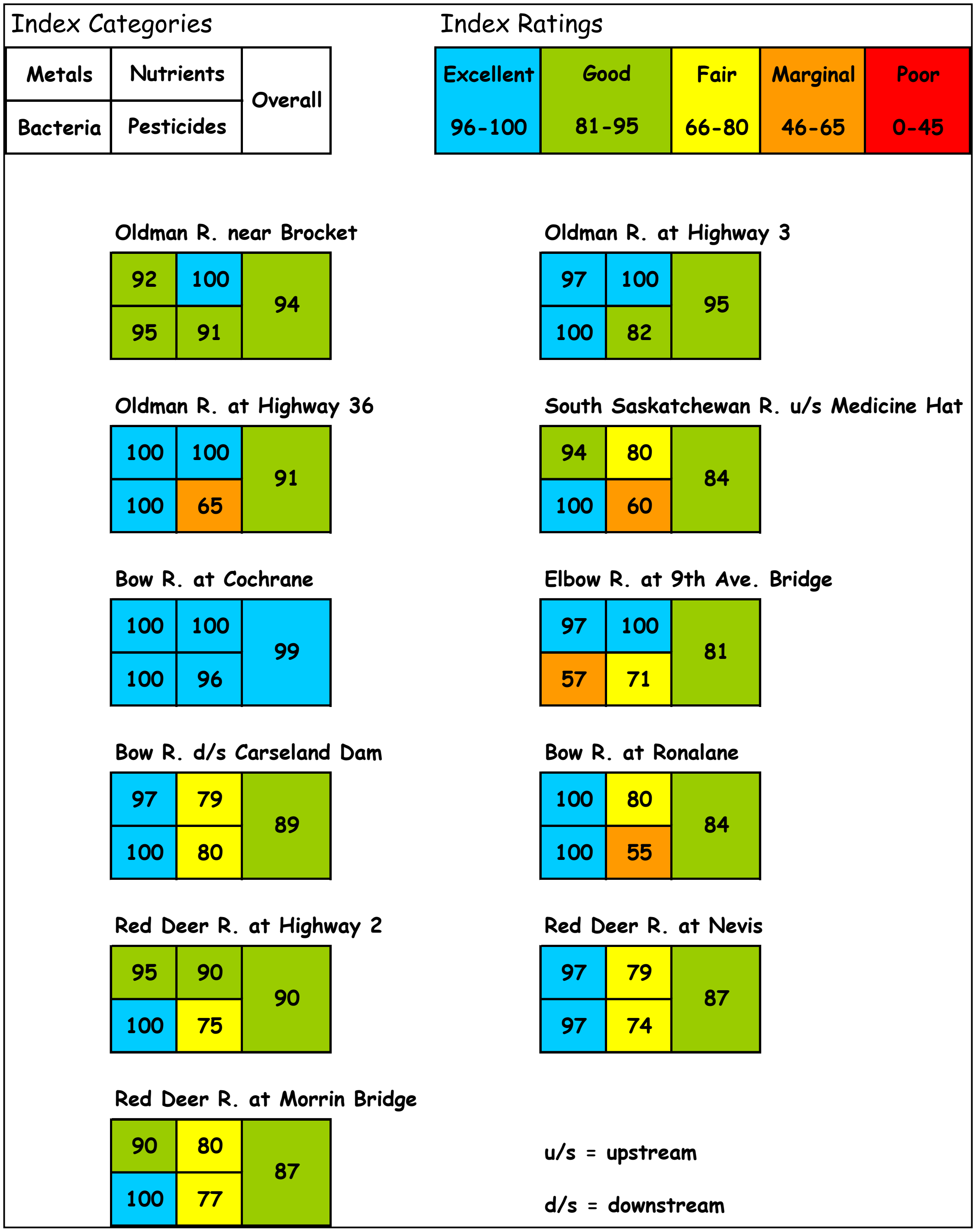
The water quality variables sampled generally include a wide range of basic descriptors and contaminants. Some are sampled on a discreet basis, and others as part of a continuous time-series sampling of temperature, dissolved oxygen, electrical conductivity and pH. A variety of shorter-term surveys, on selected lakes, reservoirs and rivers within each of the sub-basins, have yielded beneficial data for trend analysis, river health assessments, impact assessments, and modelling purposes.

Some of the water quality data collected by Alberta Environment are summarized in a water quality index that is calculated based on exceeding water quality objectives (Figure 6.1). The index varies with the number of variables that exceed objectives, and the magnitude and frequency of exceedences (Wright et al. 1998, Saffran and Anderson 1999, Saffran et al. 2001). This information is published annually and is available on-line at the provincial government website (www.gov.ab.ca). Some of these variables or classes of variables could be considered for IFN work, but in most cases, variables such as nutrients, metals and pesticides are best managed by source control, rather than by managing streamflow. Source control typically refers to the appropriate level of treatment at a municipal or industrial wastewater treatment plant (point source discharges), and better management practices (BMP's) for urban, forestry and agricultural diffuse runoff.

Water quality instream flows focus primarily on water temperature, concentration of dissolved oxygen (DO), and concentration of ammonia in some reaches. These characteristics are amenable to management by flow regulation. Temperature and DO are the most critical water quality variables in southern Alberta rivers for fisheries protection and assimilation of organic wastes. Dissolved oxygen levels are used to establish the assimilative capacity of a river reach.

6.1.1 Instream temperature and dissolved oxygen

Summer stream temperatures tend to track ambient air temperatures, typically reaching maximum values in late July and August. Exceedences of temperature guidelines for protection of fish species may occur during extended periods of high ambient temperatures and low cloud cover, in particular when river flows are low. Higher flows provide a buffer against instream temperature exceedences.



Index Categories

Metals	Nutrients	Overall
Bacteria	Pesticides	

Index Ratings

Excellent	Good	Fair	Marginal	Poor
96-100	81-95	66-80	46-65	0-45

Oldman R. near Brocket

92	100	94
95	91	

Oldman R. at Highway 3

97	100	95
100	82	

Oldman R. at Highway 36

100	100	91
100	65	

South Saskatchewan R. u/s Medicine Hat

94	80	84
100	60	

Bow R. at Cochrane

100	100	99
100	96	

Elbow R. at 9th Ave. Bridge

97	100	81
57	71	

Bow R. d/s Carseland Dam

97	79	89
100	80	

Bow R. at Ronalane

100	80	84
100	55	

Red Deer R. at Highway 2

95	90	90
100	75	

Red Deer R. at Nevis

97	79	87
97	74	

Red Deer R. at Morrin Bridge

90	80	87
100	77	

u/s = upstream

d/s = downstream

Figure 6.1. Alberta surface water quality index for southern rivers, 2000-2001.

Temperature guidelines are often established in relation to sport fish, as these are often the most intensively studied of the stream biota. Instream temperatures that exceed guidelines have a negative effect on fish metabolism and can cause fish mortality. Oxygen becomes less soluble as stream temperatures increase, causing a reduction in DO levels. Upper temperature limits for select sport fish species in Alberta are reviewed in Taylor and Barton (1992). They propose:

- ***Chronic (7 day average limits)*:** mountain whitefish, 18 °C; rainbow trout, 19 °C; brown trout, 20 °C; and walleye/sauger 24 °C.
- ***Acute (maximum limits)*:** mountain whitefish, 22 °C; rainbow trout, 24 °C; brown trout: 25°C; and walleye/sauger 29 °C.

Of the above species, mountain whitefish are most sensitive to both acute and chronic upper temperature limits; walleye/sauger are the least sensitive.

The Alberta provincial guideline for dissolved oxygen for fish protection (all fish species) is 5 mg/L for protection against acute DO deficit; and 6.5 mg/L seven-day average DO concentration for protection against chronic deficit (Alberta Environment 1999).

In keeping with the guiding principle of the Technical Team work, water quality based IFN flows for protection against summertime temperature exceedences in most cases do not exceed natural flows. There is some question as to whether this is appropriate or not, particularly in low flow years when natural flows would naturally lead to frequent guideline exceedences. The natural flow regime represents a condition to which fish population distributions have become adapted. The population can therefore be expected to absorb the impact of these natural occurrences and recover from them. In these cases, flow augmentation to eliminate guideline exceedences may not be appropriate.

However, the river ecosystem may face multiple water quality stressors (pesticide residues, industrial contaminants, elevated metals, etc.) under current conditions that were not present under natural conditions. Therefore, augmented flows may be needed during times of temperature exceedences, to minimize cumulative stress on fish and ensure the frequency of guideline exceedences is not greater than would occur naturally. EMA (1994) note that natural exceedences of temperature and DO guidelines occur with natural flows in some reaches of southern Alberta rivers. The IFN values they recommend are set to allow for these natural occurrences.

6.1.2 Assimilation of Wastes

Under the Provincial *Water Act* (Section 1(1)(iii)), assimilation of wastes is identified as an allowable use of provincial waterways. This use is allowed provided there is sufficient flow to dilute the wastes, to allow for biological breakdown of organic wastes, and to protect the aquatic environment from significant impact. Assimilation flows are typically intended to ensure that dissolved oxygen and ammonia levels remain within guidelines for the protection of aquatic life. To establish assimilation flows, water quality modelling is conducted based on current and/or future contaminant loadings from various sources; in particular below the municipal wastewater treatment plants downstream of the major cities (Red Deer, Calgary, Lethbridge, and Medicine Hat).

River flows for waste assimilation can be considered a consumptive use of our waterways and are therefore dissimilar to the other IFN components described in this document. To meet assimilation needs, streamflow must be allocated to this use, thus eliminating other options for the water. To ensure sufficient flows for waste assimilation, flows may be elevated above natural levels downstream of major cities, particularly during winter months. Without improvements in wastewater treatment, flows for waste assimilation will need to continually increase to keep up with population increases, and agriculture and industrial activities.

During the 1980s and 90s, there were significant improvements to the municipal wastewater treatment processes at Red Deer, Calgary, Lethbridge, and Medicine Hat. These improvements have been very beneficial to water quality in the receiving rivers. In addition, management of urban storm water runoff, a second major source of contaminant loadings to our waterways, has improved during the past decade. Agricultural and forestry practices near waterways, and riparian protection in general, are becoming subject to better management practices to reduce non-point (diffuse) runoff from these potential sources of contamination. Provided all these contaminant-loading sources are sufficiently addressed, total loading does not increase, and scouring flows are provided as described in Section 6.1.3, there would be no need to further increase flows for waste assimilation. Flow recommendations for waste assimilation could be reduced in the future if total loadings are reduced, thereby freeing water for other uses. If total waste loadings increase, due to an increase in population and economic activity, the recommended water quality IFN would need to increase, even with improvements in wastewater treatment and management.

6.1.3 Scouring Flows

Water quality, mainly in terms of dissolved oxygen, is impacted not only by temperature and waste loadings but by the presence of nutrient-rich sediments, aquatic plants and algae. Rivers are adapted to receiving a spectrum of flows that affect sediment composition and plant growth. In regulated rivers, (i.e. those with onstream water storage facilities) this spectrum of flows is attenuated to varying extents.

Of particular importance to water quality are the high flows due to snow melt in late spring and early summer. These flows are called flushing or scouring flows because they dislodge sediments and other materials that accumulate on and within the riverbed, and carry them downstream. In some cases, the net sediment movement might be just a few centimetres or metres in distance. This helps reduce the embeddedness of sediments in the gravels and can be important for spawning fish. In other cases, the accumulated sediments are carried further downstream, thereby reducing their impact through dilution or assimilation. In cases where these sediments are rich in nutrients and organic matter due to upstream human activities, moving the sediments with high flows removes materials that would otherwise exert an oxygen demand within the reach. High sediment oxygen demand leads to lower dissolved oxygen levels and can be a significant influence on water quality, even to the point of causing fish kills.

High flows in spring and early summer also impede the establishment of both new and existing aquatic vegetation (macrophytes) (Chambers et al. 1991, Sosiak 2002), including algae. Without these high flows, macrophyte and algal growth can increase compared with natural levels and can exert a very significant increase in oxygen demand during night-time periods in late summer, when growth can be prolific. The biochemical oxygen demand (BOD) and sediment oxygen demand (SOD) during winter can also be increased beyond natural levels, as the greater vegetative biomass decays. High macrophyte biomass has been identified as a consumptive demand of river flow, requiring 10 to 50 m^3/s flow for the Bow River downstream from Calgary (Golder-WER 1994). The potential water quality impact of increased macrophyte growth requires further study for the Red Deer River downstream of the City of Red Deer (AGRA Earth and Environmental Ltd. et al. 1995).

Specific flows for scouring riverbed sediments to protect water quality are not recommended in this section. It is expected that the high flows recommended for maintenance of channel dynamics (Section 8.0) will fulfill this need.

6.2 Recommended Flows for Water Quality Instream Flow Needs

Water quality based instream flow needs values were generated in the early to mid 1990s for the Red Deer, Bow and Oldman rivers. Private consulting firms working under contract to Alberta Environment conducted the work. Work was also conducted on the Southern Tributaries, but at a lesser level of effort. A general ranking of the availability of reach-specific water quality modelling necessary to provide water quality IFN determinations within the SSRB WMP is shown in Figure 6.2.

6.2.1 Red Deer River

Water-quality based IFNs were generated by consultants in the early to mid 1990s. This was followed by more recent modelling work by AENV staff in 2001-03. The IFN water quality determinations are presented in Table 6.1.

Table 6.1. Red Deer River water quality IFN determinations.

Reach Boundaries	Reach Code	Water Quality IFN (m^3/s)			
		Winter Weeks 1-11, 51-52	**Spring** Weeks 12-24	**Summer** Weeks 25-37	**Fall** Weeks 38-50
Dickson Dam to u/s of Medicine River confluence	RD7	16	16 - 23	18 - 33	17 - 22
Medicine R. confluence to u/s of Blindman R. confluence	RD6	16	16 - 23	18 - 33	17 - 22
Blindman R. confluence to u/s SAWSP diversion	RD5	16 - 17	17 - 23	17 - 33	17 - 21
SAWSP to Drumheller	RD4	16 - 17	17 - 22	18 - 35	18 - 22
Drumheller to Dinosaur P.P.	RD3	16 - 18	17 - 23	22 - 40	18 - 25
Dinosaur P.P. to u/s Bindloss	RD2	16 - 18	17 - 22	21 - 39	18 - 25
Bindloss to Border	RD1	16 - 18	17 - 22	21 - 39	18 - 25

***Note:**- Ranges refer to weekly values.*

Previous work

Water quality based IFN values for the Red Deer River below the Dickson Dam were provided in AGRA et al. (1995). The water quality model that was used is called Dynamic Stream Simulation and Assessment Model with temperature (DSSAMt), developed by Rapid Creek Research Inc. The hydraulic model is a steady-state, one dimensional flow model. It was developed to simulate dissolved oxygen and nutrient concentrations under various flow conditions and operates as a dynamic model with respect to some environmental conditions (solar radiation and other meteorological constituents), but not with flow.

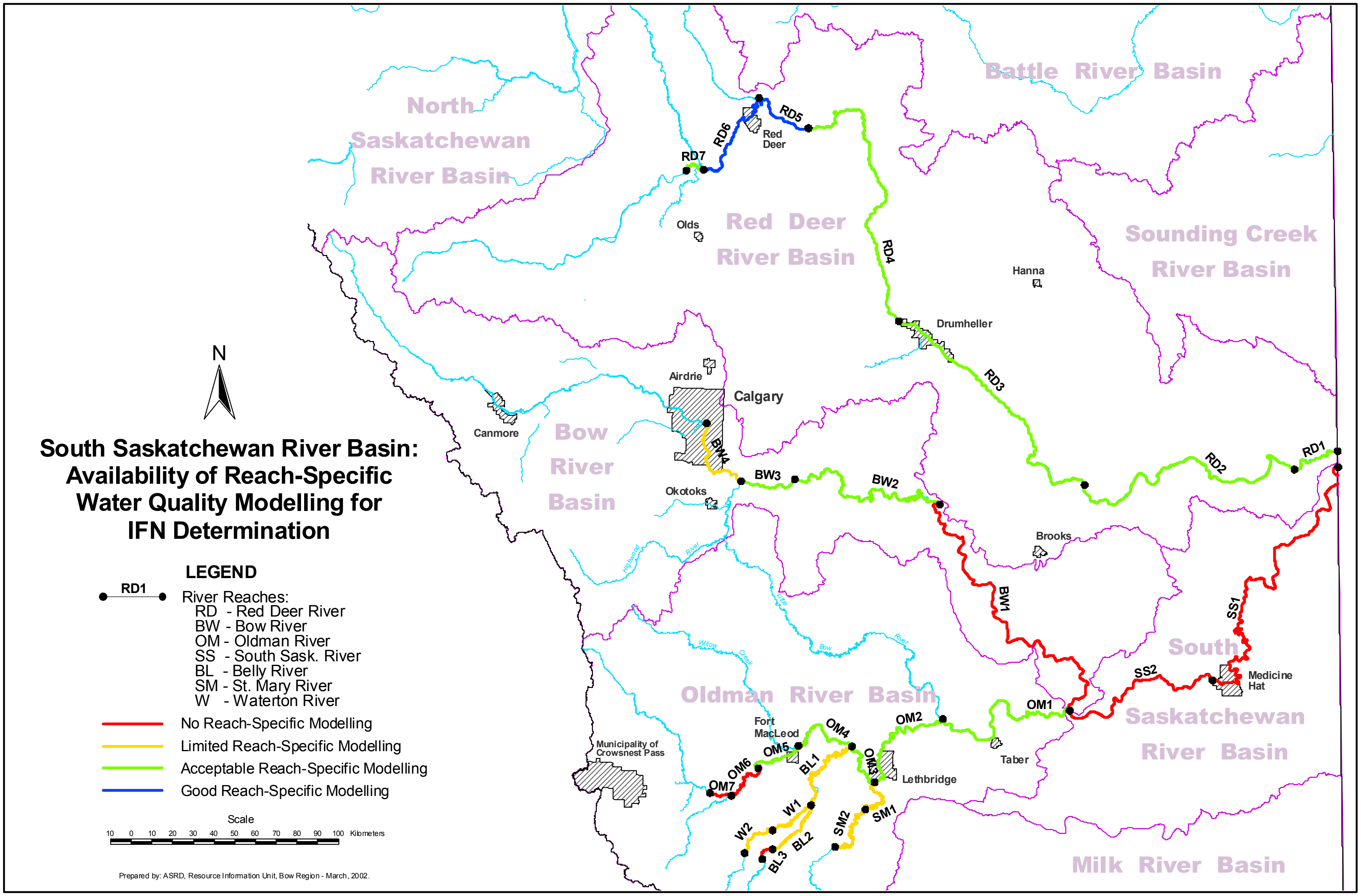


Figure 6.2. Availability of reach-specific water quality modelling for IFN determinations within the SSRB WMP.

Water quality modelling was carried out for the ice free months (Apr - Oct) at five locations on the Red Deer River: Fort Normandeau, Nevis, Big Valley, Jenner and Bindloss. The model was calibrated with 1992 data, and tested against 1983 data. Five flow scenarios discharged from the Dickson Dam (10, 20, 25, 30 and 40 m^3/s) were assessed (AGRA et al. 1995).

Macrophyte characteristics were not modelled, but reference was made to macrophyte abundance in the Red Deer River and their potential impacts on water quality in the Red Deer River. For example, the report states

> *"Several years without scouring flows could allow organic sediments and macrophytes to accumulate to the extent that their oxygen demand combined with attached algae could create conditions prone to dissolved oxygen violations" (AGRA et al. 1995).*

The 1995 report recommends that the issue of macrophyte biomass build-up undergo further investigation.

The IFN analysis conducted by AGRA et al. (1995) focused on the simulation of water quality conditions relevant to fish survival, specifically water temperature, dissolved oxygen, and un-ionized ammonia. AGRA conducted a low flow analysis of the Red Deer River using Water Survey of Canada (WSC) discharge data for the period 1912-1982 (pre-impoundment). The flows were ranked and it was determined that the minimum mean monthly natural observed flow (i.e., lowest percentile) at Red Deer in July and August are 32 and 29 m^3/s, respectively. Based on these figures, the July-August minimum natural flow in the area of Dickson Dam was determined to be 25 m^3/s. Using reference case conditions (1992), a series of simulations were then conducted to determine the relationship between downriver conditions and flow release from Dickson Dam.

AGRA et al. (1995) also carried out a limited review of ammonia and dissolved oxygen conditions in the Red Deer River. Their review suggests that under 1992 loading conditions, and at summer flows of 25 m^3/s discharge from the dam, ammonia and DO violations would not occur.

Winter water quality was not addressed in AGRA et al. (1995). However, since the initial filling and operation of the Dickson Dam (1983), a minimum release of 16 m^3/s from the dam has been part of the operational plan. To date, this has been sufficient for protection of instream water quality (based on instream dissolved oxygen requirements).

Temperature IFN

Below the Dickson Dam the river is split into two sections, based on instream temperature requirements of resident fish species. Different fish species were targeted for management by provincial fisheries biologists. From Dickson Dam to Big Valley (km 0 to km 175), brown trout and mountain whitefish are the target species. From Big Valley to the Alberta-Saskatchewan border (km 175 to km 560), walleye and goldeye are the target species.

Daily maximum instream temperatures were used to evaluate acute exposure for fish, and a seven-day running mean was used to assess chronic temperature effects of a specified flow regime. Simulation results indicated that releases from Dickson Dam of 30 m^3/s or higher were required to meet the acute criteria for mountain whitefish upstream of Red Deer (RD6). The 25 m^3/s flow scenario resulted in violations 1% of the days (two days). Twenty five cubic metres per second was required for absolute attainment of brown trout acute criteria from Dickson Dam to Nevis. At the 25 m^3/s discharge, acute criteria for mountain whitefish were violated up to 15% of the time at Nevis (RD4). Chronic temperature criteria for brown trout were met at Ft. Normandeau at dam releases of 20 m^3/s or higher. However, chronic criteria for brown trout were exceeded at Nevis even at dam releases of 40 m^3/s. Chronic criteria for mountain whitefish were exceeded at all flows at all stations below Dickson.

Overall, it was concluded that a minimum release from Dickson Dam of 25 m^3/s during the ice free season enabled acute temperature criteria for brown trout and mountain whitefish to be met at Ft. Normandeau 100% and 99% of the time, respectively. Walleye/sauger criteria were met at all study sites 100% of the time. Other flow scenarios suggested that

> *"a point of diminishing returns is reached with respect to the benefits of additional levels of flow augmentation, especially once the river has reached equilibrium with local weather conditions."*

Accordingly, it was recommended "...that the minimum flow... at Dickson Dam not be permitted to drop below 25 m^3/s during the period April-October" (AGRA et al. 1995). A reduction to 20 m^3/s was identified as acceptable during the cooler months of spring and fall. However, the report also recommends dam discharge flows of 30 m^3/s in the summer months to provide a 5 m^3/s safety factor due to "uncertainty in the model."

During the open water season, there is a gradual increase in water temperature with increased distance downstream of the dam. AGRA modelling shows that an August instream temperature of 20.5 °C at Dickson Dam can peak to 26 °C at Drumheller and remain unchanged through the remainder of the distance to the border. Flow volume appears to account for a relatively small fraction of the variability in stream temperature for the scenarios tested. For example, doubling the release from the Dickson Dam from 20 to 40 m^3/s lowers simulated temperatures at Nevis by 1.8 °C, and at Drumheller by only 0.6°C.

Scenario Evaluation for DO

In the modelling by AGRA et al. (1995), the 25 m^3/s scenario was not substantially affected by a 20% increase of municipal loading, or by a withdrawal of 7.1 m^3/s for the Special Areas Water Supply (SAWSP). Simulated August DO values downstream of the City of Red Deer in Reach RD5 for both scenarios dropped from 7.2 mg/L (reference scenario) to 6.9 mg/L. Similarly, both reduced spring runoff (spring peak flow reduced by 40%, as in a dry year) and elevated spring runoff (increased by 100 m^3/s in late June) had little effect on summer DO concentrations, resulting in a change of no more than 0.2 mg/L. Nonetheless, recent modelling work by AENV suggests that these scenarios may significantly affect water quality during certain periods (D. McDonald 2002, pers. comm.).

Un-ionized Ammonia

AGRA et al. (1995) states that

> *"Monitoring during 1992, as well as all simulations of alternative scenarios, revealed no violations of un-ionized ammonia under existing (1992) conditions..."*

However, data on diurnal variability suggest that high fluctuations can occur in the Red Deer River during a diurnal cycle. Considering that the DSSAMt model predicts ammonia levels for single, large compartments (with respect to time and space), an exceptional combination of environmental conditions would have to exist to produce ammonia loads in excess of threshold criteria. The occurrence of localized ammonia toxicity problems is more likely, due to point source impacts during the winter, and point and non-point sources during runoff periods.

Caveats to Modelling Results

Water quality modelling can be a complex and iterative process, and it is important to place modelling results in context. The recommendation of releasing 25 m^3/s at Dickson Dam to meet water quality objectives is preliminary and is based on minimum pre-impoundment, observed flows for July and August. The model indicated that at this flow, acute temperature criteria for brown trout, mountain whitefish and walleye/sauger were met most of the time, for weather conditions observed in 1992. However, summer air temperatures were unusually cool in 1992, and the adequacy of the flow recommendation was not tested for other weather conditions. Thus, the model may have been calibrated for conditions that are not representative of the historical variability of the Red Deer system.

Conditions evaluated in mid summer 1992 (i.e. DO concentrations fell to 6.0 mg/L) suggest that dissolved oxygen conditions could reach problem levels under several possible scenarios. This premise is supported by data from other years. For example, observed DO at Red Deer fell to less than 6.5 mg/L for several consecutive days in July - August 1997 at flows greater than 30 m^3/s, with a dam release of 28 m^3/s (Saffran and Anderson 1997). The most obvious cause of low DO levels in the river would be effects due to oxygen consuming effluents. However, other causes could be primarily flow related. For instance, in the absence of scouring flows, organic material could accumulate to the extent that increased oxygen demand could produce critically low DO. Similar conditions could occur after a rapid decrease in flow, following a long controlled-release from the dam. In this case, the build-up of plant biomass increases with the high flow, but is not sustained by lower flows. The death and decay of the additional biomass may also reduce DO concentrations significantly.

Uncertainty in Red Deer River DO predictions also exists on a smaller, daily time-scale. Predicted diurnal DO minima and maxima are consistently higher and lower, respectively, than observed concentrations (i.e. the DSSAMt model underestimates diurnal minima). Therefore, for a recommended flow, actual DO concentrations can be expected to drop lower than predicted values.

The DSSAMt hydrodynamic model used was steady-state, and therefore cannot provide accurate estimates during periods of fluctuating flows; this introduces an additional level of error in temperature and DO predictions during such times. Moreover, the model used hydraulic parameters, developed for a limited reach at the City of Red Deer, and applied them to the entire river segment from Dickson to the border. In the context of DSSAMt, this was a necessary assumption, but it could introduce significant bias in the prediction of water quality parameters. To illustrate, an assessment of the sensitivity of water quality to hydraulic coefficients was provided in the AGRA report; the mean depth was doubled, and top width increased by 50% compared with the reference calibration. This resulted in as much as a 0.8 mg/L change in DO, indicating (according to AGRA et al. 1995) that "the DO is very sensitive to variations in hydraulic coefficients."

Overall, it is apparent that a relatively large error-margin exists in the AGRA et al. (1995) predictions of DO. This has implications for the use of these predictions in the context of IFN work. Although 30 m^3/s (25 m^3/s plus recommended error margin) may be sufficient to meet minimum DO criteria, it is possible that such criteria would not be met, at least some of the time, at some locations in the river. The choice of 30 m^3/s was a compromise based on preliminary investigation, rather than a conclusive value offering full protection. This summertime value was the best estimate, based on the science reported at that time. (James Martin, PhD., P.Eng., Water Quality Modelling Expert, US Corp of Engineers, Vicksburg, based on contract work done in 2000-01 for AENV in reviewing existing SSRB modelling).

Winter IFN

Numerical water quality modelling for winter conditions has not previously been conducted for the Red Deer River. Nevertheless, winter flows could have a more restrictive influence on water quality than summer flows. Under ice, flow volume influences DO concentrations and the dilution of point discharges. Flows needed to maintain acceptable DO levels and adequate effluent dilution (assimilation) depend, in part, on ambient conditions (ice thickness, snow pack, etc.) and the effluent load. Historical data are not available to define the influence of ambient conditions (relative to flow) on dissolved oxygen levels.

However, empirical analyses have been carried out to determine the minimum flows required in winter months. A primary study in this regard was carried out in the Red Deer River in 1974 (Grant 1974). Based on data from winter sampling surveys, oxygen depletion rates were determined and applied to calculate the flow necessary to maintain DO levels of 5.0 mg/L. The minimum flow recommended to maintain this level was 16 m^3/s. Historically, DO concentrations frequently dropped to critically low levels in the portion of the river below Reach RD4 at Highway 27. A major reason for construction of the Dickson Dam in 1983 was to increase winter flows by releasing a minimum of 16 m^3/s during the winter months. Since that time, flow regulation has resulted in a significant increase in DO levels at Red Deer, Morrin Bridge, and Drumheller. At all long-term monitoring sites (Red Deer, Morrin Bridge, Drumheller, and Bindloss) the frequency with which dissolved oxygen falls below the guideline of 5.0 mg/L has decreased since winter flows were augmented (Shaw and Anderson 1994).

Based, in part, on post-impoundment winter flows, industries have taken a consistent approach in environmental impact assessments (EIA). They have evaluated the impact of effluent loading on river water quality during low flow periods (approximately 15 m^3/s at Red Deer) to determine whether water quality guidelines are exceeded. There is an expectation that minimum flows at the City of Red Deer will be maintained. If minimum acceptable flows were reduced for the reach downstream of the City of Red Deer, the effects of industrial discharge would have to be re-evaluated.

In essence, minimum flows are defined by existing operating requirements for the dam and by the acceptance of the anticipated increase in municipal and industrial effluent loading to the Red Deer. It may, therefore, become necessary to increase minimum flow requirements to maintain downstream water quality objectives. Alternatively, effluent treatments may be enhanced to stabilize loads at an acceptable level. Based on available information, the recommended minimum winter IFN to protect water quality remains at 16 m^3/s release from the Dickson Dam, for Weeks 1 to 13 (January through March) and 44 to 52, (November and December) inclusive.

Current Water Quality Modelling Work for the Red Deer River

To support informed water resource management decisions, it is important that predictive work to evaluate the effects of current and potential human activities on river systems, at both local and watershed scales, be carried out. Alberta Environment has initiated predictive work to update the water quality modelling in the Red Deer River. Key issues have been identified, and modelling of the Red Deer River system is ongoing (D. McDonald 2003, pers. comm.).

In order to maintain water quality in the Red Deer River, instream flow needs have been specified in the past. However, since only limited data were used in the DSSAMt simulations, some problems occurred in the model calibration. Empirical methods have been explored to define minimum flows needed to maintain acceptable temperature and DO conditions. However, a more rigorous modelling exercise is requisite to resolving the relationships between flow, DO, temperature, and other water quality variables at varying longitudinal scales. Hence, construction of a new modelling platform for the Red Deer River was required.

Based on an internal review by AENV limnologists of available water quality models, the model CE-QUAL-W2 (v.3.1), developed jointly by the U.S. Army Corps of Engineers, and Dr. Scott Wells at Portland State University (Wells 1997, 1999, Cole and Wells 2002), was identified as the most appropriate model for application to Alberta river and reservoir systems. At present, the Red Deer model is set up and running for the reach extending from the Dickson Dam through to the Saskatchewan Border (570 km). The Gleniffer reservoir itself, impounded by the Dickson Dam, is not presently being modelled, though this could be integrated into the model in the future. The current iteration of the model includes the influences of all significant tributaries and withdrawals, and initially is testing and refining the modelling work of AGRA et al. (1995).

CE-QUAL-W2 is a two-dimensional (2-D), longitudinal/vertical, hydrodynamic and water quality model. The model consists of directly coupled hydrodynamic and water quality transport models. The current version of the model extends its utility to provide state-of-the-art capabilities for modelling entire water basins in two dimensions. Because the model assumes lateral homogeneity, it is best suited for long and narrow water bodies exhibiting longitudinal gradients, such as rivers and reservoirs. With two dimensions depicted, point and non-point loading can be spatially distributed. Relative to other 2-D models, CE-QUAL-W2 is efficient and cost-effective to use. The model has been under continuous development since 1975.

The model predicts water surface elevations, velocities at different depths, and temperatures, that are included in the hydrodynamic calculations. The model also calculates onset, growth, and break-up of ice cover. The primary data that drive the model consist of the system's bathymetry, developed into the model grid; the boundary condition flows, temperature and water quality; tributary and effluent discharge, temperature and water; and meteorological data. With respect to water quality, a large number of constituents can be included in a simulation. For the Red Deer River model, these constituents include total dissolved solids, bacteria, phosphorus, ammonium, nitrate-nitrite, dissolved and particulate organic matter, BOD, algae, epiphyton, and dissolved oxygen.

The model has been calibrated for the Red Deer River, for a number of representative years (1997 to 2002), using flow data from Water Survey of Canada (WSC) sites, and water quality data from the long-term river monitoring network, continuous monitoring installations, and a number of site-specific and parameter-specific studies conducted by both government and industry. The model has been set up to run continuously through a two-year cycle (e.g., 1997-98), outputting data at increments of 10 times per day. This allows evaluation of both diurnal (daily) and longer-term (seasonal) cycles. To date, simulated temperature and dissolved oxygen concentrations compare very well with measured data.

The method recently used to derive the Red Deer River IFN values is similar to that used by AGRA et al. in the 1990s. The system was modelled at a range of flows, with resultant water quality evaluated at discreet points in each downstream reach. However, rather than use a fixed IFN at Dickson Dam, and progressive downstream addition of tributary flow, as AGRA et al. did, the CE-QUAL-W2 model was used to determine the IFN flow for each reach. A number of scenarios were run with respect to flow, using meteorological conditions and loading values for 2001, an appropriate year to evaluate worst case conditions as it ranks as the 11th warmest of the past 55 years (Environment Canada 2003). Summer flows in this year ranked very low for both the mainstem and the tributaries. Based on the current modelling, the earlier IFN recommendations of AGRA et al. are sustained, though with some refinement (Table 6.1). Additional work on these predictions will be carried out in 2003.

6.2.2 Bow River

Water quality based IFN values for three reaches of the Bow River (Table 6.2) are based on the work of Golder/W-E-R (1994). The three reaches in the report, and the corresponding Technical Team reach codes, are as follows:

- Reach 3 - WID weir to Bonnybrook Sewage Treatment Plant (STP), to the Highwood River confluence (reach code BW4 in the Technical Team evaluation);
- Reach 2 - Highwood River confluence to Carseland weir (reach code BW3 in the Technical Team evaluation); and
- Reach 1 - Carseland weir to 11 km downstream of the Hwy 547 bridge (south of Gleichen) for summer water quality modelling, from the weir to the Bassano dam for modelling ammonia in winter (reach code BW2 in the Technical Team evaluation).

Table 6.2. Bow River water quality IFN determinations. Water quality IFNs are based on minimum flows for protection of aquatic life, and are specifically based on actual fish species present per reach.

Reach Boundaries	**Reach Code**	**Water Quality IFN (m³/s)**			
		Winter	**Spring**	**Summer**	**Fall**
WID weir to u/s Highwood Confluence	BW4	20 – 40*	N/A	100	N/A
Highwood R. confluence to u/s Carseland weir	BW3	30	N/A	100	N/A
Carseland weir to u/s of Bassano Dam	BW2	35 - 40	N/A	90	N/A
Bassano Dam to Mouth	BW1	35 – 40*	N/A	N/A	N/A

Notes
***** - *Estimate only***,** *provided due to more recent ammonia concerns that may not have been addressed in the modelling. For Reach BW4 in winter, Golder/WER recommended 20 m³/s. "Estimate" refers to an IFN based largely on professional opinion and additional water quality data, and not on modelling results (for example, the value for Reach BW1 in winter.)*
N/A *– IFN values are not available. Modelling has not been carried out for this period.*
The IFN in Reach BW2 in summer is provided by Sosiak (1996). Golder/W-E-R (1994) recommended 100 m³/s.

The Bow River reaches from Jumping Pound Creek to Bearspaw Dam and from Bearspaw Dam to the Elbow River were not modelled, but the water quality data records from these reaches were reviewed, with the authors concluding that water quality problems with respect to temperature, dissolved oxygen and ammonia were not apparent (Golder/W-E-R 1994). In other words, flows present at the time of the report were adequately providing for water quality based instream needs in this reach. The uppermost reaches of the Bow River were not addressed. Eventually, as Banff and Canmore increase in population size and activity, the upper reaches will likely require water quality based IFN values. The most downstream reach, from Bassano Dam to the mouth, was also not addressed in this study.

Reports by the Bow River Water Quality Task Force (1991, 1994) and Golder/W-E-R (1994) provide a concise overview of problems and issues in the Bow River. Primary water quality concerns included water temperature and dissolved oxygen. Dissolved oxygen levels were shown to have been reduced by wastewater releases and density of macrophytes. Golder/W-E-R (1994) indicated there were no measurements available for sediment oxygen demand, a potentially critical parameter in some sections of the river.

Target fish species for management in the three Bow River reaches (BW2, 3, and 4) were rainbow trout, brown trout and mountain whitefish.

The WQRRS (Water Quality for River-Reservoir Systems) model was used to simulate dissolved oxygen and temperature in the three Bow River reaches (BW2, 3, and 4) from May through September. WQRRS was recommended by CH2M Hill (1982) as the best model to use for SSRB water quality modelling. The hydraulics component of WQRRS and initial river chemical and biological conditions were based on Hamilton et al. (1989).

The WQRRS was developed by the US Army Corps of Engineers Hydrologic Engineering Center and historically has been fairly widely used in the U.S. and elsewhere. The modelling system has been incorporated into the HEC-5Q model package, which is in more common use today than the original WQRRS system. The WQRRS and HEC-5Q package includes a series of models for the dynamic simulation of river-reservoir systems. The system allows prediction of vertical profiles of water quality conditions in reservoirs and longitudinal conditions in river networks of branching channels and/or around islands. The stream hydraulic module routes the flow using several different methods (St. Venant equations, Kinematic Wave, Muskingum, Modified Puls), and is able to model both steady and unsteady flow regimes.

The WQRRS model was calibrated for water temperature and dissolved oxygen, using data from May to September 1989, from Lafarge Bridge (km 354) and Fish Creek (km 346), and verified against data from 1981 and 1984 from Stiers Ranch (km 335). For the analysis of instream flow needs, the WQRRS model was applied by Golder to the period of May-September for 1981, 1984, 1989 and 1990, where 1981 and 1990 were relatively high flow years and 1984 and 1989 were low flow years. Flow needs recommendations were developed by Golder/W-E-R for each reach simulated (1994).

Other water quality models have been employed on a more limited basis, but contribute to the understanding of water quality dynamics along the Bow River. In Reaches BW3 and 4, the DOSTOC (Dissolved Oxygen, Stochastic River Quality Model), developed by HydroQual Consultants Inc., and Gore and Storrie Ltd., was used to model DO in winter, based on existing and future wastewater treatment plant (WWTP) treated effluent loadings (Golder/W-E-R 1994). The DOSTOC model was calibrated to measured winter DO data from Reid Crowther (1990). The CCREM (1987) guidelines were used to identify DO, temperature and ammonia toxicity values. Three effluent profiles were evaluated:

- Historic Conditions in 1989-90;
- Expansion Scenario F1, in which the existing plants operate to their pre-1994 design capacity; and
- Expansion Scenario F2, as per F1, plus the incorporation of the Bonnybrook WWTP expansion of 1994. WWTP loadings beyond 2000 were not accounted for.

The WASP 4.2 (Water Quality Analysis Simulation Program, Version 4.2) model (developed by Hydroscience Inc.) was used to model the ammonia-mixing zone below the Bonnybrook and Fish Creek WWTPs. Reach BW2 was modelled with macrophyte data from 1990; Reaches BW3 and BW4 with data from a 1989 study. The recommendations provided by Golder/W-E-R (1994) are supported with results from the DOSTOC and WASP modelling exercises. Recent independent review found the water quality IFN determinations to be reasonable, but recommended re-evaluation during future studies. (James Martin, PhD., P.Eng., Water Quality Modeling Expert, US Corp of Engineers, Vicksburg, based on the contract performed in 2000-01 for AENV, in reviewing existing SSRB modelling work).

6.2.3 Oldman River

Preliminary water quality based IFN estimates were provided in the original Oldman RiverDam operational plan of the 1980s. These were refined by HydroQual Consultants Inc. and form the basis for the IFN recommendations of Alberta Environment (Trimbee et al. 1993). Trimbee et al. (1993) defined instream needs as quantity and quality of water for the protection of instream channel and riparian environments. This is similar to the current approach taken by the Technical Team.

The recommended IFN flows for the Oldman River below the LNID canal withdrawal (Reach OM5) are 8.5 m^3/s, Apr-Oct; and 6.5 m^3/s, Nov-Mar (Trimbee et al. 1993). Recommended flows for below Lethbridge (Reach OM2) are 11.5 m^3/s Nov-Mar; 15 m^3/s, Apr, Sep, Oct; and 20 m^3/s May-August (Table 6.3). Effluent loading at the Lethbridge municipal wastewater treatment plant and industrial effluent loading at the Taber sugar refinery (Reach OM1) (Golder 1993) were taken into account for these IFN estimates.

Table 6.3. Oldman River water quality IFN determinations.

Reach Boundaries	**Reach Code**	**Water Quality IFN (m^3/s)**			
		Winter	**Spring**	**Summer**	**Fall**
Oldman Dam to u/s of Pincher Creek	OM7	Historic flows, post impoundment			
Pincher Creek confluence to u/s of LNID weir	OM6	Historic flows, post impoundment			
LNID weir to u/s of Willow Creek	OM5	6.5	8.5	8.5	8.5
Willow Creek confluence to u/s of Belly River	OM4	6.5	8.5	8.5	8.5
Belly R. confluence to u/s of St. Mary River	OM3	6.5	8.5	8.5	8.5
St. Mary River confluence to u/s of Little Bow River	OM2	11.5	15	20	15
Little Bow R. confluence to the Grand Forks	OM1	11.5	15	20	15

Notes:

Water quality IFNs *are based on minimum flows for protection of aquatic life, specifically on fish species actually present per reach.*

Historic flows *- where WQ IFNs have not yet been determined, (recently recorded) historic flows are recommended based on existing water quality monitoring data that indicates few exceedences of guidelines, i.e. good water quality being present.*

Target fish species *for management below Lethbridge are walleye and sauger.*

Several documents provide information on the Oldman River Basin water quality and minimum flow development. The majority of documents provide present and historical water quality conditions in the river. It was reported in the current documents of the Oldman River Basin Water Quality Initiative, that during the first two years of the initiative, data were collected at

38 locations along the Oldman River, including mainstem, tributary, effluent and return flow sites (www.oldmanbasin.org).

The WQRRS model has been applied to the Oldman River (Hamilton and Cross 1985, HydroQual 1990a, 1990b). The WQRRS application had two primary components: analysis of management alternatives, and analysis of minimum flow requirements. HydroQual, using data from the period 1982-1986, simulated the post-impoundment flows and water quality. A water balance for the period was developed using the Water Resource Management Model (WRRM). The Laterally Averaged Reservoir Model (LARM, a precursor to CE-QUAL-W2) was used to simulate potential reservoir conditions for the period. Output from these models, and meteorological data from the same period, were then used with WQRRS to simulate river water quality for the period 1982-1986.

For the Oldman River water quality IFN work, natural flows were converted from mean monthly flows, given in the WRMM flow model, to daily flows for use in the WQRRS water quality model (Trimbee et al. 1993). WQRRS was used to model DO, ammonia, and dissolved phosphorus for the critical summer (July-August) and winter (February) conditions. The evaluation focused on instream conditions experienced during the historic low flow period of 1984-85.

It should be noted that recommended flows for the Oldman River below Lethbridge (Trimbee et al. 1993) are based on the premise that future ammonia problems will be solved by means other than flow dilution. Recent upgrades to the City of Lethbridge municipal WWTP are expected to reduce ammonia loading to Reach OM2 and have a positive impact on flows required for waste assimilation.

6.2.4 The Southern Tributaries of the Oldman River

Summer WQ IFNs (Table 6.4) were generated for the Waterton, Belly and St Mary rivers, based on data from the late 1980s and early 1990s (Shaw 1994). The work of Shaw (1994) is based on the earlier work reported in EMA (1994).

In 1989, a technical committee was formed to generate instream needs recommendations for the Southern Tributaries based on fish habitat, water quality, riparian vegetation, recreation, and reservoir operation (Alberta Environment 1989). Extensive instream temperature analyses (HydroQual 1991) and identification of biological constraints (low summer flows and high temperatures in Julian calendar weeks 27-34) were used to identify target management fish species. Rainbow trout and mountain whitefish were selected in the upper reaches of the Waterton and St. Mary rivers. Walleye and brown trout were selected for the Belly River and the lower reaches of the Waterton and St. Mary rivers (EMA 1994).

Extensive water quality data were collected in the summer of 1988 (late June to mid September) to calibrate the WQRRS water quality model for the project. Data on benthic algal and macrophyte biomass, and benthic macro-invertebrate density were limited, leading to various assumptions as a substitute for the missing data. Data were also needed to determine travel times, re-aeration rates, sediment oxygen demand (SOD), and other water quality variables (WQA 1989). In 1989, HydroQual Consultants conducted a dye and tracer study to determine travel times and re-aeration rates. They also collected data to determine nutrient levels and abundance of benthic algae and aquatic macrophytes. In 1990, they collected further field data at the upper and middle reaches of the southern tributaries. HydroQual (1991) predicted water temperature and dissolved oxygen concentrations from 1988 and 1990 flows for three scenarios for each river. The three scenarios were based on low, medium and high flows for the ODO5-2 run of the WRMM water balance model. The water quality modelling results were evaluated against acute and chronic temperature and dissolved oxygen criteria for adult and fry of the fisheries target management species, brown trout, rainbow trout, mountain whitefish and walleye.

Table 6.4. Oldman Tributaries water quality IFN determinations.

Reach Boundaries	Reach Code	Water Quality IFN (m^3/s)
Belly River		
St. Mary Canal to 125km u/s of Oldman	BL3	Historic flows
125km u/s of Oldman to u/s of Waterton confl.	BL2	Summer: 5
Waterton R. confluence to mouth	BL1	Summer: 5 - 10
St. Mary River		
37km upstream of the Oldman River upstream to the St. Mary River Dam	SM2	Summer: 6 - 12
Confluence with the Oldman River to 37km upstream	SM1	Summer: 6 - 12
Waterton River		
Waterton Reservoir to 45km u/s of the Belly River	W2	Summer: 6
45km u/s of the Belly River to mouth	W1	Summer: 6

Notes

Water quality IFNs *are based on minimum flows for protection of aquatic life, specifically on fish species actually present per reach.*

Historic flows *- where WQ IFNs have not yet been determined, recently recorded historic flows are recommended based on existing water quality monitoring data indicating few exceedences of guidelines, i.e. good water quality being present.*

Natural exceedences of instream temperature and dissolved oxygen occur in the Southern Tributaries. The IFNs were therefore set so there would be no increases in the frequency, magnitude and duration of these exceedences (EMA 1994). In all scenarios, temperature was the main driver (had the most exceedences). Therefore all IFN recommendations were based on avoiding temperature exceedences. For example, based on water quality conditions in July-Sept 1988, the percent of time simulated water temperatures exceeded a target value of 22.5 °C was:

- for the lower Belly River – 9% under natural flow conditions and 13% under recorded flows;
- for the lower St Mary River – 2% under natural flow conditions and 9% under recorded flows; and
- for the lower Waterton River – 4% under natural flow conditions and 15% under recorded flows (EMA 1994).

The IFN recommendation would increase recorded flow levels to reduce the occurrence of temperature exceedence events to near natural levels.

Interim flow recommendations

The recommended interim water quality IFN for the Waterton River below the Waterton Dam is 6 m^3/s (Shaw 1994). According to Shaw (1994), the value is interim because additional data are required to better calibrate the water quality model. The 6 m^3/s corresponds to the 90% exceedence flow (natural flow) in July and August. Recorded flows were frequently well below this value. Based on socio-economic considerations, the instream objective (IO) for the Waterton River in 2002 was 2.26 m^3/s, less than half the recommended IFN value.

For the Belly River, an interim IFN of 5 m^3/s was assigned (Shaw 1994) that corresponds to the 70% exceedence flow (natural) downstream of the Belly diversion weir, and the 97.5% exceedence in the middle to lower reaches. Shaw (1994) notes there are still frequent exceedences of brown trout temperature requirements at 10 m^3/s, but to firmly justify recommending higher than 5 m^3/s would require additional data collection and model calibration. The current instream objective for the lower reaches of the Belly River is 0.93 m^3/s; that is, about 20% of the recommended water quality IFN reported in Shaw (1994). The water quality IFN for the lowest reach of the Belly River (BL1) was estimated as being near the 90% exceedence flow (natural). The 90% exceedence flow (natural) in the Belly River, above the confluence with the Waterton River (Reach BL2), in late August is 4.5 m^3/s. The 90% exceedence flow (natural) at the confluence with the Oldman River is 9.6 m^3/s. The IFN for Reach BL1 is therefore given as a range of 5-10 m^3/s.

The scenarios for the St. Mary River were evaluated under 1988 and 1990 conditions for summer flows of 3, 6 and 12 m^3/s (low, medium and high summer flows). The recommended interim IFN is a range of 6-12 m^3/s for the St. Mary River (Shaw 1994). A single value was not given due to lack of sufficient data and model calibration. The current IO for the St. Mary River is 2.75 m^3/s. The 90% exceedence flow (natural) is 8.2 m^3/s in late August.

Much work was carried out by Shaw (1994) to determine the above water quality based IFN values for the Southern Tributaries. However, additional data gathering and modelling are required to confirm the interim values. Values are also required for the spring, fall and winter months. With high temperature being a critical factor in sustaining fish populations, it was appropriate to first identify summer IFN values. The next priority is winter, under ice IFN requirements.

6.2.5 South Saskatchewan River sub-basin

Currently, there are no water quality based IFN values for the South Saskatchewan River sub-basin. The instream objective values being used are based on Alberta-Saskatchewan Apportionment Agreement requirements (at the border) and aesthetics (at Medicine Hat). Currently there are few water quality exceedences on this river. Therefore present flows are considered to be adequate for water quality protection pending further investigations (Table 6.5).

Table 6.5. South Saskatchewan River water quality IFN determinations.

Reach Boundaries	**Reach Code**	**Water Quality IFN (m^3/s)**
Grand Forks to Medicine Hat	SS2	Historic flows, post-impoundment
Medicine Hat to Border	SS1	Historic flows, post-impoundment

Notes - Historic flows *- where WQ IFNs have not yet been determined, historic flows are recommended based on existing water quality monitoring data indicating few exceedences of guidelines.*

6.3 Conclusion

Water quality in our rivers is determined by a wide variety of variables and conditions affected by natural and anthropogenic processes and conditions, many of which cannot be satisfied by only managing flow. Water quality IFN development is only one part of a larger water quality management system that includes control of point and non-point sources of contaminants to water. Within the context of larger watershed protection programs, water quality-based minimum flows are an effective management tool.

The water quality IFNs provided in this report are based on instream temperature, dissolved oxygen, and below the major municipal wastewater treatment plants, ammonia. There are many other water quality variables that are important in the river ecosystems that make up the SSRB. However, most of these (e.g. metals, pesticides, etc.) are better managed by source control than by flow manipulations.

Water quality based IFN values are present for most mid to lower reaches of the Red Deer, Bow and Oldman rivers. These values were generated in the early 1990s by water quality modelling using the available site-specific data on water quality, effluent loading, hydrology and meteorology. They form a basis for assigning minimum flows for protection of water quality in the mainstem reaches of the three rivers. Water quality IFN values in each of the three major rivers vary due to different environmental conditions between the rivers (e.g., the degree of ice cover in winter), the length of each river requiring protection (e.g., the Red Deer River below the City of Red Deer is much longer than the Oldman River below Lethbridge); and due to variations between the three rivers in fish species identified by provincial fisheries management staff.

Work has also been carried out on the Southern Tributaries of the Oldman River, but the IFN values are considered interim and require confirmation by additional data gathering and modelling. Water quality modelling has not be carried out on the South Saskatchewan River, but based on few water quality exceedences on this river at this time, the actual flows in recent years are thought to be adequate to meet water quality objectives pending further investigations.

6.3.1 Further Work

In the 1990s, much was learned about instream needs for the protection of water quality in the South Saskatchewan River Basin. However, data gaps still exist. In most reaches, water quality based IFN values have been provided for the summer low flow season and the winter low flows in the reaches below major cities. In some reaches of the Oldman and Red Deer rivers, IFNs have been provided for all four seasons. Water quality IFNs are still required for:

- the Bow River in spring and fall (all reaches);
- the Bow River from the WID weir to the confluence with the Highwood River (winter IFN value is uncertain);
- the Bow River below Bassano (spring, fall and summer; and confirmed for winter);
- the South Saskatchewan River (all four seasons); and
- the Southern Tributaries (spring, fall and winter).

Additional recommendations for water quality IFN development include the following:

- New and updated modelling should be carried out on the Bow and Oldman rivers and the major tributaries, in particular for those reaches and periods that currently do not have water quality based IFN values.
- Additional macrophyte data may be required below the major cities.
- Monitoring the effect of high spring flows on macrophyte and algae beds should occur in the river reaches immediately downstream of the major cities to determine the efficacy of flows in reducing biomass and subsequent influences on water quality (e.g. dissolved oxygen).
- Routine water quality monitoring (monthly within each reach) should be continued in order to assess current conditions and to evaluate any new or unexpected changes in water quality.
- Assessment of the diversity and abundance of benthic invertebrate communities in various reaches of the rivers can also provide beneficial information on IFN flow determinations.

IFN flows downstream of the major cities ought to be revisited in light of the implementation of improved wastewater treatment technology. However, any water quality benefits could be offset by concurrent increases in population and human activity in the watershed. Climate change may affect water quantity that would then have an effect on water quality. Climate change impacts are not part of the IFN Technical Team's Terms of Reference, but may be addressed in a future phase of the SSRB Water Management Plan.

7.0 RIPARIAN ECOSYSTEM INSTREAM FLOW NEEDS

The following section is largely a re-presentation of the work by Gom (2002) and Gom and Mahoney (2002) outlining a method for determining instream flow needs to sustain riparian poplars. These reports have benefited from external, independent review and encapsulate the latest developments in managing water resources for riparian ecosystems.

7.1 Introduction

Riparian zones in Alberta are highly diverse and include a number of habitat and vegetative community types (Thompson and Hansen 2002). Although riparian poplars (cottonwoods) are an important part of riparian forest ecosystems in the South Saskatchewan River Basin, they are only one component of the full array of community types.

In the semi-arid prairie regions of southern Alberta, cottonwoods are often the only native tree species present providing essential habitat and food sources for many wildlife species. Cottonwood forests also directly influence the associated aquatic ecosystem by contributing organic debris and shade to the aquatic ecosystem. Indirect effects on the aquatic ecosystem occur through stabilization of streambanks and trapping of floodplain sediments, thereby altering the channel forming process and the rate of channel movement.

Despite their overall importance, meeting the hydrological needs of riparian poplars does not necessarily mean the hydrological needs of all riparian species are met. Work in fisheries management has shown that management for a single species rarely gives positive results for all species present (Section 5). Further work on the links between river hydrology and other riparian species is needed before a comprehensive riparian Instream Flow Need (IFN) can be determined. However, maintaining the full range of hydrological variability when determining riparian cottonwood IFNs is expected to extend benefits to other riparian species.

Cottonwoods are well adapted to their riparian existence in this dry region known for its extremes in temperature. Despite being sensitive to drought stress, riparian cottonwoods are able to survive because they are phreatophytic; they are linked directly to a dependable water supply from the riparian water table through a deep root system. Cottonwood reproduction is also adapted to riparian conditions. Each mature female tree releases millions of seeds every year at a time that coincides with the spring peak in river flows (Bessey 1904). Seed germination occurs rapidly on moistened sediments that have been cleared of vegetation by spring flooding. Seedling root growth is rapid enough to maintain contact with the moist capillary fringe above the receding water table. Although they are vulnerable to flow-related scouring and burial in their first several years, saplings become increasingly resilient as they grow to maturity. After the roots are established, saplings are capable of re-sprouting vigorously when buried or decapitated.

Cottonwoods have adapted to natural river flow patterns over thousands of years and are sensitive to changes in streamflow. They are especially vulnerable to flow management that changes minimum, moderate and peak flows. Reduced minimum flows can result in a corresponding lowering of the riparian water table. If the water table is dropped below the depth that cottonwood root systems can access, the trees will become drought stressed. This stress can lead to branch dieback or tree death depending on the severity and duration of the drought condition (Tyree et al. 1994). Reductions to moderate flows impact cottonwoods because moderate flows elevate the floodplain water table and saturate floodplain substrates. The added moisture enhances overall forest health by providing moisture for young saplings and trees on higher floodplain terraces. In addition to minimum and moderate flows, higher flows are essential to cottonwoods because the magnitude, duration, and seasonal timing of peak flows are essential to the recruitment and long-term survival of seedlings. Changes to peak flows can reduce seedling recruitment and lead to the gradual deterioration of riparian forests (Bovee and Scott 2002).

The following section discusses the biological basis for determining the instream flows needed to sustain riparian cottonwoods in southern Alberta. The instream flow requirements are then applied to natural flow conditions to develop a set of operational flow targets based on naturalized historic flows. The 'Poplar Rule Curves' (PRC) are designed to provide practical flow-management guidelines for meeting the minimum, moderate and high flow requirements of cottonwoods and to help preserve and restore riparian forest ecosystems.

7.2 Links Between Cottonwood Biology and Hydrology

Riparian cottonwoods are intimately dependent on the riparian water table that is connected directly to the nearby stream. Water is either percolating towards or away from the streambed, depending on surrounding hydraulic conditions (Dunne and Leopold 1978, Linsley et al. 1986). The zone of saturation extends horizontally from the stream's surface into the floodplain and fluctuates with stream elevation.

Despite growing in the driest regions of southern Alberta, cottonwoods are extremely sensitive to drought stress (Tyree et al. 1994). They are able to survive in such dry environments only because their phreatophytic root systems tap into the riparian water table, connecting them to a reliable water supply even during natural seasonal changes in temperature and precipitation. Although the limit of cottonwood root growth is not fully known, it can be deduced that the roots of mature cottonwoods growing on raised floodplain terraces may penetrate to depths greater than 5 m to reach the saturated zone.

Although poplars can grow vigorously, they are relatively short-lived trees, usually living less than 100 years. Combined with the fact that riparian areas are prone to disturbances that can continually reset forest succession, riparian poplar forests require ongoing reproduction to drive forest colonization and replenishment. Every year, each mature female cottonwood can release millions of seeds during a 2-3 week period in early June (Bessey 1904). Each cottonwood seed is only about 3 mm long and has a cottony enclosure of fine hairs that aids dispersal by wind and water. The small energy reserve stored in the seed limits seed viability to a few weeks. Germination will occur on any moist substrate, but for a cottonwood seedling to successfully grow into a mature phreatophytic tree, it requires specific substrate and moisture conditions during its first few weeks and subsequent growing season.

Fresh sediments, those scoured by ice or flood flows, provide the moist, barren seedbeds that are suitable for cottonwood seedling establishment. Once moistened, a cottonwood seed will germinate within 24 hours and immediately begin root elongation at a rate of about 0.5 to 1 cm/day, reaching a length of about 60 cm after the first growing season (Mahoney and Rood 1998). As springtime streamflows recede, so does the riparian water table. Young cottonwood seedlings will only survive if their root growth is able to keep pace with the moist capillary fringe above the declining water table. If the substrate dries out too quickly, the young cottonwoods will be vulnerable to desiccation. If the site is repeatedly flooded, seedlings can be buried by sediments or scoured away.

The precarious establishment of cottonwood seedlings is therefore limited to a narrow elevational band above the river water level. This 'recruitment zone' is defined at the top by a combination of root growth potential plus the extent of capillary fringe above the water table during late summer streamflows. It is defined at the bottom by the potential for subsequent scouring and deposition (Figure 7.1). Consequently, the recruitment zone extends from about 60 cm to about 150-200 cm above base flow depending on substrate texture (Mahoney and Rood 1998). For seedlings to survive in this zone, stream stage decline must be gradual enough to allow root growth to keep pace. The maximum survivable rate of decline suggested by Mahoney and Rood (1998) is 5 cm/day, although more gradual declines are more effective at limiting seedling mortality.

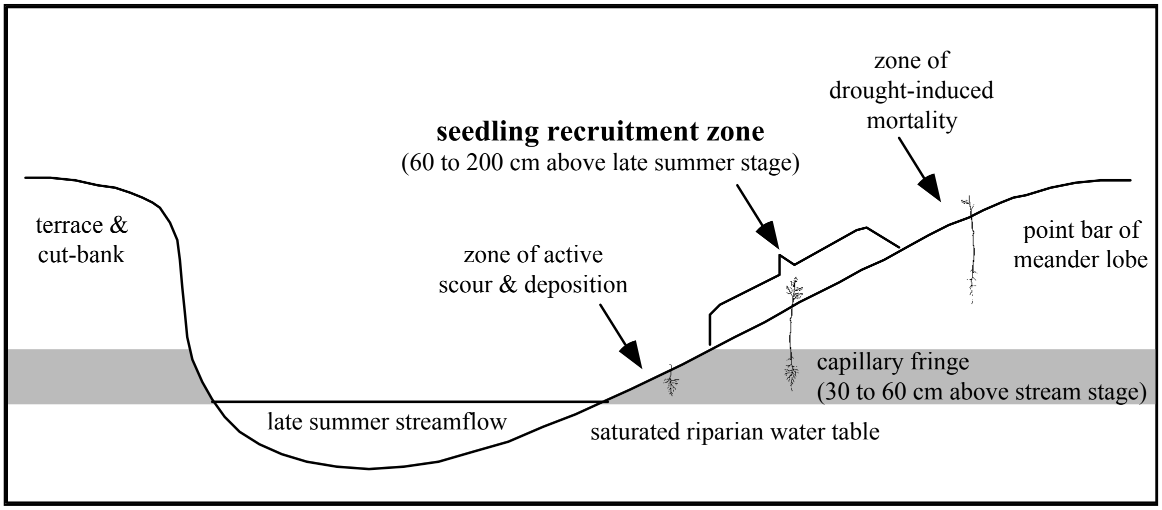


Figure 7.1. Cross-section of a streambank showing the extent of moistened substrates and the suitability of zones for cottonwood seedling establishment (adapted from Mahoney and Rood 1998).

Given the specific moisture requirements for successful cottonwood seedling establishment, it is not surprising that dendrochronological analyses have shown natural cottonwood recruitment is associated with 5 to 10 year-return flood events along the Southern Tributaries of the Oldman River (reviewed by Mahoney and Rood 1998). These moderate floods recharge the riparian water table and mobilize sediments to create new seedling nursery sites in the form of meander lobes and lateral bars. Due to the geomorphic changes they cause, larger scale floods can improve recruitment opportunities for the next several years or even decades. In early June of 1995, the highest flows on record occurred along many streams in the Oldman River watershed. Following the flood peak, releases from the tributary dams were coordinated to deliver a gradual flow recession of about 2.5 to 5 cm/day. Unprecedented numbers of cottonwood seedlings were observed to survive through 1996 and 1997 at elevations of 1.7 to 3 m above base flow (Rood et al. 1998).

7.3 Impacts of Damming and Diversions

Water management projects have been implicated in the decline of riparian cottonwood ecosystems across large areas of North America (Rood and Mahoney 1990). Subsequent research suggests it is not the presence of a dam or diversion, but rather the way it is operated that has the greatest impact on downstream vegetation. The purpose of a flow regulatory structure dictates the type of flow regime that is produced downstream and consequently, the impacts it has on downstream riparian forests.

Many factors, including agricultural clearing, domestic settlement, livestock grazing, direct harvesting, onstream reservoirs, gravel mining, channelization, herbicide spraying, and beavers, can have a negative impact on riparian cottonwood forests (Rood and Mahoney 1991b). Therefore, the contributing effects of each of these factors must be considered in any program to conserve or replenish declining riparian forests. The regulation of streamflow appears to affect the most basic functioning of the system. Riparian cottonwood forest decline is usually attributed to one or both of two problems: inadequate seedling replenishment to balance natural attrition in aging populations, and/or accelerated mortality due to chronic or cumulative water stresses (Table 7.1). Although both effects are related to modifications in natural streamflow variability and/or volume, they tend to involve different aspects of the natural annual flow pattern (annual hydrograph).

Table 7.1. Documented examples of riparian cottonwood declines associated with flow regulation along streams in North America.

Authors:	**River and region**	**Inadequate replenishment**	**Forest stress or mortality**
Auble et al. 1997	Boulder Cr., CO	X	X
Bradley and Smith 1986, Bradley 1982	Milk R., AB & MO	X	X
Cordes et al. 1997	Red Deer R., AB	X	
Fenner et al. 1985	Salt R., AZ	X	X
Howe and Knopf 1991	Rio Grande, NM	X	
Johnson 1992, Johnson et al. 1976	Missouri R., ND	X	X
Johnson 1998	Platte R., NB	X	X
McKay 1996	Nisqually R., WA	X	
McKay 1996	Cowlitz R., WA	X	
Miller et al. 1995	North Platte R., WY	X	X
Rood et al. 1998 and 1999, Rood and Bradley 1993	Bow R., AB	X	
Rood and Mahoney 2000, Rood et al. 1995	St. Mary R., AB	X	X
Reid et al. 1992, Rood and Heinze-Milne 1989	Waterton R., AB	X	X
Rood and Mahoney 1995	Marias R., MO	X	
Snyder and Miller 1992	Colorado R., CO	X	X
Snyder and Miller 1991	Arkansas R., CO	X	X
Stromberg and Tiller 1996	San Pedro R., AZ	X	X

As discussed previously, cottonwood seedling recruitment is adapted to capitalize on the barren, moist seedbeds revealed after high springtime streamflows recede. Failed seedling establishment has been consistently linked to reductions or delays of peak flows and abrupt or sustained low flows during the growing season. High flows drive erosion and deposition along the channel, scouring competing vegetation and laying down new seedbeds. Reduction of peak-flows below certain geomorphic thresholds can cause channel stabilization and meander stagnation that allows encroachment of upland vegetation. This can result in a paucity of nursery sites for cottonwood seedling establishment. Reduction of springtime peak-flows can also result in a lower, narrower elevational band available for recruitment, leaving seedlings susceptible to burial or removal by subsequent flooding and ice scour.

The timing of peak flow is also critical because mature cottonwoods release their short-lived seeds during only a few weeks in June. Provided peak flows position newly germinated cottonwood seedls appropriately, seedling survival depends on subsequent streamflow. The roots of the tiny, drought-sensitive seedlings must maintain contact with the moist, capillary fringe above the floodplain water table. If the rate of water table decline is more rapid than the seedling's root growth, the seedling will loose contact with its water supply and die. Alternatively, if streamflow rises enough to inundate the site again, new seedlings are likely to be washed away or buried by sediment.

Streamflow conditions conducive to cottonwood seedling replenishment do not need to occur every year. Consecutive years with high peak flows can repeatedly remove previously established seedlings. Successful seedling recruitment occurs on average only about once every 5 to 10 years in southern Alberta (reviewed by Mahoney and Rood 1998). Recruitment tends to occur most frequently (1-5 years) along meandering reaches with sandy beds (Bradley and Smith 1986, Hughes 1994). Widespread recruitment events, such as the one that occurred in 1995 along the Oldman River (Rood et al. 1998), are more rare, occurring, on average, less than once every 30 to 50 years (Rood and Mahoney 1991a, Stromberg et al. 1993, Hughes 1994). Thus, in the time scale of a cottonwood's lifespan (about 100 years), natural streamflows that support cottonwood recruitment occur relatively infrequently. When streamflow is regulated, these events may occur less frequently, if at all. Reduced frequency of forest replenishment may lead to unbalanced age distributions and eventually to population collapse if left uncorrected.

Cottonwoods remain sensitive to drought stress as they mature. Because their root systems are deeper and more established, mature trees are less likely to become drought stressed than seedlings and saplings. However, they are still dependent on the riparian water table for survival. If the water table drops below their rooting-zone, cottonwoods become water stressed and show symptoms such as premature leaf senescence, branch dieback, and complete trunk mortality (Albertson and Weaver 1945, Rood and Mahoney 1991a, Tyree et al. 1994). The effects of repeated drought stress can be cumulative, weakening the trees and leading to increased stress sensitivity.

7.4 Targeting Flows to Sustain Riparian Forests

The flows required to sustain riparian cottonwood forests may vary greatly from reach to reach because each stream has its own combination of environmental constraints and species present. Logically, the natural flow regimes that riparian forests have been established under, and continue to be maintained by, should be adequate to support those forests' long-term survival. A new equilibrium of vegetation composition may be expected to develop if the pattern of streamflow is altered significantly. For example, consistently lowered flows may produce a new equilibrium state favouring the encroachment of grasslands rather than establishment of pioneer tree species such as cottonwoods. A less extreme change in flow regime may only favour cottonwoods closer to the water source, resulting in a narrower band of forest that tightly parallels the river channel. Although such a regime may feature a reasonably viable riparian forest, a more extensive forest, supported by natural conditions, would be more diverse and robust, thereby providing more resiliency and greater value for associated wildlife. Thus, the approach taken here will target flows for maintaining and restoring the natural extent and character of riparian cottonwood forests, rather than simply trying to ensure the survival of remnant groves of trees.

Cottonwood streamflow requirements can be grouped into four general categories, flows for:

- tree survival (minimum flows),

- tree growth (moderate flows),
- seedbed preparation (peak flows), and
- seedling and sapling survival (flow ramping and extended moderate flows).

It is necessary to recognize the tolerance ranges for each of these categories when targeting flows to sustain riparian forests as a whole.

7.4.1 Base flows for forest survival and maintenance

Many documented instances of riparian cottonwood decline have been associated with minimum base flows that have lowered the riparian water table. Water table declines of 1 to 4 m or more have been shown to cause extensive mortality (approximately 50 to 100%) in adjacent cottonwood groves (Reid 1991, Stromberg and Tiller 1996, Scott et al. 1999, Scott et al. 2000). These extreme cases define a threshold of unacceptable water table decline. A flow regime for sustaining natural cottonwood groves must avoid crossing this threshold by providing adequate base flows. Base flows required for the survival and maintenance of riparian cottonwoods have been estimated at between 40 and 60% of average weekly flow (Stromberg and Patten 1991).

A single minimum flow determination will not suffice for every situation because each reach has unique characteristics that dictate tolerable water table levels for the cottonwoods residing there. For example, different reaches have different channel widths and substrate textures that affect the relative depth of the water table and the extent of the capillary fringe. The moisture requirements of individual trees also vary, due to differences in species, age and general health.

Naturally occurring riparian cottonwoods are adapted to tolerate natural extremes of streamflow, and can survive occasional acute drought conditions. However, natural minimum flows can be detrimental if the seasonal timing, frequency, and/or duration are altered. For example, cottonwoods are relatively unaffected by low flows during their winter dormancy, but are sensitive to moisture stress during the hottest, driest months of the growing season, typically in July and August. Cottonwoods can survive periods of drought during their growing season. However, the cumulative effects of prolonged or excessively frequent drought conditions may lead to reduced resiliency to subsequent stresses and gradual forest deterioration. Base flows should be selected with the goal of maintaining cottonwood survival under chronic implementation. Although isolated instances of more acute stress may be tolerated by cottonwoods, chronic exposure to that same level of stress would be detrimental.

7.4.2 Moderate flows for tree health and growth

Base flows alone are inadequate to sustain a healthy riparian forest. Moderate flows are required for optimal growth of cottonwoods. Tree growth, which can be measured using radial and branch growth increments, is strongly correlated with streamflow (Stromberg and Patten 1990, 1991, 1996, Willms et al. 1998). Thus, as with choosing minimum flows, it is recommended that moderate flows be modelled after trends in naturally occurring streamflows. For example, Stromberg and Patten (1990, 1991, 1996) have suggested that normal growth requires natural average streamflows, with 40 to 60% of natural streamflow being necessary for healthy tree canopies and 74 to 313% of long-term average annual flows being needed for maximum growth. These single streamflow values provide a general guide for selecting moderate flows for cottonwoods.

Cottonwoods are adapted to natural patterns of gradual flow recession following springtime flooding. This natural variability in moderate flows is important for maintaining the resilience of cottonwood populations. By exposing trees to a broader range of dynamic riverside conditions, as tends to occur naturally, the resiliency of the forest population can be improved to ensure its survival despite the inevitable disturbances and stress associated with high and low flow fluctuations. Thus, instead of implementing a single moderate streamflow, it is recommended the timing and variability of natural moderate flows be incorporated into the planning of flow regimes to meet riparian poplar needs.

7.4.3 Peak flows for seedling establishment

Although base and moderate flows will favour the survival of young and mature cottonwood trees, higher flows are also essential to the ongoing viability of riparian forests. Peak flows are important for driving channel dynamics that control erosion and deposition of sediment (sections 4 and 8). As discussed previously, reducing or eliminating peak flows can lead to channel stabilization, meander stagnation and the encroachment of upland vegetation. The resulting shortage of barren, moist nursery sites at required elevations will negatively impact cottonwood seedling establishment, and so reduce the long-term viability of the riparian forests.

A single, prescribed peak discharge is not suitable for every situation. Because each reach has its own unique combination of bed texture, stream gradient, and vegetation, each will require a slightly different rate of flow to mobilize sediments and create point or lateral bars. Thus, it is useful to refer to natural benchmarks, such as bankfull discharge, that incorporate this variability and relate to important flow levels.

Bankfull discharge is recognized as a threshold of flow magnitude conducive to cottonwood seedling replenishment (Bradley 1982, Howe and Knopf 1991, Johnson 1992, Auble et al. 1997). Flows beyond the bankfull threshold may be especially valuable to cottonwoods. A model developed by Richter and Richter (2000) suggests that 125% of bankfull discharge is instrumental in driving channel processes that support the long-term survival of cottonwood forests. Bovee and Scott (2002) recommend a flow slightly greater than bankfull, to balance flows that support riparian cottonwood seedling recruitment while meeting flood control objectives.

The flow magnitude required for channel maintenance increases with the coarseness of the bed material. For example, flows up to 130% and 160% bankfull have been reported as important for transporting bedload along coarser-substrate streams (Andrews and Nankervis 1995, Emmett and Wolman 2001). These larger floods can enhance recruitment for the next several years (Howe and Knopf 1991, Scott et al. 1993, McKay 1996, Scott et al. 1997). This is probably because larger floods, such as those with greater than 10 year return intervals (Stromberg et al. 1993), cross the geomorphic thresholds that cause channel and floodplain instability. Instability in the channel promotes the mobilization of sediments that are subsequently deposited as point and lateral bars and become nursery sites for cottonwood seedling establishment. Smaller peak flows may be able to maintain a dynamic channel until a new, stable channel alignment develops.

The seasonal timing of peak flows is important for ensuring successful seedling establishment. Cottonwoods naturally release seeds when peak flows are most likely to be receding. Consequently, a barren, moistened recruitment zone is immediately available to be colonized (Mahoney and Rood 1998). The window of seed release beginns in early June in southern Alberta, and can extend for several weeks depending on local weather conditions (Gom 2002).

7.4.4 Flow-ramping and moderate flows for seedling survival

The recruitment zone targeted for cottonwood seedling germination can be positioned up to 2 m above the late summer stream stage. In order for the drought sensitive seedlings to survive their first year, their root elongation must keep pace with the capillary fringe above the declining riparian water table. In general, the maximum survivable rate of stage decline suggested by Mahoney and Rood (1998) is 2.5 cm/day. The survivable rate of stage decline along reaches with very fine or very coarse substrates may need slight adjustment up or down respectively, because the extent of the capillary fringe is affected by substrate texture. The best way to ensure that the gradual rate of decline is delivered is to monitor the daily operations of the involved water control structures. This is a level of detail beyond the water balancing process completed for the present planning level study.

Following their first year, young cottonwood saplings continue to be more sensitive to drought stress than mature trees with more established root systems. Saplings are particularly vulnerable to abrupt reductions in flow because their roots are not yet fully established and root expansion may not be able to keep pace with rapid water table declines. Thus, in order to promote long-term survival of cottonwood saplings, variability in the flow regime should not exceed that which would occur naturally. By preserving the natural range of high and low flows that affect the riparian water table, cottonwood root systems will be encouraged to establish at depths that promote healthy tree growth and resiliency to future flow fluctuations.

7.5 Drafting the 'Poplar Rule Curve'

An important part of developing the necessary streamflow regime for supporting riparian cottonwoods is recognizing the seasonality of flow requirements for forest survival and maintenance, tree growth, seedbed preparation, and seedling or sapling survival. Using cottonwoods along the Oldman River at Lethbridge as a general index, Table 7.2 describes the annual calendar of events related to poplar growth and development (phenology). The cottonwood-growing season extends from mid-April until mid-September, and it is the pattern of flow during this period that is particularly important to the growth and development of riparian cottonwoods. Therefore, the growing season defines the Poplar Rule Curve's period of concern.

The events that occur during the cottonwood growing season have varied moisture requirements. These requirements are presented in Table 7.3 for cottonwoods along the Oldman River at Lethbridge. The flow requirements are based on minimum values and, as such, are not mutually exclusive. For example, although the streamflow requirements for seedling establishment exceed those for tree maintenance, mature trees will also benefit from the higher flows. These overlaps can be seen when displayed in the context of an annual hydrograph (Figure 7.2).

It would be impractical and could be environmentally damaging to generate a standard hydrograph, similar to the one shown in Figure 7.2, every year. To do so, operators would be required to predict wet versus dry year cycles, and so would face the uncertainty of being able to provide exact flows regardless of upstream supply. Even if it were possible to regulate flow in this manner, the lack of variability in streamflow would probably create artificial channel and forest characteristics, leading to overall reduced resiliency in the system. For example, it would be detrimental to have the same peak recruitment streamflows every year because the previous year's seedlings would be repeatedly removed by high flows the following spring. For these reasons it is necessary to incorporate a natural degree of variability in the design of flow regimes for sustaining riparian cottonwoods and the channel processes they depend on.

Table 7.2. Weekly calendar of riparian cottonwood phenology along the Oldman River at Lethbridge, AB. The growing season is shaded (after Gom, 2002).

Week	1st day of week	Growth & Development		Seedlings (< 1 year old)		Saplings (> 1 year old)	
1-5	Jan.	dormant				dormant	
6-9	Feb.	dormant				dormant	
10-13	Mar.	dormant				dormant	
14	Apr.2	dormant				dormant	
15	Apr.9	dormant				dormant	
16	Apr.16		flowering			dormant	
17	Apr.23		flowering			bud flush	shoot & root growth
18	Apr.30	bud flush	flowering			bud flush	shoot & root growth
19	May.7	bud flush	flowering			bud flush	shoot & root growth
20	May.14	shoot growth	flowering			bud flush	shoot & root growth
21	May.21	shoot growth					shoot & root growth
22	May.28	shoot growth	seed release	germination	root growth		shoot & root growth
23	Jun.4	shoot growth	seed release	germination	root growth		shoot & root growth
24	Jun.11	shoot growth	seed release	germination	root growth		shoot & root growth
25	Jun.18	shoot growth	seed release	germination	root growth		shoot & root growth
26	Jun.25	shoot growth		germination	root growth		shoot & root growth
27	Jul.2	shoot growth		germination	root growth		shoot & root growth
28	Jul.9	shoot growth			root growth		shoot & root growth
29	Jul.16	shoot growth			root growth		shoot & root growth
30	Jul.23	shoot growth			root growth		shoot & root growth
31	Jul.30	bud set / leaf maintenance			root growth		shoot & root growth
32	Aug.6	bud set / leaf maintenance			root growth	bud set	shoot & root growth
33	Aug.13	bud set / leaf maintenance			root growth	bud set	shoot & root growth
34	Aug.20	bud set / leaf maintenance			root growth	bud set / leaf maintenance	
35	Aug.27	bud set / leaf maintenance			root growth	bud set / leaf maintenance	
36	Sep.3	senescence			root growth	leaf maintenance	
37	Sep.10	senescence			root growth	leaf maintenance	
38	Sep.17	senescence		bud set	root growth	senescence	
39	Sep.24	senescence / abscission		bud set	root growth	senescence	
40	Oct.1	abscission		bud set	root growth	senescence / abscission	
41	Oct.8	abscission		bud set	root growth	abscission	
42	Oct.15	dormant		dormant		dormant	
43	Oct.22	dormant		dormant		dormant	
44	Oct.29	dormant		dormant		dormant	
45-48	Nov.	dormant		dormant		dormant	
49-52	Dec.	dormant		dormant		dormant	

Table 7.3. Weekly flow requirements of riparian cottonwoods along the Oldman River at Lethbridge, AB. The growing season is shaded (after Gom, 2002).

Week	Date	**Mature Trees:**		**Saplings (> 1 year old)**		**Seedlings (< 1 year old)**	
		Survival & Maintenance	**Growth & Reproduction**	**Survival**	**Growth**	**Fringe Establishment (1 : 5-10 yr)**	**General Establishment (1 : 30-50 yr)**
1-5	Jan.	nat ave min		nat ave min		nat ave min	
6-9	Feb.	nat ave min		nat ave min		nat ave min	
10-13	Mar.	nat ave min		nat ave min		nat ave min	
14	Apr.2	nat ave min		nat ave min		nat ave min	
15	Apr.9	nat ave min		nat ave min		nat ave min	
16	Apr.16	40% nat wk ave	nat wk ave	60% nat wk ave	nat wk ave	nat wk ave	
17	Apr.23	40% nat wk ave	nat wk ave	60% nat wk ave	nat wk ave	nat wk ave	
18	Apr.30	40% nat wk ave	nat wk ave	60% nat wk ave	nat wk ave	nat wk ave	
19	May.7	40% nat wk ave	nat wk ave	60% nat wk ave	nat wk ave	nat wk ave	
20	May.14	40% nat wk ave	nat wk ave	60% nat wk ave	nat wk ave	nat wk ave	
21	May.21	40% nat wk ave	nat wk ave	60% nat wk ave	nat wk ave	nat wk ave	
22	May.28	40% nat wk ave	nat wk ave	60% nat wk ave	nat wk ave	1:10yr peak	1:30yr peak
23	Jun.4	40% nat wk ave	nat wk ave	60% nat wk ave	nat wk ave	1:10yr peak	1:30yr peak
24	Jun.11	40% nat wk ave	nat wk ave	60% nat wk ave	nat wk ave	1:10yr peak	1:30yr peak
25	Jun.18	40% nat wk ave	nat wk ave	60% nat wk ave	nat wk ave	- 2.5 cm/day to nat wk ave	
26	Jun.25	40% nat wk ave	nat wk ave	60% nat wk ave	nat wk ave	- 2.5 cm/day to nat wk ave	
27	Jul.2	40% nat wk ave	nat wk ave	60% nat wk ave	nat wk ave	- 2.5 cm/day to nat wk ave	
28	Jul.9	40% nat wk ave	nat wk ave	60% nat wk ave	nat wk ave	- 2.5 cm/day to nat wk ave	
29	Jul.16	40% nat wk ave	nat wk ave	60% nat wk ave	nat wk ave	- 2.5 cm/day to nat wk ave	
30	Jul.23	40% nat wk ave	nat wk ave	60% nat wk ave	nat wk ave	- 2.5 cm/day to nat wk ave	
31	Jul.30	40% nat wk ave	nat wk ave	60% nat wk ave	nat wk ave	- 2.5 cm/day to nat wk ave	
32	Aug.6	40% nat wk ave	nat wk ave	60% nat wk ave	nat wk ave	- 2.5 cm/day to nat wk ave	
33	Aug.13	40% nat wk ave	nat wk ave	60% nat wk ave	nat wk ave	- 2.5 cm/day to nat wk ave	
34	Aug.20	40% nat wk ave	nat wk ave	60% nat wk ave	nat wk ave	- 2.5 cm/day to nat wk ave	
35	Aug.27	40% nat wk ave	nat wk ave	60% nat wk ave	nat wk ave	- 2.5 cm/day to nat wk ave	
36	Sep.3	nat ave min		60% nat wk ave	nat wk ave	- 2.5 cm/day to nat wk ave	
37	Sep.10	nat ave min		60% nat wk ave	nat wk ave	- 2.5 cm/day to nat wk ave	
38	Sep.17	nat ave min		nat ave min		nat ave min	
39	Sep.24	nat ave min		nat ave min		nat ave min	
40	Oct.1	nat ave min		nat ave min		nat ave min	
41	Oct.8	nat ave min		nat ave min		nat ave min	
42	Oct.15	nat ave min		nat ave min		nat ave min	
43	Oct.22	nat ave min		nat ave min		nat ave min	
44	Oct.29	nat ave min		nat ave min		nat ave min	
45-48	Nov.	nat ave min		nat ave min		nat ave min	
49-52	Dec.	nat ave min		nat ave min		nat ave min	

Notes: nat wk ave = natural weekly average flow, nat ave min = natural weekly average minimum flow.

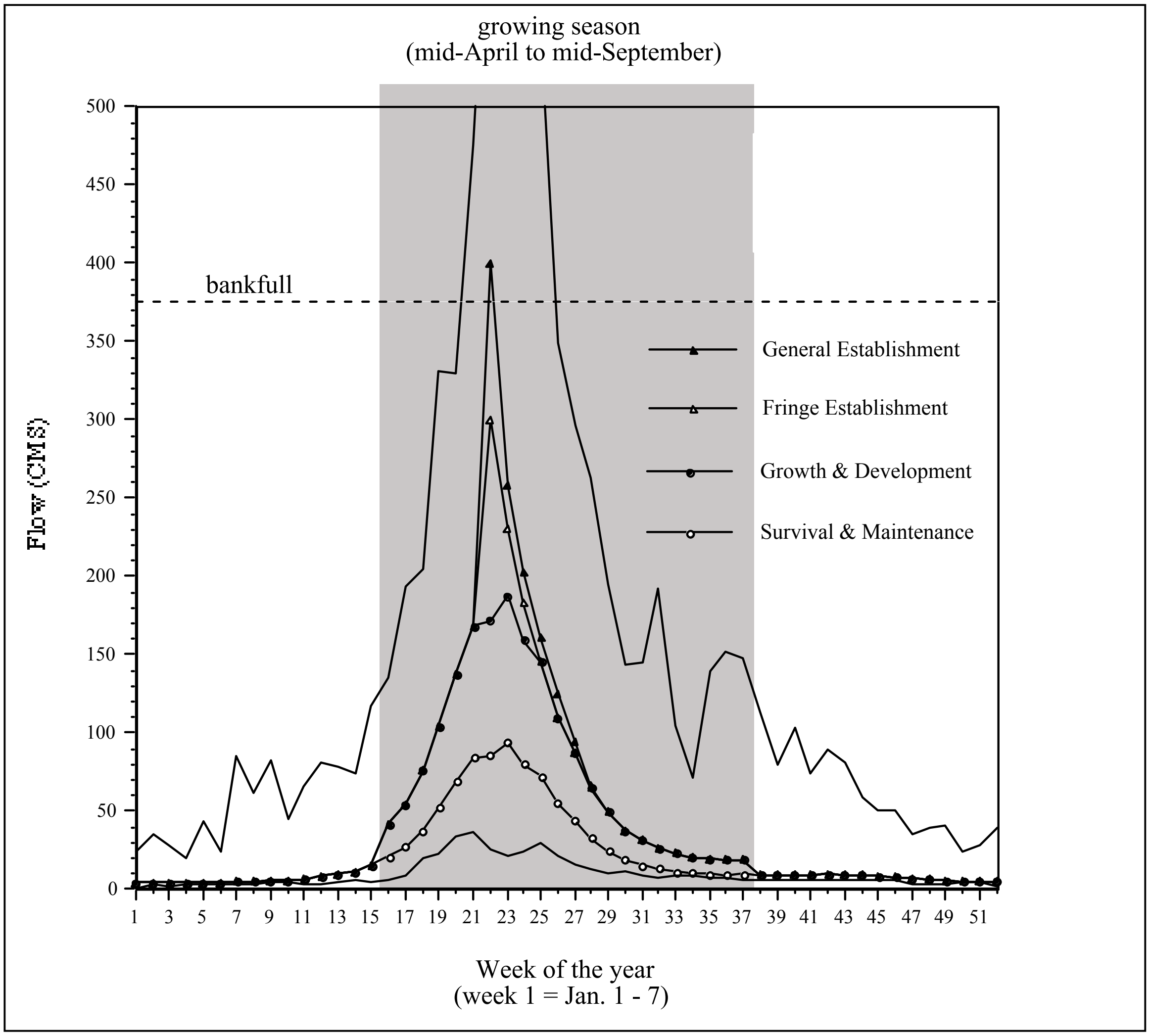


Figure 7.2. Generalized flows required by cottonwoods along the Oldman River near Fort Macleod. Flows required for growth and development consist of natural weekly average flows. Flows for survival and maintenance are 50% of the natural weekly average. Flows for fringe seedling establishment consist of a 1:10 year peak flow during the period of seed release, followed by a 2.5 cm/day rate of river stage decline. Flows for general seedling establishment include a 1:30 year peak flow followed by a 2.5 cm/day rate of river stage decline. The natural ranges of weekly minimum and maximum flows (from 1912 to 1995) are indicated as solid lines without symbols.

Where available, the annual record of natural flow can be used to estimate the degree of variability expected to occur naturally. The longer the historic record of flow, the more accurate this estimate will be. Using a weekly interval, flow variability can be described as the probability of occurrence of a particular flow and can be depicted on an exceedence curve (Figure 7.3). Each point on the exceedence curve corresponds with the flow observed during the same week (week 22 in Fig. 7.3) of each year during the period of record, in this case 1912 to 1995. Thus, a flow of 225 m^3/s corresponds with an exceedence of 20%, meaning that in 20% of years, flows of this magnitude or greater have been recorded along the Oldman River at Lethbridge during week 22 (Fig 7.3). The frequency probability of any given point can be calculated by inverting the exceedence value to produce the return interval (RI). Thus, the flow of 225 m^3/s, that has an exceedence of 20%, equates with a RI of 5. This means that on average, this magnitude of flow has been met or exceeded once every 5 years. Likewise, it may be expected that 100% exceedence flows will be exceeded every year, and 1% exceedence flows may be expected to recur less frequently than once in 100 years.

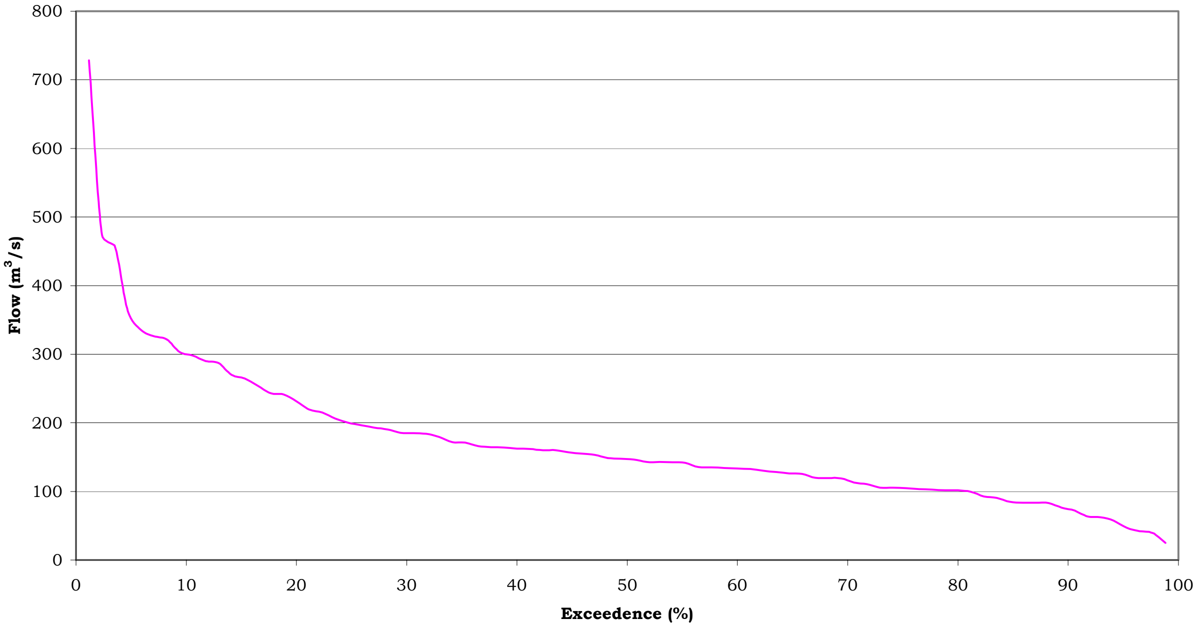


Figure 7.3. Exceedence curve for naturalized streamflows along the Oldman River near Fort Macleod during week 22 (May 28 - June 3), 1912-1995.

If streamflow was regulated each year to meet one of the four general flow requirements for cottonwoods described in Section 7.4 and shown in Figure 7.2, up to four distinct, artificial ‘steps’ would be created in each weekly exceedence curve (Figure 7.4). Although these steps may be based on meeting the basic flow requirements of cottonwoods they do not provide the continuum of flow variability that would be present in the natural system. (Where survival flows are met or exceeded every year, flows for growth are provided in 50% of years, and flows for seedling establishment are met in 10% of years.)

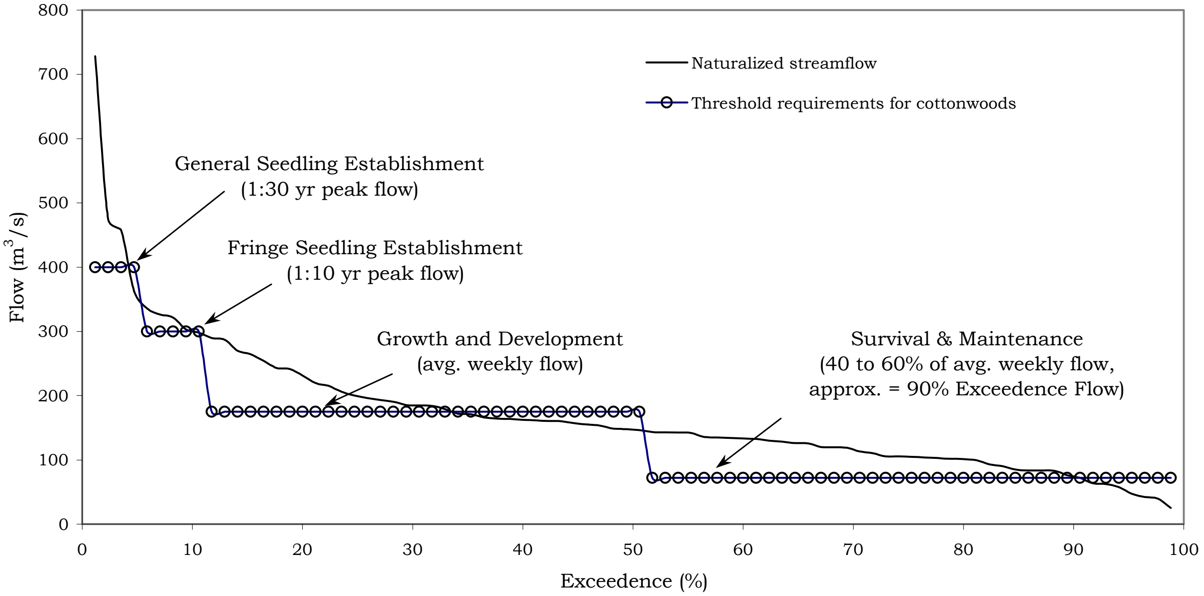


Figure 7.4. Threshold streamflow requirements for cottonwoods in relation to the exceedence curve for naturalized streamflow along the Oldman River near Fort Macleod during week 22 (May 28 - June 3), 1912-1995.

The goal of the PRC is to integrate the base, moderate, and high flow requirements of cottonwoods with a more natural pattern of flow variability. This will produce a more continuous exceedence curve that is somewhat flattened when compared with the exceedence curve for natural streamflow. Instead of depending solely on threshold flow values, the PRC is defined by a composite of three exceedence-based curves (Figure 7.5) and bankfull discharge. Each of these four components defines a portion of the overall PRC (Figure 7.6) for any given week of the year according to certain criteria (Table 7.4).

The first curve included in the PRC defines the base streamflow required for long-term cottonwood survival and maintenance as the 90% exceedence flow. Flows at this level of exceedence approximate the minimum requirement for 40% of natural average weekly flow that is outlined in Table 7.3. Lower flows will occur naturally, but cottonwoods should be able to tolerate these extreme events as long as the frequency and/or duration of these events is not increased. Thus, natural flows with exceedences greater than 90% are not reduced or increased (Figure 7.5).

Moderate to high PRC flows are defined by the higher of either the 75% of naturalized flow curve, or that flow corresponding with a 50% increase in the RI (e.g. a flow that has naturally occurred once every 10 years, now occurs once every 15 years). In general, the 75% curve defines a moderate range of PRC flows and the 50% RI shift defines a higher range of PRC flows. Thus, these two curves form a gradual bridge that connects the minimum flow requirements for cottonwood survival with those for healthy tree growth and seedling establishment as described in Figure 7.5.

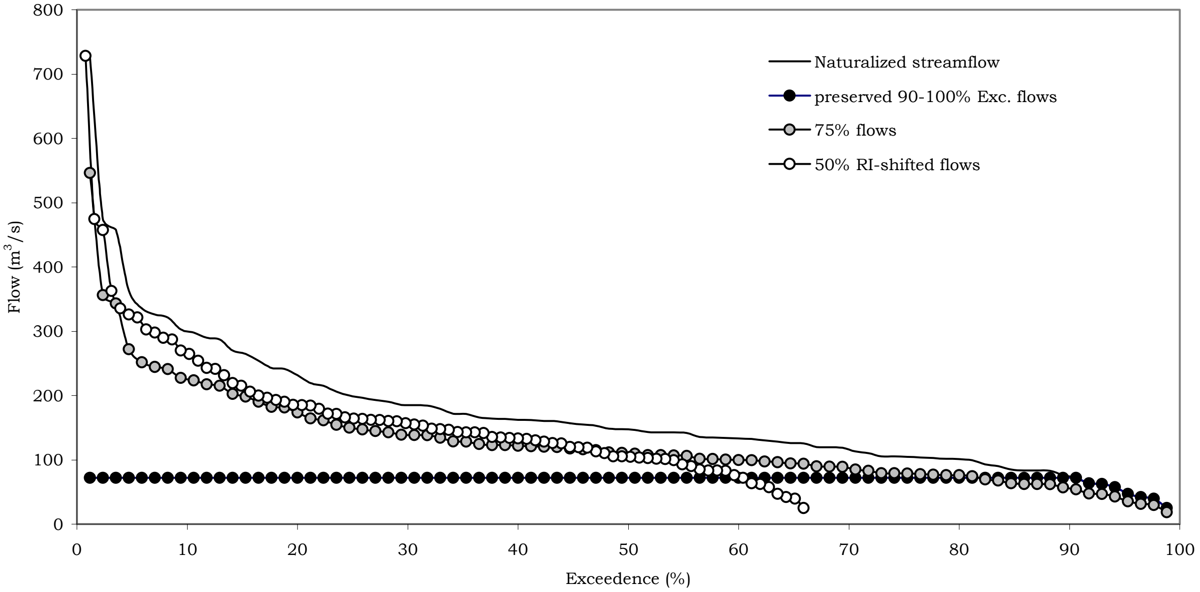


Figure 7.5. Three exceedence-based curves that each satisfy a portion of the streamflow requirements of cottonwoods along the Oldman River near Fort Macleod during week 22 (May 28 - June 3), 1912-1995.

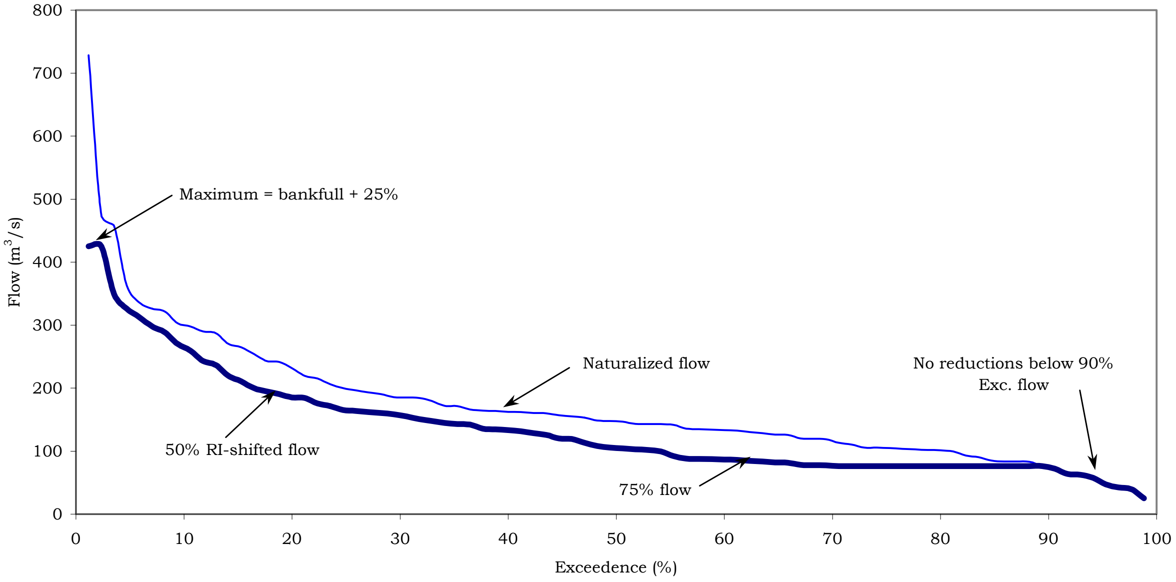


Figure 7.6. PRC for cottonwoods in relation to the exceedence curve for naturalized streamflow along the Oldman River near Fort Macleod during week 22 (May 28 - June 3), 1912-1995.

Table 7.4. Criteria for calculating PRC flows during a given week of the year.

Criteria:	**Condition:**	**PRC Flow:**
1. If natural flow exceedence	1a) >/= 90%	1a) **natural flow**
	1b) < 90%	*1b) (refer to criterion 2)*
2. If 75% of natural flow	2a) </= natural 90% exc. flow	2a) **natural 90% exc. flow**
	2b) > natural 90% exc. flow	*2b) (refer to criterion 3)*
3. If reduction to 75% of natural flow causes an RI increase of	3a) </= 50% of the natural RI	3a) **75% natural flow**
	3b) > 50% of the natural RI	*3b) (refer to criterion 4)*
4. If 75% of natural flow	4a) < 125% bankfull	4a) **flow corresponding to 50% increase of natural RI**
	4b) >/= 125% bankfull	*4b) 125% bankfull*

Finally, the maximum flow required by the PRC has been set at 125% of bankfull discharge. This threshold is slightly above bankfull to include flows that may be critical for maintaining the channel dynamics necessary to create nursery sites for poplar seedling establishment. Richter and Richter (2000) support the importance of flows at or above the 125% bankfull threshold for maintaining lateral channel migration. However, these flows may not be adequate, on their own, to provide all the functions required to maintain channel structure. More detailed analyses, including sediment transport, are carried out in Section 8.0. Figure 7.6 depicts the combined profile of the three curves and the maximum flows that have been integrated to form the final PRC curve for a given week along a particular reach.

The calculation of the PRC can be simplified into four rules (Table 7.4). These rules dictate that:

1. There be no reductions to flows with natural exceedences of 90% or greater;
2. Flows may not be reduced below the 90% exceedence level;
3. Reduction of up to 25% of naturalized flow is acceptable provided that the resulting RI shift is not greater than 50%; and
4. The maximum flow required is 125% of bankfull.

The PRC approach is designed to meet the flow requirements for cottonwood survival, growth and reproduction, within the context of a continuum of natural flow variability. To ensure both intra- and inter-annual variation are accommodated within a PRC recommendation, the PRC decision criteria are applied to weekly exceedence curves throughout the cottonwood growing season. A complete PRC recommendation is therefore comprised of a series of natural weekly exceedence curves adjusted according to the decision criteria described above.

7.6 Applying the PRC within the South Saskatchewan River Basin

The proposed PRC approach is based on information drawn from a variety of studies on many different stream systems. The weekly PRC is calibrated based on general flow requirements of riparian cottonwoods. These hydrological requirements need to be adjusted for application within the SSRB.

Streamflow regulation within the SSRB provides many examples of the effect a range of flow alterations has had on streamside forests. Of particular interest are the impacts of the different flow regimes of the St. Mary, Waterton, and Belly rivers in southern Alberta (Figure 7.7). Inventories of forest abundance upstream and downstream of major water management structures collected both pre- and post-regulation have been conducted along these rivers (Rood and Heinze-Milne 1989, Reid et al. 1992, Rood et al. 1995). Their analyses indicate that flow modification along the St. Mary River has contributed to severe declines in downstream cottonwood forests. In comparison, the flow regime imposed on the Waterton River is associated with more moderate declines of downstream cottonwoods, whereas regulation of the Belly River appears to have had little impact and may even have had a slightly favourable effect on its riparian forests. These three rivers provide an excellent opportunity to compare PRC flows with actual test cases.

Subsequent to adjustment of the proposed PRC to meet conditions on the Southern Tributaries of the Oldman River, it is expected that the details of the PRC rules will need to be revised slightly to address variability present along other reaches and sub-basins within the South Saskatchewan River Basin. This variability may relate to channel profiles and sediment characteristics, species present, or historic suitability of sites for forest establishment. Regardless of these final refinements, the PRC approach should preserve a natural range of variability to protect the dynamics and diversity present in these riparian ecosystems.

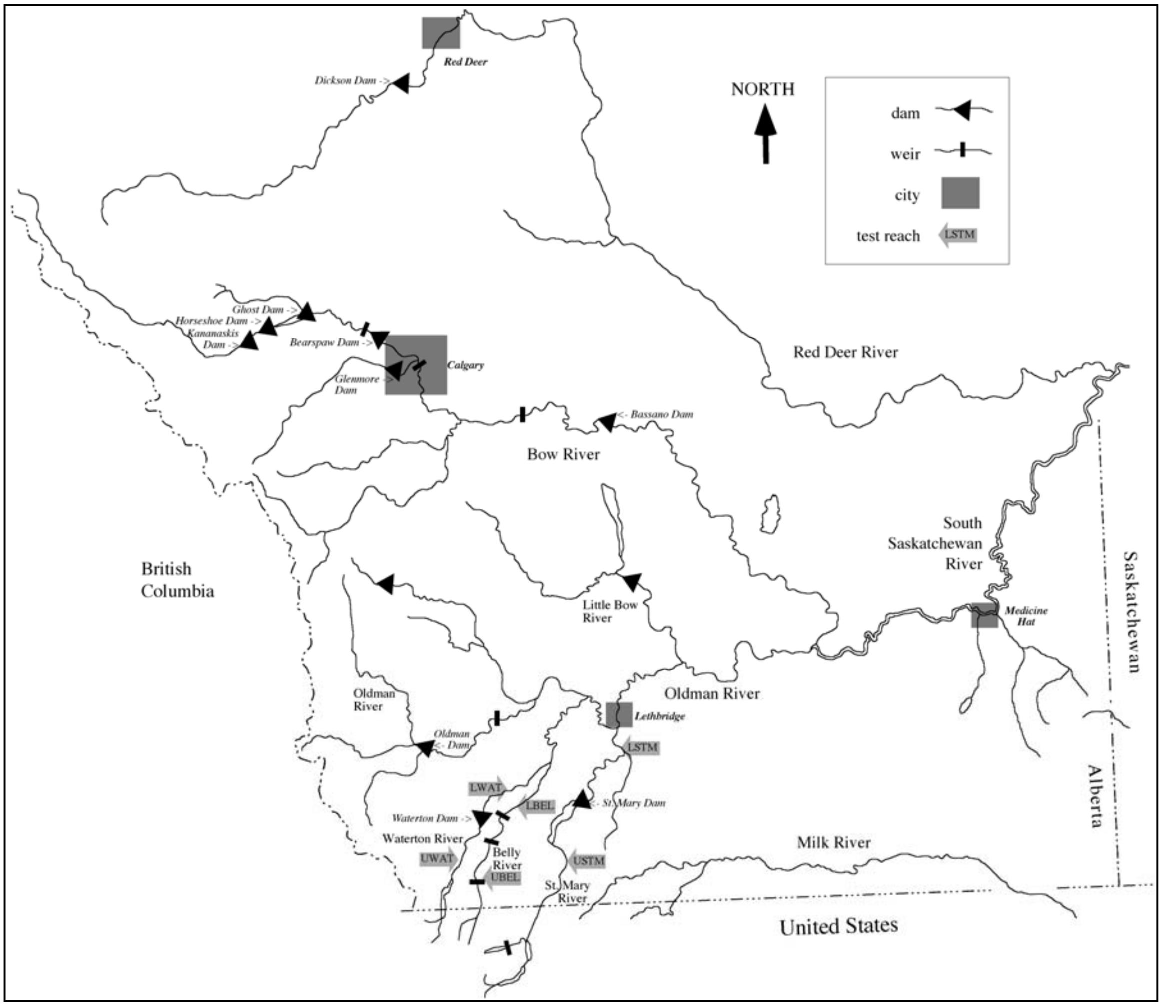


Figure 7.7. Major flow regulating structures and PRC calibration reaches in the SSRB (UWAT/LWAT = upper/lower Waterton River, UBEL/LBEL = upper/lower Belly River, USTM/LSTM = upper/lower St. Mary River).

7.6.1 Flow modifications that affect riparian cottonwoods

Many different flow regimes have been implemented along river reaches in the SSRB. Accordingly, the effects on riparian cottonwood forests have been varied. Careful analysis of these flow regimes and their effects identify trends that have been beneficial or detrimental to riparian cottonwoods. These findings were compared with the proposed PRC to evaluate its potential as a prescription to restore and maintain the long term health of riparian cottonwood forests downstream from flow regulating structures in the SSRB, and possibly within other regulated river basins.

Because riparian cottonwoods are adapted to natural patterns of streamflow, regulated flow regimes will affect downstream riparian cottonwoods in different ways depending on how flows have been altered from their natural condition. Depending on the extent of change to the magnitude, timing, frequency and duration of natural flow, the impact on downstream vegetation may vary from slight to severe and from temporary to permanent. Symptoms of acute stress due to sudden, extreme changes in streamflow tend to involve premature leaf senescence (yellowing), branch dieback, or tree death. The effects of more chronic stress due to gradual, long term changes in streamflow may not be evident for many years, and may involve reduced branch or radial growth, and diminished reproduction leading to widespread changes of population structure. Considering that a cottonwood's lifespan may exceed 100 years, symptoms measurable in less than 10 to 20 years indicate catastrophic impacts.

Reduced or prolonged low flows

Flow regulation in the SSRB may involve diverting a significant portion of natural streamflow offstream. The implication for riparian cottonwoods is greatest when diversion to meet water demands is high during periods of already naturally low streamflow.

Riparian cottonwoods are adapted to naturally occurring low flows. However, they may not be able to tolerate increased drought stress if the frequency or duration of low flows is increased. Additionally, if flows are reduced below natural minima, the occurrence of acute drought stress and tree mortality will be increased.

The extent and permanence of the damage caused to riparian cottonwood forests by drought stress tends to correlate with the severity and duration of the stress condition. Occasional, slight drought stress may cause no appreciable long term harm to these forests, because the trees have the opportunity to recover from slight setbacks in subsequent years. Forests exposed to more frequent or severe stress may suffer more widespread and long term consequences, including progressive forest deterioration and recruitment failure.

In addition to maintaining healthy cottonwood forests, preventing flow reductions below natural minima is also likely to encourage the recovery of drought-stressed and declining forests. The severity of the damage will largely determine the potential for recovery, but as long as living trees are present, protection of base flows will promote tree survival and associated forest recovery.

Increased low flows

If high flows are stored for more gradual release during drier periods, natural low flows will be supplemented. Initially, increases to low flows may enhance riparian cottonwood health, by reducing the incidence of drought stress and promoting survival of trees in otherwise marginal areas. Thus, permanent increases to low flows are likely to result in some degree of population expansion. However, long term changes to the extent of flow variability may also have negative consequences. During occasional periods of low flow, cottonwood roots are encouraged to grow deeper to access moisture. These deep roots tend to protect cottonwoods from drought stress during subsequent dry periods. This resiliency may be lost as root penetration is limited in response to the elevated water table provided by prolonged, supplemented low flows. Consequently, as their roots become shallower, cottonwoods may suffer increased drought stress by low flows that were previously tolerable.

In situations where riparian forests have become accustomed to elevated low flows, natural minima are no longer adequate for maintaining downstream cottonwoods. Abrupt reduction back to natural low flow levels could cause drought stress, especially to trees in areas of forest expansion facilitated by the elevated low flows. To limit drought stress for these forests, a higher minimum low flow needs to be maintained indefinitely. Alternatively, the forest may be restored to its natural state by gradually reintroducing natural flow variability over a period of several years. Consequently, areas of forest expansion may return to being only marginally suitable for cottonwoods, so some stress and decline might be expected in those areas.

Stabilized moderate flows

Flow regulation may involve the moderation of high and low flows, resulting in a more constant level of flow.

Moderated flow regimes do not accommodate the life strategy of cottonwoods, as these trees are adapted to naturally dynamic streamflows. Stabilized, moderate flows are likely to lead to the combined effects of decreased high flows and increased low flows. Stabilized streamflows tend to limit the elevational extent of the riparian forest above the water's surface as the cottonwood root systems become habituated to the stabilized water level. Consequently, the forest will become less resilient to drought stress caused by future low flows.

The dynamics of high and low streamflows also drive channel forming processes that involve the erosion and deposition of sediment. In contrast, stable moderate streamflows tend to cause channel stabilization as point and lateral bars become stagnant. As a result, sediments are not transported as regularly and vegetation tends to encroach to the water's edge. This gradual elimination of barren nursery sites for cottonwood seedling establishment will threaten the long term viability of the affected riparian forests. Seedlings that manage to establish under a stabilized streamflow regime may be prone to drought stress because root elongation that connects them to the water table during unusual periods of lower flows is not encouraged.

Prospects for the restoration of cottonwood forests affected by stabilized flow regimes are good. A full recovery could be expected in most cases where a natural range of flow variability was gradually reintroduced, allowing the forest to re-acclimatize over a period of years.

Reduced, delayed, or eliminated peak flows

Natural streamflow can be inadequate to satisfy human demand during dry periods, so flow regulating structures may be operated to compensate by storing water during wetter periods for release during dry periods. The resulting reduction or elimination of peak flows impacts riparian cottonwoods in various ways, depending on the degree and timing of flow modification.

An occasional reduction to peak flows is not likely to cause drought stress to cottonwoods, because these flows usually surpass the levels required to maintain healthy tree growth. If reduced flood flows fail to recharge the riparian water table, trees in higher, more marginal areas would have an increased risk of drought stress. However, an occasional peak flow reduction may promote the health of trees at lower elevations by lessening the scouring effects associated with flood flows.

Frequent reduction, delay, or complete elimination of peak flows is detrimental to the long-term health of riparian cottonwood forests. Natural flood flows drive channel processes involving erosion and deposition that prepare nursery sites required for successful seedling recruitment. The natural magnitude and timing of flood flows encourage establishment of seedlings higher on streambanks, thereby lessening the chances they will be washed away or buried during subsequent, moderate streamflows. Thus, modifications to peak flows may disrupt the frequency and pattern of natural cottonwood reproduction, resulting in reduced long-term viability of the affected riparian forests.

To remedy situations where peak flow modifications have already impacted cottonwood forest seedling regeneration, natural peak flows can be reintroduced. Provided an adequate seed source is still available, the natural frequency and occurrence of cottonwood seedling recruitment will be restored immediately. Forests that are exhibiting accelerated declines may need greater than natural rates of recruitment to expedite recovery.

Abrupt changes and pulsed flows

Riparian cottonwoods are adapted to the natural patterns of streamflow variability. Artificial changes in the rate of change of flows can have many effects on downstream forests. Changes that affect cottonwoods include abrupt flow increases or decreases and flow pulsing. The effects of these changes depend on their magnitude, duration, frequency, and timing relative to the pattern of natural streamflows.

Artificially rapid flow declines can lead to cottonwood drought stress. This may occur if the water table is reduced below the effective rooting zone too rapidly for root growth to keep pace. Young seedlings are most susceptible to this disturbance because their roots are not deeply established. However, saplings and even mature trees may become stressed if flow declines are severe. Cottonwoods may become increasingly less stress resilient if root elongation is not encouraged by gradual water table declines.

The destabilizing effect of repeated bank de-watering and re-watering can lead to increased erosion and channel incision. Susceptibility to such deterioration, due to changes in river stage, increases with stream gradient and progressively finer-textured substrates. Excessive bank erosion can perpetually reset the cottonwood seedling establishment process and accelerate the removal of saplings and established trees. In addition to the effects of horizontal streambank erosion, vertical downcutting or incision of the channel can lower the riparian water table. This can cause stress or die-back to trees in drier, higher areas, and result in narrowing of the forested riparian zone.

The regular, daily pulsing of flows characteristically produced downstream from hydropower generating facilities can produce artifacts in channel geomorphology and associated riparian forests. For example, repeated pulses of similar magnitude will tend to cause erosion and deposition on a limited portion of the floodplain. This may lead to artificially structured streambanks that are either more or less stable than the natural state. Consequently, this will influence the availability and location of barren sediments necessary for cottonwood seedling establishment.

The severity and permanence of impacts resulting from abrupt flow changes or repeated flow pulsing can be highly variable. The prognosis for restoration is similarly variable. While riparian cottonwoods are able to re-colonize areas relatively quickly, (within years or decades) when suitable conditions are restored, degradation of channel geomorphology tends to be a more permanent impact lasting decades or centuries. In most cases, the more severe the impact, the longer the period required for recovery.

7.6.2 PRC flows for test reaches in the Oldman River Basin

Six reaches of the Southern Tributaries of the Oldman River were analyzed. Two test reaches were defined along each of the Belly, Waterton, and St. Mary rivers in the Oldman River Basin. These included an upstream and downstream reach relative to the Belly River diversion weir, the Waterton Dam, and the St. Mary River Dam (Figure 7.7). The upstream and downstream reaches are also referred to as upper and lower respectively, and have been abbreviated throughout these discussions as UBEL and LBEL, UWAT and LWAT, and USTM and LSTM (upper and lower Belly, Waterton, and St. Mary rivers, respectively). The approximate location of each test reach is indicated in Figure 7.7.

All available actual (recorded) and naturalized (reconstructed) weekly streamflows, (generally during the period from 1912 though 1995,) were acquired for each test reach from Alberta Environment (2001b). Descriptions of how naturalized flows were reconstructed are found in

Alberta Environmental Protection (1998). The station locations and the types and periods of flow records used for each reach are summarized in Table 7.5. The weekly 125% bankfull flow for each test reach was estimated based on historic weekly flows during weeks when an instantaneous flow of 125% bankfull magnitude (Table 7.5) occurred at least once. Bankfull values for each reach were provided by Alberta Environment, Water Management Operations, Lethbridge.

Table 7.5. Weekly and bankfull flows used to calculate the PRC along test reaches in the Oldman River Basin (* indicates that flows for several weeks of that year are not available).

Reach	Station	Location	Weekly flow record available		Instantaneous 125% Bankfull (m^3/s)	Weekly 125% Bankfull (m^3/s)
			natural (estimate)	actual (recorded)		
UBEL	05AD005	Mountain View	1912-95	1912-95		50
LBEL	05AD002	Standoff	1912-95	1912-31*, 1949-85*	100	65
	05AD041	Glenwood		1986*-95		
UWAT	05AD003	Waterton Park	1912-95	1912-31*, 1948-95	180	117
LWAT	05AD008	Standoff	1912-95	1916-31*, 1935-66	205	175
	05AD028	Glenwood		1965-95		
USTM	05AE027	US/Canada border	1912-95	1912-95		140
LSTM	05AE006	Lethbridge	1912-95	1912-95	200	180

Abbreviations: UBEL = upper Belly River, LBEL = lower Belly River, UWAT = upper Waterton River, LWAT = lower Waterton River, USTM = upper St. Mary River, LSTM = lower St. Mary River.

Weekly PRC flows were calculated for each of the six test reaches using the available records of naturalized flows and the five criteria outlined in Figure 7.8.

The PRC flow was calculated for each weekly naturalized flow in the 1912-1995 dataset, using a series of logical decisions. If the exceedence of the naturalized flow was less than 90%, the lesser of naturalized flow or 125% bankfull flow was prescribed for the PRC. If both 65% of the naturalized flow and the 50% return interval-shifted flow were less than the naturalized 90% exceedence flow, the formula prescribed the lesser of naturalized 90% exceedence flow or 125% bankfull flow. Otherwise, the PRC was prescribed as the greater of 65% naturalized flow or the 50% return interval-shifted flow, to a maximum of 125% bankfull flow.

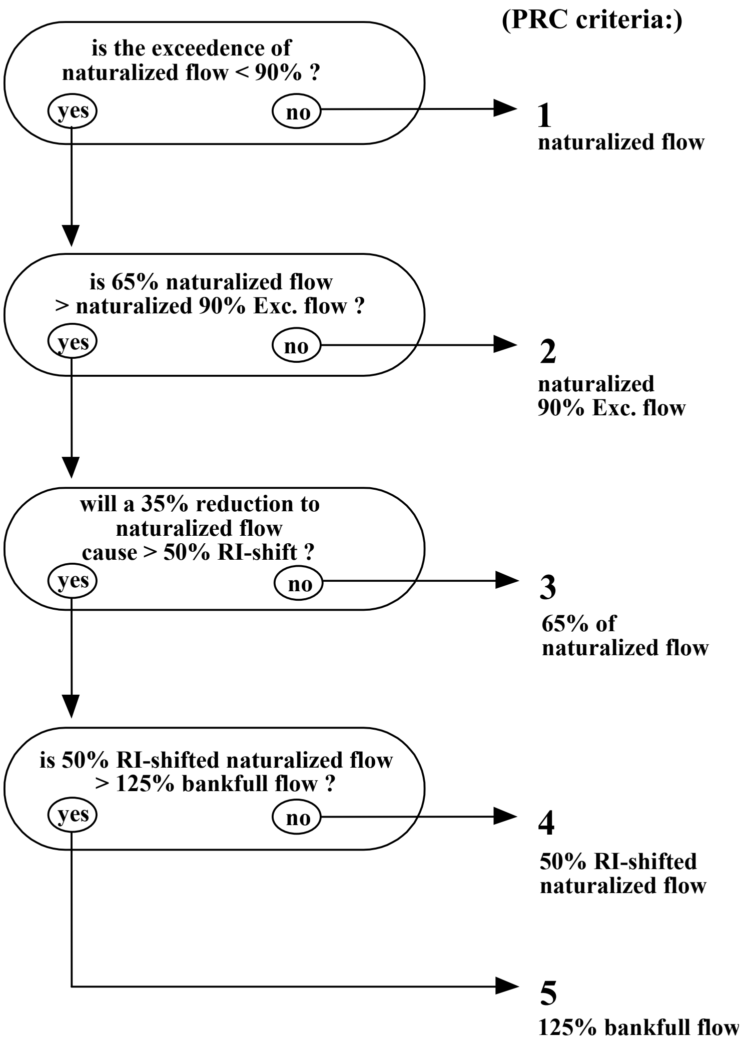


Figure 7.8. Flow-chart of criteria-based decisions for calculating PRC flows.

Evaluating PRC flows along test reaches

To estimate the potential long-term effect of a PRC based flow regime on riparian cottonwoods, the calculated PRC flows were compared with actual regulated flow regimes that have had known impacts on associated riparian poplar forests.

It should be noted that although the St. Mary River Dam has operated somewhat longer than the Waterton Dam, the St. Mary River Dam has still only influenced approximately the last half of the flow record represented (since 1951). For this reason, the severity of modifications to natural flow exceedences have probably been underestimated in representations featuring the full period of record (1912-1995).

Suitability of PRC flows along the Belly River

Selected annual weekly hydrographs comparing actual and PRC flows along upper and lower portions of the Belly River are provided in Figure 7.9. Similar depictions of natural versus actual flows are provided in Figure 7.10.

The regulated flow regime along the Belly River has not had strongly negative effects on downstream riparian woodlands (section 3.6.2). However, there has been an increased incidence of chronic drought stress symptoms in forests downstream from the Belly River Diversion Weir (Reid et al. 1992). Because increased frequency and duration of low flows are the most likely cause, further reductions to low flows should be avoided. Otherwise, the pattern of flow regulation downstream from the BRDW appears to be adequate for sustaining downstream riparian cottonwood forests in this context.

The flow regime along the lower portion of the Belly River that would have resulted if PRC flows were implemented during the period of record differ in two main ways from the flows that were actually recorded during the same period. Firstly, the PRC would permit greater reductions to extremely high flows than actually occurred. The affected peak flows have natural exceedences of less than about 5% (>1:20 year recurrence interval), and would equate with over-bank flooding. Considering the magnitude and infrequency of these extreme events, these high flows probably exceed the basic moisture requirements for keeping established cottonwood trees healthy. Instead, as described in Section 8.3, extremely high flows may be necessary for driving the geomorphic processes that set the stage for episodic, widespread cottonwood seedling recruitment events. In theory, the PRC's threshold peak flow of 125% bankfull discharge (Table 7.6) seems a reasonable limit for high flow events. It should allow some over-bank flooding to continue to occur at a natural frequency that would preserve processes key to seedling recruitment. However, the stage relationships of bankfull and 125% bankfull discharge must be verified in the field to fully evaluate the implications of completely eliminating peak flows beyond this threshold.

The second main difference between the actual flow and the PRC flow regimes along the Belly River is that the actual flows feature greater reductions to extremely low flows (85-100% exceedence) than the PRC. Although this difference seems subtle, comparisons of annual hydrographs particularly during low flow years, show that the PRC's protection of minimum flows is important for preventing extended periods of extremely low flow, as occurred during 1977 (Figure 7.9 and 7.10). Following the PRC would not prevent extremely low flows, but rather would simulate the natural frequency, magnitude and duration of low flow periods. In this way, the PRC's protection of minimum flows would reduce the occurrence of chronic drought stress reported downstream from the BRDW.

Historically, there has been very minor flow modification upstream from the BRDW (Figure 7.10). Riparian cottonwood forests in this reach are considered to be in relatively pristine condition. Implementation of PRC flows along this reach would result in the same types of flow modifications as downstream, except at lesser magnitudes proportional to the naturally smaller volumes of flow (Figure 7.9). The similarity in the contexts between upstream and downstream forests, suggest their moisture requirements would be essentially the same. Therefore, PRC flows should be acceptable for sustaining riparian cottonwoods along the Belly River as a whole. However, in reducing natural flow variability, the PRC flow regime is likely to result in a minor degree of reduced diversity in the floodplain landscape over a long period of time.

Table 7.6. Average naturalized flow exceedences of 125% bankfull flow for each test reach during peak flow weeks (Julian weeks 21-27).

Test Reach:	Weekly 125% Bankfull Flow (m^3/s)	Average Naturalized Weekly Exceedence of 125% Bankfull Flow
UBEL	50	6.4 %
LBEL	65	2.8 %
UWAT	117	7.2 %
LWAT	175	4.0 %
USTM	140	6.4 %
LSTM	180	2.6 %

Abbreviations: UBEL = upper Belly River, LBEL = lower Belly River, UWAT = upper Waterton River, LWAT = lower Waterton River, USTM = upper St. Mary River, LSTM = lower St. Mary River

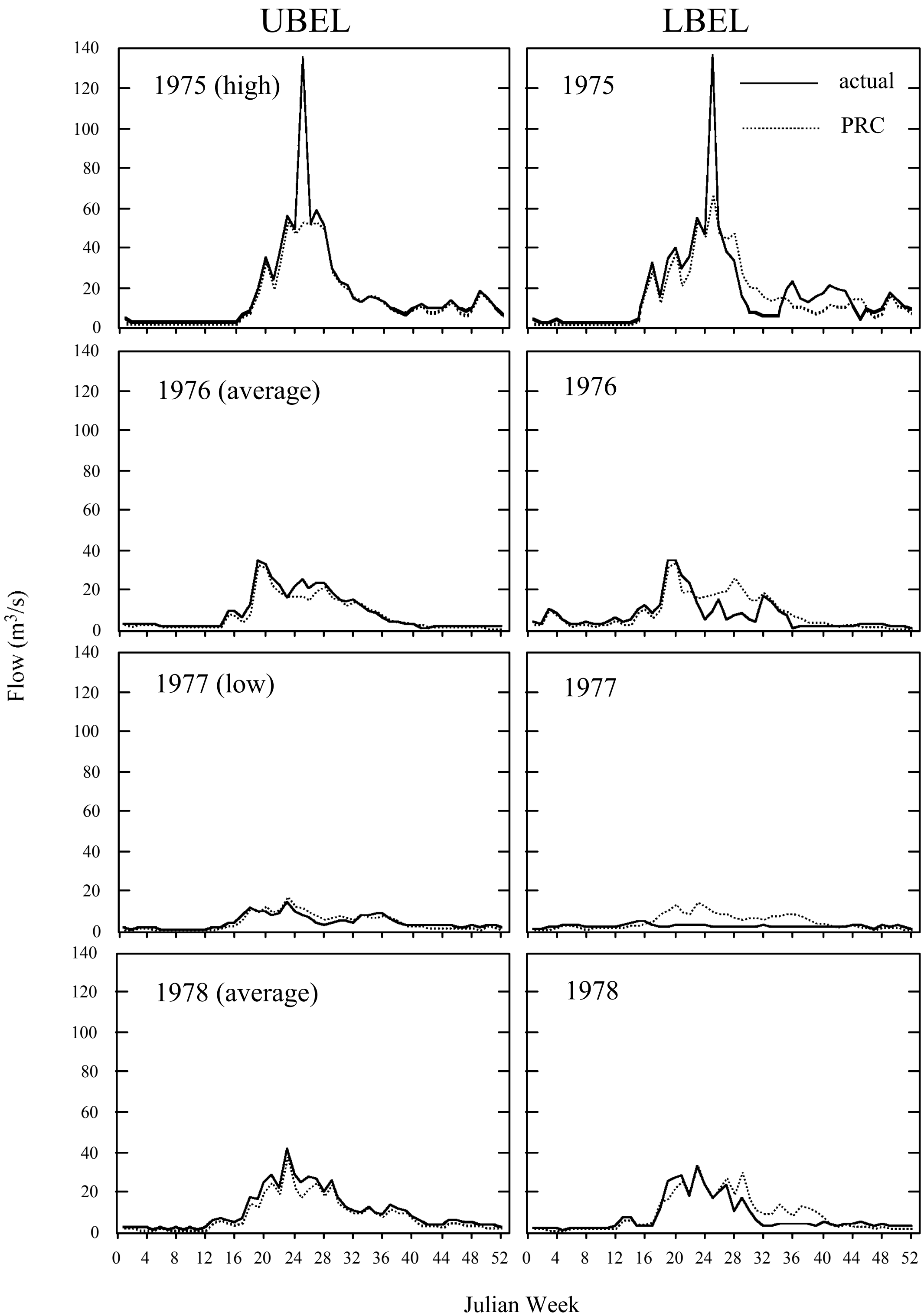


Figure 7.9. Actual and PRC weekly flows during a high flow year (1975), a low flow year (1977), and two average flow years (1976 & 1978) along the upper (left) and lower (right) reaches of the Belly River (at Mountain View and Standoff respectively).

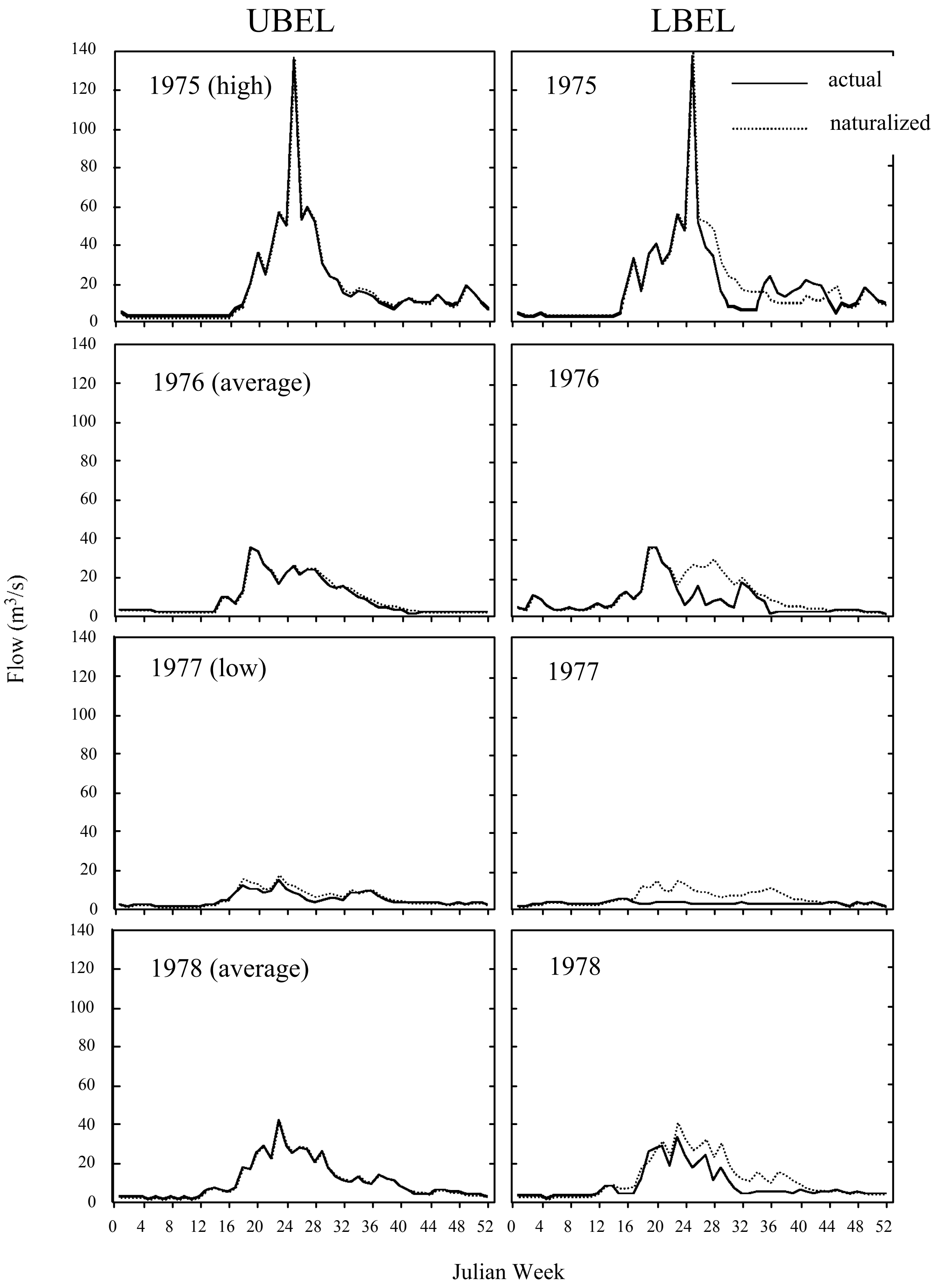


Figure 7.10. Naturalized and actual weekly flows during a high flow year (1975), a low flow year (1977), and two average flow years (1976 & 1978) along the upper (left) and lower (right) reaches of the Belly River (at Mountain View and Standoff respectively).

Suitability of PRC flows along the Waterton River

Selected annual weekly hydrographs comparing actual and PRC flows along upper and lower portions of the Waterton River are provided in Figure 7.11. Similar depictions of natural and actual flows are shown in Figure 7.12.

The regulated flow regime generated by the Waterton Dam has had measurable negative impacts on downstream riparian forests (detailed in Section 3.6.2). Symptoms of these impacts include acute and chronic drought stress, reductions to the mature canopy, and conditions detrimental to seedling recruitment. Regime modifications associated with these impacts include inadequate flows during the growing season, depressed natural low flows, and abrupt reductions following annual peak flows.

The pattern of flow that would have resulted if the PRC had been implemented along lower portions of the Waterton River from 1912 to 1995 differs in several ways from the actual regime that occurred during this period. As was the case along the Belly River, the PRC permits large reductions to extremely high flows (1975 in Figure 7.11). The PRC's upper flow limit of 125% bankfull discharge equates to flows with natural exceedences of generally less than 5% (Table 7.6). As was the case for the Belly River, the long-term geomorphological consequences of eliminating flows beyond the 125% bankfull magnitude need to be more fully investigated. The PRC would permit peaks somewhat greater than bankfull discharge to occur at relatively natural frequencies and would enable more gradual declines following these peak annual flows than has occurred historically (Figure 7.11). If delivered properly on a daily time-step, this modified pattern of flow should still be sufficient to recharge the riparian water table and promote the 'fringe' recruitment of cottonwood seedlings (producing narrow bands of seedlings that parallel the channel at a common stream-stage elevation).

With respect to improving the status of riparian cottonwood forests below the Waterton Dam, the most important difference between PRC and actual historic flow regimes along the Waterton River relates to natural low flows (90-100% exceedence). The actual reductions made to these natural low flows exceed amounts prescribed by the PRC. It should be remembered that the Waterton Dam has been in operation since 1964, and so has only influenced the latter 40% of the flow-record analyzed (1912-1995). Although a larger than average proportion of low flow years have occurred since 1964, the operation of Waterton Dam has caused very large reductions to already naturally low flows (Figure 7.12). By preventing reductions to already naturally low flows in the 90 to 100% exceedence range, implementation of PRC flows would have reduced the acute and chronic drought stress that is presently widespread downstream from the Waterton Dam (section 3.6.2).

The flow regime upstream from the Waterton Dam has remained relatively unaltered from its natural state (Figure 7.12). Flow reductions prescribed by the PRC (Figure 7.11) would produce PRC flows similar to those downstream from the Dam, except that they would be proportional to the smaller magnitude of natural flows along the upstream reach. Because the physical context of the floodplain and the distribution of riparian forests above and below the dam are similar, the PRC flow regime is expected to be suitable for sustaining cottonwoods along the Waterton River as a whole. However, PRC associated reductions to natural flow variability could result in a slightly reduced diversity in the floodplain landscape over a long period of time.

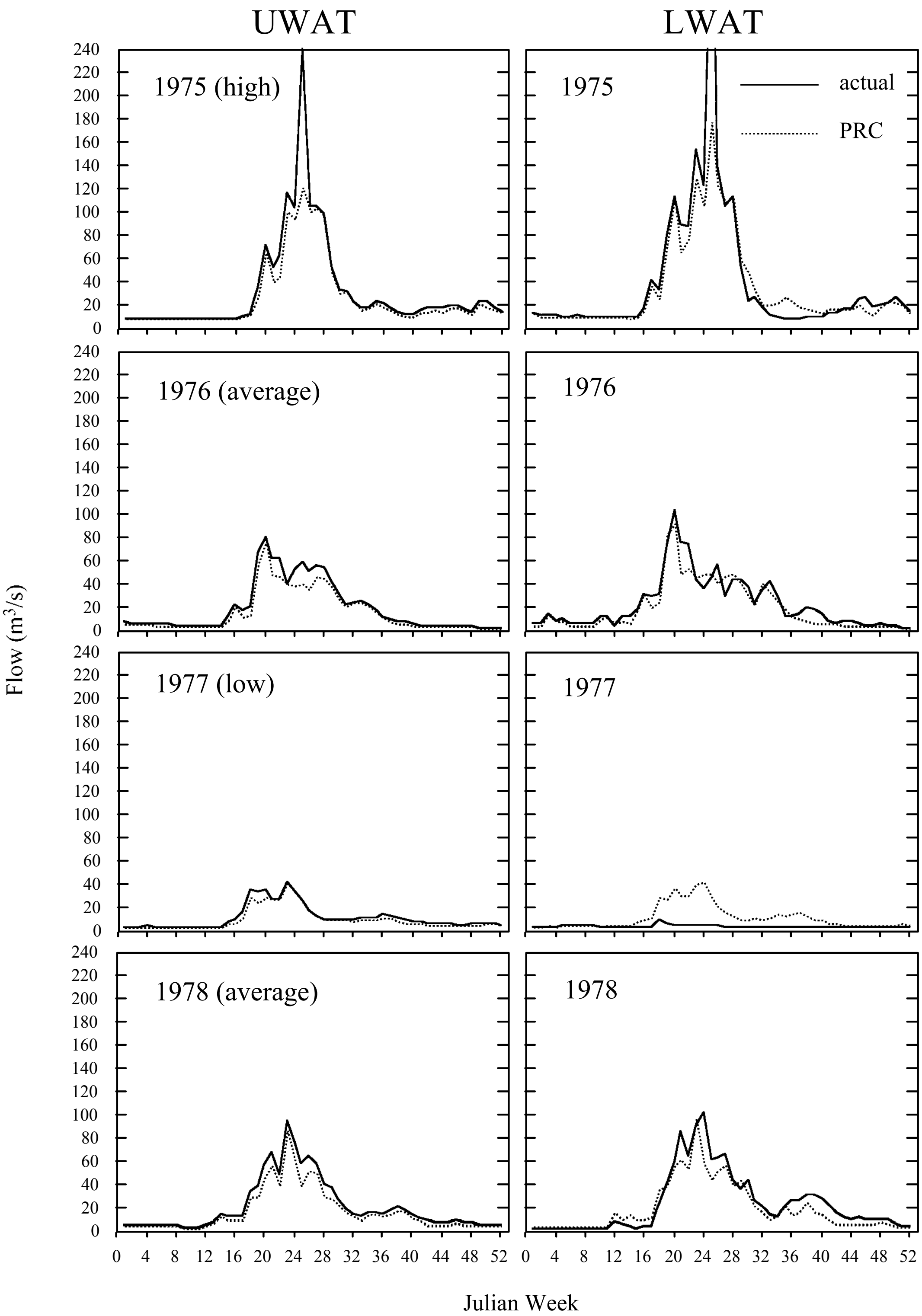


Figure 7.11. Actual and PRC weekly flows during a high flow year (1975), a low flow year (1977), and two average flow years (1976 & 1978) along the upper (left) and lower (right) reaches of the Waterton River (at Waterton Park and Glenwood respectively).

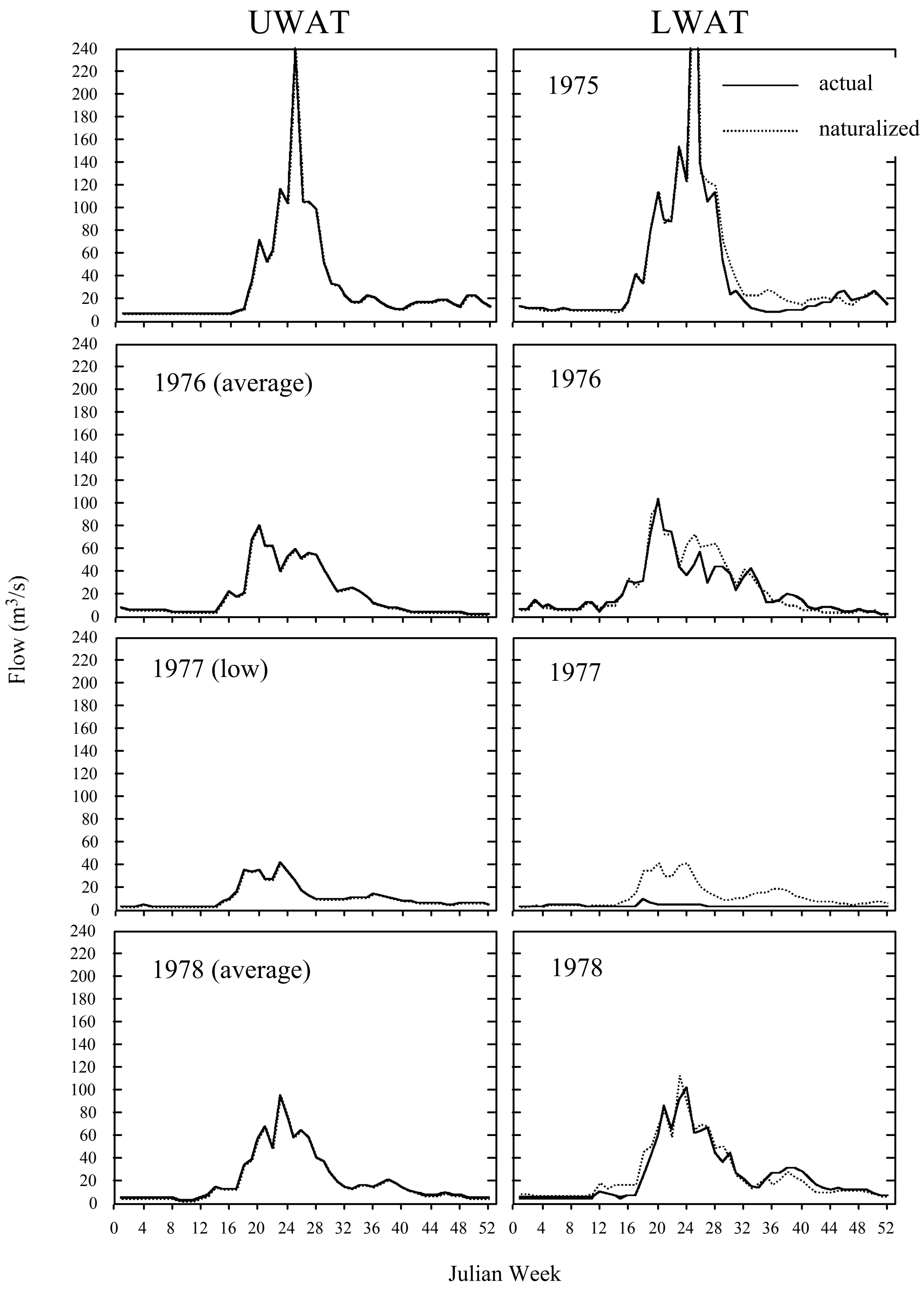


Figure 7.12. Naturalized and actual weekly flows during a high flow year (1975), a low flow year (1977), and two average flow years (1976 & 1978) along the upper (left) and lower (right) reaches of the Waterton River (at Waterton Park and Glenwood respectively).

Suitability of PRC flows along the St. Mary River

Selected annual weekly hydrographs comparing actual and PRC flows along upper and lower portions of the St. Mary River are provided in Figure 7.13. Similar depictions of natural and actual flows are shown in Figure 7.14.

The regulated flow regime downstream from the St. Mary River Dam has been associated with the near collapse of its associated cottonwood population (section 3.6.2). Symptoms include signs of acute and chronic drought stress, significant reductions in forest abundance, and the failure of seedling recruitment. Flow regime modifications implicated by these impacts include inadequate flows during the growing season, depressed naturally low flows, abrupt reductions following annual peak flows, and altered timing of high flow events.

If the PRC had been implemented along the St. Mary River from 1912 through 1995, the resulting flow regime would differ substantially from that which actually occurred. In general, the PRC would have permitted greater reductions to extremely high peak flows, less severe reductions to moderate flows, and no reductions to extremely low flows. Additionally, because the PRC is based on natural flow exceedences, it would have incorporated a more natural seasonal pattern of high and low flows than actually occurred (Figures 7.13 and 7.14).

The elimination of flows greater than 125% bankfull discharge affects peak flows with exceedences of less than about 5% (Table 7.6). These extremely high flows surpass the magnitude necessary for recharging the riparian water table and creating nursery sites for cottonwood seedling establishment. However, less direct effects of extreme peak flows may involve the geomorphic complexity of the floodplain landscape by influencing rates of channel migration or sediment transport. The long-term consequences of eliminating flows beyond 125% bankfull magnitude need to be more fully investigated.

The PRC would allow high flows that were reduced to 125% bankfull to occur at relatively natural frequencies and would provide more gradual declines following these peak annual flows than has occurred historically (Figure 7.13). If delivered properly, this pattern of flow should be sufficient to recharge the riparian water table and provide adequate flow to promote seedling recruitment. While high to moderate flows are important for seedling establishment, the subsequent rate of flow decline is also essential to ensure seedling survival. Recent efforts to produce gradual rates of decline following peak flows, by careful management of daily operations, have been successful in promoting initial seedling establishment along the lower portion of the St. Mary River (Rood and Mahoney 2000).

Compared with the actual flow regimes recorded along the upper and lower portions of the St. Mary River, the flow regime created by the PRC would be considerably more favourable to sustaining healthy riparian cottonwood forests. In particular, flow reductions permitted by the PRC would be less severe, and their timing and frequency across flow magnitudes would follow a more natural pattern of flow (Figures 7.13, 7.14).

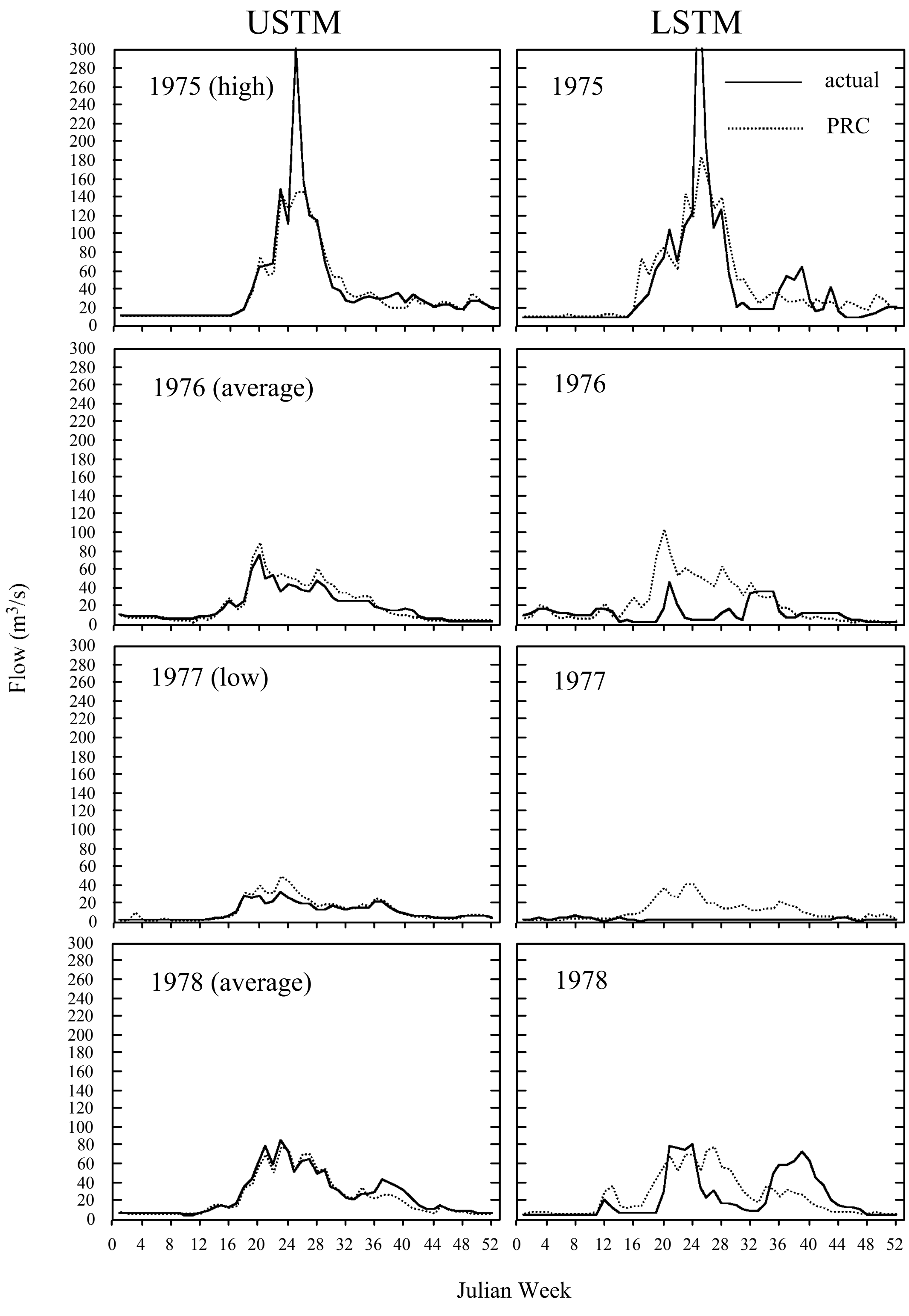


Figure 7.13. Actual and PRC weekly flows during a high flow year (1975), a low flow year (1977), and two average flow years (1976 & 1978) along the upper (left) and lower (right) reaches of the St. Mary River (at the US/Canada border and Lethbridge respectively).

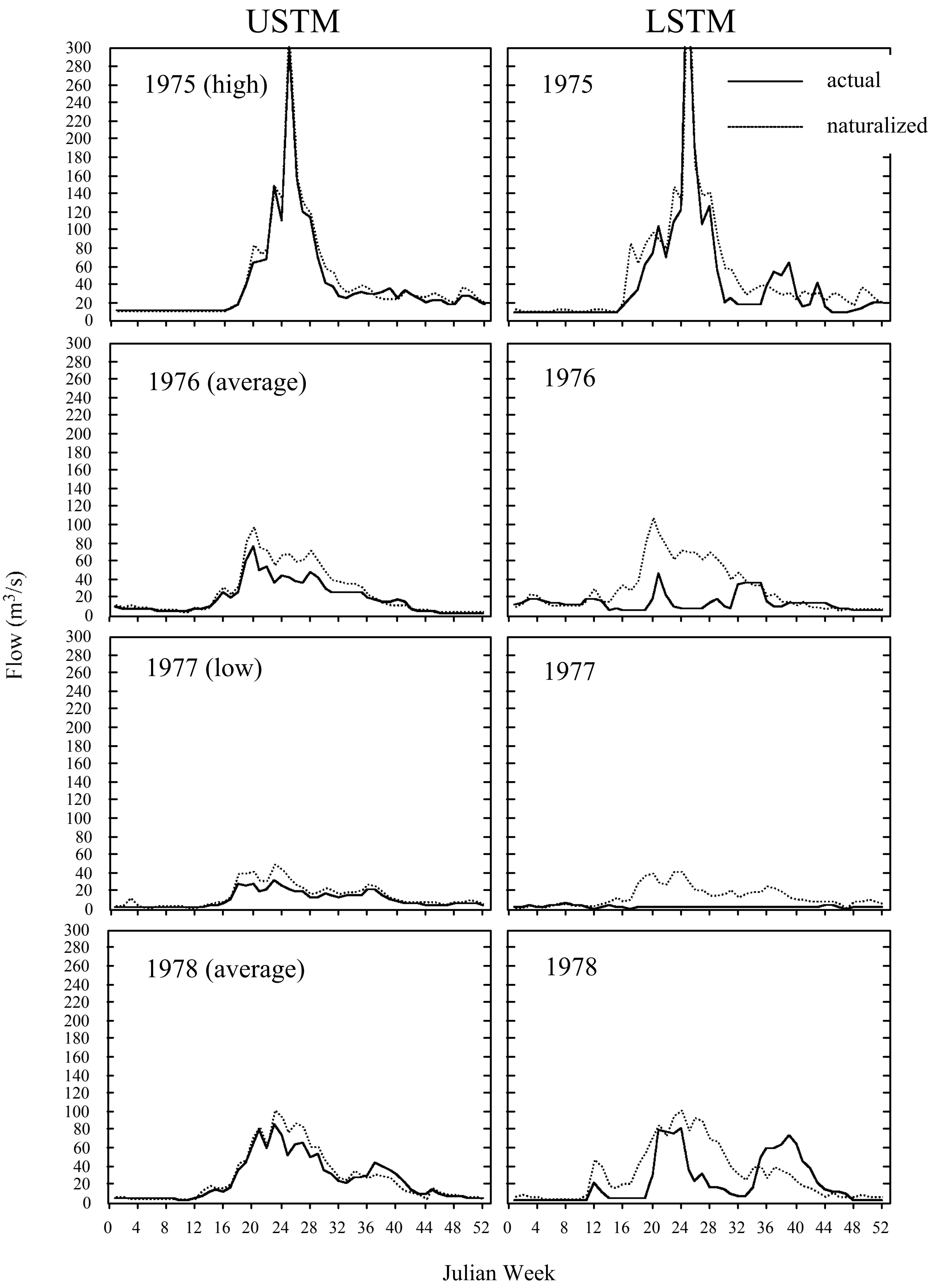


Figure 7.14. Naturalized and actual weekly flows during a high flow year (1975), a low flow year (1977), and two average flow years (1976 & 1978) along the upper (left) and lower (right) reaches of the St. Mary River (at the US/Canada border and Lethbridge respectively).

Overall suitability of PRC flows

The comparative evaluation of PRC flows, as they relate to naturalized and actual flow regimes along the six test reaches, indicates that PRC flows would maintain riparian cottonwood forests along these reaches. PRC flows are expected to provide more favourable conditions along the three downstream reaches, and identify an acceptable flow regime along the three upstream reaches.

The impact of regulated flow regimes on riparian cottonwoods along the downstream reaches of the Belly, Waterton, and St. Mary rivers have been relatively neutral, moderately negative, and severely negative, respectively (Table 7.7).

Table 7.7. A) Documented changes to cottonwood abundances in the Oldman River Basin from the 1950s to the 1980s, along reaches upstream (upper) and downstream (lower) from the Belly River diversion weir (operational since 1935), Waterton River Dam (1964), and St. Mary River Dam (1951). The standard error for lineal measures is approximately < ± 5% and for area measures is about ± 20% (bold values indicate highly significant changes). **B)** Summary of magnitude of changes in cottonwood abundance using ranked categories (>10% = +2, 10 to 5% = +1, 5 to -5% = 0, -5 to -10 = -1, -10 to -20 = -2, <-20% = -3).

A)	**Percent change in the abundance of cottonwoods along:**					
	non-regulated reaches			**regulated reaches**		
	UBEL	UWAT	USTM	LBEL	LWAT	LSTM
Rood and Heinze-Milne 1989						
- 2D area (1961 to 1981)	-4.6	-6.1	-4.7	-0.1	**-22.9**	**-47.8**
Reid et al. 1992						
- lineal distance (1951-1985)	-7.4	-5.8	-7.2	+0.4	-9.0	**-73.7**
- lineal distance (1961-1981)	-4.5	-8.0	-7.1	-0.9	**-20.4**	**-45.4**
- 2D area (1951 to 1990)	-13.1	+4.7	-4.8	**+21.2**	+2.6	**-40.0**
Rood et al. 1995						
- 2D area (1951 to 1985)	-9.1	+1.9	-0.5	**+52.2**	+3.5	**-61**
- lineal distance (1951 to 1985)					-9.0	**-68**

B)	**Ranked change in abundance:**					
	non-regulated reaches			**regulated reaches**		
	UBEL	UWAT	USTM	LBEL	LWAT	LSTM
lineal distance:	-1	-1	-1	0	-2	-3
2D area:	-1	0	-1	+2	-1	-3
absolute value of total:	2	1	2	2	3	6
extent of change:	moderate	slight	moderate	moderate	severe	extremely severe

Abbreviations: UBEL = upper Belly River, LBEL = lower Belly River, UWAT = upper Waterton River, LWAT = lower Waterton River, USTM = upper St. Mary River, LSTM = lower St. Mary River

Along all three rivers, reduction of low flows has been associated with drought stress and declines in cottonwood forests. PRC flows address this situation by preventing reductions below naturally low flow levels. This flow adjustment should correct the symptoms of drought stress observed along the lower part of the Belly River. The PRC otherwise resembles the actual regulated flow regime along this reach.

Along the downstream reach of the Waterton River, reductions affecting medium and larger flows have also been implicated with negative impacts on riparian cottonwoods. The PRC would improve this situation by moderating those reductions. The combination of protected low flows and moderated reductions to larger flows along the Waterton test reach would be expected to remedy its declining condition.

Along the severely impacted lower part of the St. Mary River, natural flow variability has also been significantly altered. The PRC approach should correct this problem because it is based on natural flow variability. Thus, combined with protecting low flows and moderating reductions to larger flows, the more natural pattern and timing of flow variability proposed by the PRC should prevent further deterioration and enable the rehabilitation of riparian forests along the lower reach of the St. Mary River.

The part of the PRC that cannot be adequately evaluated, based on comparisons with the implemented flow regimes for these test reaches, is the reduction of peak flows that exceed 125% bankfull. It is not possible to infer the effects of such a change, because none of the flow regimes along the test reaches have been modified in this way.

7.7 Evaluating the PRC Criteria

7.7.1 Relative contribution of each PRC criterion

Results of comparisons between PRC flows and actual flow regimes along the selected test reaches (section 7.6) have generally supported the utility of the PRC for sustaining riparian cottonwood populations. A more detailed validation of the PRC is possible through the individual assessment of each of the five PRC criteria (Figure 7.8) whose exceedence curves form the basis of the final PRC (Figure 7.15). Each individual criterion influences a particular range of flows in the final PRC (Figure 7.16, Table 7.8). To evaluate each criterion, the flows in the affected exceedence range have been compared with the corresponding regulated flows implemented along the various test reaches. Based on these comparisons, flows proposed by each PRC criterion have been assessed relative to the effects they are likely to have on downstream cottonwood health as suggested by trends reported along the various test reaches. A summary of these assessments is presented in Table 7.9.

Table 7.8. The ranges of flow affected by each PRC criterion.

PRC Criteria:	Range of affected naturalized flow exceedence:
1) Naturalized Flow	100 - 90% Exceedence
2) Naturalized 90% Exceedence Flow	90 - 60% Exceedence
3) 65% of Naturalized Flow	50 - 70% Exceedence
4) 50% RI-shifted Naturalized Flow	5 - 60% Exceedence
5) 125% Bankfull Flow	0 - 10% Exceedence (during weeks 21 - 27)

Table 7.9. Summary comparing recorded flows along each test reach to flows required by each individual PRC criterion (++ exceeds PRC, + meets PRC , - fails PRC, and - - severely fails PRC).

(PRC Criteria)	UBEL	UWAT	USTM	LBEL	LWAT	LSTM
1. Natural Flow	-	+	-	- -	- -	- -
2. Natural 90% Exceedence Flow	+	+ +	-	- -	- -	- -
3. 65% Natural Flow	+ +	+ +	+	-	-	- -
4. 50%RI-shifted	+	+ +	-	-	-	- -
5. 125% Bankfull	+ +	+ +	++	++	++	++
Overall Ranking :	2	1	3	4	4	5
Change in forest abundance (Table 7.7)	moderate	slight	moderate	moderate	severe	extremely severe

Abbreviations: UBEL = upper Belly River, LBEL = lower Belly River, UWAT = upper Waterton River, LWAT = lower Waterton River, USTM = upper St. Mary River, LSTM = lower St. Mary River

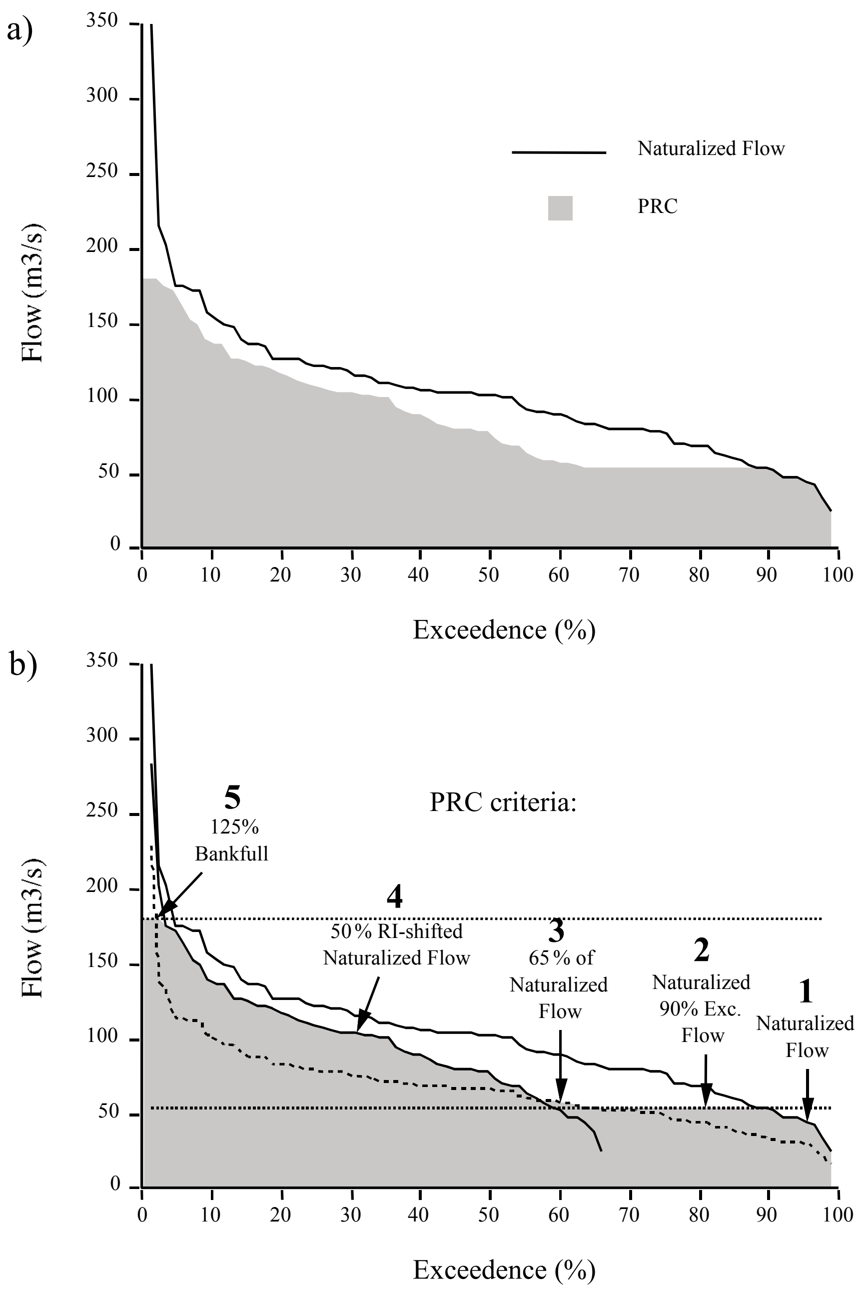


Figure 7.15. a) Example of a weekly PRC and a naturalized exceedence curve for flows along the St. Mary River near Lethbridge during Julian week 24, and **b)** individual exceedence curves for each criterion of the PRC.

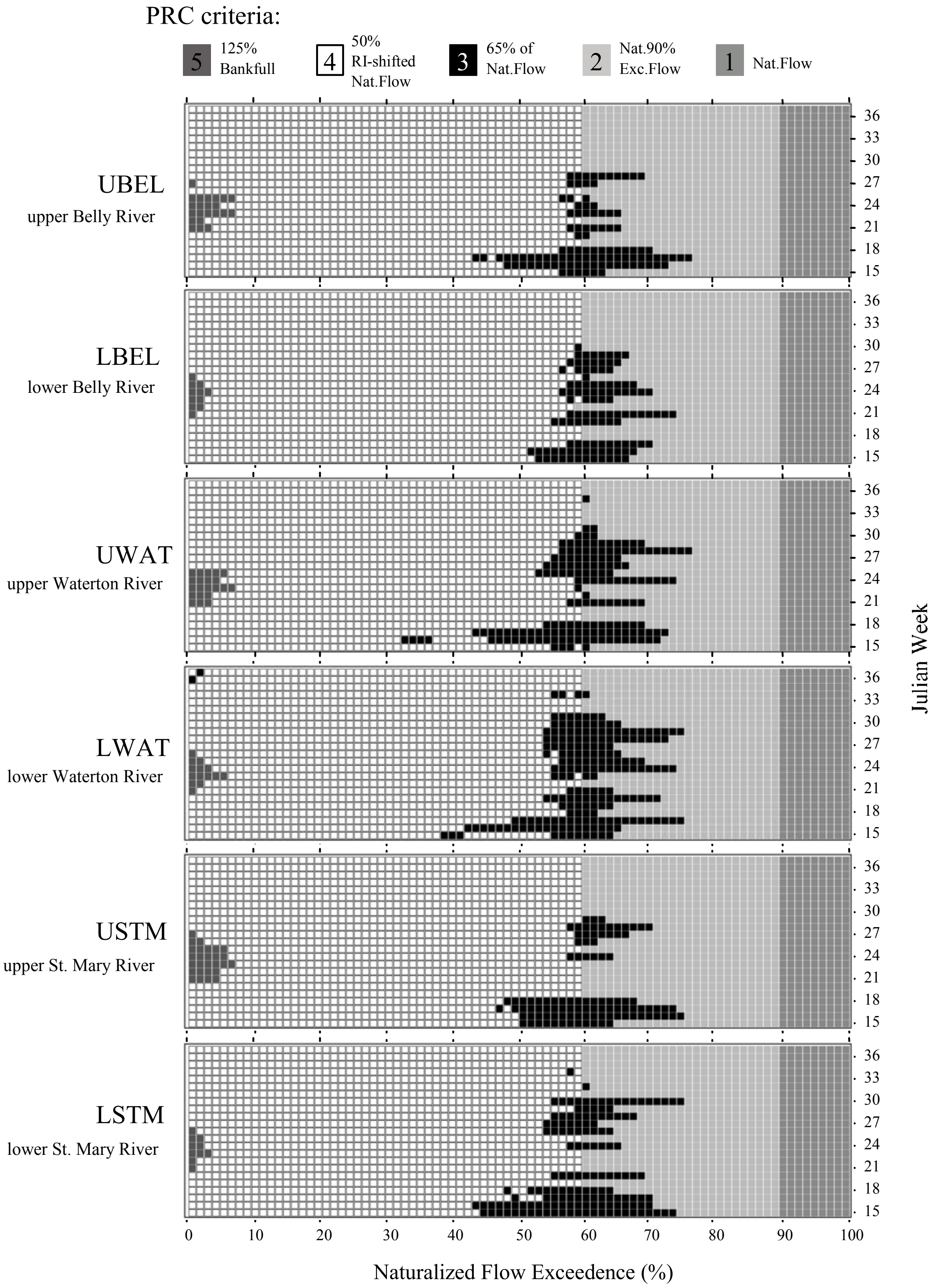


Figure 7.16. Ranges of naturalized flow affected by each PRC criterion for each test reach.

7.7.2 PRC criterion 1: Naturalized flow

PRC criterion 1 prevents reductions to natural low flows that have exceedences between 90 and 100% (Figure 7.16, Table 7.8). Natural 90% exceedence flows generally qualify as base flows because they are met or exceeded (on average) in 90% of years. The averaged magnitudes of reductions that have actually been made at each test reach within this category of minimum flows are summarized in the shaded portions of Figure 7.17. The PRC proposes no reductions to flows with natural exceedences in this range. Thus, the change to weekly flows (y-axis) would be 0% (dashed line) for exceedences between 90 and 100% (Figure 7.17b).

The upper reach of the Waterton River is unregulated, having no significant alterations to its flows, including those in the range from 90 to 100% naturalized exceedence. Thus, its flows meet the requirements for PRC criterion 1 (Table 7.9). In contrast, regulation along the other five test reaches has caused reductions ranging from about 20 to 95% to the already low flows, in the range from 90 to 100% natural exceedence (Figure 7.17b). The three downstream test reaches have been particularly severely impacted by greater than 80% reductions to these natural low flow events. This trend corresponds with the frequencies of acute drought stress reported along the lower reaches compared with the less-regulated upstream reaches, and suggests that this range of reduction to low flows is not acceptable in the PRC.

The magnitudes of flow reductions affecting natural 90 to 100% exceedence flows are generally comparable along the upper St. Mary and upper Belly rivers, ranging from about 20 to 40% reduction. However, signs of drought stress have been reported for cottonwoods along the upper St. Mary River and not along the upper Belly River. This disparity appears to be related to differences in flow reductions across the rest of the exceedence range (exceedences of < 90%), because overall weekly flow reductions along the upper St. Mary have been more severe than along the upper Belly (averaging 25% versus 10% respectively, un-shaded portion of Figure 7.17a). This trend suggests that although the maintenance of low flows is critical to cottonwood health, moderate and higher flows are also important. Additionally, the size and geomorphic context of the Belly River is quite different from that of the St. Mary River (Table 7.10) and these differences may affect the ultimate resiliency of each system to similar levels of flow reductions.

The moderate rate of 20 to 40% flow reduction affecting low flows along the upper Belly River, combined with lesser reductions (about 10%) to flows with exceedences less than 90%, are associated with no discernable drought stress in the affected riparian forests. However, along the upper St. Mary River, the same moderate rate of 20 to 40% flow reduction, extended over the full range of flow exceedences, has contributed to symptoms of drought stress. Considering that criterion 3 of the PRC allows marginally greater reductions (35%) than those experienced along the upper St. Mary River (30%) for moderate flows with 50 to 70% exceedence, reductions of more than 30% to low flows should be avoided. This will prevent reproducing the drought stress observed along the upper St. Mary River.

Criterion 1 of the PRC is conservative, permitting 0% reduction to flows between 90 and 100% natural exceedence. Based on the available evidence, reductions of up to about 30% may be acceptable if flows are conserved across the rest of the exceedence range. Conversely, the complete protection of these low flows would probably compensate to some extent for reductions made to moderate and higher flows.

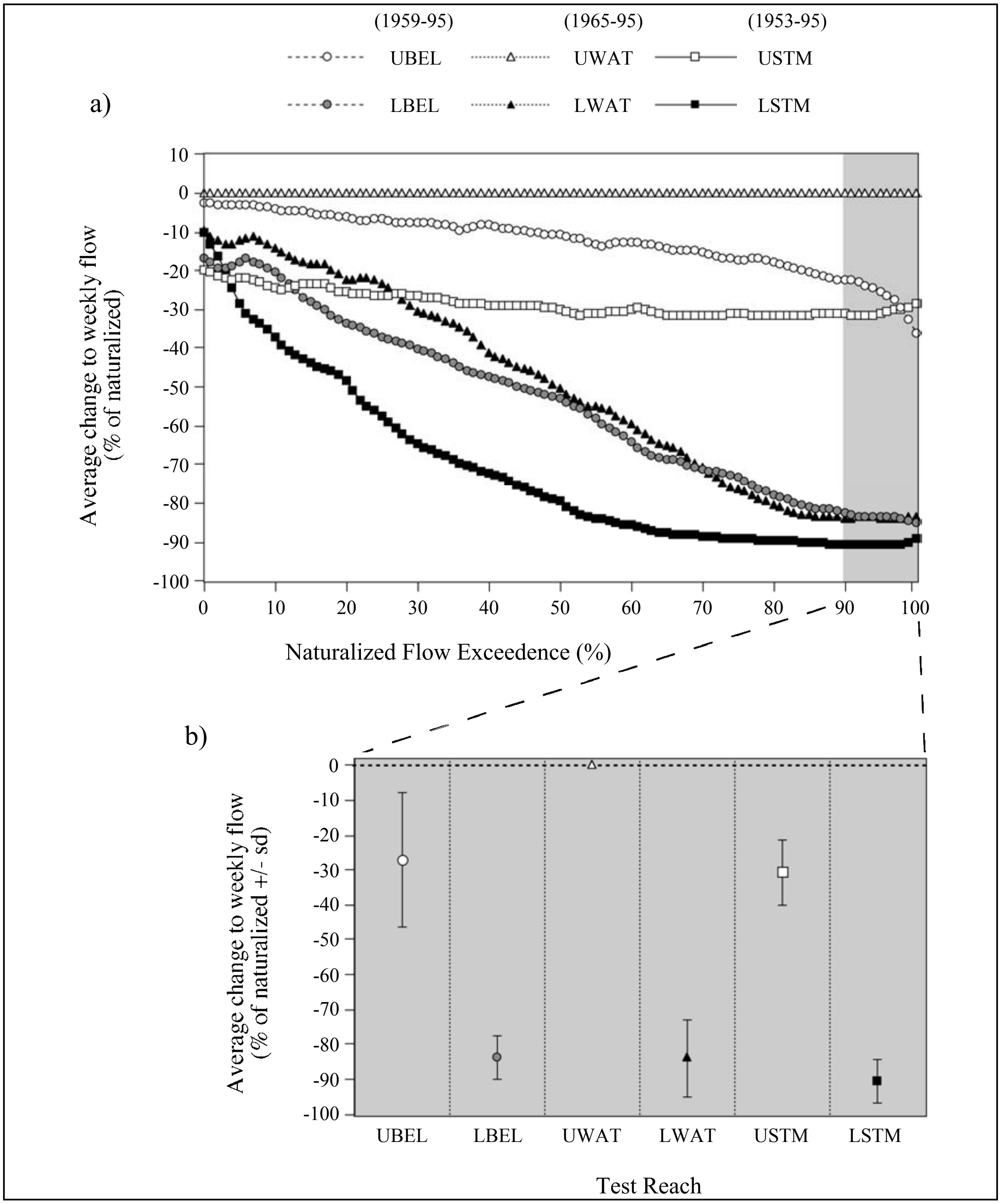


Figure 7.17. a) Average change from naturalized to actual weekly flows for each 1% exceedence interval during the growing season (Julian weeks 15-37) for a series of flow-regulated years. **b)** Summary of changes to flows between 90 and 100% naturalized exceedence (shaded areas), corresponding with flows affected by PRC criterion 1 along each test reach (UBEL/LBEL = upper/lower Belly River, UWAT/LWAT = upper/lower Waterton River, USTM/LSTM = upper/lower St. Mary River).

Table 7.10. Assessments of riparian forest abundances along various tributaries of the SSRB in the 1880s, 1950s, 1980s, and late 1990s using historic surveys and aerial photographs (reach equivalents in this study: SM1 = upper St. Mary River, SM2 = lower St. Mary River, BL1 = upper Belly River, BL2 = lower Belly River, W1 = lower Waterton River).

		-----------1980s-----------			Riparian Poplar Density:				General Change
River:	**Reach:**	**Length (km)**	**Floodplain Width (m)**	**Channel Type**	**1880s**	**1950s**	**1980s**	**1997-99**	**1880-1999**
St. Mary	SM1	25.4	300-700	FM	3 to 5		4	4	
	SM2	115.51	200-(1000)	CM	2		1	1	-
Belly	BL1	28.82	300-500	FM	3 to 5		3	3	-
	BL2	48.81	500-1200	FM	2		5	5	+
(below inflow of Waterton R.)	BL3	37.59	1000-1500	FM-BR	3 to 5		4	4	
	BL4	34.74	700-1500	FM	3 to 5		3	3	-
Waterton	W1	75.31	500-700	FM	3 to 5		3	3	-
Oldman	OM1	17.26	200-500	FM	3 to 5	2	2	2	-
	OM2	98.82	1500-1700	BR-FM	3 to 5	5	5	5	+
	OM3	21.28	200-1000	ST	3 to 5	2	2	2	-
	OM4	61.93	500-2000	FM-CM	3 to 5	4	4	4	
	OM5	78.64	300-2000	CM-FM	2	2	2	2 to 3	
	OM6	62.08	300-700	ST-CM	2	1	1	1	-
S. Sask.	S1	197.2	200-3000	ST-CM-FM	2	2	2	2	
	S2	35.95	200	ST		1	1	1	
	S3	54.89	200-750	ST-CM		1	2	1 to 2	+
Red Deer	R1	22.86	200-300	CM		3	3	2	-
	R2	32.06	300-400	CM		2	2	2	
	R3	32.13	200-400	CM-ST	1	3	3	3	+
	R4	39.98	100	CM-ST	2	2	2	2	
	R5	16.48	300-500	CM	2	3	3	3	+
	R6	78.23	500	CM	3 to 5	4	4	4	
	R7	37.14	200-300	CM-ST	1	3	3	3 to 4	+
	R8	51.33	500-1300	CM-FM	2	3	4	3 to 4	+
	R9	18.45	300-500	ST-CM		3	3	3	
	R10	37.99	1000-1500	FM-BR		3	3	3 to 4	
Bow	B1	42.58	300-1500	FM-CM	3 to 5	3	3	3	-
	B2	38.86	500-1500	FM-BR	3 to 5	4	4	4	
	B3	48.14	500-2500	FM-BR	3 to 5	4	5	5	
	B4	36.26	500-1000	FM	3 to 5	3	3	3	-
	B5	60.38	200-500	ST	1	2	2	2	+
	B6	55.79	200-500	ST	1	1	1	1	
	B7	41.39	200-500	ST	1	1	1	1	
	B8	23.22	200-500	ST	2	2	2	2	

(1880-1980 content adapted from Bradley et al. 1991)

Channel Type categories:

FM = freely meandering

CM = confined meandering

ST = straight

BR = braided

Density categories:

1 = none / negligible

2 = sparse

3 = moderate

4 = dense

5 = very dense

7.7.3 PRC criterion 2: Naturalized 90% exceedence flow

PRC criterion 2 allows flows to be reduced only to the naturalized 90% exceedence flow. This criterion generally affects flows with naturalized exceedences between 90 and about 60% (Figure 7.16, Table 7.8). A comparison of regulated (actual) weekly flows and natural 90% exceedence flows is summarized for each test reach in Figure 7.18. The shaded portions in this figure encompass the exceedence range that is generally affected by PRC criterion 2 (natural 60 to 90% exceedence). Flows greater than the 90% exceedence flow are recorded as positive values; flows less than the 90% exceedence flow are negative.

The six test-reaches show considerable variation relative to 90% exceedence flow levels (Figure 7.18b). On average, 60 to 90% exceedence flows along the upstream reaches of the Waterton and Belly rivers have remained greater than natural 90% exceedence flows. The same group of flows along the upper portion of the St. Mary River has averaged about 15% less than the 90% exceedence flow level. Flows along the lower reaches of the Belly and Waterton rivers have had reductions between 50 and 80%, relative to natural 90% exceedence flow levels. Flows along the lower reach of the St. Mary River average even less, showing 90% reductions below natural 90% exceedence flow levels. The magnitudes of reductions below natural 90% exceedence flow levels correspond closely with the increasingly poor state of riparian forest health across the six test reaches (Table 7.7).

Declining riparian cottonwood health along the lower test reaches suggests that the 50% or greater reductions in streamflow below natural 90% exceedence flows (in the range from 60 to 90% exceedence) recorded along the lower reaches will not support riparian cottonwoods. Similar to the logic developed in evaluating PRC criterion 1, a 'safe' level of reduction for flows affected by criterion 2 is likely between that recorded along the upper part of the Belly River (where forests are healthy) and the upper St. Mary River (where forests are showing symptoms of drought stress). The PRC criterion 2 proposal of 0% reduction to 90% exceedence flows (dashed line in Figure 7.18b) falls within this range and is thus justified. Reductions greater than 10% are discouraged to avoid duplicating the stressed condition of riparian cottonwoods along the upper reach of the St. Mary River.

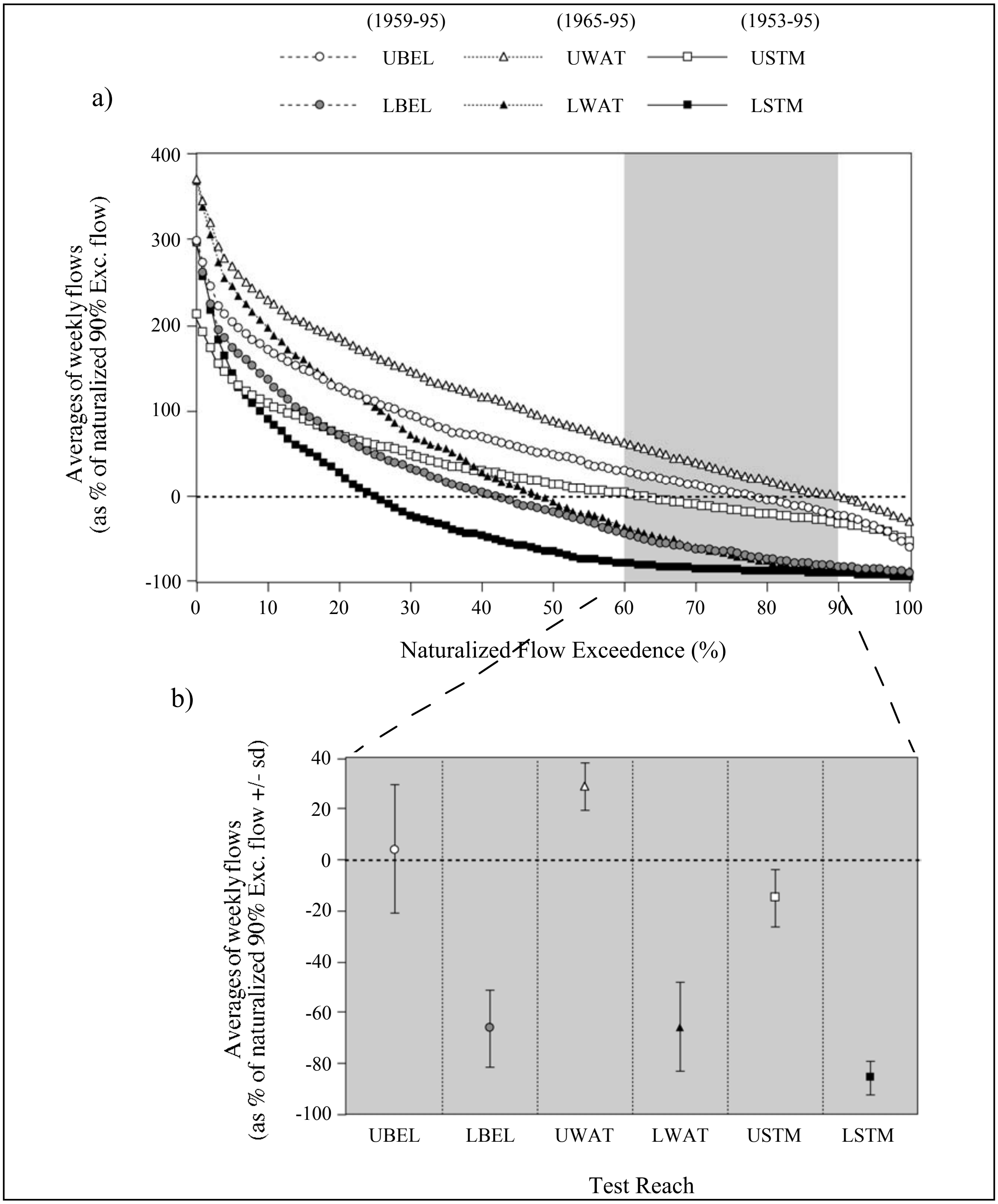


Figure 7.18. a) Average actual weekly flows relative to naturalized 90% exceedence flows for each 1% exceedence interval during the growing season (Julian weeks 15-37) for a series of flow-regulated years. **b)** Averages of actual weekly flows relative to naturalized 90% Exc. flows between 60 and 90% naturalized exceedence (shaded areas), corresponding with flows affected by PRC criterion 2 along each test reach (refer to Figure 7.17 for abbreviations).

7.7.4 PRC criterion 3: 65% of naturalized flow

PRC criterion 3 proposes a 35% reduction to flows with natural exceedences between about 50 and 70% (Figure 7.16, Table 7.8). The average magnitude of reductions that have been actually made at each test reach within this category of flows is summarized in the shaded portions of Figure 7.19 (the 35% reduction permitted by criterion 3 is indicated by the dashed line). All the upper test reaches have averaged less than this 35% reduction (Figure 7.19b). Flow reductions along the upper St. Mary closely parallel the 35% value. Flow reductions recorded along the lower Belly and lower Waterton reaches range between 40 and 80%. Along the lower St. Mary, reductions are even more severe, ranging from 80 to 90%.

As was the case for PRC criterion 1 and 2, flow modifications recorded along the upper reach of the St. Mary River probably coincide with the threshold of reduced flows that can still maintain healthy cottonwoods. The 35% flow reduction permitted by PRC criterion 3 is slightly more severe than the average 30% reduction that has occurred along the upper St. Mary reach. Combined with the conservative approaches of criterion 1 and 2, this more moderate reduction may still be reasonable in the PRC. However, reductions greater than 40% are expected to be increasingly detrimental, as evidenced along the lower reaches of the Waterton River and the St. Mary River in particular.

Although setting a valid limit to the level of flow reduction that will maintain the health of riparian cottonwoods, the value for criterion 3 should also provide a gradual 'bridge' between the exceedence curves of criterion 2 and 4 (Figure 7.15b). This will ensure that the natural pattern of flow variability intrinsic to the natural functioning of the system will also be preserved. In about one third of growing season weeks, criterion 3 does not register in the PRC (Figure 7.16). In these instances, the intended gradual transition between criterion 2 and 4 is absent. The adjustment of criterion 3 from 65% to 70% naturalized flow may correct this anomaly and also lessen flow reductions that would otherwise be equivalent to the marginal flow conditions along the upper St. Mary River.

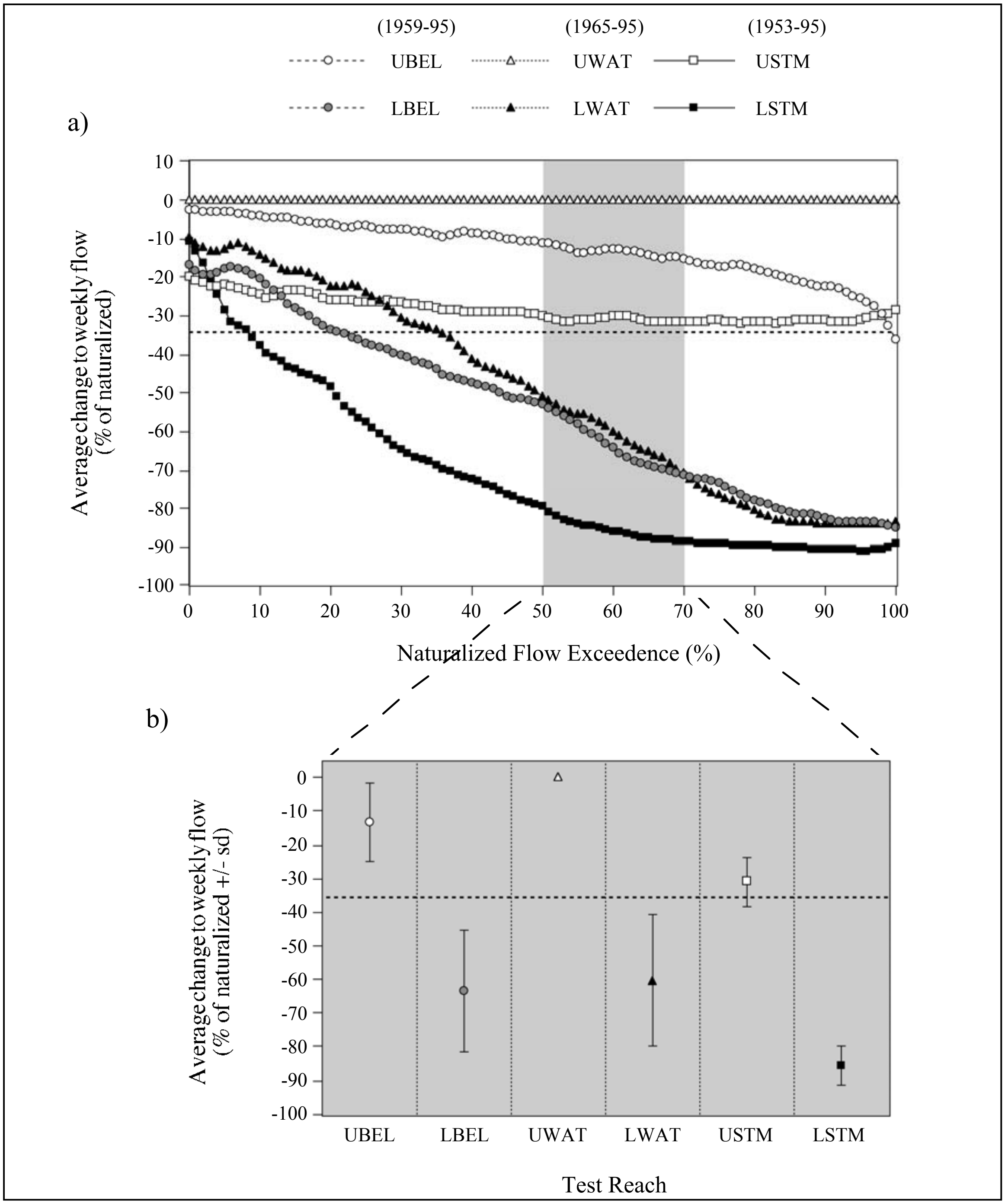


Figure 7.19. a) Average change from naturalized to actual weekly flows for each 1% exceedence interval during the growing season (Julian weeks 15-37) for a series of flow-regulated years. **b)** Summary of changes to flows between 50 and 70% naturalized exceedence (shaded areas), corresponding with flows affected by PRC criterion 3 along each test reach (refer to Figure 7.17 for abbreviations).

7.7.5 PRC criterion 4: 50% return interval-shifted naturalized flow

PRC criterion 4 would allow flow reductions equivalent to a 50% increases of return interval. This criterion defines the broad portion of the PRC between about 5% and 60% naturalized exceedence (Figure 7.16), and so affects mainly average and greater weekly streamflows. The actual RI shifts recorded during a selection of flow regulated years along each test reach are summarized in Figure 7.20. Here, the range of influence of criterion 4 is shaded. The threshold RI shift of 50% is indicated by a dashed line.

RI shifts have been consistently greater along the lower reach compared with the upper reach of each river. The RI shifts recorded along the lower St. Mary have been the most severe, averaging greater than 200% (Figure 7.20b). Shifts along the lower Belly, lower Waterton, and upper St. Mary have been moderately severe, averaging between 100 and 200%. RI shifts along the upper Waterton and upper Belly have been much smaller, averaging less than 50%. Thus, increasing magnitude of RI shifts correlates with decreasing riparian forest health along the test reaches (Table 7.7).

RI shifts are not solely responsible for trends in decreasing riparian forest health. Among the six test reaches, declines in cottonwood abundance and general health have been most closely associated with reductions to low flows. A test reach where low flows remain completely unchanged, while moderate and larger flows are altered, is not available to isolate the effects of modifications to greater flows. However, lower flows (naturalized 60 to 100% exceedence) along the upper reaches of the Waterton, Belly, and St. Mary rivers have been less altered than along the lower reaches (Figures 7.17, 7.18). In particular, the slight reductions that have been made to these low flows along the upper Belly and upper St. Mary reaches are similar, making these reaches good candidates for evaluating the effects of changes made to larger flow events.

Riparian cottonwoods along the upper reach of the Belly River are in reasonably good health, whereas those along the upper reach of the St. Mary River show signs of stress and increased seedling mortality (Reid et al. 1992). Considering that the slight reductions to low flows along both reaches have been relatively similar, this difference in cottonwood health and reproductive success could be related to differences in modifications to larger flows. The large RI shifts of 100 to 300%, relative to naturalized return intervals that have been recorded along the upper St. Mary River, suggest a threshold of tolerable reductions to larger flows. The shifts of less than 50% recorded for the upper Belly River probably represent a more acceptable range (Figure 7.20). Because the 50% RI shift permitted by the PRC (dashed line in Figure 7.20) is slightly greater than shifts recorded for the upper Belly River, this value is likely acceptable in the overall PRC. Due to the scarcity of controls among the test reaches, it is not possible to determine with certainty a level of flow reductions beyond the 50% RI shift threshold that would be safe for maintaining riparian cottonwoods.

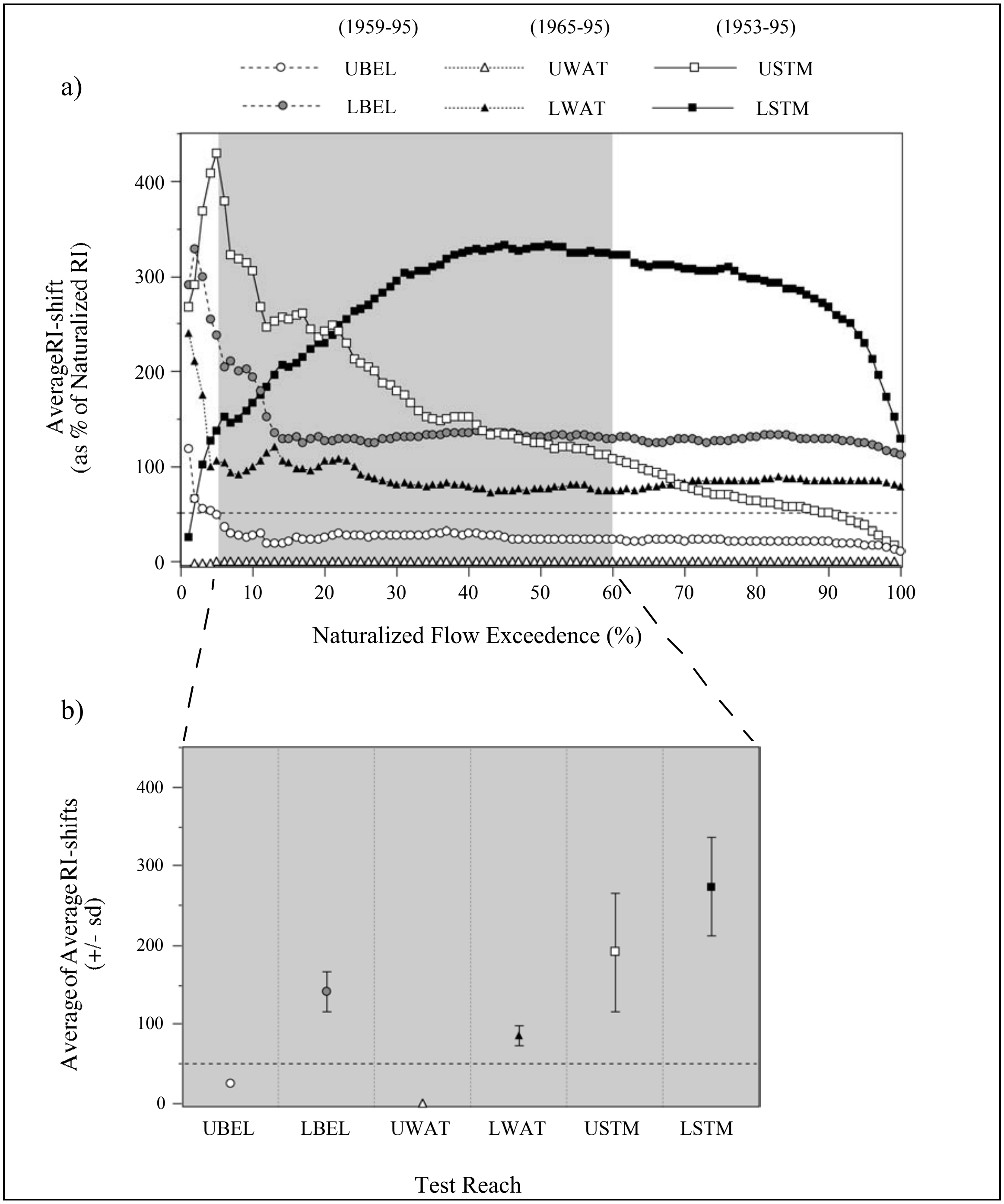


Figure 7.20. a) Average return interval shifts from actual to naturalized weekly flows for each 1% exceedence interval during the growing season (Julian weeks 15-37) for a series of flow-regulated years. **b)** Summary of changes to return interval shifts of flows between 5 and 60% naturalized exceedence (shaded areas), corresponding with flows affected by PRC criterion 4 along each test reach (refer to Figure 7.17 for abbreviations).

7.7.6 PRC criterion 5: 125% bankfull flow

PRC criterion 5 would permit high flows to be limited to the weekly equivalent of instantaneous 125% bankfull discharge (Figure 7.16, Table 7.8). Instantaneous bankfull discharge is the flow magnitude required to completely fill the active channel. This value varies across reaches as it relates to the physical dimensions of the cross-section of each channel.

A weekly equivalent for 125% instantaneous bankfull discharge was required in criterion 5 to accommodate the PRC weekly exceedence curve. The weekly time-step used in the PRC is not compatible with the naturally shorter duration of greater than bankfull flows that often last only one to three days. This complicates the selection of a weekly equivalent for instantaneous 125% bankfull flows. For the purposes of this report, weekly 125% bankfull flow values have been estimated based on historic data where flows of instantaneous 125% bankfull magnitude occurred at least once. The instantaneous 125% bankfull value and its weekly equivalent, used in calculating the PRC, are presented in Table 7.5 for each test reach. Based on these weekly estimates of 125% bankfull flow, PRC criterion 5 would affect flows with naturalized exceedences less than 10% (Table 7.6) during weeks of peak annual streamflow, usually Julian weeks 21 through 27 (Figure 7.16) that correspond with the last week of May through the first week of July.

Natural peak flows equivalent to 125% bankfull magnitude or greater occur infrequently along the Southern Tributaries of the Oldman River (< 1 in 10 year recurrence during peak flow weeks). Considering the relatively short period of available flow records (< 50 years), the evaluation of this value based on the test reaches is problematic. Historic reductions to natural peak flows greater than 125% bankfull have occurred to a limited extent along the test reaches (Figure 7.21). Test cases where this criterion has not been met are not available for analysis because flow regulation has not generally reduced these peak flows below the 125% bankfull level (Table 7.9). Thus, it is not possible to verify the 125% bankfull value directly along the test reaches. Even the most severely impacted reach, the lower St. Mary River, has not had peak flows reduced to this extent. A qualitative approach, to overcome the lack of specific quantitative data, has been used to assess the level of peak flows necessary for preserving functional riparian forests.

The importance of peak flows to cottonwoods (as detailed in Section 7.4.3) is mainly related to riparian water table recharge and the geomorphic processes that prepare nursery sites for cottonwood seedling establishment. As such, long-term reductions to these peak flows may cause drought stress to trees in marginal areas and to seedlings or saplings that lack well-established root systems. Reductions to peak flows may also interrupt natural patterns of nursery site formation, resulting in less frequent opportunities for successful seedling establishment. Because channel and floodplain topography and the elevational distribution and composition of riparian forests are highly variable, the choice of a maximum peak flow could have complex and varied effects on riparian and aquatic ecosystems. The implications of 125% bankfull as a maximum flow needs to be further investigated. Therefore, the physical parameters that define cottonwood requirements for high flows need to be investigated along each test reach to better define acceptable reductions for peak flows in each case.

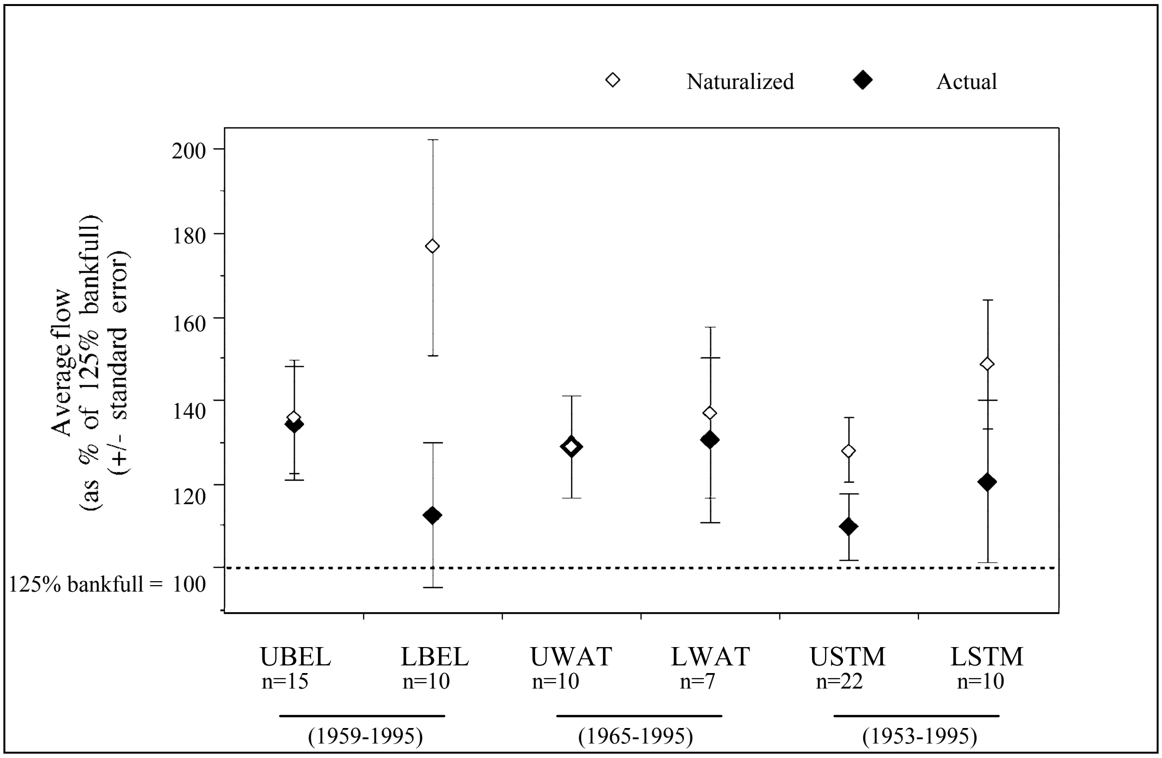


Figure 7.21. Comparison of naturalized weekly flows greater than 125% bankfull with their corresponding actual weekly flows (recorded during flow-regulated years for each test reach). The number of flows incorporated into each set of averages is indicated under the x-axis labels. (UBEL/LBEL = upper/lower Belly River, UWAT/LWAT = upper/lower Waterton River, USTM/LSTM = upper/lower St. Mary River).

7.7.7 Summary of evaluation of PRC criteria

PRC criterion 1 protects flows below the naturalized 90% exceedence level. Occasional, slight reductions (<30%) to flows in this exceedence range alone might not be seriously harmful. However, combined with moderate reductions to larger flows, there is an increasing likelihood of inducing chronic drought stress in downstream forests.

PRC criterion 2 would prevent reductions below naturalized 90% exceedence flow. Similar to the case for criterion 1, occasional, slight reductions below the 90% exceedence threshold may not have serious consequences. However, reductions greater than 10% may not be acceptable.

The assessment of PRC criterion 3 suggests that although the 35% reduction might be adjusted to 40% without harming riparian forests, such a reduction would prevent PRC criterion 3 from providing a gradual transition between criteria 2 and 4. The resultant exceedence curves would have an unnatural step function imposed in this range. This would somewhat negate the effort to maintain the inter-annual variation of the natural system. Thus, the 35% flow reduction allowed by criterion 3 should only be altered in concert with a similar adjustment in the exceedence curve for criterion 4.

PRC criterion 4 permits flow reductions equivalent to a 50% increase in return interval. Based on the trends in riparian poplar health along the test reaches, this value seems generally acceptable. Due to the variability among the reaches, it is not clear if a further reduction would still be adequate for maintaining healthy downstream forests. Without additional evidence from other test-reaches, the limit of 50% increase in RI should be maintained.

PRC criterion 5 would permit peak flows to be limited to 125% bankfull. Considering that actual reductions to flows beyond this magnitude have been relatively minor along the test reaches, the appropriateness of the 125% bankfull value as a maximum in the PRC cannot be verified using these test cases. This criterion is the only part of the PRC that is defined by an absolute value calculated without reference to the historic flow record. The 125% bankfull value is recommended only as an initial approximation. It requires further consideration on a reach-specific basis. The high flow criteria may be better estimated through other evaluation metrics, such as those for maintaining channel dynamics (Section 8).

The individual assessments of the five PRC criteria (summarized in Table 7.9) have generally supported their use in the PRC approach to meeting the flow requirements of riparian cottonwoods in the SSRB. Trends observed along the test reaches suggest that only minor revisions to any of the criteria used in calculating the overall PRC could be made safely.

7.8 Applicability of PRC flows for other systems:

As discussed previously, the details of a PRC-based recommendation may be altered by the particular fluvial, hydrological, geomorphic, and biological characteristics of a river. The foregoing discussion is related to a specific area within the South Saskatchewan River Basin. Although the evaluation of the PRC indicates it is appropriately suited for implementation within the Oldman River sub-basin, the diversity of fluvial systems within the South Saskatchewan River Basin suggests the detailed criteria may not be directly applicable to all reaches. A general assessment of the availability of site-specific data required for the PRC approach for each reach being evaluated in the SSRB WMP is provided in Figure 7.22. The riparian evaluation is based on the availability of hydrology data, such as the bankfull discharge, as well as site-specific poplar biology information.

The Red Deer River sub-basin can be considered to be the fluvial system most distinct from the Oldman River sub-basin. Should an assessment of the PRC with respect to the Red Deer River indicate it is reasonably suited for implementation there, it might considered acceptable for implementation in the South Saskatchewan River Basin in general.

Recent work by Cordes et al. (1997) identified several hydrological characteristics that must be met to sustain the long-term viability of the riparian forests along the Red Deer River. Included within their evaluation were the following recommendations to help mitigate the decline of cottonwoods along the Red Deer River:

- Preserve the magnitude, timing and duration of greater than 1 in 5 year flood flows and attenuate large floods to no lower than 1 in 20 year discharge (the minimum flood flow that is required for maintaining recent levels of regeneration);
- Do not modify very high floods, of greater than 1 in 50 year magnitude (flows are necessary for widespread regeneration);

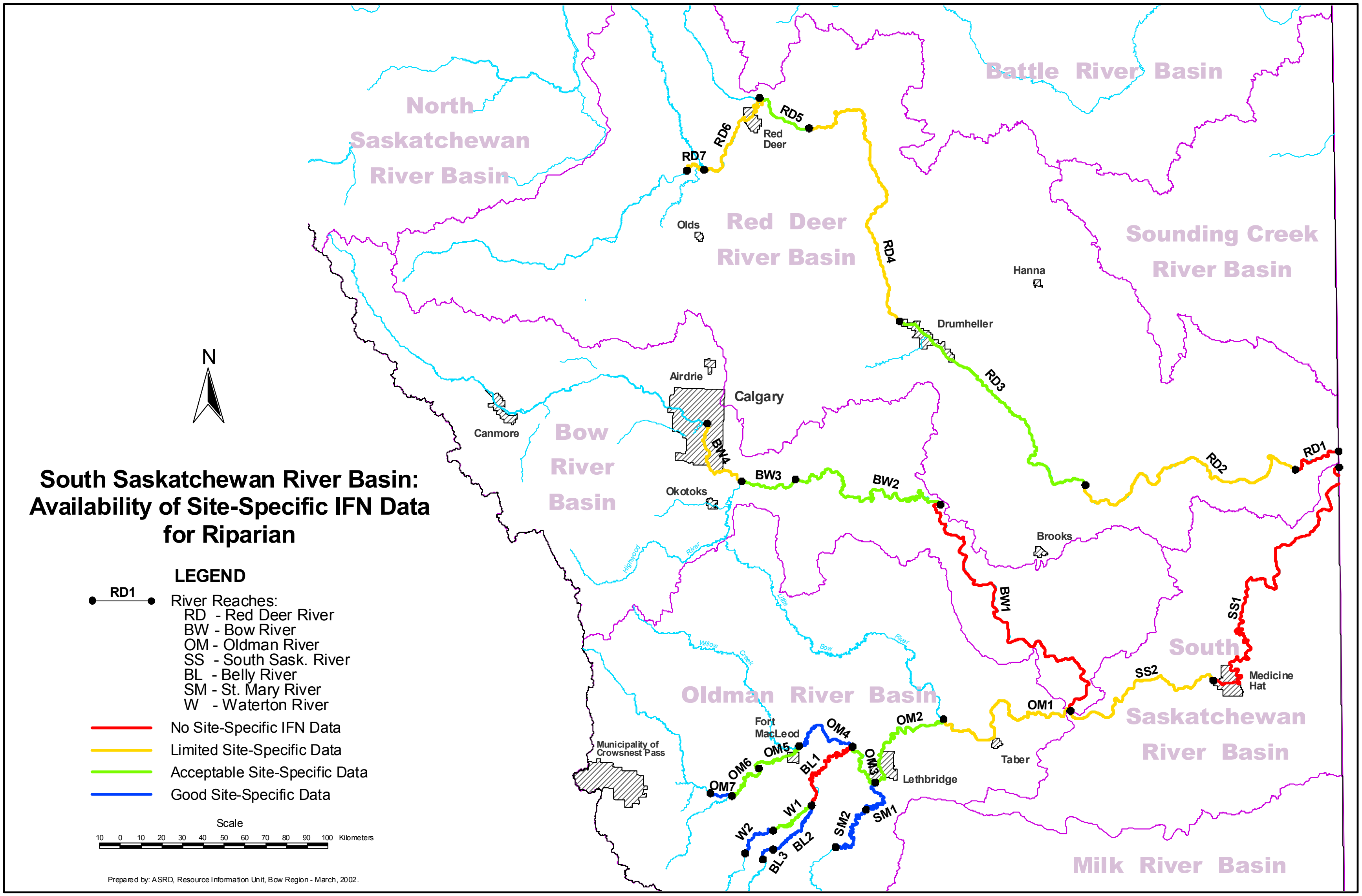


Figure 7.22. Availability of site-specific data required to develop a PRC for every reach in the SSRB WMP evaluation.

- Following greater than 1 in 10 year floods, leave flows unaltered for the rest of that year and the next, to maintain moisture levels for seedling survival; and
- Always maintain minimum flows during the ice free period to prevent stress.

In his critique of Cordes et al. (1997), Rood (1997) re-emphasizes the importance of the 1 in 10 to 1 in 100 year flood flows for floodplain processes and cottonwood seedling recruitment along the Red Deer River. Additionally, Rood (1997) suggests that a gradual rate of flow decline, following the peak of flood flows, may be as important or more important than the magnitude of the flood peak. A flow decline rate of 2.5 cm per day should allow seedling root growth to keep pace with the receding water table (Mahoney and Rood 1998), thus improving seedling survival by reducing the incidence of drought stress. Rood (1997) also suggests that clonal propagation may provide a natural buffer to compensate for periods that are less conducive for seedling based regeneration.

Considering the above values, the PRC approach to determining IFN for riparian cottonwood forests seems appropriate for managing cottonwood forests along the Red Deer River. The PRC has provisions for protecting minimum flows, natural seasonal flow variability, and some degree of flooding. Probably the most important issue for cottonwoods along the Red Deer River is the inadequate level of seedling replenishment. Successful seedling recruitment generally requires high springtime flows, to prepare nursery sites, followed by gradual flow recessions to promote seedling root growth and prevent drought stress. The PRC should provide sufficient flows for daily operations to be successful in providing these types of conditions at a natural frequency.

In the case of the Red Deer River, reductions to peak flows have been associated with insufficient seedling replenishment. Thus, it would be essential to verify the 125% bankfull limit to peak flows. The 125% bankfull values for the test reaches are generally equivalent to a 5% weekly exceedence flow (Table 7.6). These 1 in 20 year flood discharge events approximate the flood levels advocated by Cordes (1997).

Additional detailed work is required to confirm the suitability of the PRC approach for supporting riparian cottonwoods within the Red Deer River sub-basin. This initial assessment suggests the PRC would be a good first step in providing instream flows to meet the needs of riparian cottonwoods along this river in particular, and within the South Saskatchewan River Basin in general.

8.0 CHANNEL MAINTENANCE INSTREAM FLOW NEEDS

8.1 Background - Channel Maintenance Flows

The objective of this section is to define the flow regime needed to maintain the channels of the South Saskatchewan River Basin study reaches. This flow is referred to as the Channel Maintenance Flow (CMF). In the literature terms such as Regime Flow and Channel Forming Flow have also been used for this type of flow.

In the Regime Theory of self-formed channels (Blench 1967), channel maintenance flow is defined as a steady flow that will maintain a channel in the same hydraulic regime (i.e. same average width, depth and slope) over a long period of time. The channels are referred to as alluvial channels, meaning they flow in deposits of unconsolidated or partially consolidated river laid material, in a stream valley. The basic assumption in Regime Theory is that the channels are free to adjust the hydraulic variables (width, depth and slope) in response to imposed variables of discharge (Q), sediment load (Q_S) and bed material (D_S).

Flushing Flows is the term used to describe flows with velocities that will move fines (silt, sand) out of coarser riverbed materials and keep them in motion. Such flows do not have enough power to remove gravels (Milhous 1990). Flushing flows are important for reducing silt build-up in the coarse bed material habitats used for the spawning and incubation life stages of many fish species. Coarse bed materials also provide cover habitat for many species of fish and a variety of benthic invertebrate species.

Bed mobilization or channel maintenance flows are of a greater magnitude than flushing flows and are sufficient to initiate general bed material transport. Bed mobility flows result in the formation and movement of physical habitat features such as riffles, pools, runs, point bars.

McNamara et al. (2000) provide the following definition for Channel Maintenance Flow:

> *"… Instream Flow that is intended to maintain the physical characteristics of the channel so that the ability of the channel to convey stream flow and bed load sediment is maintained. These flows are initiated only during periods of high stream flow and are required to accomplish channel maintenance – it is assumed that channel maintenance flow would at the same time provide adequate flows to sustain riparian vegetation".*

Andrews and Nankervis (1995) provide another definition for Channel Maintenance Flow:

> *"…dimensions, morphology and other physical characteristics of… gravel-bed rivers are primarily determined by a well-defined relatively narrow range of discharges… these results establish the basis for forming a regime of stream flows which will substantially maintain the existing physical characteristics of… river channels when natural flows are appreciably altered."*

The above definitions convey the concept that, under natural conditions, the bed of a stream channel becomes mobilized over a certain range of flows and that there are reasons to favour maintaining this regime under regulated conditions. Decreasing the natural extent, frequency and duration of mobile bed conditions could result in encroachment of vegetation into the channel, reduced channel widths, self-armouring of bed surfaces, and reduced channel capacity.

Milhous (1980) applied single case methods for determining flushing flows that had previously been suggested by various authors. He obtained a six-fold range of recommended discharges; evidence that there was no generally agreed upon concept or definition of flushing flows. Milhous suggested defining the term on the basis of specific values of the Shields (Mobility) Number, as calculated from hydraulic and sediment parameters.

Andrews and Nankervis (1995) proposed a procedure to establish an effective discharge (ED) as part of determining the CMF for a gravel bed river. It was argued:

> *"…The relationship between discharge and the characteristics of a channel is complex. Thus one must consider a range and frequency of occurrence for the Channel Forming Flows rather than a single (or dominant) discharge".*

They incorporated a concept by Wolman and Miller (1960) that essentially states that most of the sediment transported over a period of years is associated with an intermediate range of discharges. Andrews and Nankervis (1995) point out however, that most researchers had applied this concept to suspended load and that their results were more applicable to problems like the impact of deforestation in a basin. They went on to suggest that an effective discharge for maintaining the bed load regime (magnitude and frequency) in a river would be more related to the Channel Forming Discharge. They computed rates and durations of bed load transport for 17 reaches using a bed load function by Parker. Based on the results, the following conclusions were drawn:

> *"On the average, those flows that transported the modal 80 percent of the long-term bed-material load ranged from 0.8 to 1.6…bank full discharge…"*
>
> *" The bank full discharge of 17 gravel-bed rivers are in excellent agreement with the interval of discharge that carries the largest quantity of bed material over the period of record…it was concluded that the range of effective bed-material transporting discharge are flows which construct and maintain these channels over time."*
>
> *"A substantial majority of channel maintenance flows, both number of days and volume, would occur during large runoff years. Little or no maintenance flows would occur during years with below average runoff."*
>
> *"Commonly in gravel-bed streams, the bed is active only 5% to 10% of the time. With appropriate selection of flow conditions when diversion is allowed, up to 60% of natural flow volume can be diverted without reducing channel capacity and channel maintenance flows."*

Annear et al. (2002) state that the structure and function of riverine systems are based on five riverine components: hydrology, biology, geomorphology, water quality, and connectivity. Therefore, the objective of an instream flow prescription should be to sustain the intra- and inter-annual variability of the natural flow regime as closely as possible. Flow regimes must address both instream and out-of-stream needs and integrate biotic and abiotic processes. For these reasons, inter- and intra-annual instream flow prescriptions are needed to preserve the ecological health of a river.

Flows in the range between overbank flows and those that initiate the movement and suspension of the smallest particles provide a number of ecosystem functions, including hydraulic habitat for riverine organisms and the support of floodplain vegetation. As detailed in Section 7.1, high flows are essential to the survival of riparian cottonwood seedlings. The magnitude, duration and seasonal timing of peak and overbank flows all affect the success or failure of annual seeding events. Changes to any of these characteristics of peak flows can reduce seedling recruitment and lead to gradual deterioration of riparian forests.

Hydraulic habitat is related to the shape of the channel, the bed and bank sediments, and the water that flows through and sometimes over the channel. As such, instream flow determinations must not focus solely on habitat-discharge relationships. Rather, they must also address the dynamic nature of alluvial channels and sustain the processes that define the channel.

It is important to recognize that the physical habitat essential to aquatic and riparian communities is dependent on periodic disturbance that in the short term may be detrimental to individual organisms. High flows reset the system by forming new channels, scouring vegetation, abandoning side channels, and creating habitat beneficial for some species over the long term. Such a resetting of the system is an essential and naturally occurring process. Any comprehensive instream flow analysis must account for these kinds of changes by prescribing the flows necessary to maintain the dynamic nature of an alluvial channel.

Channel form has been described as a direct result of interactions among eight variables: discharge, sediment supply, sediment size, channel width, depth, velocity, slope, and roughness of channel materials (Leopold et al. 1964, Heede 1992, Leopold 1994). For many alluvial streams, the channel exists in a state of dynamic equilibrium in which the sediment load is balanced with the stream’s transport capacity over time (Bovee et al. 1998). When sediment load exceeds transport capacity, aggradation and alteration of the channel form will occur. When transport capacity exceeds sediment load, as is often the case below a storage reservoir, the channel may adjust by degrading the bed. Clearly, alteration of flow regimes (Schumm 1969), sediment loads (Komura and Simmons 1967), and riparian vegetation will cause changes in the morphology of stream channels (Johnson 1998).

Bankfull flows are important for forming and maintaining stream channel cross-sectional area and habitat in alluvial streams (Leopold et al. 1964). Bankfull stage is generally defined as the height of the floodplain surface or the flow that "just fills the stream to its banks" (Gordon et al. 1992), or the stage at which water starts to flow over the floodplain (Dunne and Leopold 1978). The floodplain is the relatively flat depositional area adjacent to the river that is formed by the river under current climatic and hydrologic conditions (USFS 1995). Bankfull flow is subject to minimum flow resistance (Petts and Foster 1985) and transports the most sediment over time (Inglis 1949, Richards 1982, Andrew and Nankervis 1995). Bankfull events have been determined to have a recurrence interval of approximately 1.5 to 3.0 years (Leopold et al. 1964, Mosley 1981), but in streams with sharp peak flows and accentuated low flows, the channel capacity may be more influenced by less frequent, greater magnitude events (Gregory and Walling 1973). Studies by Smith (1973) of Alberta rivers found an average bankfull recurrence interval of 16.7 years, varying between 2.4 to 45 years. Smith hypothesized this was due to high channel capacity. He proposed ice jamming as the mechanism for channel enlargement (Smith 1973). Aquatic habitat is also related to bankfull flows because scour in pools and deposition of bedload in riffles and bars is most predominant at bankfull flow (Leopold et al. 1964).

Determination of the bankfull flow condition through field observation is difficult and subjective (Johnson and Heil 1996). Floodplains may not be obvious along all stream channels. They are most noticeable along low gradient streams. In steep gradient channels, floodplains may be intermittent, on alternate sides of meander bends, or completely absent. It is also important not to confuse the level of a low terrace, located up to several metres above the present streambed, with that of the floodplain, and to be able to recognize disturbed and incised channels (USFS 1995). The use of regional relations between bankfull discharge and channel characteristics, such as those found in Dunne and Leopold (1978), can be helpful for determining where to look for the floodplain and bankfull stage in specific geographic regions of the country. In severely altered systems, the bankfull discharge concept may be too simplistic. In these cases, site-specific studies of bedload relations and transport capacity may be needed (Rosgen 1996).

Geomorphological considerations require more than providing bankfull flows. It is also important to accommodate channel migration, sediment transport, scour and deposition, bank erosion, and vegetation encroachment in determining channel maintenance flows. Changes in bed profile, bed material distribution, instream cover, overhead cover, velocity patterns, island or bar formation and removal, among others, should be considered (Annear et al. 2002).

One of the most difficult challenges that must be addressed in an IFN study, is to determine the entire range of channel maintenance flows, with magnitude, frequency of occurrence, and duration similar to the natural flow regime (Andrews and Nankervis 1995). Producing only flushing flows will not maintain, in perpetuity, the hydraulic characteristics of the channel, or the habitats of the stream dwelling organisms that rely upon them. What is needed to maintain the channel regime is a description of an instream flow requirement based on the naturally-occurring frequency of discharges within the natural range of flow variability. The objective of specifying channel maintenance instream flow needs is to maintain the hydraulic characteristics of the river channel, an important component in providing for the protection of the aquatic ecosystem.

8.2 Review of Methods

The following principles, as outlined by Wolman and Miller (1960), form a reasonable basis for reviewing various methods available for calculating the channel maintenance flows:

- Channel maintenance flows are needed in the range between streamflows that begin to mobilize bedload materials and the highest natural flow on record.
- Incrementally higher percentages of flow are needed as flow approaches bankfull, because that is when the river does most of its work in transporting sediment and maintaining fish habitat.
- Ideally, a range of flows is needed (as opposed to a single, specified high flow). Though higher discharges move more sediment, they occur less frequently, so that over the long-term, they move less bedload than more frequent, lesser discharges.

The Technical Team reviewed several well-documented sediment transport models that can be used to determine flows that move bed material. These included, among others:

- HEC-6 (US Army Corps of Engineers 2001a);
- Bed Material Transport Methodology (Reiser et al. 1988);
- Incipient Motion Methodology based on the Meyer-Peter Mueller formula (Meyer-Peter and Mueller 1948, Reiser et al. 1988); and
- Rosgen geomorphic stream classification system (Rosgen 1985, 1994, 1996).

The Instream Flow Council suggests all these methods are acceptable for determining channel maintenance flows (Annear et al. 2002). In addition to the above methods, an approach used by the U.S Forest Service (Gordon 1995), and an approach used by the State of Wyoming, (Annear and Day 2000) were reviewed. These appeared to be promising in that they take into account the pattern of natural flow variability (i.e. duration, frequency, magnitude and timing).

All the methods are useful and if properly applied, should provide meaningful guidance. Some will provide channel maintenance instream flow recommendations. The Rosgen geomorphic stream classification system is a classification system rather than a method to define site specific instream flow recommendations. From the review it was found that some of the methods are data intensive. As directed by the SSRB Steering Committee, no additional data could be collected for this study. Therefore, the HEC-6 model could not be used. Data did exist from previous studies, however, that allowed for the use of a type of sediment transport model. The application of this approach is described in detail in Section 8.3.

The Wyoming Fish and Game Department (Annear and Day 2000) developed a channel structure flow model based on the one developed by Leopold, as described by the U.S. Forest Service (1994) and Gordon (1995). The original model used the average annual flow as the flow at which bed-material movement begins. Emmett (1975) recorded movement of fine sediment (silt and sand) at the mean annual flow, which related to 0.25 of bankfull discharge, for the Snake River, Idaho. Other studies have defined the channel maintenance flow where coarse particles begin to move to be in the range of 0.5 to 0.6 times the bankfull discharge (Ryan 1996, Leopold 1994, Andrews and Nankervis 1995). The average annual flow term in the model was re-defined by the Wyoming Fish and Game Department as the bed material mobilization flow and was assigned a value of 0.5 times bankfull flow.

In a recent study in Alberta, the Wyoming model was investigated as a possible tool to define channel maintenance flows for the Highwood River. Clipperton et al. (2002) reported that, as a general rule, the movement of bed material in east slope streams in Alberta, such as the Highwood River, begins at flows that are greater than average annual flows. Therefore, certain parameters were modified and at the study site in question, 28.3 m^3/s was used for the bed material mobilization flow parameter and 152.9 m^3/s was used as the bankfull flow (Alberta Environment 1993). These parameters were used in the following modified version of the Wyoming model:

$$Q_{cs} = \left\{ (Q_n) \bullet \left[\frac{(Q_n - Q_m)}{(Q_b - Q_m)} \right]^{0.1} \right\} \qquad \text{Equation 8.1}$$

Where:

Q_{cs} = Recommended channel maintenance flow

Q_n = Natural streamflow (Mean Weekly Flow in Highwood Study)

Q_m = Bed-material mobilization flow

Q_b = Bankfull flow

For this approach, the instream need for flows in the range between bankfull and the 25 year recurrence flow are set to the actual flow that maintains floodplain function and stream channel form (Annear and Day 2000, U.S. Forest Service 1994). On the basis of the Wyoming analysis, all flows between bankfull and the 25 year flood flow (509.7 m^3/s) are required as an instream flow need for channel maintenance. At flows greater than the 25 year flood flow, only the 25 year flood flow is needed. An example of the channel maintenance instream flow needs, as determined with the modified Wyoming model, are illustrated, and compared with the natural flows for Week 21 in Study Site 4 of the Highwood River, as shown in Figure 8.1

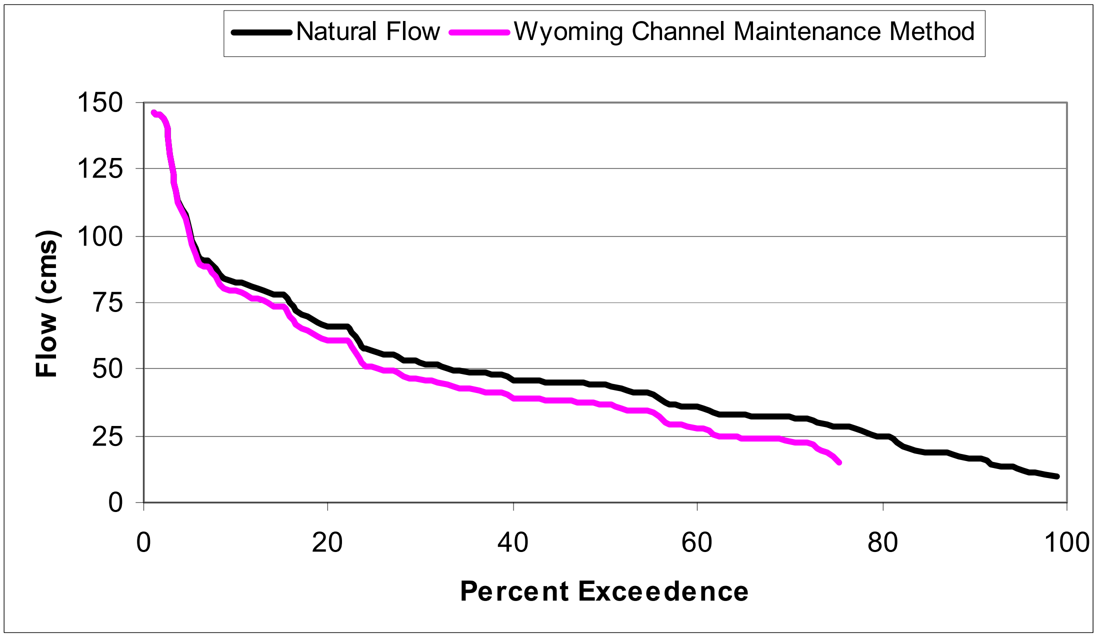


Figure 8.1. Example of channel maintenance instream flow needs, determined using the modified Wyoming Model, for Week 21 in Study Site 4 of the Highwood River Channel (Source: Clipperton et al. 2002).

8.3 Calculating a Channel Maintenance Flow (CMF), Shields Method

Although each of the reviewed methods holds promise for use in the SSRB, the more detailed methods could not be used due to data requirement limitations. It was therefore decided to adopt a sediment transport model similar to the one used in a recent study on the Highwood River (Clipperton et al. 2002). In that study, channel maintenance flow recommendations were based on a channel maintenance flow method as outlined in a report prepared by Northwest Hydraulics (Neill and Yaremko 2001). As stated in this reference,

> *"Quantification of bed mobility is fundamental to consideration of channel maintenance. Understanding how bed load and suspended loads of sediment behave naturally allows the investigator to make rational assessment of the potential impact of changes in hydraulic parameters".*

The study used an incipient motion method based on the Shields entrainment function (S_N) (Shields 1936). The Shields equation is:

$$S_N = hS/(s-1)D$$ Equation 8.2

Where: S_N = Shields Number

h = mean depth of flow
S = Hydraulic gradient (Channel Slope x 0.85)
s = Dry density of bed material
D = D_{50} of the bed material size distribution

Values for D_{50}, h, S, s and Q (discharge) for each reach in the SSRB are provided in Appendix F. Appendix F also shows the calculation of S_N for different discharges for each reach. It is acknowledged that the absolute initiation of motion is difficult to define, even in a laboratory setting. The following values of S_N are generally accepted as indicators of different levels of bed activity:

$S_N = 0.03$	Occasional grain movement
$S_N = 0.045$	Effective beginning of transport
$S_N = 0.06$	General transport of all sizes

For each reach, hydraulic data parameters (hydraulic gradient, mean depth of flow) were obtained from either an existing hydraulic database, a flood risk study, or in some cases, from sources such as Kellerhals et al. (1972). The bed material data were mostly taken from Shaw and Kellerhals (1982).

Calculation of the Shields equation is straightforward for wide, straight and uniform channels with flat beds. In these cases, the hydraulic resistance is derived from the roughness of the gravel surface and the slope is taken as the channel slope (energy gradient). In natural rivers, additional sources of resistance, such as bends, cross sectional and profile irregularities, and bed forms, consume additional energy. Therefore, in these cases “S” is taken as a portion of the total slope for effective bed movement. In this analysis, effective slope was taken as 0.85 of the channel slope.

The S_N values are mainly influenced by D_{50} values and by the effective reach slope (0.85 x S). Therefore, reliable D_{50} values are needed to accurately calculate S_N values. Most of the available data used in this analysis is based on localized reach values (S and D_{50}), usually near a Water Survey of Canada gauge site. However, these sites may not be representative of the whole reach under consideration. Detailed reach surveys are required to capture the variability of the hydraulic parameters (h, S, D_{50}) to incorporate in the determination of channel maintenance flows.

To provide a measure of bed mobility, the Shields Number was calculated for a range of flows at each cross-section, using 0.85 of the average reach slope as described above. Results are shown in Figures 8.2 – 8.5. These plots show the relationship between the calculated Shields Number and discharge for the Red Deer, Bow, Oldman, and South Saskatchewan rivers respectively. The plots show the variability of the S_N values with discharge for different reaches of each river. Horizontal lines are drawn on these plots to show different levels of bed material movement.

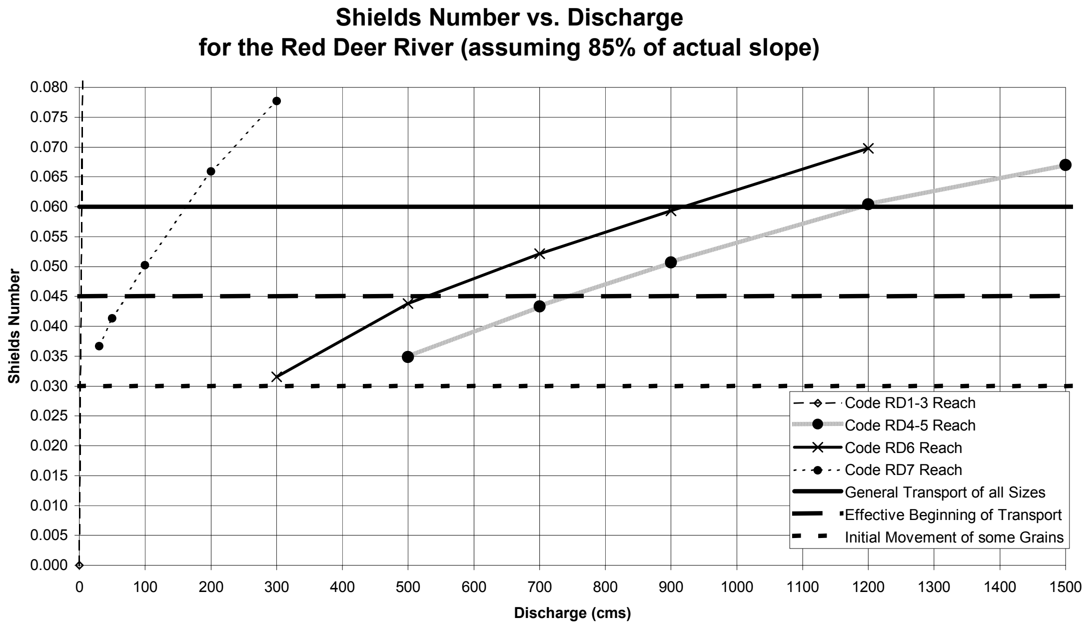


Figure 8.2. Shields number versus discharge relationship for the Red Deer River.

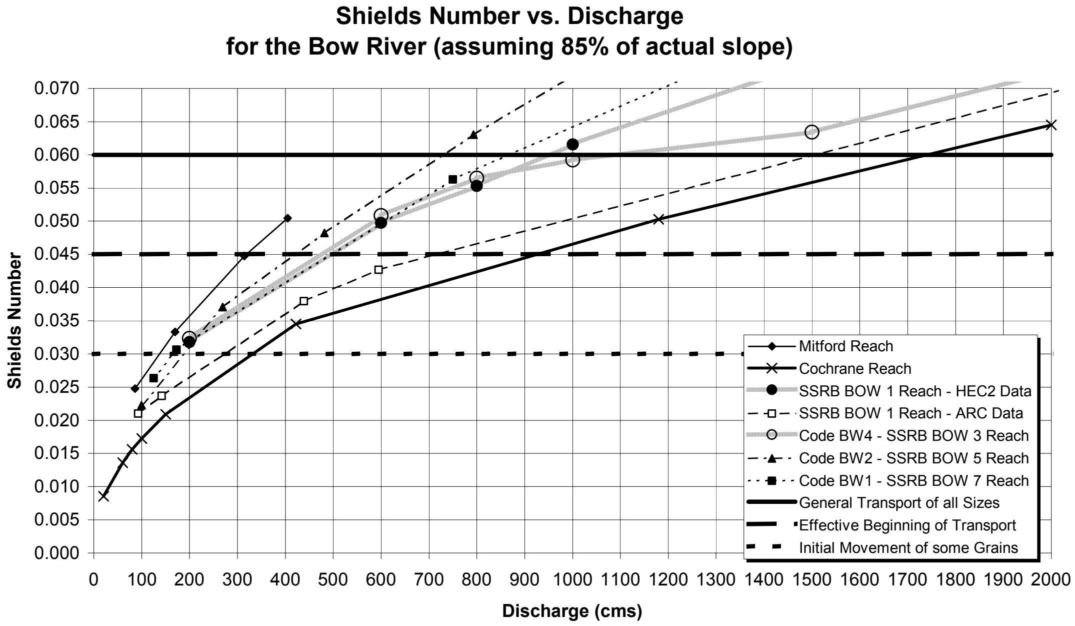


Figure 8.3. Shields number versus discharge relationship for the Bow River.

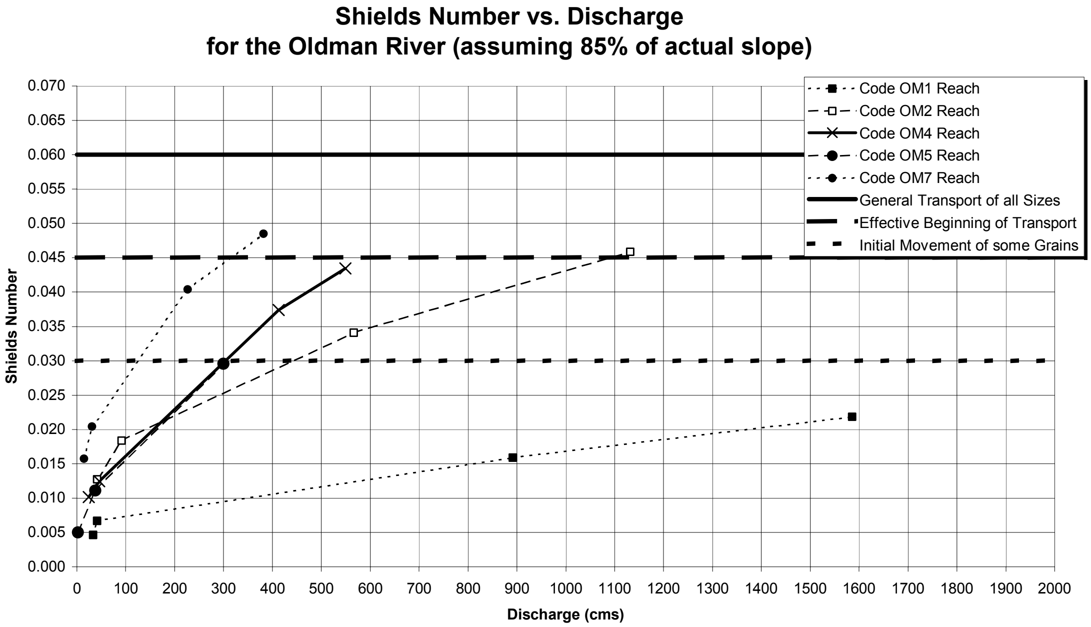


Figure 8.4. Shields number versus discharge relationship for the Oldman River.

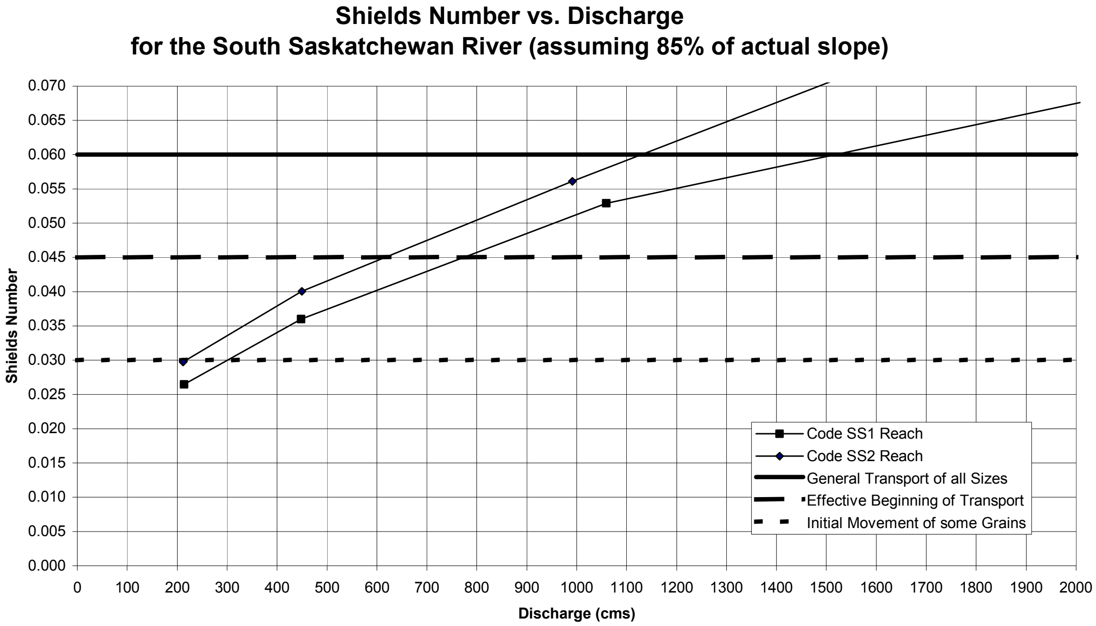


Figure 8.5. Shields number versus discharge relationship for the South Saskatchewan River.

8.4 Summary of Channel Maintenance Flows for SSRB Reaches

The Shields Equation generates a flow magnitude, but does not stipulate the timing or duration of the needed flow. The frequency of the calculated CMF values was approximated from the nearest flood frequency curves (Kellerhals et al. 1972). These frequency curves are based on maximum instantaneous flows, whereas the flow duration curves used in IFN are based on weekly flows. The required duration of the channel maintenance flow was not calculated in this study, due to the lack of daily flow data. In the literature reviewed (Neill and Yaremko 2001), it has been suggested that the natural duration of the CMF should be maintained. Therefore, it is recommended that the natural duration of the prescribed CMF flows be determined before any implementation of IFN determinations is initiated.

The discharges corresponding to S_N values of 0.045 (beginning of transport) and 0.06 (general bed movement) were derived from the plots in Figures 8.2 to 8.5 and are summarized in Table 8.1. The lesser flow values related to $S_N = 0.045$ and the higher flow values related to $S_N = 0.06$ are given as the CMF flow range in Table 8.1. From a review of Table 8.1, it is not possible to establish any general relationship between the S_N values and the flood frequencies (2- and 5-year return interval flows). The only exception is the Bow River, where the initiation of motion (S_N=0.045) closely relates to the one in two year flow. A number of factors contribute to this discrepancy, especially the lack of general reach hydraulic data (h, S, D_{50}). Flood frequencies are also localized (WSC gauge site) and based on flow records only up to 1972 (Kellerhals et al. 1972). Re-assessment of the flood return intervals, after updating flow data files to include the most recent flows, may help clarify these relationships.

As shown in Table 8.1 and illustrated in Figure 8.6, the data for the Belly, St. Mary and the Waterton rivers were insufficient to calculate channel maintenance flows. Therefore, an estimate for the CMF flows was made using the 5 year return interval flow as the bankfull flow, from the nearest gauge data available (Kellerhals et. al., 1972). This was based on the assumption that in this case, the bankfull flow will provide a close approximation of CMF.

8.4.1 Overbank Flows Needed for Geomorphic Activity

Overbank flooding is vital to sustain channel meandering and overbank processes. The data in the current study are not detailed enough to determine the bankfull flows accurately and specify a level of overbank flow that will maintain the overbank processes. From a review of the literature, and from general observation, a flow equivalent to 125% of the bankfull flow is considered sufficient to maintain the overbank processes. Experience from a number of floods in Alberta shows that once a flood is overbank, channel meandering, bank erosion, channel cutoffs, and overbank deposition of silts and sands become prominent. The Technical Team believes 125% of bankfull maintains the erosion and deposition processes needed to support the long term viability of cottonwood forests (Section 7.1).

Table 8.1. Recommended channel maintenance flows (CMF).

REACH DESCRIPTION	Reach Codes	CMF Range* (m^3/s)	2 Year Return Flow (m^3/s)	5 Year Return Flow (m^3/s)	COMMENTS
Red Deer River					
Dickson to Medicine River	RD7	70-160	266	505	Sand bed, based on 1 in 5 year flow
Medicine River to Blindman River	RD6	530-920	284	552	
Red Deer to Drumheller	RD4 & 5	750-1200	431	793	
Drumheller to border	RD1 - 3	679			
Bow River					
WID to Highwood	BW4	460-1050	413	821	
Highwood River to Carseland	BW3				No D_{50} data for BW3
Carseland to Bassano Dam	BW2	410-730	481	792	
Bassano to Mouth	BW1	490-860	750		
Oldman River					
Dam to Pincher Creek	OM7	320-590	226	382	
Pincher Creek to LNID	OM6				No data
LNID to Willow Creek	OM5	530-?	300	577	
Willow Creek to Belly River	OM4	549-?	413	549	
Belly River to St. Mary River	OM3				No data
St. Mary River to Little Bow River	OM2	450-?	566	1132	
Little Bow to Grand Forks	OM1	580-?	891	1582	
Belly River					
St. Mary Canal to Mouth	BL1, 2 & 3	100		100	Poor Hydraulic data. CMF based on 5 Year flow
St. Mary River					
Reservoir to Mouth	SM1 & SM2	175		175	Poor Hydraulic data. CMF based on 5 Year flow
Waterton River					
Reservoir to Mouth	W1 & W2	153		153	Poor Hydraulic data. CMF based on 5 Year flow
South Saskatchewan River					
Grand Forks to Medicine Hat	SS2	620-1140	1085	2265	Riverbed material is fine (D_{50}~0.25mm).
Medicine Hat to Red Deer Confluence	SS1	770-1340	991	2123	

Notes: * FLOW RANGE – Flows needed for initiation of motion to fully developed in-depth bed movement, based on Shield's Number range of 0.045-0.060.

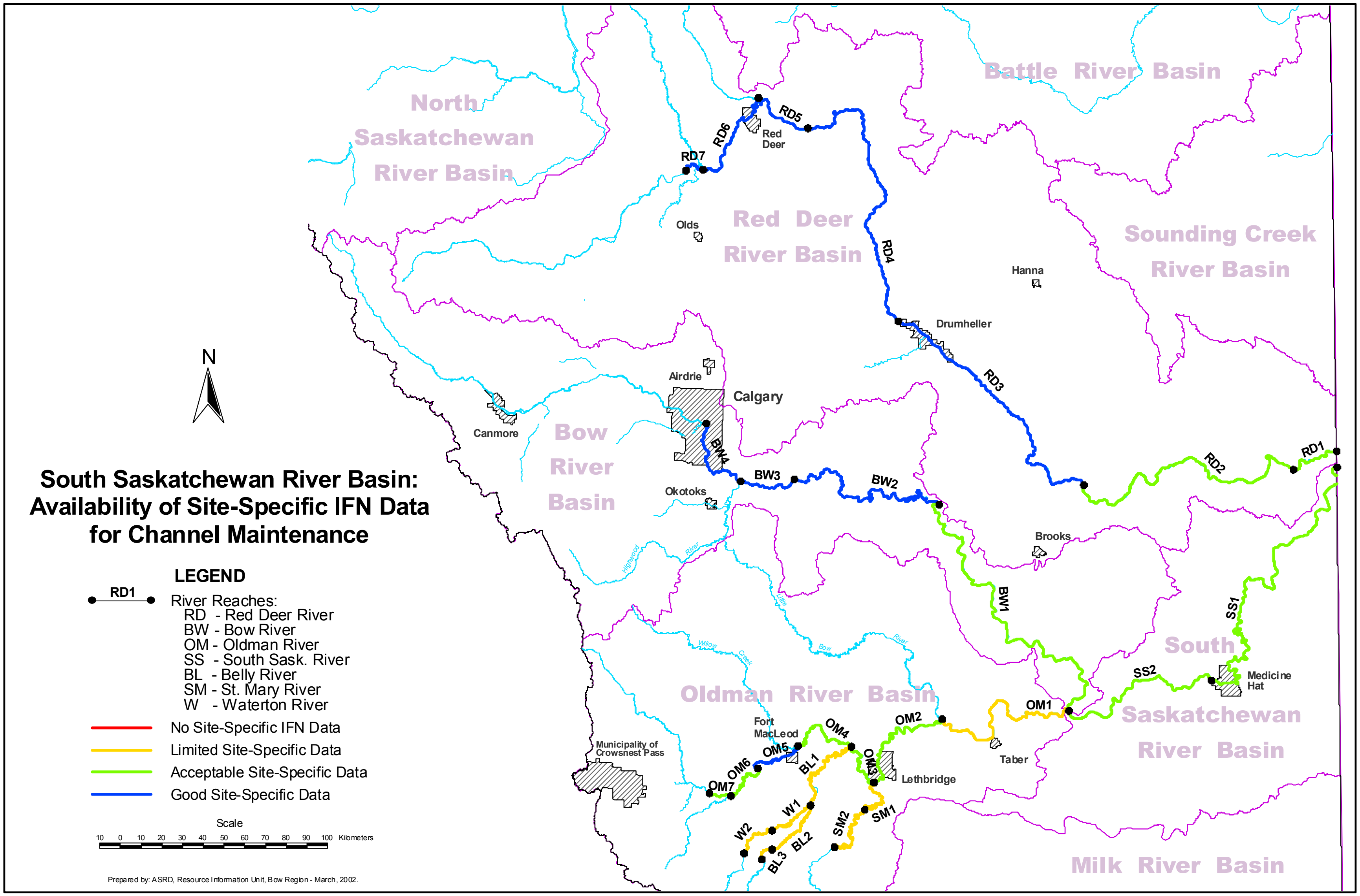


Figure 8.6. Availability of site-specific data required for the Shield's equation to calculate the channel maintenance flows.

8.5 Conclusion and Recommendations

For the purpose of this study, the channel maintenance flow was defined as the flow that maintains the physical characteristics of the channel so that the ability of the channel to convey streamflow and bedload is maintained.

Shields bed mobility criteria were adopted to determine the channel maintenance flows for the reaches of the SSRB study. This decision was based on the fact that insufficient hydraulic reach data (cross-sections, slope, and bed material size data) were available to implement more detailed procedures for the study reaches. The data used in the analysis were extracted from isolated reach studies and were assumed to apply to the full reach length under study.

The CMF values given in Table 8.1 specify a range of flows between the beginning of sediment transport and general bedload transport. These values represent the range between flushing flows and channel maintenance flows referred to in the literature. The higher flow value is the prescribed CMF for each reach considered.

The CMF values in Table 8.1 show no consistent correlation with either the 2 year or 5 year return flow. A lack of reach specific hydraulic and flow data is considered to be one of the main reasons for the lack of correlation. The data in Table 8.1 show that the 5 year return flow approximately covers the upper range of the calculated CMF. Therefore, the 5 year return interval flow is the recommended criterion for CMF when insufficient data are available to calculate the CMF using the Shields method.

No analysis was done to determine the duration and frequency of the CMF calculated. It is recommended that natural duration of the calculated flows should be maintained until a comprehensive analysis can be completed.

A flow equivalent to 125% of bankfull flow is recommended to maintain overbank geomorphic activity.

It is recommended that detailed hydraulic and hydrologic data be collected for all study reaches. The collected data should then be used to:

- Enable determination of CMFs for all study reaches within the SSRB;
- Improve our understanding of the correlation between CMF determinations and the 2 and 5 year return interval flows;
- Allow the implementation of more rigorous methods for making CMF determinations;
- Facilitate an analysis of the high flow requirement (125% bankfull) to support fluvial geomorphic activity;
- Permit investigation of the frequency and duration characteristics of CMFs that need to be met; and
- Clarify the relationship between instantaneous CMF values and those proposed for modelling on a weekly time step.

9.0 INTEGRATED AQUATIC ECOSYSTEM IFN

9.1 Background

As outlined in Section 4, there is a growing body of evidence to indicate that if protection of the aquatic ecosystem is the management goal for a river system, there must be a consideration of the interdependence between ecosystem components and processes, rather than the traditional narrow focus on fish habitat or water quality criteria. The case has been made that a single minimum flow determination does not result in the long term maintenance of the resource the recommendation was intended to protect (Stalnaker 1990, Annear et al. 2002). In those situations where a simple minimum instream flow objective has already been prescribed, based on only fish habitat or water quality criteria, a review of the IFN to incorporate the most recent scientific advances would be prudent. This was an essential task for the Technical Team for the SSRB WMP, where many reaches have instream flow objectives based on historical approaches.

9.2 IFN Integration Method

In spite of the wide recognition by IFN practitioners of the need to consider all elements of the aquatic ecosystem in defining an IFN, there is no universally accepted method for combining the different ecosystem components to develop an integrated flow recommendation.

The method developed by the SSRB Technical Team for integrating the different ecosystem IFN results is a straightforward process that generates results in a flow duration curve format, using a weekly time step compatible with the WRMM format. Inclusion of the IFN determination in the WRMM will only show whether or not various water management scenarios support meeting IFN targets. Operational details have not been considered at this point in the analysis, and are beyond the scope of the current report.

In general, water quality IFN determinations are provided as a single value for each week of the year for each reach where data were available. They are typically in the low flow range. Water quality values are often available for both winter and the open water seasons. The fish habitat IFN determination is a variable flow curve applied seasonally for each week in the open water season, excluding the typical spring freshet period. It generally applies to the moderate and low flow range. The riparian IFN determination is also a variable flow curve and is applied only during the growing season in the spring and summer, including the highest flow range. There was typically some overlap among the components, although one component often became the primary driver of the ecosystem IFN on a seasonal basis. The channel maintenance IFN determination was provided as a threshold flow, with a specified duration and frequency of occurrence. The channel maintenance IFN was not readily incorporated into a weekly duration format. Instead, a comparative analysis was conducted to ensure the IFN determination, using the riparian vegetation curve at the higher discharges, provided adequate flows for channel maintenance.

Both the fish habitat and riparian IFN determinations identified a base flow, below which no further reduction in flow is recommended. These are the uncommon low flow events that naturally stress a population and may limit overall population size. In situations when the natural flow is below these base flow determinations, the final integrated ecosystem IFN will be the same as the natural flow and no flow reductions are recommended. In most cases, the integrated IFN flows are always below or equal to the natural flow. The exception to this rule are flows that are required to meet the water quality IFN determination, based on the current loadings in the system (e.g. see Figures 9.1 and 9.2). Although the cases when water quality IFN exceeds the natural flow are typically limited to the winter weeks, it can also occur in the summer during dry years.

The IFN data for fish habitat, riparian vegetation, water quality, and the winter Tessmann values were entered into a spreadsheet for analysis. The recommended IFN value for each ecosystem component was compared, on a week by week basis, for every data point in the period of record. The component with the highest flow recommendation was selected as the flow value for the integrated IFN. The integrated flows were then sorted into weekly flow duration curves. In the simplest case, when all ecosystem components had IFN numbers available, the ecosystem component with the highest flow requirement defines the integrated IFN at that point (Figure 9.1).

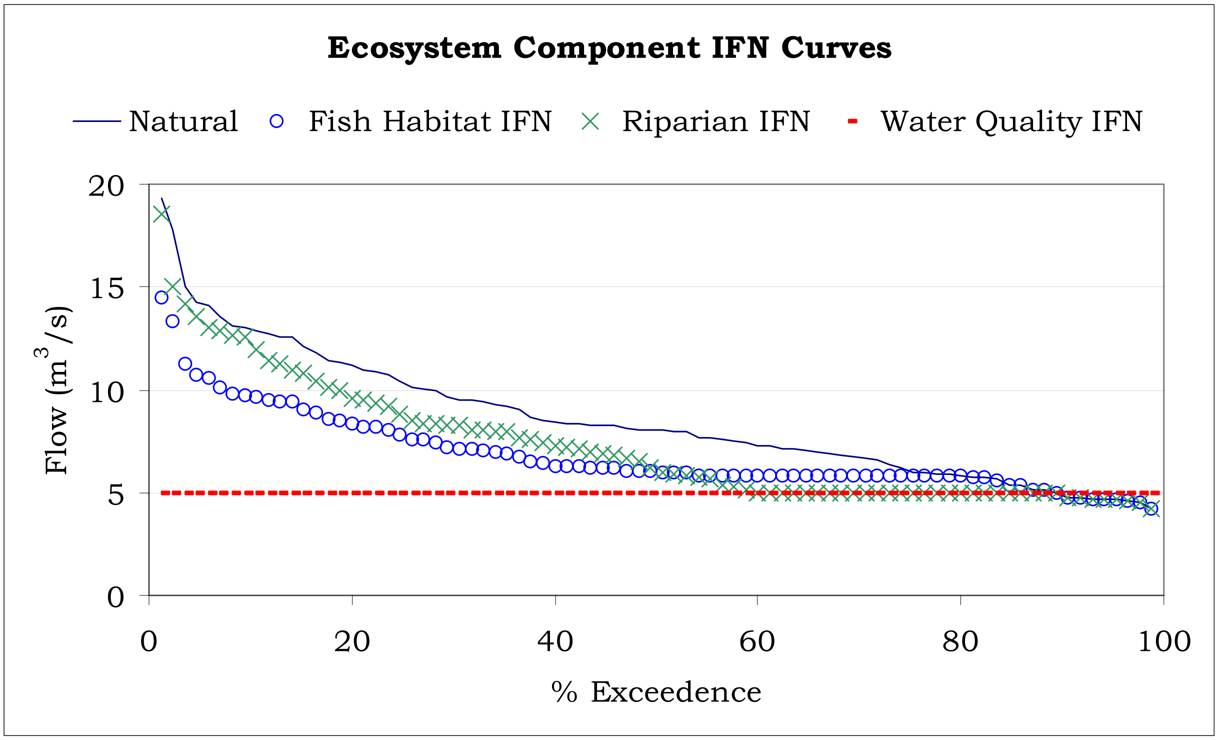
However, not every component has data available, or suitable, for the entire year or for every reach under review. As an example, the riparian IFN determination was only applied during the period when the riparian poplars are not dormant. Therefore the integrated IFN only has a riparian component incorporated during weeks 15-37 (early April to mid-September). The fish habitat derived IFN values were not applied during the spring freshet period (typically mid-May through mid-July) for every reach under review. Therefore, the integrated IFN during the spring is often defined entirely by the riparian IFN determination, regardless of the flow. This reflects the seasonality of the hydrograph and the corresponding biological functions that have adapted to the timing of high flows, such as riparian poplar recruitment.

Although a fish habitat IFN determination is not made during the spring freshet using fish habitat information, these flows are still necessary for fish and other aquatic biota. They form and maintain the habitats and energy pathways that define the aquatic ecosystem. Fish habitat data were also not available for the winter weeks, and the integrated IFN is comprised entirely of either the water quality IFN determination or an office based method for fish habitat (the Tessmann calculation).

An annual hydrograph showing the typical chronology of each of the ecosystem components and the resulting integrated ecosystem IFN is presented in Figure 9.2. Of particular note in Figure 9.2 are the seasonal distribution of the ecosystem component IFN determinations and the flow magnitude distribution shown in Figure 9.1. In this example for the Oldman River near Monarch (reach OM4), there is no fish habitat IFN determination for weeks 17-28 inclusive.

Figure 9.1 provides an example of how the integration process follows the basic criteria for selecting component values, to build the integrated IFN related to both timing and flow magnitude. However, this general pattern of integration does not occur in all cases. As an example, the water quality IFN can often be below both the fish habitat and riparian IFN for most of the year, and not form part of the integrated IFN curve. Another common pattern was that the fish habitat and riparian curves were very similar in some flow ranges, and the two curves occasionally crossed back and forth. As a result, a clean transition between ecosystem components as illustrated in Figure 9.1 does not always occur.

Another consequence of the integration process is that similar IFN flows can be prescribed by any of the three components, depending on the time of year (Figure 9.3). The reason for this pattern is two-fold: first, not all components provide an IFN determination for every week of the year; and secondly, the hydrograph is seasonal. The second reason refers to the fact that a flow of a given magnitude may be greater than normal at one time of the year, but that very same flow value may be much below normal at a different time of year.



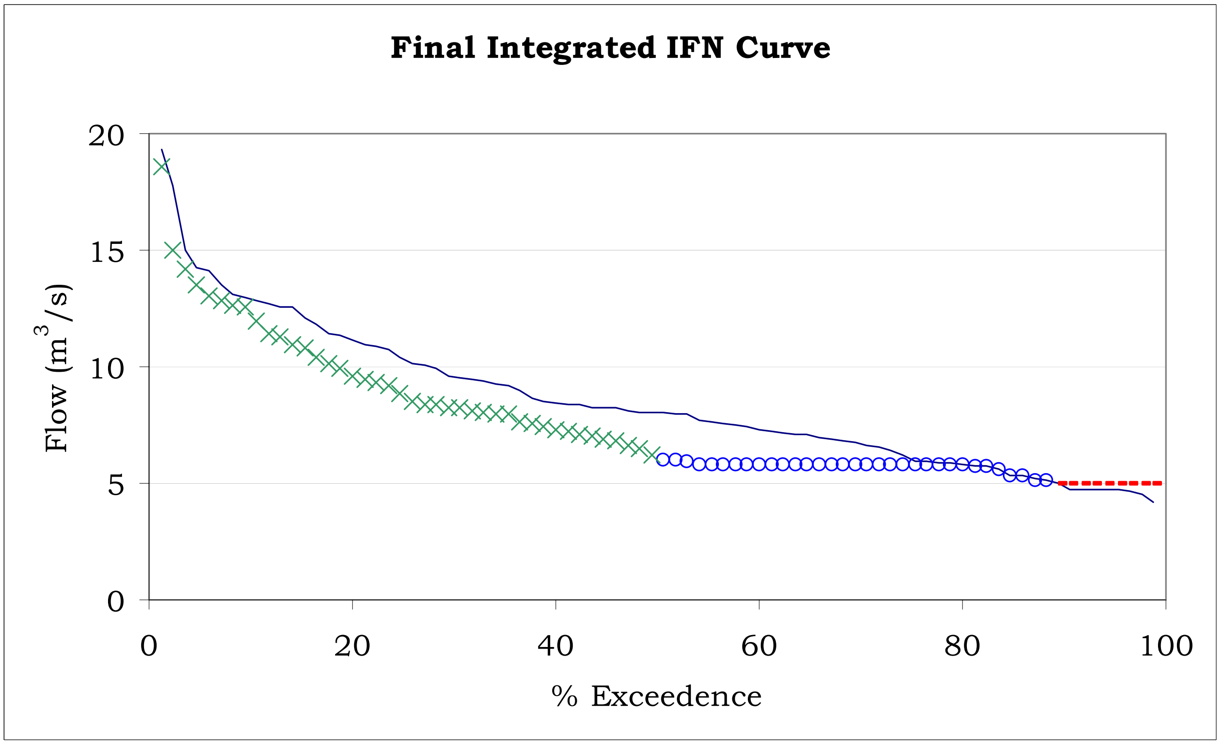
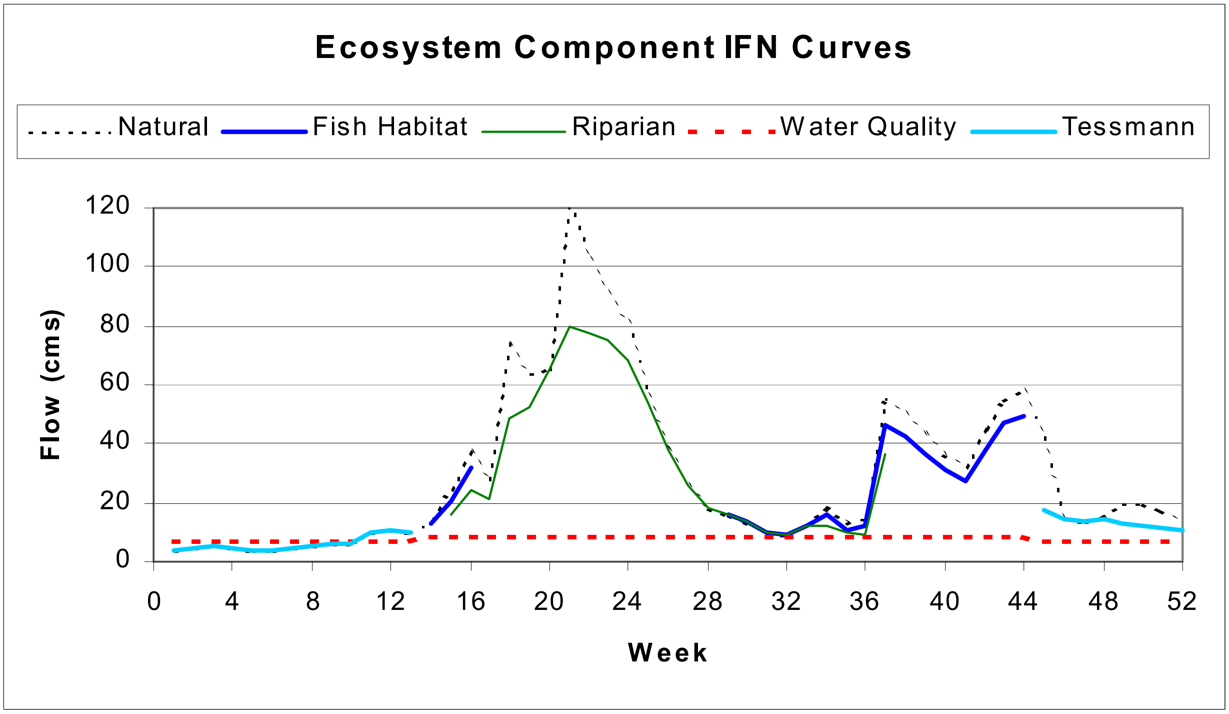


Figure 9.1. Illustration of how each ecosystem component was integrated into the final ecosystem IFN curve for Week 33 on the Belly River near Standoff (reach BL2).



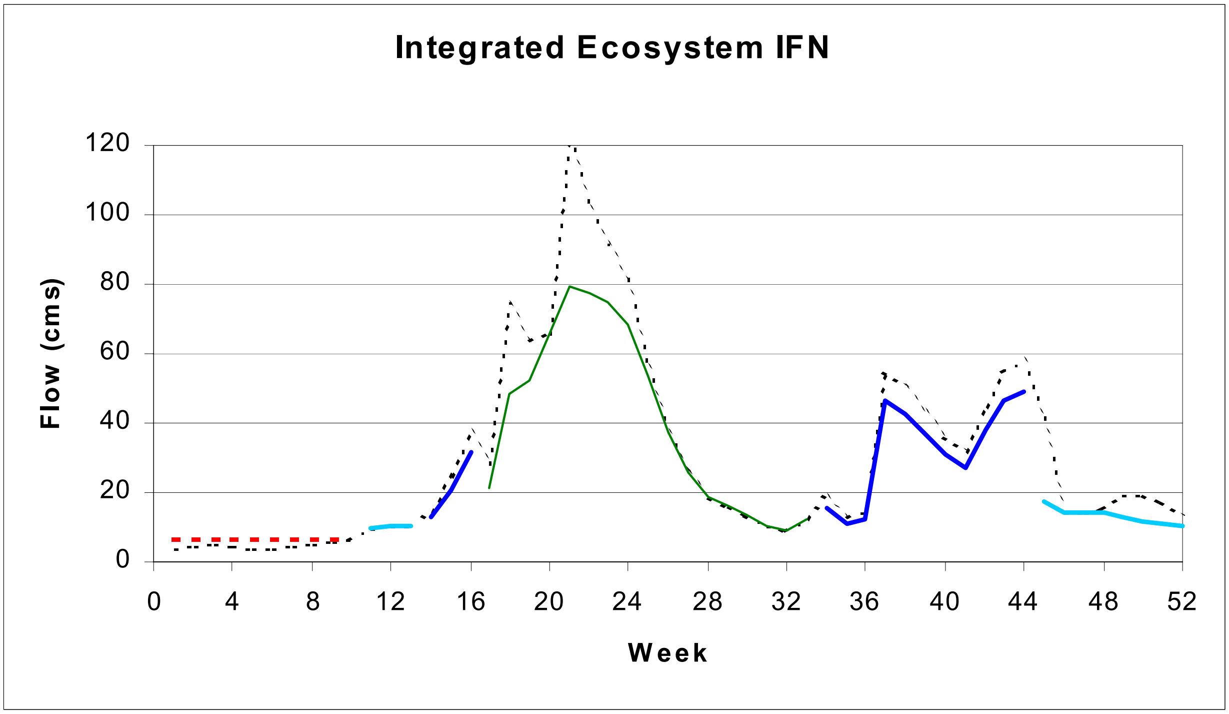


Figure 9.2. Illustration of the seasonality of each ecosystem component (top graph) for 1985, a drier than average water year (based on the mean annual flow) and the resulting integrated ecosystem IFN (bottom graph). The Oldman River near Monarch (OM4).

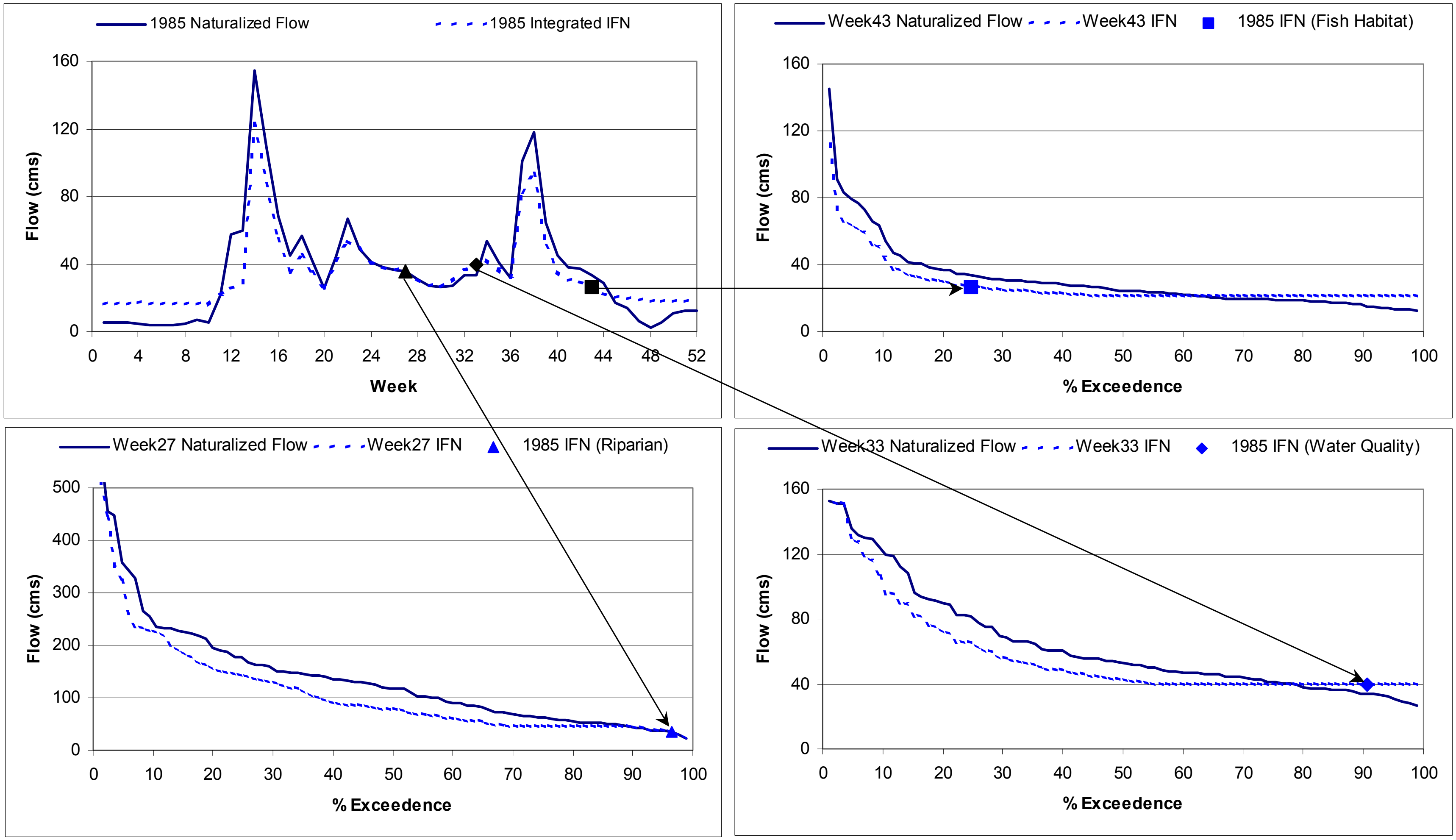


Figure 9.3. An illustration of the seasonality of the naturalized hydrograph and the resulting integrated ecosystem IFN for the Red Deer River (reach RD3) using 1985, a drier than average year. The weekly duration curves indicate the individual ecosystem component that determined the IFN for that week in 1985.

As discussed in previous sections, the seasonal timing of flow magnitude can be very important biologically. A relatively high flow occurring in the late fall may not be as important to some biological processes as it would be if that same flow had occurred during the spring freshet, when many biological functions are directly linked with high flow events. Therefore, the IFN determination would be expected to indicate that little water should be removed from the river in the spring to protect riparian processes, but that a greater reduction would be acceptable in the late fall, depending on the site-specific fish habitat and water quality requirements.

Figure 9.3 provides an example of this situation on the Red Deer River at Drumheller (Reach RD3) for 1985, a drier than normal year. In week 27 at the beginning of July, a flow of 35.9 m^3/s is an uncommonly low flow (~96% flow exceedence). The resulting IFN determination is therefore the same as the naturalized flow at 35.9 m^3/s, based on riparian IFN requirements. For week 33 in mid-August, the flow is once again uncommonly low at 33.6 m^3/s (~91% flow exceedence). However, at this time in the summer, water quality becomes a greater concern and the resulting IFN is increased over the naturalized flow to 39.9 m^3/s to meet IFN requirements for water quality. In week 43 at the end of October, when the flows in the Red Deer River are normally low, the naturalized flow at 33.4 m^3/s is higher than average for that time of year (~25% flow exceedence). The resulting IFN determination allows for a reduction to 26.7 m^3/s based on the fish habitat IFN results.

Although the naturalized flows in Figure 9.3 for the three weeks indicated are very similar (35.9, 33.6, and 33.4 m^3/s), the resulting IFN determination and the ecosystem component that defines the integrated IFN for each week are quite different. This is due to the seasonality of the natural hydrograph and the seasonality of each ecosystem component. In the other weeks of the year it can be seen in Figure 9.3 that the IFN varies, depending on both the natural flow and the time of year. The rationale for this is provided in Section 4 and is also discussed throughout the report. In essence, the reason the IFN varies within each year is to protect the intra-annual flow variability to which the riverine ecosystem is well adapted. The other component of flow variability that the Technical Team identified as critical for the protection of the aquatic ecosystem is the inter-annual, or between years, flow variability. As witnessed in Alberta in the last decade, there were years of very high flows, such as 1995 in the Oldman River sub-basin, and drier years, such as 2002 was for many locations across the province. The ecosystem IFN is designed to protect both this inter-annual flow variability and the intra-annual seasonality of flows.

To help explain this step, Figure 9.4 illustrates three consecutive flow years for the Oldman River near Monarch (OM4). From 1988 through 1990, the Oldman River experienced a very dry year (1988), a slightly drier than average year (1989), and a wetter than average year (1990), based on the mean annual flow. If a single week of the year is taken, such as the first week in June (week 23), and all available flows for every year that data are available are sorted from highest to lowest, a flow duration curve is generated (Figure 9.4). The flows from the three years indicated above can be identified as points on the duration curve. The exceedence values for week 23 in 1988, 1989 and 1990 were 86%, 49%, and 27% respectively. Using the IFN exceedence curve for week 23, a different IFN flow is prescribed for that week in each of the three years (Figure 9.4). These different flows protect long term inter-annual flow variability.

The exact component and the time of year that each component contributes to the IFN should not be of concern because the end goal of the Technical Team is to provide a singular ecosystem IFN curve that should be viewed as protecting the entire ecosystem on a seasonal and inter-annual basis. The Technical Team produced an IFN evaluation for each component separately, but always with the intent that the individual results would be used to form an integrated ecosystem IFN determination that would protect the complex physical and biological interactions of a natural aquatic ecosystem.

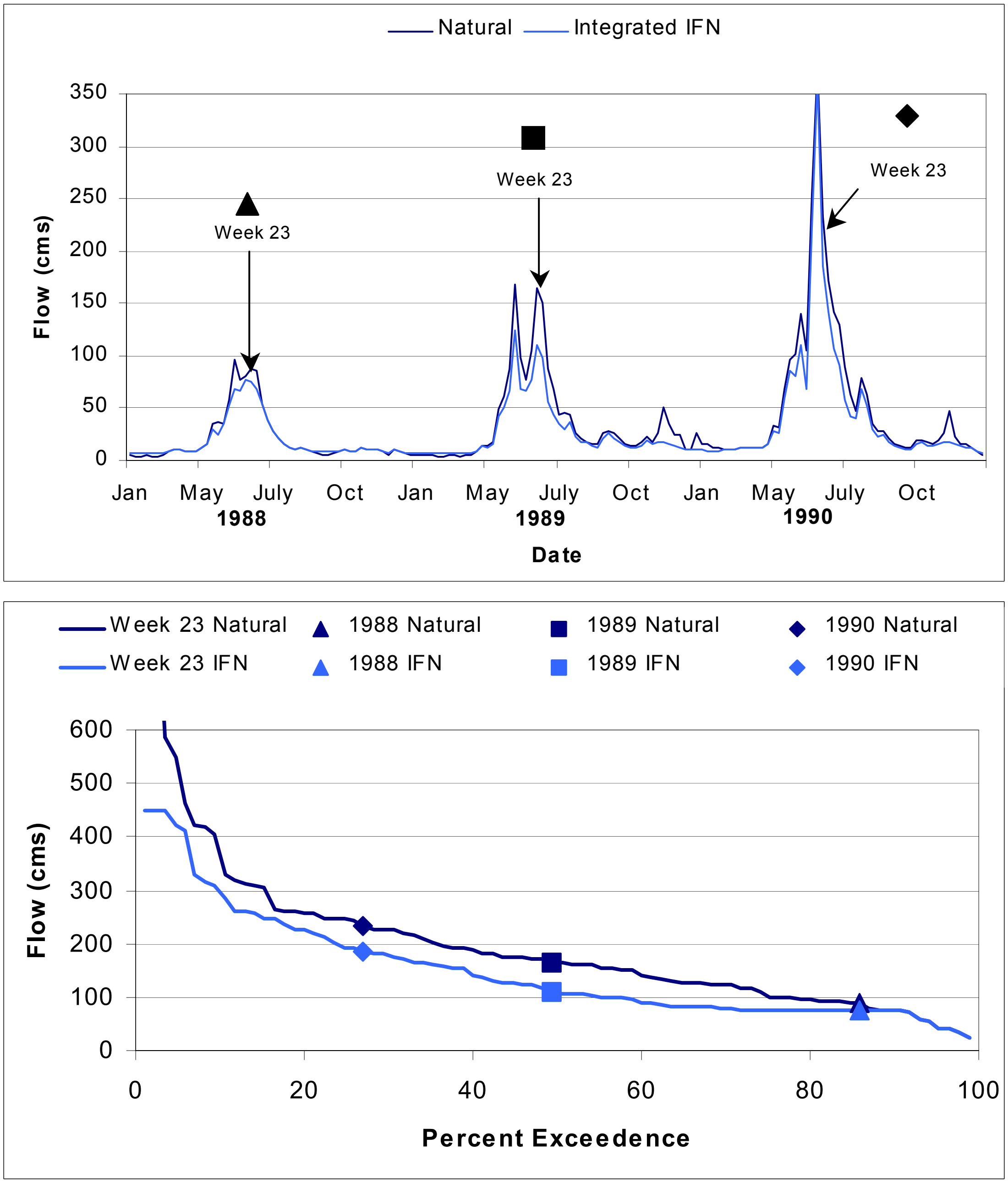


Figure 9.4. An illustration of inter-annual flow variability (top graph) for a dry (1988), average (1989) and wet (1990) flow year for the Oldman River near Monarch (reach OM4) and the associated flow duration curves (bottom graph) for week 23 illustrating the variable ecosystem IFN determination.

9.3 Integrated Ecosystem IFN Determinations

Using the approach described above, an integrated ecosystem IFN determination was derived for each week, for each of the 27 reaches being evaluated as part of the SSRB WMP (see Tables 3.1-3.5 for reach descriptions). Due to the site-specific hydraulics, channel form, species composition or locations of nutrient loadings, the IFN will vary both from week to week and from reach to reach. An ideal pattern would result if the IFN followed a pattern similar to the hydrology from upstream to downstream, that is, IFN prescriptions would increase progressively with distance downstream. This is not always the case. In some instances, the IFN can decrease from one reach to the next downstream reach, and then increase again for the following downstream reach. The IFN determinations were not ‘balanced’ from upstream to downstream to adjust or account for these differences. However, this is a necessary step before proceeding into the next phase of water management planning for both the main stems and the tributaries.

A representative reach was selected for each of the main rivers assessed, to illustrate the integrated IFN results within each sub-basin. The selection of representative reaches was done, in part, by using the overall availability of the site-specific data for each reach. A map indicating overall data availability is provided in Figure 9.5. The evaluation of available input data required to make a site-specific IFN determination was made for each component using four categories: no site-specific data or modelling (score = 0), limited site-specific data or modelling (score = 1), acceptable site-specific data or modelling (score = 2), and good site-specific data or modelling (score = 3). The rating provided in Figure 9.5 is based on the sum of the individual component evaluations, and the category scores are then defined as 0-3, 4-6, 7-9, and 10-12 for no data, limited data, acceptable data, and good data respectively.

The availability of input data for each component is evaluated slightly differently. The water quality evaluation is based primarily on available modelling information that is used for IFN evaluations, rather than on the availability of water quality data. Most reaches have sufficient water quality data, but for some reaches, such as for the lower Bow River and the South Saskatchewan River, the modelling required to develop the water quality IFN has not been done. For fish habitat, the evaluation is based on the availability of PHABSIM modelling data. For reaches with no PHABSIM data, the provincial standard office-method (Tessmann) was applied. Within the riparian IFN process, the lack of site-specific IFN data indicates an inability to verify flow determinations. However, the robustness of the riparian model on other reaches suggests that although additional validation work is needed before refining IFN estimates, the determination provided is adequate for a planning level study. For reaches with no channel maintenance data, the 5 year return flow was used as the surrogate against which integrated IFN determinations were compared.

Although it is indicated in Figure 9.5 that no data or limited data are available for determining IFNs for some reaches, it should not be concluded that the IFN provided is not valid. In situations where site-specific data or modelling are not available, an acceptable surrogate has been found that is adequate to define the flows required for ecosystem protection in a planning level study.

A sample reach for each sub-basin is provided in Figures 9.6 through 9.12. The natural flow exceedence curve and the integrated ecosystem IFN determinations are shown for weeks 9, 23, 33, and 40 of each sample reach, to illustrate seasonal variability. Week 9 at the beginning of March is included to represent the winter low flow period. Week 23 at the start of June is used to represent the freshet weeks, typical of the spring and early summer. Week 33 in mid-August is used to represent the late summer conditions. Week 40 at the beginning of October is used

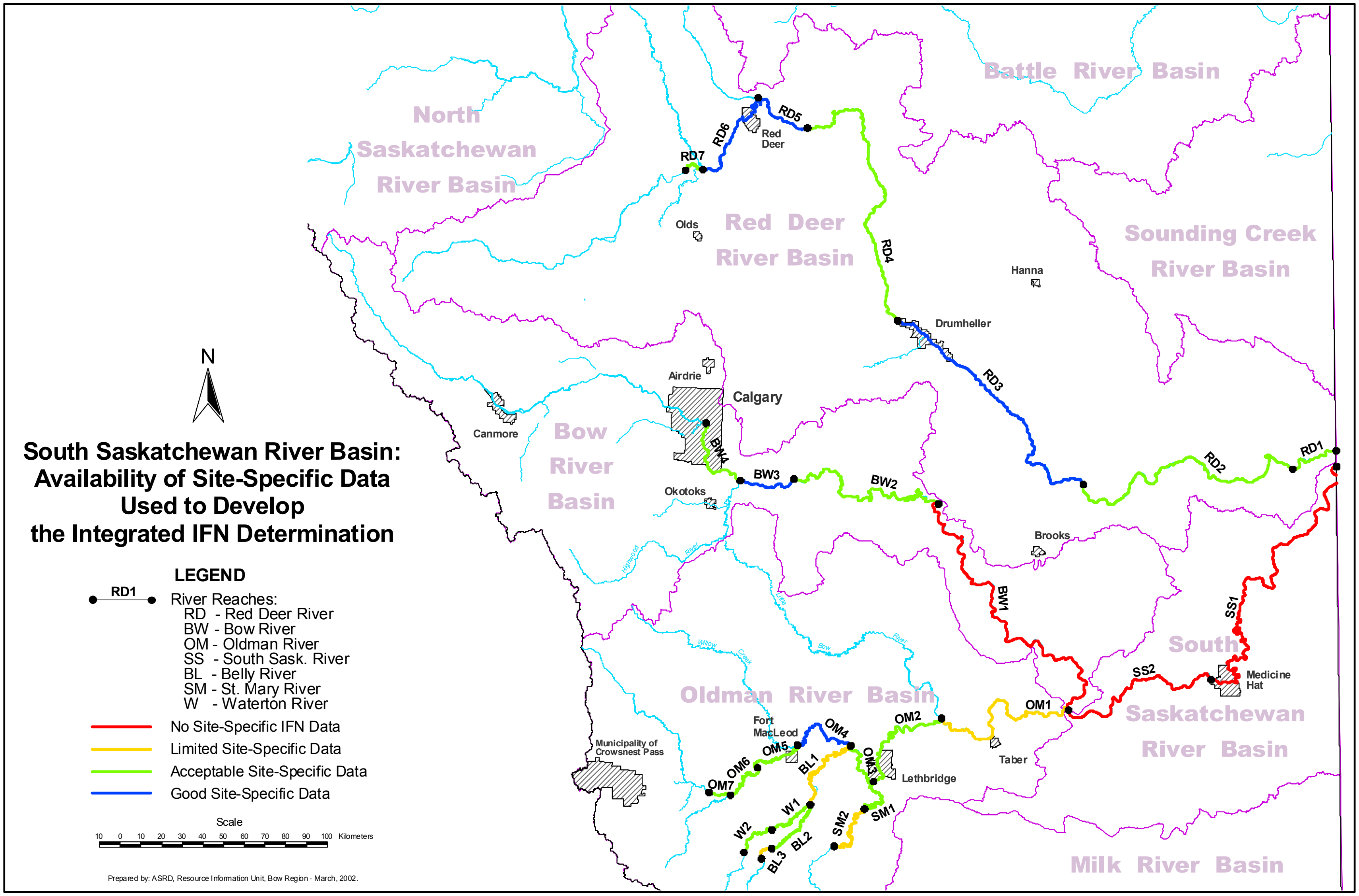


Figure 9.5. Summary of the combined reach-specific input data availability required for a detailed IFN determination to develop the integrated ecosystem IFN throughout the SSRB.

to represent the fall season. The natural flow and the integrated IFN are presented in flow duration format to help illustrate the inter-annual flow variability for each reach at different times of the year. The reaches chosen as examples are provided to show the general pattern within each sub-basin. The ecosystem IFN is similar for each sub-basin, in that the IFN curve provides a variable flow that follows the general pattern of the natural flow variability. However, there are some differences among the sub-basins as well.

The Red Deer sub-basin is characterized as having an IFN that exceeds the natural flow for much of the winter and, to a lesser extent, in the summer weeks of dry years (Figure 9.6). This is due to the water quality IFN necessary to meet the current loadings into the Red Deer River. The Bow River also has water quality IFN values above the natural flow in the winter. However, this rarely occurs for the remainder of the year (Figure 9.7). The Oldman River and the Southern Tributaries IFN rarely exceed the natural flow in order to meet water quality requirements (Figures 9.8 - 9.11). The South Saskatchewan River IFN is characterized by a lack of fish habitat data, resulting in a flat-line IFN at certain times of the year (Figure 9.12). This indicates limited inter-annual flow variability that needs to be addressed in future work.

The data for every week and every reach are available in Appendix G.

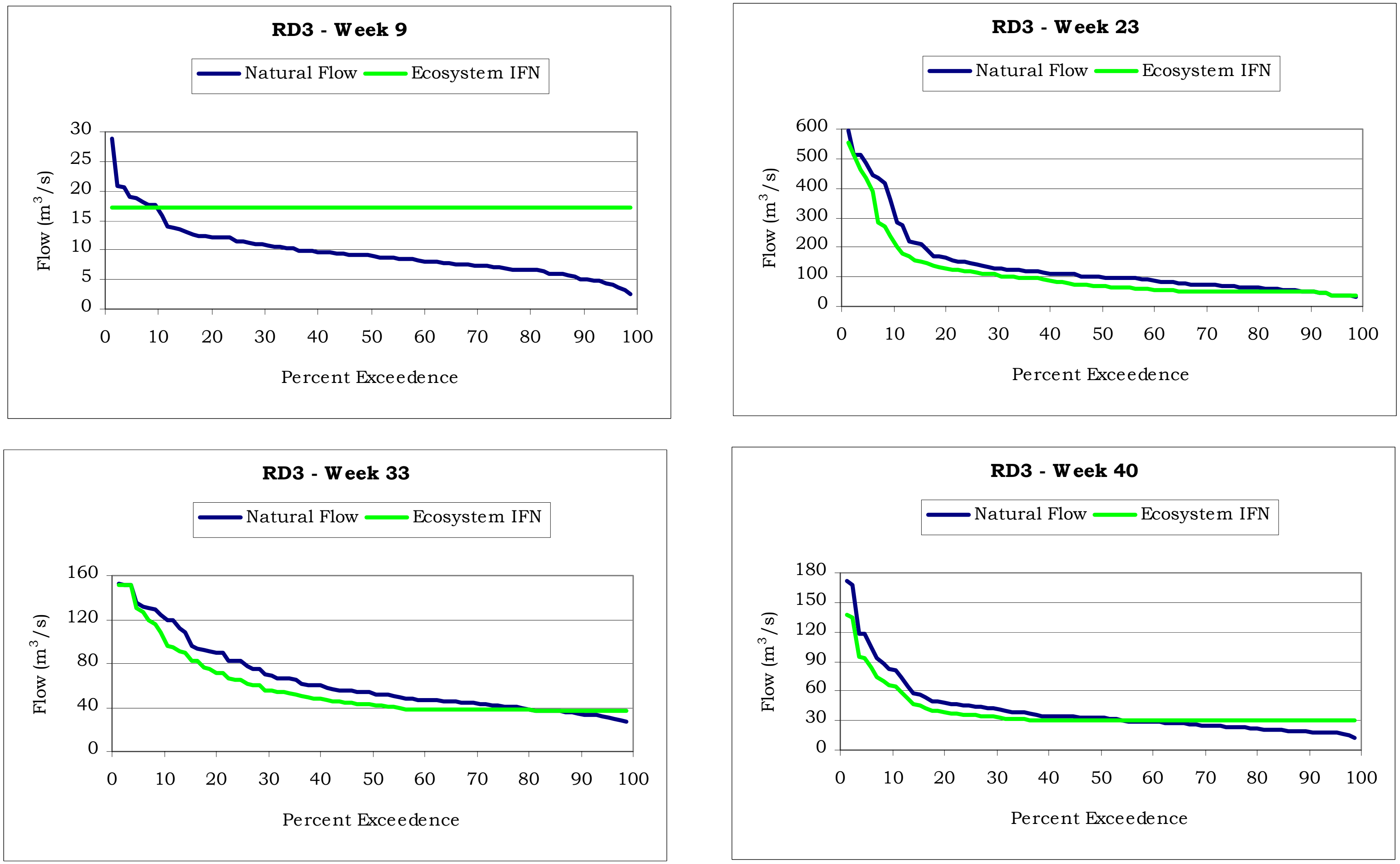


Figure 9.6. The Red Deer River at Drumheller (RD3) integrated ecosystem IFN for weeks 9, 23, 33, and 40.

Note: the scale on the vertical axis (flow) changes between weeks.

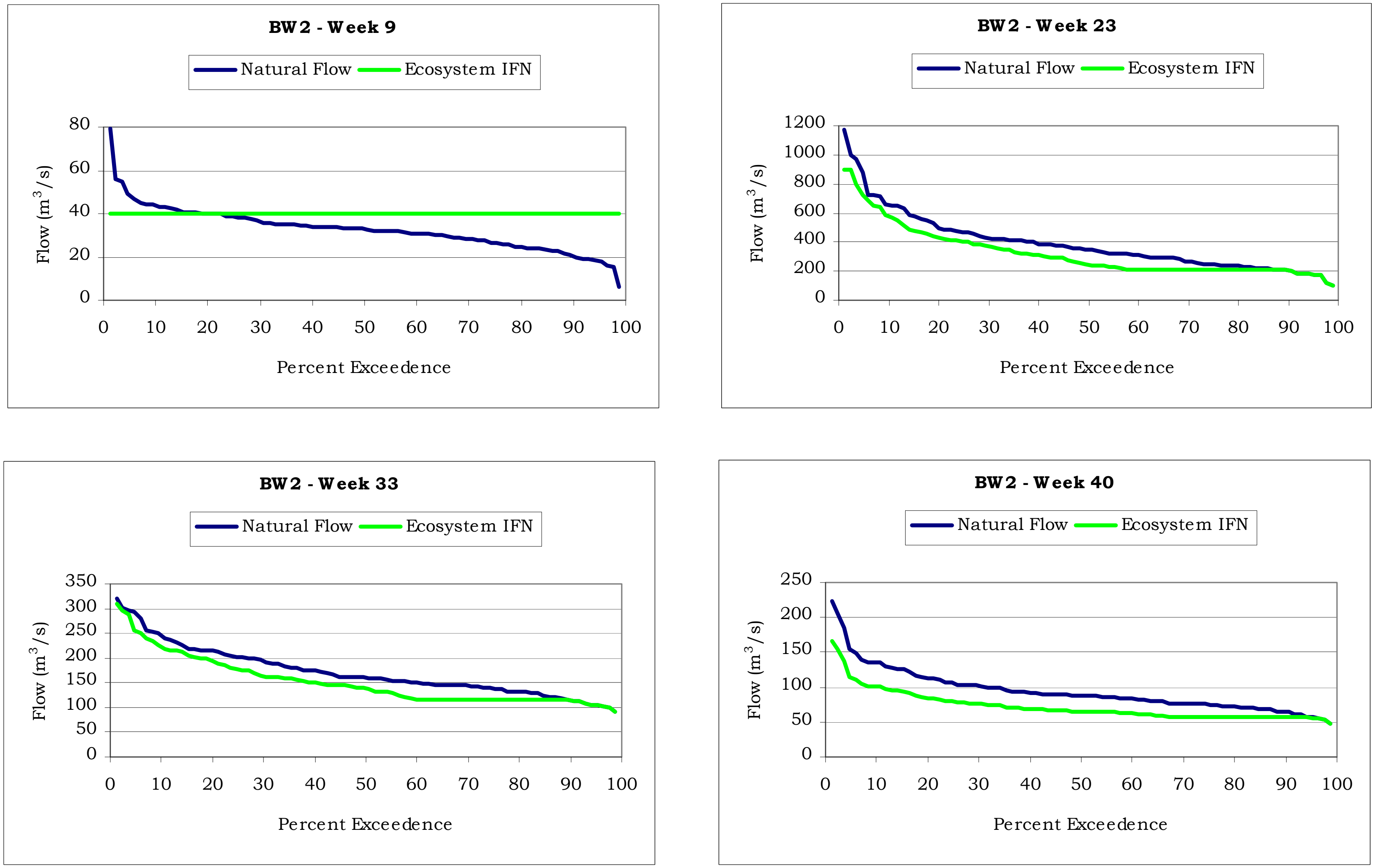


Figure 9.7. The Bow River below the Carseland weir (BW2) integrated ecosystem IFN for weeks 9, 23, 33, and 40.

Note: the scale on the vertical axis (flow) changes between weeks.

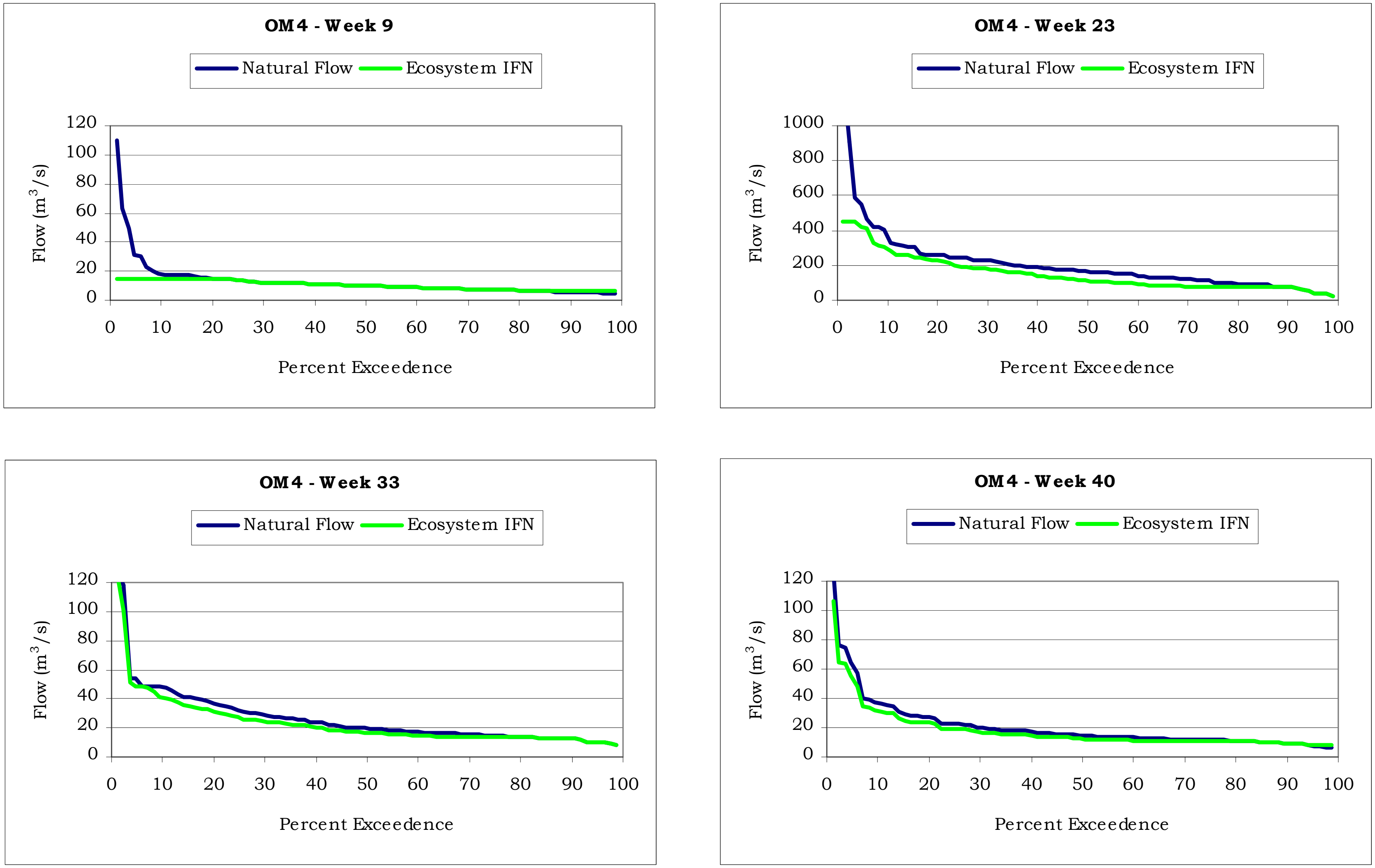


Figure 9.8. The Oldman River at Lethbridge (OM4) integrated ecosystem IFN for weeks 9, 23, 33, and 40.

Note: the scale on the vertical axis (flow) changes between weeks.

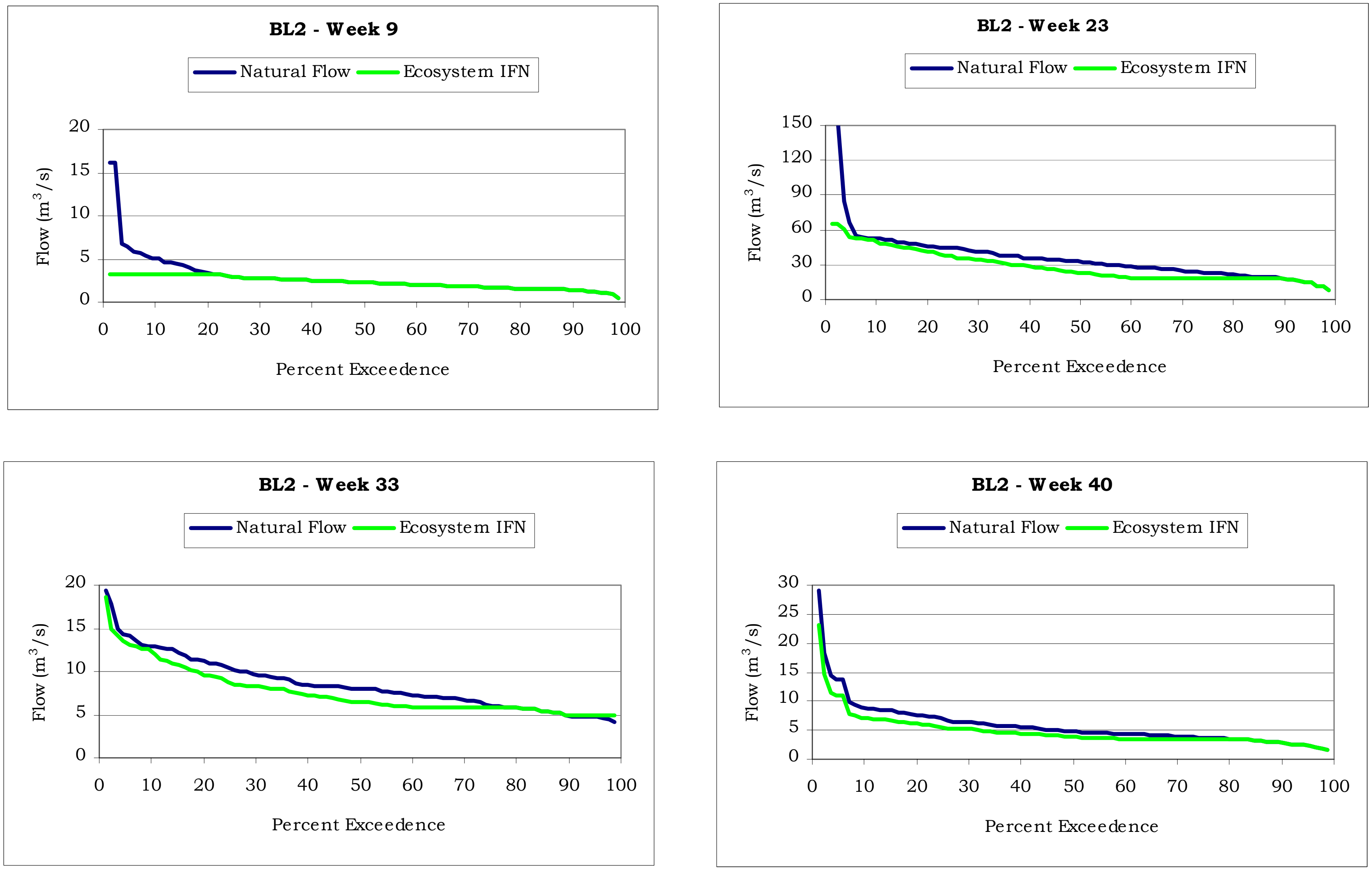


Figure 9.9. The Belly River near Standoff (BL2) integrated ecosystem IFN for weeks 9, 23, 33, and 40.

Note: the scale on the vertical axis (flow) changes between weeks.

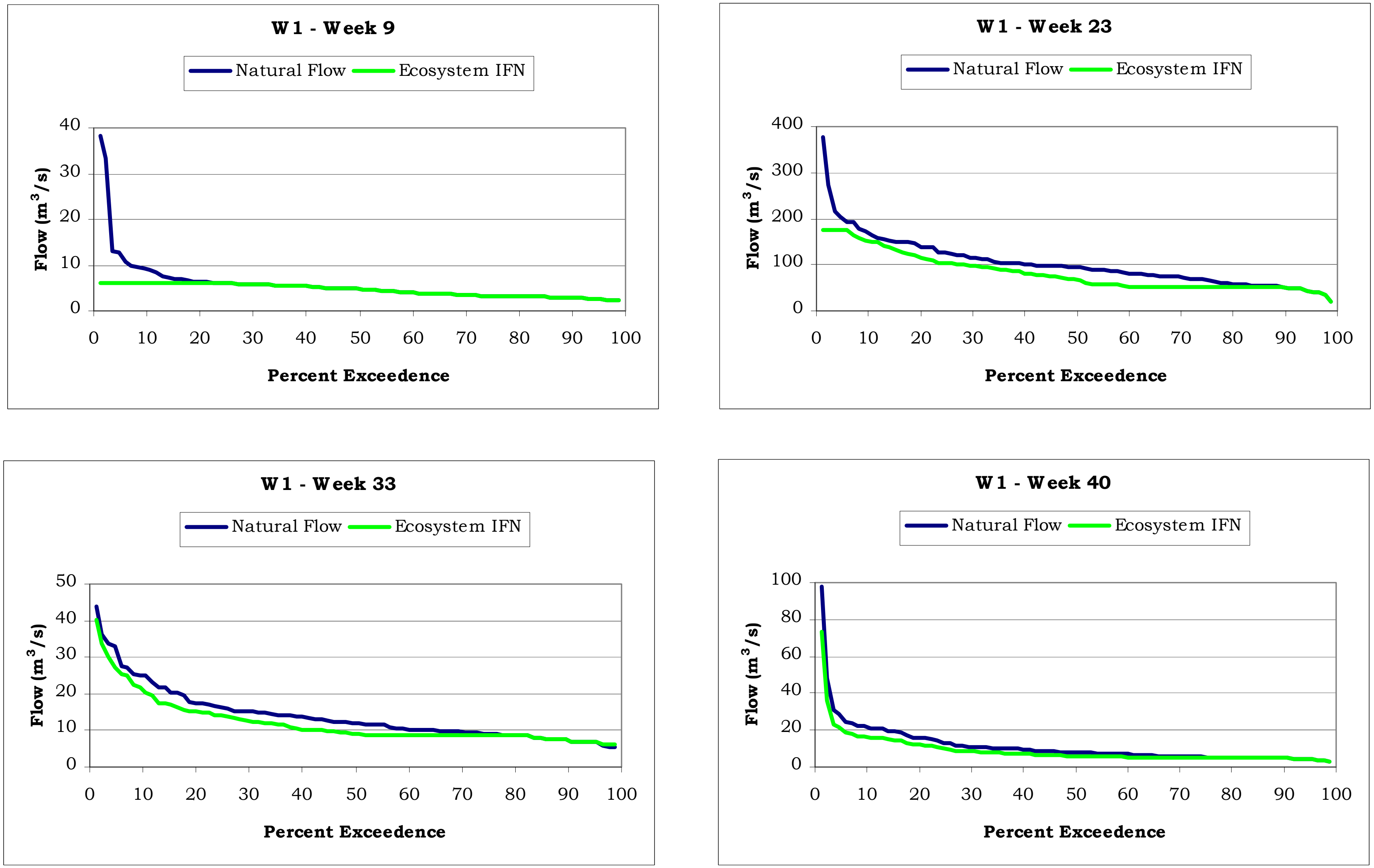


Figure 9.10. The Waterton River near Standoff (W1) integrated ecosystem IFN for weeks 9, 23, 33, and 40.

Note: the scale on the vertical axis (flow) changes between weeks.

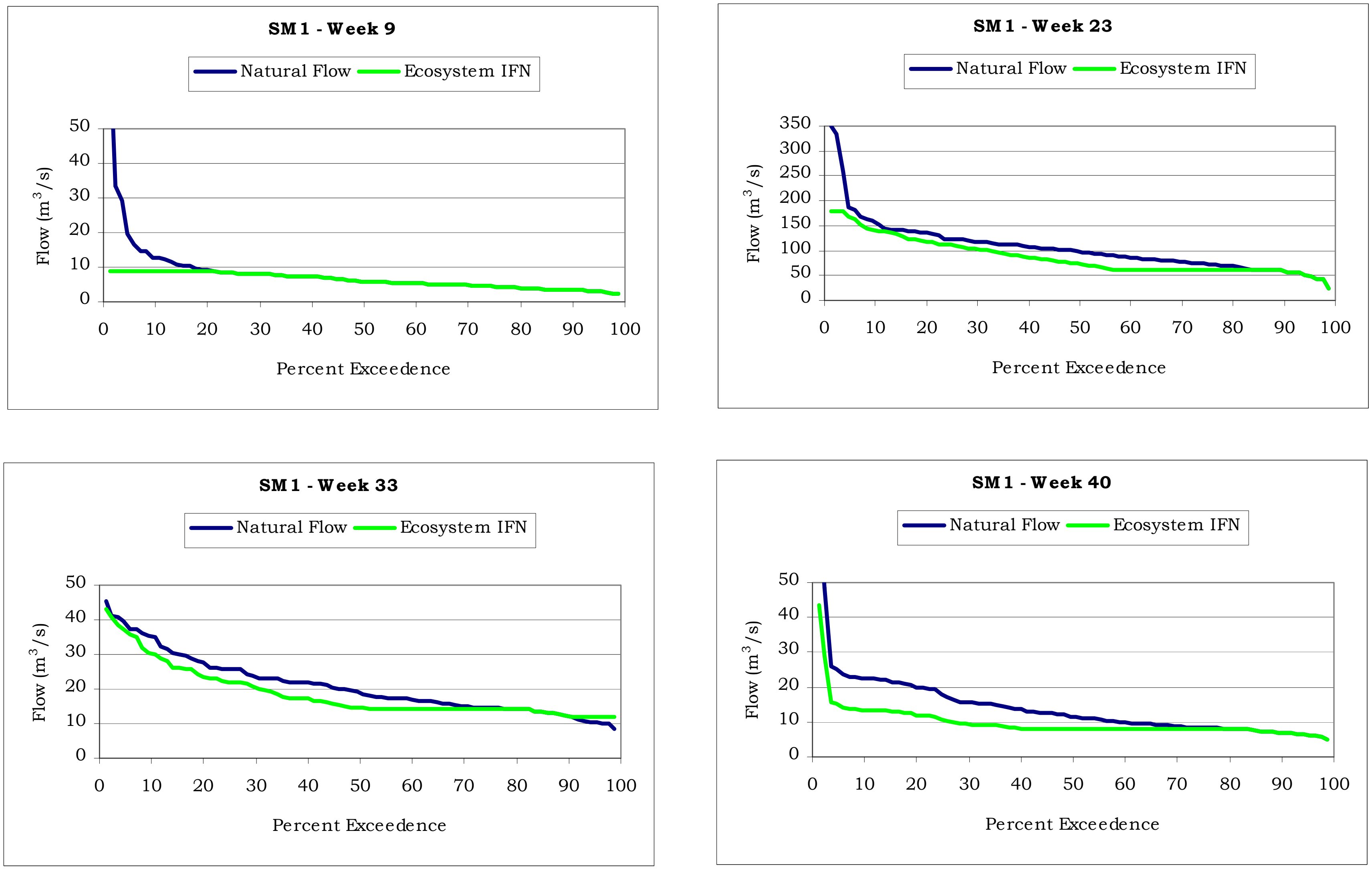


Figure 9.11. The St. Mary River near Lethbridge (SM1) integrated ecosystem IFN for weeks 9, 23, 33, and 40.

Note: the scale on the vertical axis (flow) changes between weeks.

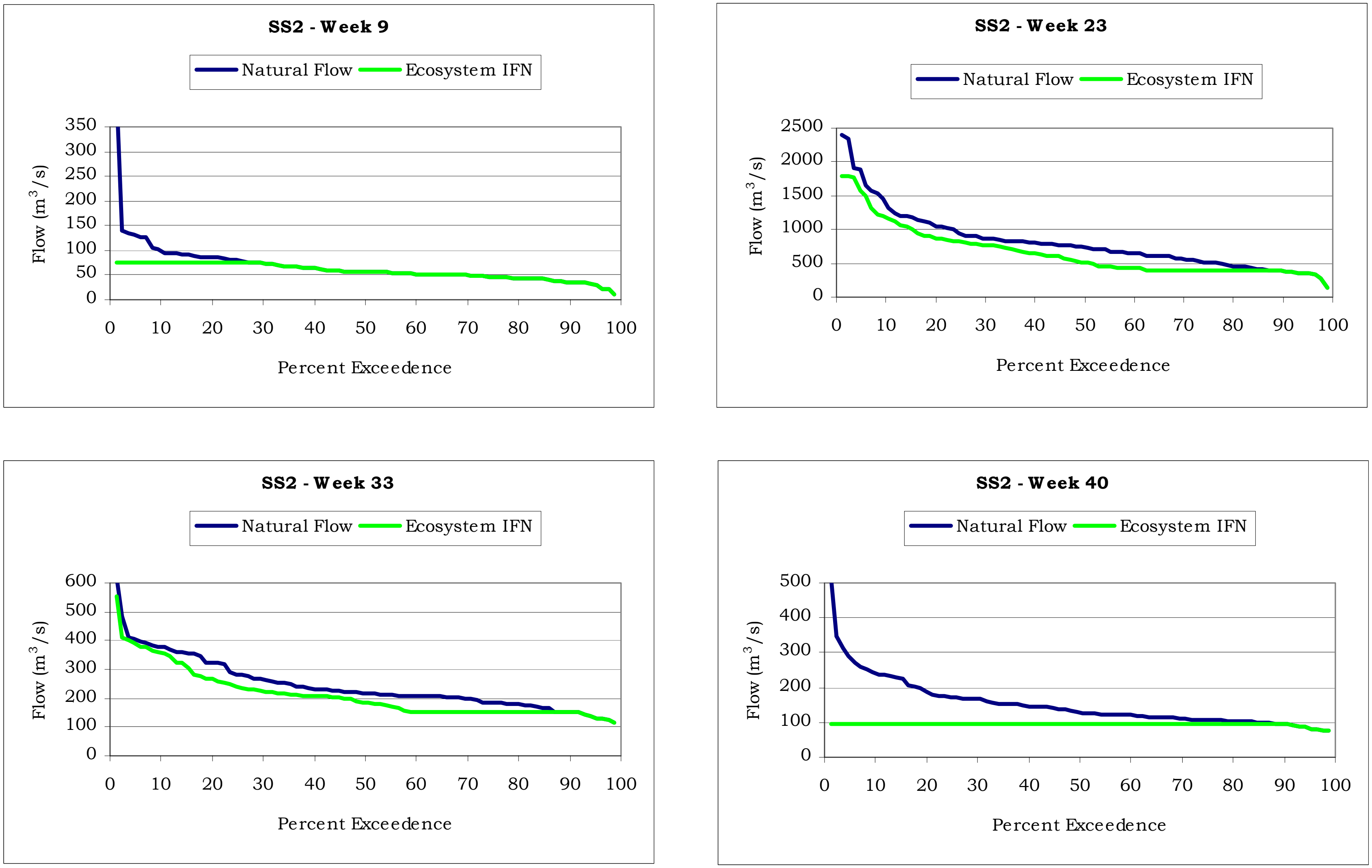


Figure 9.12. The South Saskatchewan River at Medicine Hat (SS2) integrated ecosystem IFN for weeks 9, 23, 33, and 40.

Note: the scale on the vertical axis (flow) changes between weeks.

10.0 SUMMARY AND CONCLUSIONS

This report details the method used to determine ecosystem based instream flow needs for the mainstem reaches of the Red Deer, Bow, Oldman, Waterton, Belly, St. Mary and South Saskatchewan rivers in the South Saskatchewan River Basin. These determinations are designed to protect the aquatic ecosystem. In summary, this report:

- Provides an overview of the aquatic ecosystem resources in the SSRB.
- Presents the current scientific knowledge of the flows necessary to protect the aquatic ecosystem, by recognizing the interconnectivity of different ecosystem components.
- Outlines the specific methods used by the Technical Team to develop an IFN determination for each riverine component: channel maintenance, riparian vegetation, fish habitat and water quality.
- Describes the method used to integrate the various ecosystem components into a single IFN determination for the protection of the aquatic ecosystem.
- Provides ecosystem IFN determination flows for each reach, on a weekly time step, based on the 1912-1995 flow record.
- Concludes that with an accompanying adaptive management approach to managing flows, an ecosystem based IFN determination will protect or restore the riverine resources in the SSRB.

Fundamentally, this report acknowledges that fish, wildlife and riparian vegetation communities evolved and adapted to the fluvial processes and habitats characteristic of the pre-disturbance rivers in the SSRB. Protecting, maintaining or restoring the aquatic ecosystem must be founded on rehabilitating and managing the fluvial processes that create and maintain habitats vital to fish, wildlife, and riparian species. The Technical Team was assigned the task of determining a flow regime to protect the aquatic ecosystem by the SSRB Steering Committee.

The IFN determinations made in this report for the protection of the aquatic ecosystem of the mainstem reaches of the SSRB were based on the latest scientific understanding. A key principle in aquatic ecology that has gained widespread acceptance is the Natural Flow Paradigm (Poff et al. 1997, Richter et al. 1997). The underlying concept is that the natural intra- and inter-annual variability of flow is critical in defining the aquatic ecosystem. In cases where rivers have degraded as a result of water management, restoring aspects of the natural flow variability is critical to restoring the ecological processes of the system, including the recovery of fish, wildlife and riparian populations (NRC 1992a, Rasmussen 1996, Independent Science Group 2000). Providing a simple, standard-setting IFN recommendation or single minimum flow is not considered a suitable approach if the management goal is the protection of the aquatic ecosystem (Annear et al. 2002).

Annear et al. (2002) identified five riverine components that should be addressed in an IFN study: hydrology, geomorphology, biology, water quality, and connectivity. While it would be ideal to always address all of these riverine components, it should be recognized that it is often difficult to directly incorporate every component into an IFN study due to data gaps, limited resources, or insufficient expertise available to participate in the study. The Technical Team, composed of staff from Alberta Environment and Alberta Sustainable Resource Development, was established in an effort to include expertise on as many riverine components of the aquatic ecosystem as possible within project limitations. The Technical Team accessed expertise from both within and outside the Government of Alberta as necessary to develop the new IFN determinations.

For this study, no new data were gathered, although some new modelling was carried out using existing information. Previous modelling results were also re-examined and improvements were made where possible. As described in the body of this report, the Technical Team relied on existing data for fish habitat, water quality, riparian vegetation, and channel maintenance to develop the IFN determinations. Although not every aspect of every component of the aquatic ecosystem was addressed in the current evaluation, the information used in this process is believed to be comprehensive by today's standards and incorporates the entire range of flow variability within each sub-basin of the SSRB.

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. Instream flow methods continue to evolve today. 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 selected sport fish species. In some instances, water quality issues for the selected sport fish species were also addressed. At the time, this approach was consistent from the perspective of many natural resource management agencies that placed a priority on protecting sport fish populations. The assumption was that if the flows for sport fish were provided, then the entire aquatic ecosystem was protected. While this can be a reasonable starting point, it is not necessarily true in all instances. It is now considered better to include as many riverine components as possible in an IFN determination and avoid unnecessary assumptions whenever possible.

Many myths about what a river needs or does not need have been dispelled during the past few decades. For example, it was formerly accepted that higher flows represent excess water in rivers. Therefore, it was believed that floodwater removal caused no harm and could even benefit, the ecological function of the river. However, as recognized by instream flow practitioners as early as the 1970s, seasonal high flows are critical components of river ecology. This is especially true at the terrestrial/aquatic interface, where high flows deposit sediment, shape channels, rejuvenate and maintain riparian vegetation and habitats, improve water quality, expand and enrich food webs, maintain the valley, and provide access to spawning and rearing sites in the floodplain. Similar arguments can be made about the importance of natural periods of low flow (drought).

A considerable body of accumulated knowledge indicates that in order to protect the aquatic ecosystem, there must be consideration of multiple riverine components and processes, rather than the traditional focus on a single component such as fish habitat or water quality. It is well documented that a single minimum flow determination does not result in the long term maintenance of the resource the minimum flow recommendation was initially intended to protect (Stalnaker 1990, Annear et al. 2002). Providing only minimum flows to protect low flow fish habitat conditions does not account for the flow requirements of the other ecosystem components that form and maintain the fish. Establishing instream flows on the basis of only fish habitat needs may result in the alteration of geomorphological processes, reduction or alteration of riparian vegetation, and changes in floodplain function if high flows are removed or reduced (Trush and McBain 2000). Without flows to maintain riparian poplars, poplar forests will eventually disappear, resulting in the loss of habitat in the form of large woody debris, and a loss of an energy input that forms a critical part of the aquatic food web. The removal of significant amounts of flow from some rivers can result in habitat change and a reduction or alteration in fish populations and diversity (Carling 1995, Hill et al. 1991).

The Technical Team adopted an ecosystem perspective as the basis for making an instream flow need determination for the mainstem reaches in the SSRB. Ecosystems are complex with many inter-related pathways. An IFN determination needs to be based on the well-being of the entire ecosystem, not a condition that benefits only one species or one life stage of a sport fish species. As such, the entire natural flow range was considered and flow recommendations for all flow components within the natural range of flows were made, within the limits of available data and knowledge.

For this study, four different components of the aquatic ecosystem were studied: channel maintenance, riparian vegetation, fish habitat and water quality. Each one was described in detail in the report. The following is a brief summary for each of the components.

10.1 Summary of the IFN Process for the SSRB WMP

10.1.1 Fish Habitat

The fish habitat IFN component determination is based on site-specific data and habitat modelling. The basic concept of the fish habitat based protocol is to reduce flows in incremental amounts from the natural flow and evaluate each reduction in terms of habitat losses relative to natural conditions. The protocol can be described in five basic steps:

1. Develop a series of constant-percent flow reductions from the natural flow, in 5% increments;
2. Calculate the ecosystem base flow (EBF);
3. Identify the flow range to conduct habitat time series analyses, using site-specific 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 EBF; and

7. Apply the habitat evaluation metrics to identify the fish habitat IFN.

The first step is to reduce the flow as a percentage of the natural flow in even 5% increments, starting with a 5% reduction (5%, 10%, 15%, and so on). A flow file is produced for each percent reduction from natural. Next, a threshold value, referred to as the Ecosystem Base Flow EBF) is established. This is done to reduce the impact on habitat during naturally low flow periods. Based on this premise, a highly protective ecosystem IFN should not result in an increase in the frequency or duration of naturally limiting habitat conditions. 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).

The third step is to determine a range of flows on which to carry out the fish habitat time series analysis. It is assumed there is an upper flow limit where the validity of the fish habitat based flow information, weighted usable area (WUA) curves, becomes questionable. During the spring freshet, other ecosystem tools should be used instead of WUA curves for fish. For example, it is better to evaluate flows required for riparian vegetation needs, channel maintenance processes or other ecosystem processes dependent on high flows. Weeks with median flows that are beyond the evaluation range of a WUA curve were therefore removed from the analysis. This effectively removes the spring freshet from the analysis.

As noted in Section 5, this does not mean that every individual flow data point above the peak of the highest flow WUA curve is removed from the analysis. The approach does remove weeks where the majority of flows are beyond the limits of the WUA curves, but many individual flow records remain in the analysis that are above the peaks of all of the WUA curves.

The fourth step is to complete a habitat time series as described by Bovee et al. (1998). A habitat time series is based on the calculation of available habitat for every discharge record used in the evaluation. Habitat is evaluated only during the open water season, which is defined as the period from Week 14 through Week 44 (approximately from the beginning of April to the end of October).

The fifth and final step for the fish habitat component is to assess the results using evaluation metrics. Several metrics are used to evaluate the effects of change in discharge relative to natural conditions. Although all habitat metrics are reviewed, the change in total average habitat, the maximum weekly loss in average habitat, and the maximum instantaneous habitat loss are the three most useful metrics for making comparisons.

Specific habitat loss thresholds were defined for these three evaluation metrics as part of the Highwood River IFN (Clipperton et al. 2002), and were used for the SSRB evaluation as well. As a first step, the greatest constant flow reduction from natural, that did not exceed any of the metric thresholds, is defined as the fish habitat IFN. The thresholds are:

- 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 first metric, the difference in average habitat, is viewed as an indicator of chronic effects of flow reduction on habitat availability and the aquatic ecosystem for the long term. The second metric, the maximum weekly loss in average habitat, is considered to be an indicator of intermediate chronic effects of flow reduction on habitat availability and the aquatic ecosystem over an intermediate length of time. The third evaluation metric chosen is the maximum instantaneous habitat loss. This metric is based on the habitat available during each individual week during the period of record for the natural flow and for each of the constant-percent flow departures from natural. It represents acute effects of flow reduction.

It is assumed that no single habitat evaluation metric can adequately assess the change in habitat from natural. Impacts of the same habitat loss are greater if it is long term rather than short-term. Using all three metrics gives a measure of long term chronic impacts (difference in average habitat), seasonal or short term chronic impacts (maximum weekly loss in average habitat) and acute impacts (maximum instantaneous habitat loss) on habitat.

In summary, starting with a 5% departure from the natural flow regime, habitat time series are constructed and each metric is checked to see if it is met or exceeded. If the criteria are met, then an additional 5% reduction from the natural flow regime is evaluated through a similar time series analysis. This is repeated until at least one of the three criteria is exceeded. Evaluation metrics are also calculated for each biologically significant period (BSP) for the entire open water season for all life stages present in each reach.

Some very different patterns of habitat loss arose between metrics in the SSRB evaluations that did not follow the expected pattern of habitat loss. These are attributable to site-specific hydraulics, channel geometry, and the WUA curves of the reach being evaluated. In some cases, large maximum instantaneous losses are found, while many of the other metrics showed very small habitat losses, and in some cases, habitat gains. The possible reasons for this are described in Section 5.

In situations like these, expert judgment was used to develop an instream flow need determination that balances acute and chronic habitat losses for all species and life stages, at all times of the year. While the strict application of a percent flow reduction below the threshold criterion defined for the three key evaluation metrics was intended, following this rule did not always produce results that made biological sense. Balancing and compromising between yearly habitat losses and losses within specific BSPs was required. Decisions also had to be made to balance habitat losses between life stages present for only a part of the year, such as spawning, and the other life stages present year-round. It was deemed more appropriate to manage for, and refine these complex situations at an operational level, rather than at the current planning level.

Because only a single flow determination for fish habitat was applied for the entire open-water season, some of the metrics were allowed to exceed the defined thresholds to provide a balance of habitat loss among all life stages. This assessment was based on expert opinion. Ongoing monitoring and adaptive management are critical steps to ensure the IFN is protecting the fishery as expected. Further investigation and future development of the fish habitat evaluation method could overcome some of these shortfalls.

One improvement to the fish habitat based flow recommendations for the current project, over those previously used in the SSRB, results from changes made to the habitat suitability criteria (HSC) curves. The HSC curves were altered in a workshop setting to reflect a more current and wider knowledge base than the previous ones. The HSC data are broader and, in the opinion of the Technical Team, better reflect the true microhabitat potential of the species and life stages in question. Therefore, the resultant weighted usable area curves should more accurately describe habitat-flow relationships compared with the original ones.

It is widely recognized that under-ice habitat conditions are just as important, and potentially even more critical than habitat during the open water times of the year. Consequently, IFN studies and recommendations should include the needs of aquatic organisms and habitat characteristics in both the open water period and the ice-covered period. However, conducting IFN studies during the winter or ice-covered period is extremely difficult. To date, no fish habitat studies have been carried out for the winter period in the SSRB. Therefore, instream flow needs during the ice covered period are lacking. For the purpose of this report, the winter ice-covered period was defined to be from week 45 through week 13, (i.e. November – March) for every reach.

One of the most difficult problems with using standard fish habitat models is the creation of winter Habitat Suitability Criteria (HSC) curves. To be able to create HSC curves for fish and to monitor fish behaviour for model verification, it is necessary to observe fish in the river in wintertime. Several methods are available for collecting the data needed to develop HSC curves for under-ice conditions. Each has limitations that prevent them from being widely used. Therefore, the Tessmann method was used to generate IFNs for the winter period in the SSRB until better tools are available. Winter IFN is an issue that requires a great deal more research and effort.

Future Considerations

In carrying out the fish habitat instream flow needs component, it was necessary to make several assumptions. If, in the future, it is decided to make further investigations, then it is recommended the following issues be addressed:

- The microhabitat requirements for sturgeon have not been determined. This is particularly problematic because sturgeon are a much larger fish, with unique habitat requirements compared with the largest species for which data were collected (e.g. rainbow trout). For this study, a broad assumption was made that the integrated IFN would meet the life history requirements of the sturgeon. If future studies are carried out, it is recommended the specific habitat suitability criteria data for this species be collected and directly factored into the fish habitat IFN requirement component.

- In this study, only sport fish were modelled. This means that sport fish served as a surrogate for all fish species, including forage fish. If future studies are carried out, microhabitat data should be collected for all species of fish or at the very least, one species from each family or genus. The importance of invertebrates also needs to be investigated. If they are deemed important, then collecting microhabitat data for these species should also be completed.
- For the mobile life stages, cover was not factored into the fish habitat IFN determinations because it is currently believed the cover requirements of the older life stages of the target fish in the SSRB are not critical. If future studies are carried out, then this issue should be addressed. If it is indeed found to be a critical factor, then the necessary data should be collected.
- Improving the ability of models to reflect the biology of the system is warranted for any future work. Effort should be made to develop conditional criteria for HSC curves that better reflect habitat descriptors, such as distance from shore and cover, that are biologically relevant to the species and life stages of concern.
- When using any predictive model, output may not follow an expected pattern. It is important to understand why this occurs. It is recommended that all anomalies described in this report be investigated.
- Site-specific fish habitat data did not exist for all the reaches in the SSRB. In those instances where data were missing, the hydrological flow statistic of 95% exceedence was used to set the EBF. In some reaches where habitat data were available, selecting the greater of the 95% exceedence flow or the 80% habitat retention flow was necessary, because using only the 80% habitat retention value did not adequately account for the hydrology in the late spring to fall season. It was our goal to ensure the intra-annual variability of flow, relative to the natural flow regime, was maintained. Further biological grounding regarding the setting of the EBF is essential and it is recommended that this work be carried out if future studies are undertaken.

Even though every step should be taken to validate physical fish habitat models, there have been instances where predictive physical habitat model output was not consistent with the observed biology of the system. Beecher et al. (2002) carried out model validation according to accepted practices, yet in other studies being carried out on the same streams, it was clearly demonstrated the best year class recruitment occurred during much different flows than the model predicted (H. Beecher, 2003. pers. comm.). As is the case with the use of any model, extreme care must be taken in its application. It is strongly recommended that a fisheries monitoring program be implemented to verify the impact on fish populations of any water management decisions.

10.1.2 Water Quality

Water quality based instream flow needs values were generated in the early to mid 1990s for the mainstems of the Red Deer, Bow and Oldman rivers. Summer WQ IFNs were also generated for the Waterton, Belly and St Mary rivers. Private consultants under contract to the provincial government carried out the work.

Basis of the water quality IFN values

A broad range of water quality data are collected on a routine basis throughout the SSRB and include variables such as nutrients, major ions, metals, pesticides and bacteria. In most cases, these variables are best managed by source control, rather than by instream flow determinations.

Water quality instream flow determinations focus on temperature and dissolved oxygen (and ammonia in some reaches) because these variables are amenable to management by flow regulation. For fisheries protection, these two variables are also the most critical water quality variables in southern Alberta rivers. Dissolved oxygen levels also determine the assimilative capacity of a river reach.

Protection against high temperatures and low dissolved oxygen concentrations

Summer stream temperatures tend to track ambient air temperatures, typically reaching maximum values in late July and August. Exceedences of temperature guidelines for protection of fish species may occur during extended periods of high ambient temperatures and sparse cloud cover, in particular when river flows are low. Higher flows provide a buffer against instream temperature exceedences. Instream temperatures that exceed guidelines have a negative effect on fish metabolism and can cause fish mortality. Acute temperatures for most sport fish in Alberta are between 22 and 29 °C; seven-day chronic values are between 18 and 24 °C.

Oxygen becomes less soluble as stream temperatures increase, causing a reduction in DO levels. The Alberta provincial guideline for dissolved oxygen for fish protection (all fish species) is 5 mg/L for protection against acute DO deficit, and 6.5 mg/L seven-day average concentration for protection against chronic deficit (AENV 1999).

Assimilation of Wastes

This use requires sufficient flow to dilute wastes, and allow for biological breakdown of organic wastes, while protecting the aquatic environment from significant impact. Assimilation flows are typically intended to ensure that dissolved oxygen and ammonia levels remain within guidelines for the protection of aquatic life. To establish assimilation flows, water quality modelling is conducted, based on current and/or future contaminant loadings from various sources, in particular below the municipal wastewater treatment plants downstream of major cities. River flows for waste assimilation are a consumptive use of our water in that they limit the amount of water that can be diverted for other uses. This is a fundamental difference compared with the other IFN components described in this document.

Scouring Flows

Of particular importance to water quality are high flows due to snow melt in late spring and early summer. These flows are called flushing or scouring flows, because they dislodge sediments and other materials that accumulate on and within the riverbed and carry them downstream. In cases where these sediments are rich in nutrients and organic matter, the removal of the sediments with the high flows reduces seasonal increases in oxygen demand within the reach. High sediment oxygen demand lowers dissolved oxygen levels and can cause fish kills.

Periodic high flows in spring and early summer also impede the establishment of both new and existing aquatic vegetation. Without these high flows, macrophyte and algal growth can exert a very significant oxygen demand during nighttime periods in late summer, when growth can be prolific, and during winter when the biomass decays.

Provision of the Water Quality Based IFNs

Water quality IFN values, based on temperature and dissolved oxygen, have been provided for the summer and winter low flow periods in most reaches in the project study area. In some reaches (the Oldman and Red Deer rivers), IFN values have been provided for all four seasons. Water quality IFNs still need to be determined for other reaches on at least a seasonal basis. Where WQ IFNs have not yet been prescribed, such as the South Saskatchewan River, the use of recent recorded flows is recommended. These flows should be based on existing water quality monitoring data indicating minimal exceedences of guidelines.

A provincial database contains extensive water quality data that are available and largely sufficient for further IFN work. Resources are needed to conduct additional water quality modelling using the most recent water quality data. Much work has been carried out in the past decade, but there is still great benefit in continued refinement of the existing IFN values and generation of IFN values where none currently exist.

10.1.3 Riparian Vegetation

The guidelines developed for determining 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.

Riparian cottonwoods are intimately dependent on the riparian water table. They are able to survive in the driest regions of southern Alberta only because their root systems tap the riparian water table, connecting them to a reliable water supply even during periods of natural seasonal high temperatures and low precipitation. Any IFN determination must therefore maintain the water table within reach of the root systems of established cottonwoods.

Riparian poplar forests require ongoing reproduction to drive forest replenishment. Cottonwood seeds require specific substrate and moisture conditions during their first few weeks for successful germination and establishment. Moist, barren sediments, such as those exposed by ice or flood flows, are suitable for cottonwood seedling establishment. As peak springtime flows recede, so does the riparian water table. Young cottonwood seedlings will only survive if their root growth is able to keep pace with the moist capillary fringe above the declining water table. Flows prescribed to meet poplar instream needs must therefore accommodate the natural seasonal variability of flows that support seedling recruitment.

Dendrochronological analyses have shown that natural cottonwood recruitment is associated with 1 in 5 to 1 in 10 year return flood events along streams in southern Alberta. However, larger scale floods that cause geomorphic changes can improve recruitment opportunities for the next several years.

Flows to Sustain Riparian Forests

Because each stream has its own combination of environmental constraints and species compositions, flows required to sustain riparian cottonwood forests may vary greatly from reach to reach. Logically, the natural flow regimes that have supported riparian forests historically should be adequate to maintain those forests into the future. The approach taken here targets flows for maintaining and restoring the natural extent and character of riparian cottonwood forests, rather than simply trying to ensure the survival of remnant trees.

The calculated instream flows are expected to both:

- Sustain the health of existing trees in a condition comparable to the level that would be expected under natural conditions; and
- Maintain the frequency of seedling recruitment events so that the long term viability of the riparian forest is sustained.

Cottonwood streamflow requirements can be grouped into four general categories:

- tree survival,
- tree growth,
- seedbed preparation, and
- seedling and sapling survival.

Flows for forest survival and maintenance

One minimum flow will not suffice for every reach, because each reach has unique characteristics that dictate tolerable water table levels for the cottonwoods residing there. A range of low flows is therefore required that fluctuates both within and between years.

Because naturally occurring riparian cottonwoods are adapted to tolerate natural extremes of streamflow, they can survive occasional drought conditions. However, the cumulative effects of prolonged or excessively frequent drought events will lead to gradual forest deterioration and reduced resiliency to subsequent stresses. Low flows should be calculated with the goal of maintaining cottonwood survival under chronic implementation. The lowest flows required for the survival and maintenance of riparian cottonwoods have been estimated at between 40 and 60% of average weekly flow.

Flows for tree health and growth

Chronic low flows alone will not sustain a healthy riparian forest. A range of moderate flows is required for optimal growth of cottonwoods. Thus, as when calculating a range of low flows, it is recommended that moderate flows be modelled after trends in the naturally occurring flow regime. As tends to occur naturally, exposure to a broad range of dynamic floodplain conditions can improve forest resiliency and ensure its survival, despite the inevitable disturbances and stress associated with a highly variable flow environment. Research shows that normal growth requires average natural streamflows, with 40 to 60% of natural streamflow being necessary for healthy tree canopies and 74 to 313% of long-term average annual flows being needed for maximum growth.

Flows for channel processes and associated seedling establishment

Moderate flows favour the survival of mature cottonwood trees. To ensure the ongoing viability of riparian forests, a range of high flows is also needed. These flows drive channel dynamics that control erosion, deposition of sediment and the formation of barren sites required for seedling recruitment.

Bankfull discharge is recognized as a threshold of flow magnitude conducive to cottonwood seedling replenishment. However, flows beyond the bankfull threshold are needed in channels with coarse bed materials. A number of studies show that flows up to 160% of bankfull can be important in determining the geomorphic characteristics of a stream.

Flows for long-term seedling survival

Intra-annual variability is especially important following peak flows, when seedlings are being established. A receding flow regime is required to encourage root development in seedlings, but the rate of decline cannot be so severe as to cause seedling mortality. Thus, in order to promote long term survival of cottonwood saplings, variability in the flow regime should not exceed that which would occur naturally. By preserving the natural range of high and low flows that affect the riparian water table, cottonwood root systems will be encouraged to establish at depths that promote healthy tree growth and resiliency to future flow fluctuations.

The Poplar Rule Curve

The determination of poplar instream flow needs must address the pattern of flow required to meet the varied moisture requirements of the poplars during the growing season. The natural degree of variability in streamflow was incorporated in the design of flow regimes for sustaining riparian cottonwoods and the channel processes they depend on. Therefore, riparian poplar IFNs were based on the exceedence curves of naturalized flows for each river reach assessed, for each week of the year.

The goal of the Poplar Rule Curve process is to integrate the low, moderate, and high flow requirements of cottonwoods with a natural pattern of flow variability. The PRC is defined by a composite of three exceedence-based curves and bankfull discharge.

The first curve included in the PRC defines 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 these acute level events as long as the frequency of these events is not increased. Thus, natural flows that are less than the 90% exceedence flow are not reduced or increased. Natural flows that are greater than the 90% exceedence flow are not reduced below the 90% exceedence flow in a given week.

Moderate to high PRC flows are defined by the greater of either 65% of naturalized flow, or that flow corresponding with a 50% increase in the return interval. These two values bridge the minimum flow requirements for cottonwood survival with those for healthy tree growth and seedling establishment.

The maximum flow required by the PRC has been set at 125% of bankfull discharge to include flows critical for maintaining the channel dynamics necessary for creating nursery sites for poplar seedling establishment.

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

- There be no reductions to flows with natural exceedences of 90% or greater;
- Flows may not be reduced below the 90% exceedence level;
- Reduction of up to 35% of naturalized flow is acceptable, provided the resulting RI shift is not greater than 50%; and
- The highest flows can be reduced to 125% of bankfull.

The PRC approach is designed to meet the flow requirements for cottonwood survival, growth and reproduction within the context of a continuum of natural flow variability. To ensure both intra- and inter-annual variation are accommodated within a PRC recommendation, the PRC decision criteria are applied to weekly exceedence curves throughout the cottonwood growing season.

It is expected that the details of the PRC rules will need to be revised slightly to address variability present along reaches and sub-basins within the South Saskatchewan River Basin before the integrated IFNs are implemented.

Suitability of PRC flows in southern Alberta

Results of comparisons between 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 individual assessment of each of the five criteria whose exceedence curves form the basis of the PRC. To evaluate each criterion, the flows in the affected exceedence range were compared with the corresponding regulated flows implemented along the various test reaches and related to known impacts on riparian poplar forests.

The part of the PRC that cannot be adequately evaluated, based on comparisons with the implemented flow regimes for these test reaches, is the reduction of peak flows that exceed 125% bankfull. It is not possible to infer the effects of such a change, because none of the flow regimes along the test reaches have been modified in this way.

Evaluation of PRC criteria

PRC criterion 1 protects flows below the naturalized 90% exceedence level. Occasional, slight reductions (<30%) to flows in this exceedence range alone might not be seriously harmful. However, combined with moderate reductions to larger flows, there is an increasing likelihood of inducing chronic drought stress in downstream forests. This criterion is acceptable for the current planning level analysis.

PRC criterion 2 would prevent reductions below naturalized 90% exceedence flow. Similar to the case for criterion 1, occasional, slight reductions below the 90% exceedence threshold may not have serious consequences. However, reductions of greater than 10% are not acceptable. Considering that 10% of a naturalized 90% exceedence flow represents a relatively insignificant volume of water from a management perspective, the risk associated with adjusting criterion 2 is not merited.

The assessment of PRC criterion 3 suggests that while the 35% reduction might be adjusted to 40% without harming riparian forests, such a reduction would prevent PRC criterion 3 from providing a gradual transition between criteria 2 and 4. The resultant exceedence curves would have an unnatural step function imposed in mid-range flows. This would somewhat negate the effort to maintain the inter-annual variation of the natural system. Thus, the 35% flow reduction allowed by criterion 3 should only be altered in concert with a similar adjustment in the exceedence curve for criterion 4.

PRC criterion 4 permits flow reductions equivalent to a 50% increase in return interval. Based on the trends along the test reaches, this value seems generally acceptable. Due to the variability among the reaches, it is not clear if a further reduction would still be adequate for maintaining healthy downstream forests. Without additional evidence from other test reaches, the limit of 50% increase in RI should be maintained.

PRC criterion 5 would permit peak flows to be limited to 125% bankfull. Considering that actual reductions to flows beyond this magnitude have been relatively minor along the test reaches, the appropriateness of the 125% bankfull value as a maximum in the PRC cannot be verified using these test cases. This criterion is the only part of the PRC that is defined by an absolute value calculated without reference to the historic flow record. The 125% bankfull value is recommended only as an initial approximation. It requires further consideration on a reach-specific basis.

The individual assessments of the five PRC criteria generally support their use in the PRC approach for meeting the flow requirements of riparian cottonwoods in the SSRB. Trends observed along the test reaches suggest that only minor revisions could be safely made to any of the criteria used in calculating the overall PRC.

10.1.4 Channel Maintenance Flows

Channel maintenance flows, as defined for this report, cover the range of flows that have been commonly referred to as flushing flows, bed mobilization flows, channel structure flows, and channel forming flows. Although the importance of these flows to the aquatic ecosystem is well understood, the methods used to describe these flows are just emerging. As with most IFN methods, detailed data are required along with the use of predictive models.

One of the most difficult challenges that must be addressed in an IFN study is determining the entire range of channel maintenance flows with a magnitude, frequency of occurrence, and duration as they relate to the natural flow. The Technical Team reviewed several well documented sediment transport models that can be used to determine flow. Most of these methods are data intensive. Because it was not possible to collect new data for this study, they could not be used.

Data were available to use a sediment transport model. In this study, channel maintenance flow recommendations were determined using an incipient motion method, based on the Shields entrainment function. The Shields equation uses sediment grain size and channel slope to recommend flushing flows.

The Shields equation generates a flow magnitude but does not stipulate the timing or duration of the needed flow. Therefore, it was not possible to generate weekly exceedence curves of IFN values that were similar, in terms of duration and frequency, to those compiled for the other three components: riparian vegetation, fish habitat and water quality. Instead, a comparative analysis of the integrated IFN recommendation was completed, to ensure the higher recommended discharges were adequate to provide the necessary flows for channel maintenance.

It is recommended that before finalizing IFN prescriptions, detailed models that not only provide a recommendation in terms of magnitude, but also timing, duration and frequency should be applied in the SSRB.

The channel maintenance flow determinations provided in this report are weekly averages and are intended to be used for guidance in a general water balancing model context. More detailed studies and better tools are required before any decisions are made regarding implementation of flows on an operational basis. It is most likely that regulation structures in the South Saskatchewan River Basin have already significantly altered the natural sediment regime in these rivers. Before any decisions are made to implement channel maintenance flows, it is necessary to understand these changes in sediment regime, as it is possible that changes to these higher flows from current operations could have profound and unexpected effects on the channel.

Channel maintenance flows are as important as flows prescribed for any of the other ecosystem components. Changes to the channel morphology as a result of flow regulation will result in changes to habitat and therefore, in changes to populations of stream-dwelling species. Channel maintenance flows occurring with near-natural frequency are required to maintain a near-natural ecosystem. Reduction or elimination of the physical processes associated with high flow events will greatly affect habitat that stream-dwelling and riparian species rely on.

10.1.5 Integration of the Four IFN Components

Even though there is recognition by IFN practitioners of the need to consider all elements of the aquatic ecosystem in defining an IFN, there is no universally accepted method for combining the different ecosystem components to develop an integrated flow recommendation. For this study, the Technical Team developed a straightforward method for integrating the four ecosystem component IFN results in 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. Water quality recommendations tend to dominate when the natural flow is relatively low. Water quality values are often available for both winter and the open-water seasons.

The fish habitat IFN 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 are not available for the winter weeks. Tessmann values are applied in this period. Fish habitat IFNs tend to dominate for a range of moderate flows and generally overlap with water quality and riparian flows.

The riparian IFN determination is also a variable flow curve and is applied only during the growing season in the spring and summer. The riparian IFN tends to dominate during the spring freshet, when high flows are common.

Usually, but not always, there is some overlap among the components. When this occurs, one component becomes the primary determinant of the ecosystem IFN flow. Conversely, there are times when a determination is provided by only one component. This may be due to limitations in data sets or seasonal omissions of determinations of some components.

The channel maintenance IFN determination is 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 also provide the flows necessary for channel maintenance.

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 current loadings in the system. In determining the water quality IFN, it is not realistic to factor out current loadings from municipalities. Therefore, the water quality based IFN recommendations are unlinked from the natural flows because following the natural flow would increase violations of water quality parameters beyond natural levels. Although the period when the water quality IFN exceeds the natural flow is typically limited to the winter weeks, in very dry years it can also exceed the natural flow during the summer.

The integrated IFN is determined for each reach separately by comparing the IFN value for each of three components, on a week by week basis, for every data point for that reach in the period of record. The channel maintenance IFN values are not available in a format that allows direct integration into the IFN. Therefore the final integration is initially based on the IFN values for water quality, fish habitat and riparian vegetation. The component with the highest flow recommendation is selected as the flow value for the integrated or ecosystem IFN. When there are three IFN values, one for each component, the one with the highest flow requirement defines the integrated IFN at that point.

Each component has data gaps for either some years or some reaches under review. Therefore, there are instance when the integrated IFN is only made from two, or even just one of the components. For example, during the spring, the IFN is often defined entirely by the riparian IFN determination, regardless of the flow. This reflects the seasonality of the hydrograph and the corresponding biological functions that have adapted to the timing of high flows.

It was the goal of this study to provide as broad an ecosystem based IFN determination as possible. The integrated IFN is based on several riverine components and, as such, is better than an IFN determination based on any one individual component. Combining the individual components into one integrated IFN determination reflects the interconnectivity between the components. The Technical Team believes it is best to use all available data, apply the best tools for the appropriate time of year and flow range, and to integrate and incorporate all available data in formulating IFN determinations.

For this study, all IFN determinations were made on a reach by reach basis. The IFN determinations need to be checked for consistency from upstream to downstream reaches. Before any impact assessment is done, balancing of the IFN determinations for the individual reaches must be carried out.

10.2 Application of the Ecosystem IFN in the SSRB WMP

There is no one correct or universally accepted way to define instream flow needs. Defining instream flow needs involves data collection and analysis, making assumptions, modelling, and professional judgment. Throughout the report, the Technical Team has documented its decision-making processes as thoroughly as possible and documented the rationale for all decisions. 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 the entire range of natural flows in terms of magnitude, frequency and duration.
- The inter-annual and intra-annual flow variability of the ecosystem IFN better incorporates the pattern of natural flow variations in a consistent manner for every week, as illustrated for a dry, average and wet water year in Figure 10.1.
- The current IFN has more comprehensive Ecosystem Base Flows, defined for every week.
- Improvements to the hydraulic calibrations and revisions to the fish habitat suitability criteria (HSC) curves resulted in updated WUA curves. These served as the basis for the new fish habitat based IFN analyses.

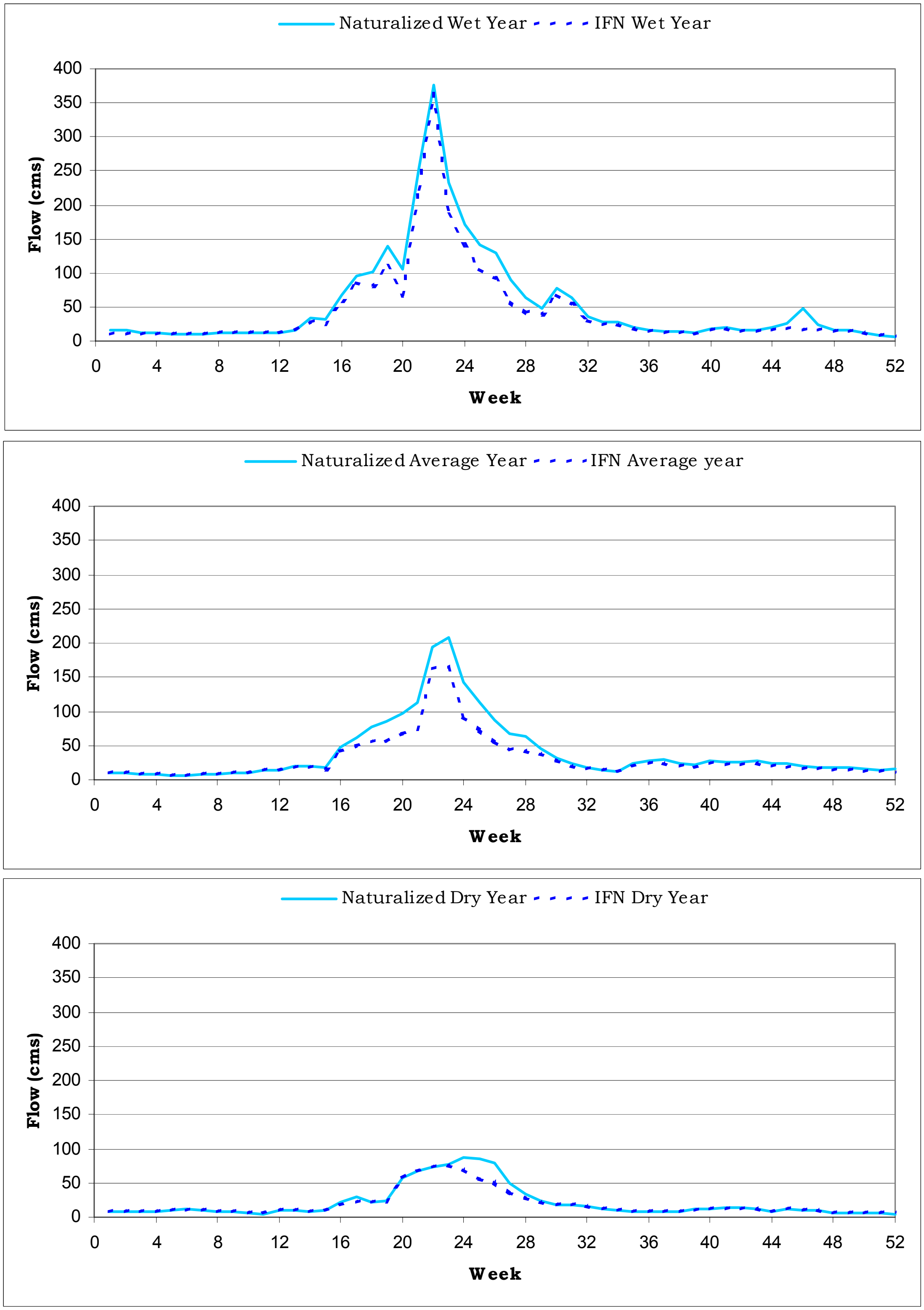


Figure 10.1. Example of inter-annual and intra-annual flow variability of the ecosystem IFN determination for the Oldman River (OM4) for a wet (top, 1990), average (middle, 1946), and dry (bottom, 1984) flow year based on the average annual flow.

As is the case with any instream flow needs determination study, there is some uncertainty. In the absence of data, assumptions must be made. It was the goal of the Technical Team to reduce to the extent possible the uncertainty inherent in studies of this nature. All decision points have been documented. The Technical Team does not wish to imply there were no arbitrary decisions. There were several instances where arbitrary decisions had to be made, but in those instances a decision was made through consensus.

For all future studies, the Technical Team wishes to stress the need for continued interdisciplinary study involving, but not limited to, hydrologists, hydraulic modellers, fluvial geomorphologists, river engineers, aquatic chemists, riparian ecologists, aquatic botanists, fisheries biologists and invertebrate biologists.

In the past there has been considerable discussion about "what the numbers mean." The intent of this report is to define an IFN that will provide for the protection of the aquatic environment by allowing all the naturally occurring ecosystem functions and services to continue. It is often the wish of many to view IFN recommendations as a very narrowly defined line that demarcates the transition from healthy to non-functioning or degraded ecosystems. The authors wish to caution those who hold this view that rarely, if ever, is it possible to define a threshold above which, for example, all natural processes, functions and services occur and below which they do not occur. This concept is an over-simplification. There is no evidence to suggest such a line exists. In the real world of complex ecosystems, it is more reasonable to expect a continuum of impacts, associated with various degrees of flow regime change, that incorporate the thresholds of many species, rather than a single threshold for the entire ecosystem (Brizga 2001).

The best guidance the Technical Team can provide in terms of interpreting the IFN determinations in the context of suggested water management options is that flow values lower than the IFN determinations will not likely protect the ecosystem over time. The ecosystem will not be able to provide all the historical natural functions and services that it used to. Based on the predictive modelling results, if the flows are at or above the recommended flows, then the ecosystem should be protected at near-natural levels.

It can also be said that when comparing two flow regimes, the flow regime that deviates further from the IFN determination will cause greater risk to the riverine ecosystem. Although it is not possible to accurately determine the degree to which the risk increases with deviation from the IFN, the Technical Team offers the following for consideration. In general, the greater the deviation from the IFN, the more likely it is that:

1. Change from natural will occur;
2. Change will occur more rapidly;
3. Change will be more severe (greater stress on a species);
4. Change will be more extensive (affect more species);
5. Recovery from change will take longer; and
6. Change will be irreversible.

There is a paucity of scientific knowledge that will help quantify the risk associated with any of the six concerns listed above. Each of these is a new area of research yet to be opened.

The ecosystem IFN determination is based on best available knowledge, but our knowledge about the complexities of ecosystems is incomplete. A fundamental difficulty in managing ecosystems for the long term is that their great complexity makes it difficult to forecast the future in any meaningful way. Not only are predictive models uncertain, common statistics may also underestimate the uncertainties of these models. Even when the best attempts are made to account for as many parameters as feasible, there are other key drivers, such as climate and technological change, that are unpredictable. Many of these parameters change non-linearly. In addition to the physical, chemical and biological factors that determine the ecosystem, the human element adds yet another dimension (Walker et al. 2002).

Regardless of the flow management decisions made in the future, it should be mandatory to validate the predictions of the models used in this report. Managing the uncertainty in any social resource decision is a prudent step to take. An adaptive environmental assessment and management program should be established. This report, and the recommendations contained herein, is based on the best available scientific information. However, alluvial river systems are complex and dynamic. Although our understanding of these systems, and our predictive capabilities, have improved in the last decades, there is still uncertainty about how the river and the riverine resources will react to any proposed water management plan. An adaptive management program provides a structured mechanism for fine tuning management operations in relation to the recommended flows.

In summary, the primary role of the IFN determinations is to give the decision makers guidance on future water management decisions in the SSRB, over the long term. If the current flows are near or above the IFN determination flows, then a decision to keep the reaches in a near natural and highly protective state can be achieved by limiting additional allocations. In those reaches where the existing flows are lower than the IFN determinations, and a decision is made to move toward the IFN determinations, then over the long term, the ecosystem should recover and function closer to a natural level. If a decision is made to hold flows below the IFN determinations, or to reduce them further through additional allocations or operational changes, it can be expected that the ecosystem will not function as it would under natural conditions.

The results of this study should be useful in future discussions regarding water planning in the South Saskatchewan River Basin. It is hoped this document will provide guidance to the decision makers and the information in this report will help decision makers better understand the consequences of their decisions.

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GLOSSARY

Abiotic – The nonliving, material components of the environment, such as water, sediment, temperature, etc.

Abscission – Separation of a leaf from a plant. Normally induced at the end of the growing season by the production of abscissic acid. Can also be triggered by adverse conditions such as drought stress.

Adaptive Management – A process whereby management decisions can be changed or adjusted based on additional biological, physical or socio-economic information.

Annual Flow – The total volume of water passing a given point in 1 year. May be expressed as a volume (such as acre-feet) but may also be expressed as an equivalent constant discharge over the year, such as cfs or m^3/s.

Aquatic Habitat – A specific type of area with environmental (i.e., biological, chemical, or physical) characteristics needed and used by an aquatic organism, population, or community.

Backwater – (1) A pool surface created in an upstream direction as a result of the damming effect of a vertical or horizontal channel constriction that impedes the free flow of water. (Bovee et al. 1998); or (2) Generally, an off-shoot from the main channel with little flow and where the water surface elevation is maintained by conditions in the main channel acting on the downstream end of the backwater.

Bankfull Discharge – The discharge corresponding to the stage at which floodplain begins to be inundated.

Bar – (1) A ridge-like accumulation of sand, gravel, or other alluvial material formed in the channel, along the banks, or at the mouth of a stream where a decrease in velocity induces deposition. (2) An alluvial deposit or bank of sand, gravel, or other material, at the mouth of the stream or at any point in the stream itself that causes an obstruction to flow:

Base Flow – The ground-water component of a stream's flow. It consists of the flow that would remain in the saturated zone below the streambed surface if surface flow were removed.

Baseline – The conditions occurring during the reference timeframe, usually referring to water supply habitat values, or population status. Baseline is often some actual recent historical period but may also represent: (1) the same climatological-meteorological conditions but with present water development activities on line; (2) the same climatological-meteorological conditions but with both current and proposed future development on line; or (3) virgin or pre-development conditions. The definition of baseline will always depend on the objectives of the study. Quite often, two or more baseline conditions may be necessary to evaluate a specific project.

Bedload – Material moving on or near the streambed and frequently in contact with it.

Benthic – Associated with the bottom of a body of water.

Biological Oxygen Demand (BOD) – An empirical test used by laboratories to determine the relative oxygen requirements of wastewaters, effluents and polluted waters. The test measures the oxygen utilized during a specified incubation period for the biochemical degradation of organic materials.

Biologically Significant Period (BSP) – A period of weeks or days when a given life stage is present or active, and for which PHABSIM modelling of that stage is relevant. For example, the BSP for rainbow trout spawning is 30 April to 17 June. Modelling habitat for spawning rainbow trout is relevant only for this period.

Biomass – The weight of a *taxon* or *taxa* per unit area. May be expressed as wet or dry weight. (Syn: Standing crop.)

Biotic – Of or pertaining to the living components of an ecosystem.

Braided – Pattern of two or more interconnected channels typical of alluvial streams.

Calibration – A means of adjusting modelled depths and velocities to obtain the most realistic depiction of hydraulic conditions in a study site.

Capillary Fringe – a zone of moisture that extends above the saturated riparian water table due to the 'wicking' effect caused by the surface tension of water (Mahoney & Rood 1998). The height of the capillary fringe is dependent upon substrate texture, ranging from 20 to 40 cm for coarse-textured mixtures of cobble and gravels, and 30 to 100 cm for fine-textured silt and sands (

CCME – Canadian Council of Ministers of the Environment

CCREM – Canadian Council of Resource and Environment Ministers

CFS – Cubic feet per second (measure of streamflow or discharge).

CFU – Colony forming units (bacteria). A measurement used in water quality assessments, with particular reference to recreational guidelines and fecal coliform bacteria, including E. coli.

Channel – The cross section containing the stream that is distinct from the surrounding area, due to breaks in the general slope of the land, lack of terrestrial vegetation, and changes in the composition of the substrate materials.

Channel Index – A general term in PHABSIM that can incorporate substrate, cover or both.

Channel Maintenance Flows – Range of flows within a stream from normal to peak runoff. May include, but is not limited to flushing flows or flows required to maintain the existing natural stream channel and adjacent riparian vegetation.

Channel Maintenance Flows – Streamflow or magnitude sufficient to mobilize significant amounts of bedload.

CMS (m^3/s) – Cubic metres per second (measure of streamflow or discharge).

Competition – Active demand by two or more organisms or species for the same environmental resources, especially in excess of the available supply.

Composite Fish – A WUA curve synthesized by combining curves for 2 or more life stages of a fish.

Connectivity – Maintenance of lateral, vertical, longitudinal and temporal pathways for biological, hydrological and physical processes

Consumptive Use – Represents the difference between the amount of water diverted and the amount of the return flow to the system (e.g., surface stream or underground basin). It is that amount by which the total resource is depleted.

Cover – Structural features (e.g., boulders, log jams) or hydraulic characteristics (e.g., turbulence, depth) that provide shelter from currents, energy-efficient feeding stations, and/or visual isolation from competitors or predators.

D_{50} – In a sediment or gravel mixture, D_{50} is the diameter that 50% of the mixture, by weight, falls short of or exceeds. (i.e., 50% of the gravel is larger than the specified diameter and 50% is smaller.)

Dam – An artificial barrier that obstructs the flow of water and that increases the water surface elevation upstream of the barrier. Usually built for water diversion, water storage, or to increase hydraulic head. Dams can affect fish passage, sediment transport, stream temperature, ice formation, and other natural processes.

Dendrochronology – The science of dating events and variations in environment in former periods by comparative study of growth rings in trees and aged wood.

Depth – The vertical distance from a point on the bed to the water surface.

Discharge – The rate of streamflow or the volume of water flowing at a location within a specified time interval. Usually expressed as cubic metres per second (m^3/s) or cubic feet per second (ft^3/s).

Dissolved Oxygen – The amount of oxygen dissolved in water, expressed in mg/L or as percent saturation, where saturation is the amount of oxygen that can theoretically be dissolved in water at a given altitude and temperature.

Diversion – A withdrawal from a body of water by means of a ditch, dam, pump or other man-made contrivance.

Diversity – That attribute of a biotic (or abiotic) system specifying the richness of plant or animal species (or complexity of habitat.

DO – Dissolved oxygen

Dry Year – A time period with a given probability of representing dry conditions; for example, a given year may be as dry or drier than 80% of all other similar periods.

Duration – (1) The percentage of time a class of events occurs. (2) An event's time span.

Duration Analysis – Examination of a certain period of record to categorize the frequency of classes of events within that period, often resulting in a duration curve.

DSSAMt – Dynamic Stream Simulation and Assessment Model with temperature

Ecosystem – Any complex of living organisms, interacting with nonliving chemical and physical components, that form and function as a natural environmental unit.

Ecosystem Base Flow (EBF) – A threshold value below which the Instream Flow Need is considered to be all of the natural flow. No diversions should take place.

Effluent – A discharge or emission of a liquid or gas.

Exceedence – That probability of an event exceeding others in a similar class. Note this may be 'equal or exceed' or 'exceed' only. Probabilities may also be expressed as non-exceedence, that is, the probability of being less than or equal or just less than.

Fish Rule Curve (FRC) – A variable flow recommendation based, in a specific way, on the WUA versus discharge curve and the natural available supply of water. The recommended flow varies, depending not only on the WUA curve, but also on the hydrologic conditions experienced (wet, dry, average) during the period.

Fishery – (1) The interaction of aquatic organisms, aquatic environments and their human users to produce sustained and ever-increasing benefits for people; (2) a product of physical, biological and chemical processes. Each component (process) is important, each affects the other, and each presents opportunities for impacting or enhancing the nature or character of fisheries resources. Fish populations are merely one attribute of a fishery.

Flood – Any flow that exceeds the bankfull capacity of a stream or channel and flows onto the floodplain.

Floodplain – Typically flat, depositional surface adjacent to a stream channel, that becomes inundated when flows exceed the bankfull capacity of a channel.

Flow – (1) The movement of a stream of water or other mobile substances from place to place; (2) Discharge; (3) Total quantity carried by a stream.

Flow Duration Curve – A plot of a discharge statistic versus its cumulative empirical probability of occurrence in the hydrologic time series. The discharge statistics are arranged in descending order and each discharge is assigned a rank from 1 (highest flow) to n (lowest flow) and its cumulative probability is calculated by:

$$P = \frac{m}{n+1}$$

where m is the rank and n is the total number of events in the time series. The plotting position represents the exceedence probability, or the probability that the associated event will be equaled or exceeded.

Flow Exceedence – A plot of river discharge (in cfs) vs. the percentage of time a given discharge is exceeded. For example, the highest discharge for the period of record has an exceedence value of 0%; the discharge that is exceeded half the time has a value of 50%.

Flow Exceedence, Naturalized – A flow exceedence curve that is constructed by adjusting gauge values for all diversions in the reach, such that natural flows are approximated.

Flow, Flushing – Artificial or natural discharge, of sufficient magnitude and duration to scour and remove fine sediments from the stream bottom, that helps to maintain the integrity of substrate composition.

Flow, Natural – The flow regime of a stream as it would occur under completely unregulated conditions, that is, not subjected to regulation by reservoirs, diversions, or other human works.

Flow Regime – The distribution of annual surface runoff from a watershed over time (hours, days, or months). See also, hydrologic regime.

Fluvial – Pertaining to streams or produced by river action.

Freshet – An increase in streamflow due to heavy rain or snowmelt.

Fry – A fish between the egg stage and the fingerling stage. Depending on the species, a fry can measure between a few millimetres and a few centimetres.

Gradient – The rate of change of any characteristic, expressed per unit of length. See Slope. May also apply to longitudinal succession of biological communities.

Habitat – The place where an organism or population lives, and its surroundings, both living and nonliving; includes life requirements such as food and shelter (see Physical Habitat).

Habitat Duration – A plot of habitat value (Weighted Usable Area, or WUA) vs. the percentage of time a given value of WUA is exceeded.

Habitat Guild – Groups of species that share common characteristics of microhabitat use and selection at various stages in their life histories.

Habitat Suitability Criteria (HSC) – A mathematical means of assigning a value between 0 and 1 to a physical variable, to describe its value as aquatic habitat for a species. For example, a velocity of 1.5 ft/s might be assigned a value of 1.0 for rainbow trout spawning.

HSC, Utilization - A type of HSC based solely on observed use of physical habitat.

HSC, Preference - A type of HSC in which utilization data are adjusted for availability. For example, a few observations in a rare habitat type may result in a high rating for that type.

HSC, Nonparametric - HSC in which a suitability index is assigned to central percentiles of the observations. For example, an index of 1.0 is commonly assigned to the central 50% of the observations, and an index of 0.2 to the central 90%.

Habitat Type – A collective term for habitats having equivalent ecological structure and function. A landscape classification system.

Headwater – The source for a stream in the upper tributaries of a drainage basin.

Headworks – A structure built across a stream to facilitate the diversion of flow into a canal. Usually consists of a diversion weir and its ancillary works.

Hydrograph - The graphical relationship of the discharge or stage with respect to time.

Hydrologic Regime – The distribution, over time, of water in a catchment. Includes precipitation, evaporation, soil moisture, groundwater storage, surface storage, and runoff.

Hydrology – The science that deals with the occurrence, circulation and distribution of water in a watershed or larger area, and includes its relationship to the environment and living things.

IFG4 – A hydraulic simulation model that uses empirical measurements of velocity, discharge, and water surface elevation to predict conditions at other discharge levels.

Instream Flow Incremental Methodology (IFIM) – IFIM is a decision-support system designed to help determine the benefits or consequences of different water management alternatives. IFIM is primarily a process for solving water resource allocation issues that include concerns for riverine habitat resources. IFIM was developed under leadership of the U.S. Fish and Wildlife Service by an inter-disciplinary team of scientists drawn from Federal and State resource agencies and academia. IFIM is composed of a library of linked analytical procedures that describe the spatial and temporal features of habitat under alternative flow regimes for a number of temporal and spatial scales.

IFN – Instream Flow Needs

Impoundment – Generally, an artificial collection or storage of water; a reservoir, pit, dugout, or sump.

Incipient Motion Method – A method that defines the hydraulic conditions at which an individual particle on a channel bed will start moving. This is accomplished by defining the relationship between the grain size of the material on a channel bed and the hydraulic shear stress acting on it.

Incremental Method – The process of developing an instream flow policy that incorporates multiple or variable rules to establish, through negotiation, flow-window requirements or guidelines to meet the needs of an aquatic ecosystem, given water supply or other constraints. Usually implies the determination of a habitat-discharge relation for comparing stream flow alternatives through time (see Standard-setting).

Indigenous – A fish or other aquatic organism native to a particular water body, basin, or region.

Instream Cover – Any material located within the water column of a stream that provides protection from predators or competitors, or mitigates the imports of other stream conditions for fish wildlife and aquatic animals.

Instream Flow Requirement – Instream flow is the amount of water flowing through a natural stream course that is needed to sustain the instream values at an acceptable level. Instream values and uses include protection of fish and wildlife habitat, migration, and propagation; outdoor recreation activities; navigation; hydropower generation; waste assimilation (water quality); and ecosystem maintenance which includes recruitment of fresh water to the estuaries, riparian vegetation, floodplain wetlands, and maintenance of channel geomorphology. Water requirements sufficient to maintain all of these uses at an acceptable level are the instream flow requirements.

Instream Objective (IO) – A river flow value that combines the instream flow value for the protection of the environment with socio-economic considerations identified by various stakeholders. The objective is to derive a workable compromise instream flow value.

Invertebrate – All animals without a vertebral column. In this report, aquatic insects.

Irrigation – The application of water to soil for crop production, or for turf, shrubbery, or wildlife food and habitat. Provides water requirements of plants not satisfied by rainfall.

Juvenile – Young of a species.

Life Stage – An arbitrary age classification of an organism into categories related to body morphology and reproductive potential, such as spawning, egg incubation, larva or fry, juvenile, and adult.

m^3/s – Cubic metres per second.

mg/L – Milligrams per litre.

Macrohabitat – Abiotic habitat conditions in a segment of river controlling longitudinal distribution of aquatic organisms, usually describing channel morphology, flow, or chemical properties or characteristics with respect to suitability for use by organisms.

Mainstem – The main channel of a river, as opposed to tributary streams and smaller rivers that feed into it.

Manning's Equation – A mathematical relationship between depth, velocity, bed roughness, slope, and discharge. This relationship is used in PHABSIM to simulate velocities at modelled flows.

MANSQ – A hydraulic simulation model that is mainly used to estimate water surface elevations at a range of discharges.

Maximum weekly loss in average habitat – A difference computed by first calculating and comparing the WUA averages for each week, for each of two scenarios, and then finding the greatest difference.

Meso-habitat – A discrete area of stream exhibiting relatively similar characteristics of depth, velocity, slope, substrate, and cover, and variances thereof (e.g., pools with maximum depth <5 ft, high gradient riffles, side channel backwaters).

Microhabitat – Small localized areas within a broader habitat type used by organisms for specific purposes or events, typically described by a combination of depth, velocity, substrate or cover.

Minimum Flow – The lowest stream flow required to protect some specified aquatic function; established by agreement or rule.

Natural Flow Paradigm – The full range of natural intra- and inter-annual variation of hydrological regimes, and associated characteristics of timing, duration, frequency, and rate of change, are critical in sustaining the full native biodiversity and integrity of aquatic ecosystems.

Natural Hydrograph – (1) a graph showing the variation in stage (depth) or discharge unaffected by human alteration, over a specific period of time; (2) a flow regime with a suitable period of record that has not been anthropogenically altered.

Non-point Source (NPS) – Runoff from diffuse sources such as fields and roadways, as opposed to runoff from a point specific site or point source.

Office-based Techniques – Using existing data, according to standard procedures.

Period of Record – The length of time for which data for an environmental variable have been collected on a regular and continuous basis.

Persistence – A non-random process within a time series of hydrological or meteorological events that tend to have high events following other highs and low events following other lows.

PHABSIM (pronounced PEE-HAB-SIM) – The Physical HABitat SIMulation system; a set of software and methods that allows the computation of a relation between stream flow and physical habitat for various life stages of an aquatic organism or a recreational activity.

Phreatophytic – Plants with a tap root system extending to the water table; they can transpire at a high rate even in the desert, so long as the water table does not drop below the tap root.

Physical Habitat – Those abiotic factors (such as depth, velocity, substrate, cover, temperature, water quality) that make up some of an organism's living space (see Habitat)

Pioneer forests – Forests capable of establishing in barren areas and initiating the first level of ecological succession.

Point Source Runoff – Effluent from a factory pipe, wastewater treatment plant or from sewer discharge or other specific points, rather than from diffuse sources.

Policy – Purposive action taken by public authorities on behalf of or affecting the public.

Pool – Part of a stream with reduced velocity, often with water deeper than the surrounding areas, which is usable by fish for resting and cover.

Poplar Rule Curve (PRC) – A set of guidelines that determine the minimum instream flow to meet the lifecycle requirements of riparian poplars. Application of the guidelines to a hydrological dataset generates an exceedence curve that specifies the instream flow for each natural flow value at a given time.

Reach – A comparatively short length of a stream, channel, or shore. One or more reaches compose a segment. The actual length is defined by the purpose of the study but is usually no greater than 5-7 times the channel width.

Recurrence Interval – The average time interval between events equaling or exceeding a given magnitude in a time series. (Also see exceedence probability.)

Regime – The general pattern (magnitude and frequency) of flow or temperature events through time at a particular location, (such as, snowmelt regime, rainfall regime).

Regulated Flow – Streamflow that has been affected by regulated releases, diversions, or other anthropogenic perturbations.

Reservoir – A pond, lake, or basin, either natural or artificial, for the storage, regulation, and control of water.

RI – Return interval.

Riparian – Pertaining to anything connected with or adjacent to the banks of a stream or other body of water.

Riparian Vegetation – Vegetation dependent upon an excess of moisture during a portion of the growing season on a site that is definitely moister than the surrounding area.

River – A large stream that serves as the natural drainage channel for a drainage basin of considerable area.

Run – A portion of a stream with low surface turbulence which approximates uniform flow, and in which the slope of the water surface is roughly parallel to the overall gradient of a stream reach.

Scour – The localized removal of material from the streambed by flowing water. The opposite of fill.

Sediment Oxygen Demand – The quantity of dissolved oxygen required for the biochemical degradation of organic materials in the stream substrate (bottom sediment). The greater the concentration of organic materials in the substrate, the greater the amount of oxygen needed for biodegradation to occur, thereby reducing the dissolved oxygen available in the overlying water column.

Segment – Terminology from IFIM meaning 1. A relatively long (e.g., hundreds of channel widths) section of a river, exhibiting relatively homogeneous conditions of hydrology, channel geomorphology, and pattern. 2. The fundamental accounting unit for total habitat.

Senescence – The final growth phase of a plant. The process of plant degeneration that generally occurs at the end of the growing season typified by chlorophyll breakdown, decreased growth rate, and transport of nitrogen from leaves to other plant parts.

Shields Entrainment Function – A relationship, developed by Shields (1936), to define streambed movement in relation to hydraulic forces acting on the channel bed.

Shields Equation – A simplified form of the Shields Entrainment Function that tests the movement of individual grain particles on a channel bed.

Side Channel – Lateral channel with an axis of flow roughly parallel to the mainstem and which is fed by water from the mainstem; a braid of a river with flow appreciably lower than the main channel. Side channel habitat may exist either in well-defined secondary (overflow) channels, or in poorly defined watercourses flowing through partially submerged gravel bars and islands along the margins of the mainstem.

Slope – The inclination or gradient from the horizontal of a line or surface. The degree of inclination can be expressed as a ratio, such as 1:25, indicating a one-unit rise in 25 units of horizontal distance or as 0.04 per length. Sometimes also expressed as feet per mile.

SOD – Sediment oxygen demand.

Spatial Variability – Pertaining to, or involving a species positioning in space, occurrence in space, and variability in occurrence in space (vertically, horizontally, and laterally).

Spawn – To lay eggs, especially of fish.

SSRB – South Saskatchewan River Basin

Stage – The distance of the water surface in a river above a known datum (e.g., relative to mean sea level).

Stream – A natural watercourse containing flowing water, at least part of the year, supporting a community of plants and animals within the stream channel and the riparian vegetative zone.

Streambank – The portion of the channel cross-section that tends to restrict lateral movement of water at normal water levels. Is usually made up of rock, soil and vegetative components. (Duff 1984)

Tessmann Method – The Tessmann Method is a variation of the Tennant Method. Tessmann adapted Tennant's seasonal flow recommendations to calibrate the percentages of the average annual flow to local hydrologic and biologic conditions including monthly variability. The Tennant method is based on percentages of average annual flow derived from estimated or recorded hydrologic records, limited field measurements, and photographs taken at multiple discharges.

WASP – Water Quality Analysis Simulation Program

WCO – Water Conservation Objectives

WRRM – Water Resources Management Model

WQRRS – Water Quality for River-Reservoir Systems

Water Table – The riparian water table consists of streamflow that has infiltrated the streambed. This zone of saturation extends horizontally from the stream's surface and slopes gradually downward.

Weighted Useable Area (WUA) – The wetted area of a stream weighted by its suitability for use by aquatic organisms. Units are square feet or square metres, usually per specified length of stream.