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

1. 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.

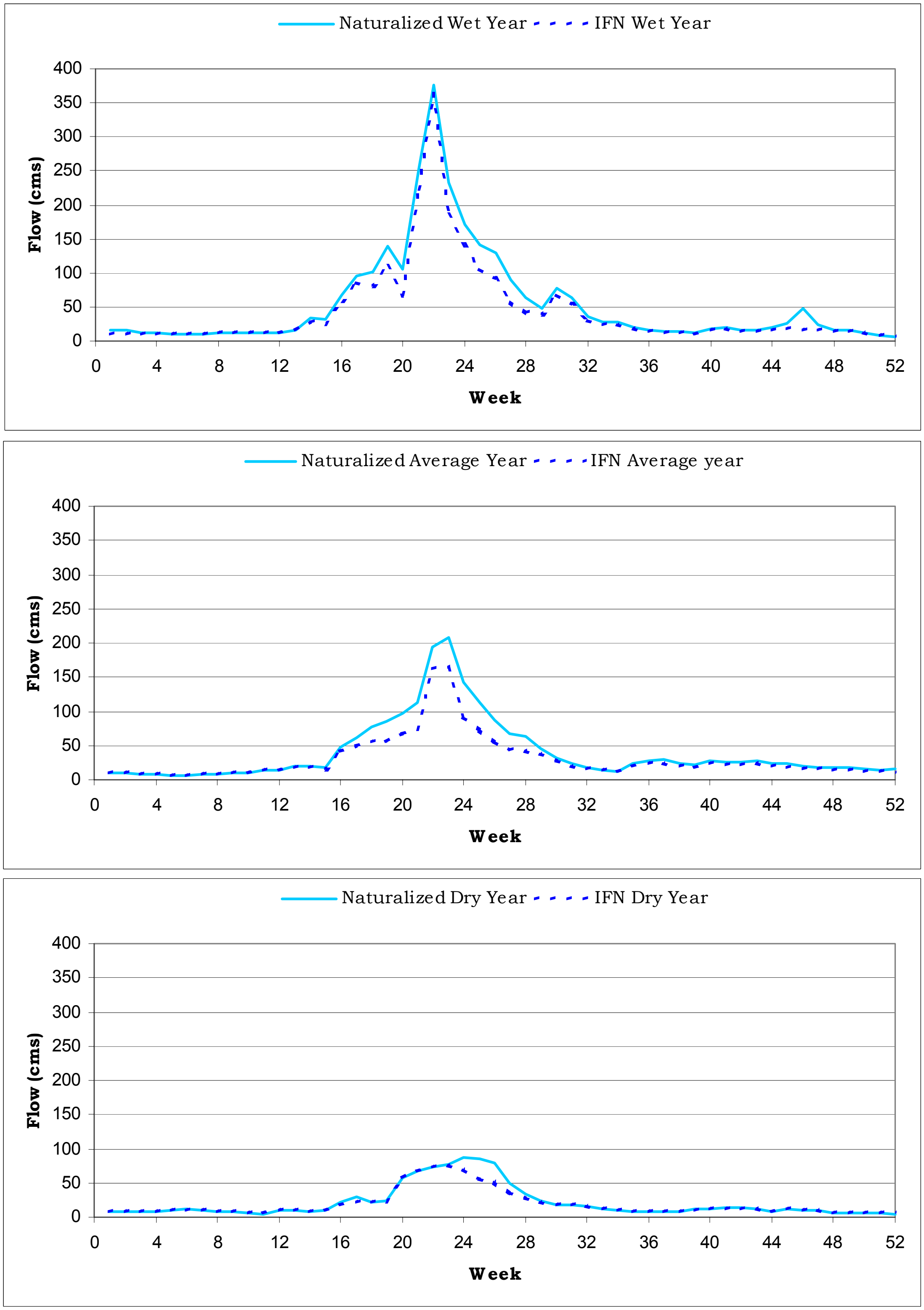

Figure 10.1. Example of inter-annual and intra-annual flow variability of the ecosystem IFN determination for the Oldman River (OM4) for a wet (top, 1990), average (middle, 1946), and dry (bottom, 1984) flow year based on the average annual flow.

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.

11.0 LITERATURE CITED

Aadland, L.P. 1993. Stream habitat types: Their fish assemblages and relation to flow. North American Journal of Fisheries Management 13:790-806.

Addley, R.C. 1993. A mechanistic approach to modeling habitat needs of drift feeding salmonids. MS Thesis. Utah State University, Logan UT.

Addley, R.C., G.K. Clipperton, T.B. Hardy, and A.G.H. Locke 2003. Fish habitat suitability criteria (HSC) curves: South Saskatchewan River Basin, Alberta, Canada. Prepared for Alberta Sustainable Resource Development, Cochrane, AB.

AGRA Earth and Environmental Limited, Rapid Creek Research Inc., and Madawaska Consulting 1995. Water quality assessment of the Red Deer River, Alberta: Summary of initial development and calibration of computer model for simulation of instream flow needs. Prepared for Alberta Environmental Protection, Environmental Protection Planning Division, Calgary.

Alberta Environment 1984. South Saskatchewan River Basin planning program: Summary Report. Water Resources Management Services, Edmonton. 88p.

Alberta Environment 1989. Instream flow needs study proposal: St. Mary, Belly and Waterton rivers. Final Approval Jan. 1990.

Alberta Environment 1990. Alberta Environment fact sheet: Water management policy for the South Saskatchewan River Basin. Edmonton. 3p.

Alberta Environment 1999. Surface water quality guidelines for use in Alberta. Environmental Sciences Division, Environmental Service. 25p.

Alberta Environment 2001a. Framework for water management planning. 37p.

Alberta Environment 2001b. South Saskatchewan River Basin historical weekly natural flows database 1912 to 1995. Microsoft Access Database Version 2.03. Water Sciences Branch, Edmonton. Compact Disk.

Alberta Environment 2002. Guidebook to water management. Prepared by Alberta Environment and the Bow River Basin Council. 346p.

Alberta Environmental Protection 1993. Flushing flow requirements for the Highwood River. Alberta Environmental Protection, Planning Division, Edmonton. 15p.

Alberta Environmental Protection 1996. 1996 Alberta state of the environment report: Aquatic ecosystems. Edmonton. 153p.

Alberta Environmental Protection 1998. South Saskatchewan River Basin historical weekly natural flows 1912 to 1995: Main report. Natural Resources Services, Water Management Division, Water Sciences Branch, Edmonton. 201p.

Albertson, F. and J. Weaver 1945. Injury and death or recovery of trees in prairie climate. Ecological Monographs 15(4):395-433.

Alfredsen, K. and E. Tesaker 2002. Winter habitat assessment strategies and incorporation of winter habitat in the Norwegian habitat assessment tools. Hydrological Processes 16:927-936.

Anderson, A. 1999. Bacterial surveys in the Red Deer River (1996-98). Water Sciences Branch, Alberta Environmental Protection, Edmonton. 35p.

Andrews, E.D. 1984. Bed-material entrainment and hydraulic geometry of gravel-bed rivers in Colorado. Geological Society of America Bulletin 95:371-378.

Andrews, E.D. and J.M. Nankervis 1995. Effective discharge and the design of channel maintenance flows for gravel-bed rivers. *in:* American Geophysical Union, Geophysical Monograph 89: Natural and anthropogenic influences in fluvial geomorphology, pp. 151-163. Annear, T.C., 2003. Instream Flow Supervisor, Wyoming Game and Fish Department, Cheyenne, Wyoming. Pers. Comm.

Annear, T.C. and P.D. Day 2000. Instream flow studies on Wagonhound Creek, Carbon County, Wyoming. Wyoming Game and Fish Department. 25p.

Annear, T.C., I. Chisholm, H. Beecher, A. Locke, and 12 other authors 2002. Instream flows for riverine resource stewardship. Published by the Instream Flow Council, Cheyenne, WY.

Arthington, A.H., J.M. King, J.H. O'Keeffe, S.E. Bunn, J.A. Day, B.J. Pusey, D.R. Bluhdorn, and R. Tharme 1991. Development of an holistic approach for assessing environmental flow requirements for riverine ecosystems. *in:* Water allocation for the environment: Proceedings of an international seminar and workshop, November 27-29, 1991. J.J. Pigram and B.P. Hopper [eds.] The Centre for Water Policy Research, University of New England, Armidale, New South Wales, Australia. pp. 66-76.

Armantrout, N.B. 1998. Glossary of aquatic habitat inventory terminology. American Fisheries Society, Bethesda, Maryland.

Armour, C.L. 1991. Guidance for evaluating and recommending temperature regimes to protect fish. U.S. Fish and Wildlife Service Biological Report 90(22). 13p.

Auble, G.T., M.L. Scott, J.M. Friedman, J. Back and V.J. Lee 1997. Constraints on establishment of plains cottonwood in an urban riparian preserve. Wetlands 17(1):138-148.

Bain, M.B. 1995. Habitat at the local scale: multivariate patterns for stream fishes. Bulletin Francais de la Peche et de la Pisciculture 337/338/339:165-177.

Baker, B.L., T.I. Ladd, S.A. Teland, J.W. Costerton, and G.W. Hodgson 1982. The biochemistry of streams: The Red Deer River. Prepared for the Research Management Division by the Kananaskis Centre for Environmental Research and the Department of Biology, University of Calgary. RMD Report 82-15. 221p.

Bardonnet, A. and P. Gaudin 1990. Diel pattern of downstream post-emergence displacement of grayling (*Thymallus thymallus* L., 1758). Journal of Fish Biology 37:623-627.

Bardonnet, A., P. Gaudin, and J. Thorpe 1993. Diel rhythm of emergence and of first displacement downstream in trout (*Salmo trutta* L.), Atlantic salmon (*Salmo salar* L.), and grayling (*Thymallus thymallus* L.). Journal of Fish Biology 43:755-762.

Bayha, K. and J.H. Gabrielsen 1979. Glossary of terms pertinent to instream flow work. Western Energy Land Use Team, U.S. Fish and Wildlife Service. Fort Collins, Co. FWS/0B5-79.

Beecher, H.A, B.A. Caldwell, and S. B. DeMond. 2002. Evaluation of depth and velocity preferences of juvenile coho salmon in Washington streams. North American Journal of Fisheries Management 22:785-795.

Beecher, H.A. 2003. Instream Flow Needs Biologist, Washington Department of Fish and Wildlife, Olympia, Washington. Personal Communication.

Beltaos. S. 1995. River ice jams. Water Resources Publications, LLC. Highlands Ranch, CO. 372p.

Bessey, D.E. 1904. The number and weight of cottonwood seeds. Science 20:118-119.

Bevelhimer, M.S. 1996. Relative importance of temperature, food, and physical structure to habitat choice by smallmouth bass in laboratory experiments. Transactions of the American Fisheries Society 125(2):274-283.

Bjornson, C.P. and D.A. Fernet 1989. Instream flow needs investigations of the St. Mary, Belly and Waterton rivers, 1988. Prepared for Habitat Branch, Fish and Wildlife Division, Edmonton, AB. Prepared by EMA, Calgary. 102p. +App.

Bovee, K.D. 1982. A guide to stream habitat analysis using the instream flow incremental methodology. Western Energy and Land Use Team, Office of Biological Services, Fish and Wildlife Service, U.S. Dept. of the Interior, Washington, D.C. Instream Flow Information Paper 12. 248pp.

Bovee, K.D. and M.L. Scott 2002. Implications of flood pulse restoration for *Populus* regeneration on the upper Missouri River. River Research and Applications 18:287-298.

Bovee, K.D., B.L. Lamb, J.M. Bartholow, C.D. Stalnaker, J. Taylor, and J. Henriksen 1998. Stream habitat analysis using the Instream Flow Incremental Methodology. U.S. Geological Survey, Biological Resources Division, Information and Technical Report USGS/BRD-1998-0004. 131p.

Bovee, K.D., T.J. Newcomb, and T.G. Coon 1994. Relations between habitat variability and population dynamics of bass in the Huron River, Michigan. National Biological Survey Biological Report 21. 63p.

Braatne, J., S. Rood, and P. Heilman 1996. Life history, ecology and conservation of riparian cottonwoods in North America. *in:* Biology of *Populus* and its implications for management and conservation. R. Stettler, H. Bradshaw, P. Heilman and T. Hinkley (eds). NRC Research Press, Ottawa, Ontario. pp.57-85.

Bradley, C.E. 1982. Modified meandering river regimes: Effects on plains cottonwood regeneration. M.Sc. Thesis. University of Calgary, Alberta.

Bradley, C.E. and D.G. Smith 1986. Plains cottonwood recruitment and survival on a prairie meandering river floodplain, Milk River, southern Alberta and northern Montana. Canadian Journal of Botany 64:1433-1442.

Bradley, C.E., F. Reintjes, and J. Mahoney 1991. The biology and status of riparian poplars in southern Alberta. Prepared for: World Wildlife Fund Canada and Alberta Forestry, Lands & Wildlife, Fish & Wildlife Division. 85p.

Brayshaw, T.C. 1965. Native poplars of southern Alberta and their hybrids. Department of Forestry Publication No. 1109, Ottawa. 40p.

Brizga, S. 2001. Proposed environmental performance measures: Pioneer Valley water resources. The State of Queensland, Department of Natural Resources and Mines. ISBN # 0 7345 2628 8. 72p.

Brown, C. and J. King 2002. Breede River basin study DRIFT application. Prepared for the Department of Water Affairs and Forestry, South Africa 66p. + appendices. www.southernwaters.co.za

BRWQTF (Bow River Water Quality Task Force) 1991. The Bow River: Preserving our lifeline. Prepared for the Bow River Water Quality Council, Calgary, Alberta. 78p.

BRWQTF (Bow River Water Quality Task Force) 1994. Preserving our lifeline: a report on the state of the Bow River. Prepared for the Bow River Water Quality Council, Calgary, Alberta. 98p.

Bunn, S.T. and A.H. Arthington 2002. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. Environmental Management 30(4):492-507.

Capra, H., P. Breil, and Y. Souchon. 1995. A new tool to interpret magnitude and duration of fish habitat variations. Regulated Rivers: Research and Management 10:281-289.

Carling, P. 1995. Implications of sediment transport for instream flow modelling of aquatic habitat. *in:* The ecological basis for river management, D.M. Harper and A.J.D. Ferguson (eds). John Wiley and Sons, Ltd.

Castleberry, D.T., J.J. Cech Jr., D.C. Erman, D. Hankin, M. Healey, G.M. Kondolf, M. Mangel, M. Mohr, P.B. Moyle, J. Nielsen, T.P. Speed and J.G. Williams 1996. Uncertainty and instream flow standards. Fisheries 2(8): 20-21.

CCREM (Canadian Council of Resource and Environment Ministers) 1987. Canadian Water Quality Guidelines. Environment Canada. Ottawa.

CDM 1986. Minimum instream flow study. Final Report. Camp, Dresser, and McKee, Commonwealth of Virginia State Water Control Board.

CH2M Hill Ltd. 1982. South Saskatchewan River Basin water quality modelling feasibility study. Prepared for Alberta Environment, Environmental Protection Service, Pollution Control Division, Edmonton. 36p.

Chambers, P.A., E.E. Prepas, H.R. Hamilton, and M.L. Bothwell 1991. Current velocity and its effect on aquatic macrophytes in flowing water. Ecological Applications 1:249-257.

Chapin, D.M., R.L. Beschta, and H.S. Shen 2002. Relationships between flood frequencies and riparian plant communities in the Upper Klamath Basin, Oregon. Journal of the American Water Resources Association 38(3):603-617.

Clipperton, G.K., R.F. Courtney, T.S. Hardin, A.G.H. Locke, and G.L. Walder 2002. Highwood River instream flow needs technical working group final report. Alberta Transportation, Edmonton.

Cole, T.M. and S.A. Wells 2002. CE-QUAL-W2: A two-dimensional, laterally averaged, hydrodynamic and water quality model, Version 3.1, User Manual. US Army Corps of Engineers Instruction Report EL-02-1, Washington, DC.

Colwell, R.K. and D.J. Futuyma 1971. On the measurement of niche breadth and overlap. Ecology 52(4):567-576.

Cooper, D. and D. VanHaverbeke 1990. Populus deltoides: Eastern cottonwood and plains cottonwood. *in:* Silvics of North America: 2. Hardwoods, R. Burns and B. Honkala (Tech. Coord.). US Department of Agriculture, Forest Service. Washington DC, pp. 530-543.

Cordes, L.D. 1991. The distribution and age structure of cottonwood stands along the lower Bow River. *in:* The biology and management of southern Alberta's cottonwoods, S.B. Rood and J.M. Mahoney (eds.). University of Lethbridge, Lethbridge, AB. pp. 13-23.

Cordes, L.D., F.M.R. Hughes, and M. Getty 1997. Factors affecting the regeneration and distribution of riparian woodlands along a northern prairie river: The Red Deer River, Alberta, Canada. Journal of Biogeography 24:675-695.

Courtney, R.F. and D.A. Fernet 1990. Bow River trout population studies, fall, 1988. Prepared by Environmental Management Associates for Alberta Forestry, Lands and Wildlife, Fish and Wildlife Division, Red Deer. 28p.

Courtney, R.F. and Walder, G.L. 1999. Instream flow requirements for fish on the Kananaskis River. Fisheries and Recreation Enhancement Working Group, Calgary, AB. 15p.

Crisp, D.T. and M.A. Hurley 1991. Stream channel experiments on downstream movement of recently emerged trout, *Salmo trutta* L., and salmon, *S. Salar* L.: II. Effects of constant and changing velocities and of day and night upon dispersal rate. Journal of Fish Biology 39:363-370.

Culp, J.M., H. Hamilton, A.J. Sosiak, and R.W. Davies 1992. Longitudinal zonation of the biota and water quality of the Bow River system in Alberta, Canada. *in:* Water quality of

North American river systems, C.D. Becker, D.A. Neitzel (eds.). Battelle Press, Columbus, Ohio.

Cunjak, R.A. 1996. Winter habitat of selected stream fishes and potential impacts from land-use activity. Canadian Journal of Fisheries and Aquatic Sciences 55(Supp. 1): 267-282.

Dawson, G.M. 1885. The geological and natural history survey and Museum of Canada report of progress 1882-83-84. Dawson Brothers, Montreal.

Dibble, E.D. and K.J. Killgore 1994. A habitat-based approach for studying fish-plant interactions. *in:* Proceedings of the 28th annual meeting, Aquatic Plant Control Program, 15-18 November 1994, Baltimore, Maryland.

Duff, D.A. 1984. A glossary of western stream habitat terms. Unpublished manuscript.

Dunbar, M. and A. Ibbotson 2001. Further validation of PHABSIM for the habitat requirements of salmonid fish. Centre for Ecology and Hydrology Final Project Report to the Environment Agency (W6-036) and CEH (C00962).

Dunne, T. and L.B. Leopold 1978. Water in environmental planning. W.H. Freeman and Company, New York, NY. 818p.

Easton, R.S. and D.J. Orth 1992. Ontogenetic diet shifts of age-0 smallmouth bass (*Micropterus dolomieu Lacepede*) in the New River, West Virginia, USA. Ecology of Freshwater Fish 1:86-98.

Emmett, W.W. 1975. The channels and waters of the upper Salmon River area, Idaho. U.S. Geological Survey, Professional Paper 870-A. 116p.

Emmett, W.W. and M.G. Wolman 2001. Effective discharge and gravel-bed rivers. Earth Surface Processes and Landforms 26:1369-1380.

Environment Canada 2003. Cimate Trends and Variations Bulletin. http://www.msc-smc.ec.gc.ca/ccrm/bulletin/regional_e.cfm).

Environmental Management Associates (EMA) 1983. The fishery resource and habitat characteristics of the Red Deer River between Dickson Dam site and Drumheller prior to reservoir operation. Prepared for Planning Division, Alberta Environment, Edmonton, AB. 142p.

Environmental Management Associates (EMA) 1989. Instream flow needs investigation of the St. Mary, Belly and Waterton rivers, 1988. Prepared for Habitat Branch, Alberta Fish and Wildlife Division, Edmonton. 104p.

Environmental Management Associates (EMA) 1994. Instream flow requirements for the fishes of the St. Mary, Belly and Waterton rivers. Prepared for Alberta Environmental Protection, Fish and Wildlife Division, Edmonton, Alberta. 87p. +App.

EPRI 1986. Instream flow methodologies: Final report. Electric Power Research Institute, Palo Alto, California. EA-4819 Research Project 2194-2.

EPRI. 2000. Instream flow assessment methods: guidance for evaluating instream flow needs in hydropower licensing. EPRI, Palo Alto, CA. Report #1000554.

Fenner, P., W.W. Brady, and D.R. Patton 1985. Effects of regulated water flows on regeneration of Fremont cottonwood. Journal of Range Management 38(2):135-138.

Fernet, D.A. and S.M. Matkowski 1986. Oldman River Dam environmental mitigation/opportunities plan instream flow study: Fish distribution, abundance, critical habitats and relationships with streamflow downstream of the Oldman River Damsite. Prepared for Planning Division, Alberta Environment. 137p.

Fernet, D.A., C.P. Bjornson, and J.J. Helwig 1992. Willow Creek instream flow needs investigations: Fisheries component. Alberta Environmental Protection, Edmonton, AB. 108p. +App.

Fernet, D.A., R.F. Courtney, and C.P. Bjornson 1990. Instream flow requirements for fishes in the Oldman River Dam. Prepared for Public Works Supply and Services, Edmonton. 137p.

Fetter, C.W. 1994. Applied hydrogeology, 3rd Edition. Prentice-Hall Inc., Upper Saddle River, NJ. 691p.

Filbert, R.B. and C.P. Hawkins 1995. Variation in condition of rainbow trout in relation to food, temperature, and individual length in the Green River, Utah. Transactions of the American Fisheries Society 124(6):824-835.

Frissell, C.A. and D. Bayles 1996. Ecosystem management and the conservation of aquatic biodiversity and ecological integrity. Water Resources Association, Water Resources Bulletin 32(2):229-240.

Geer, W.H. 1983. A method for treatment of data from the instream flow incremental methodology for instream flow determination. Pages 63-97 *in* C.R. Berry, editor. Proceedings of the Bonneville Chapter of the American Fisheries Society 1983 Annual Meeting, Logan, Utah.

Golder Associates Ltd. 1993. Lethbridge wastewater treatment plant: Receiving water assessment. Submitted to the City of Lethbridge, 36p. +App.

Golder Associates Ltd. and W-E-R Engineering Ltd. 1994. Instream flow needs investigation of the Bow River. Prepared for Alberta Environmental Protection, Fish and Wildlife Division, Edmonton. 267 p. +App.

Golder Associates Ltd. 1999. Red Deer River instream flow needs study. Prepared for Fisheries Management Division, Edmonton. 45p. +App.

Goldstein, P.Z. 1999. Functional ecosystems and biodiversity buzzwords. Conservation Biology 13(2):247-255.

Gom, L.A. 2002. Poplar rule curves (PRC): Instream flow needs (IFN) for riparian poplars in the South Saskatchewan River Basin. Part I – Drafting the PRC. Prepared for Alberta Environment, Southern Operations, Lethbridge. 29p.

Gom, L.A. and J.M. Mahoney 2002. Poplar rule curves (PRC): Instream flow needs (IFN) for riparian poplars in the South Saskatchewan River Basin. Part II – Verification and revision of the PRC. Prepared for Alberta Environment, Southern Operations, Lethbridge. 86p.

Gom, L.A. and S.B. Rood 1999. Patterns of clonal occurrence in a mature cottonwood grove along the Oldman River, Alberta. Canadian Journal of Botany 77:1095-1105.

Goodwin, P. and T.B. Hardy 1999. Integrated simulation of physical, chemical and ecological processes for river management. Journal of Hydroinformatics 01(1):33-58.

Gordon, N. 1995. Summary of technical testimony in the Colorado Water Division 1 Trial. USDA Forest Service, General Technical Report RM-GTR-270. 140p.

Gordon, N.D., T.A. McMahon, and B.L. Finlayson 1992. Stream hydrology. John Wiley & Sons. Chichester, England.

Gore, J.A. 1989. Models for predicting benthic macroinvertebrate habitat suitability under regulated flows. *in:* Alternatives in regulated river management, J.A. Gore, J.A. and G.E. Petts, (eds.), CRC Press Inc., Boca Raton, Florida. pp. 254-265.

Gorman, O.T. and J.R. Karr 1978. Habitat structure and stream fish communities. Ecology 59(3):507-515.

Grant, P. 1974. Present minimum flow requirements for the Red Deer River. Prepared for Environmental Planning Division, Alberta Environment, Red Deer River Flow Regulation Study. 16p.

Gregory, K.J. and D.E. Walling 1973. Drainage basin form and process. Edward Arnold, London.

Gregory, S.V., F.J. Swanson, W.A. McKee, and K.W. Cummins 1991. An ecosystem perspective of riparian zones. BioScience 41:540-551.

Growns, I.O. and J.E. Growns 2001. Ecological effects of flow regulation on macroinvertebrate and periphytic diatom assemblages in the Hawkesbury – Nepean River, Australia. Regulated Rivers: Research and Management 17:275-293.

Guensch, G.R., T.B. Hardy, and R.C. Addley 2001. Validation of an individual-based, mechanistic habitat selection model for drift-feeding salmonids. Canadian Journal of Fisheries and Aquatic Science 58(3):446-457.

Hamilton, H.R. and P.M. Cross 1985. The implementation of WQRRS for water quality modelling on the Bow, Oldman, South Saskatchewan, and Red Deer rivers. Alberta Environment, Water Quality Control Branch. 44p. +App.

Hamilton, H., S. Goudey, R. Lewis, and G. Macdonald 1989. Reevaluation of WQRRS for the Bow River. Prepared by HydroQual Consultants Inc. for Alberta Environment, Planning Division, Calgary.

Hardy, T.B. 1998. The future of habitat modeling and instream flow assessment techniques. Regulated Rivers: Research and Management 14:405-420.

Hardy, T.B. 2000a. A conceptual framework and technical approach for assessing instream flow needs in the Water Resource Inventory Area No. 1 (WRIA1) in Washington State (Final Draft). Utah State University, Logan, UT. 64p.

Hardy, T.B. 2000b. The theory and application of the Physical Habitat Simulation System (PHABSIM) for Windows (PHABWin-98): Lecture and laboratory manual. Institute for Natural Systems Engineering, Utah State University, Logan, UT. 273p.

Hardy, T.B. 2001. WRIA1 habitat suitability criteria workshop summary report.

Hardy, T.B. 2002. Water surface and velocity model calibration for selected rivers in the South Saskatchewan River Basin, Alberta, Canada. Prepared for Alberta Environment, Cochrane, AB.

Hardy, T.B. and C. Addley 2001. Evaluation of Interim Instream Flow Needs in the Klamath River, Phase II. Institute for Natural Systems Engineering, Utah Water Research Laboratory, Utah State University, Logan, Utah. 84322-8200.

Hawkins, J.A., E.J. Wick, and D.E. Jennings 1997. Ichthyofauna of the Little Snake River, Colorado, 1994. Final Report. Contribution 91 of the Larval Fish Laboratory. Colorado State University, Fort Collins, CO. 44p.

Hazewinkel, R.R.O. and K.A. Saffran 2002. Temperature and dissolved oxygen in the Oldman River following construction of the Oldman Dam (draft). Environmental Evaluation and Monitoring Section, Alberta Environment, Edmonton. 54p +App.

Hearne, J., I. Johnson, and P. Armitage 1994. Determination of ecologically acceptable flows in rivers with seasonal changes in the density of macrophytes. Regulated Rivers: Research and Management 9:177-184.

Heede, B.H. 1992. Stream dynamics: An overview for land managers. U.S. Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO. General Technical Report RM-72.

Heland, M., P. Gaudin, and A. Bardonnet 1995. First behavioral adjustments in relation to habitat use after emergence in running water salmonids. Bulletin Francais de la Peche et de la Pisciculture 337/338/339:191-197.Hill, J. and G.D. Grossman 1993. An energetic model of microhabitat use for rainbow trout and rosyside dace. Ecology 74:685-698.

Hill, M.T., W.S. Platts, and R.L. Beschta 1991. Ecological and geomorphological concepts for instream and out-of-channel flow requirements. Rivers 2(3):198-210.

Howe, W.H. and F.L. Knopf 1991. On the imminent decline of Rio Grande cottonwoods in central New Mexico. The Southwestern Naturalist 36(2):218-224.

Hughes, F.M.R. 1994. Environmental change, disturbance and regeneration in semi-arid floodplain forests. *in:* Environmental change in drylands: Biogeographical and geomorphological perspectives. John Wiley & Sons Ltd. pp. 321-345.

Hughes, F.M.R., W.M. Adams, E. Muller, C. Nilsson, K.S. Richards and 13 others 2001. The importance of different scale processes for the restoration of floodplain woodlands. Regulated Rivers: Research and Management 17:325-345.

Hughes, R.M. and R.F. Noss 1992. Biological diversity and biological integrity: Current concerns for lakes and streams. Fisheries 17(3):11-19.

HydroQual Canada Ltd. 1990a. Data summary on Oldman River water quality projections. Prepared for Alberta Environment, Planning Division, Calgary 160p. +App.

HydroQual Canada Ltd. 1990b. Re-evaluation of dissolved oxygen in the lower Oldman River. Meeting briefing notes (unpublished) 21 November and 18 December, 1990. Prepared for Planning Division, Alberta Environment.

HydroQual Canada Ltd. 1991. WQRRS modelling update for the Belly, St. Mary and Waterton rivers. Prepared for Alberta Environment, Planning Division. 38p. +App.

Independent Scientific Group 2000. Return to the river. Northwest Power Planning Council, Report 2000-12. 536p.

Inglis, C.C. 1949. The behavior and control of rivers and canals. U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS.

Jager, H.I., D.L. Deangelis, M.J. Sale, W. Van Winkle, D.D. Schmoyer, M.J. Sabo, D.J. Orth, and J.A. Lukas 1993. An individual-based model for smallmouth bass reproduction and young-of-the-year dynamics in streams. Rivers 4:91-113.

Johnson, I.W. and F.M. Law 1995. Computer models for quantifying the hydro-ecology of British rivers. Journal of CIWEM 9:290-297.

Johnson, I.W., C.R.N. Elliot and A. Gustard 1995. Modelling the effect of groundwater abstraction on salmonid habitat availability in the River Allen, Dorset, England. Regulated Rivers: Research and Management 10:229-238.

Johnson, P.A. and T.M. Heil 1996. Uncertainty in estimating bankfull conditions. Water Resources Bulletin 32(6):1283-1291.

Johnson, W.C. 1992. Dams and riparian forests: Case study from the upper Missouri River. Rivers 3(4):229-242.

Johnson, W.C. 1998. Adjustment of riparian vegetation to river regulation in the Great Plains, USA. Wetlands 18(4):608-618.

Johnson, W.C., R.L. Burgess and W.R. Keammerer 1976. Forest overstory vegetation and environment on the Missouri River floodplain in North Dakota. Ecological Monographs 46(1):59-84.

Jowett, I.G. 1992. Models of the abundance of large brown trout in New Zealand rivers. North American Journal of Fisheries Management 12:417-432.

Jowett, I.G., J. Richardson, J.F. Biggs, C.W. Hickey, and J.M. Quinn 1991. Microhabitat preferences of benthic invertebrates and the development of generalized *Deleatidium* spp. habitat suitability curves applied to four New Zealand streams. New Zealand Journal of Marine and Freshwater Research 25:187-199.

Karr, J.R. 1991. Biological integrity: A long-neglected aspect of water resource management. Ecological Applications 1:66-84.

Karr, J.R., K.D. Fausch, P.L. Angermeier, P.R. Yant, and I.J. Schlosser 1986. Assessing biological integrity in running waters: a method and its rationale. Special Publication 5. Illinois Natural History Survey, Champaign, IL. 28pp.

Keller, E.A. and F.J. Swanson 1979. Effects of large organic material on channel form and fluvial processes. Earth Surface Processes and Landforms 4:351-380.

Kellerhals, R., C.R. Neill, and D.I. Bray 1972. Hydraulic and geomorphic characteristics of rivers in Alberta. Cooperative Research Program in Highway and River Engineering. Edmonton.

Komura, S. and D.B. Simmons 1967. River bed degradation below dams. American Society of Civil Engineers, Journal of the Hydraulics Division 93:1-14.

Kondolf, G.M. 1998. Development of flushing flows for channel restoration on Rush Creek, California. Rivers 6:183-193.

Koning, C.W. 1999. Riparian Assessment and Prescriptions Procedure. Ministry of Environment, Lands and Parks, and Ministry of Forests, Watershed Restoration Program, Vancouver. Technical Circular 6. 85p.

Lancaster, J. and A.G. Hildrew 1993. Flow refugia and the microdistribution of lotic macroinvertebrates. Journal of the North American Benthological Society 12(4):385-393.

Leclerc, M., A. Boudreault, J.A. Bechara, and G. Corfa 1995. Two-dimensional hydrodynamic modeling: A neglected tool in the instream flow incremental methodology. Transactions of the American Fisheries Society 124(5):645-662.

Leopold, L.B. 1994. A view of the river. Harvard University Press, Cambridge, MA. 298p.

Leopold, L.B., M.G. Wolman, and J.P. Miller 1964. Fluvial processes in geomorphology. W.H. Freeman, San Francisco.

Levine, C. and J. Stromberg 2001. Effects of flooding on native and exotic plant seedlings: Implications for restoring south-western riparian forests by manipulating water and sediment flows. Journal of Arid Environments, 49:111-131.

Locke, A.G.H. 1989. Instream flow requirements for fish in the Highwood River. Prepared for Fish and Wildlife Division, Edmonton. 43p. +App.

Longmore, L.A. and C.E. Stenton 1981. The fish and fisheries of the South Saskatchewan River Basin: Their status and environmental requirements. Prepared for Planning Division, Alberta Environment. 335p.

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

Maki-Petays, A., T. Muotka, and A. Huusko 1999. Densities of juvenile brown trout in two subarctic rivers: Assessing the predictive capability of habitat preference indices. Canadian Journal of Fisheries and Aquatic Sciences 56:1420-1427.

Marken, S. 1993. Plains cottonwoods and riparian plant communities on the lower Red Deer River. M.Sc. Thesis, Department of Geography, University of Calgary, AB. 173p.

Martin J. Paetz Enterprises 1986. The fish and fisheries of the Bow River sub-basin: Their status, environmental requirements and management considerations. Prepared for Fish and Wildlife Division, Alberta Energy and Natural Resources. 194p.

May, R.M. and R.H. MacArthur 1972. Niche overlap as a function of environmental variability. Proceedings of the National Academy of Sciences, USA 69(5):1109-1113.

McDonald, D. 2002. Limnologist, Alberta Environment, Calgary, Alberta. Pers. Comm.

McGurk, B.J. and B.A. Paulson 2002. Developing streamflow recommendations: Tools that work. Hydro Review October 2002.

McKay, S.J. 1996 The impact of river regulation on establishment processes of riparian black cottonwood. M.Sc. Thesis, University of Washington, Seattle, WA.

Merritt, D. and D. Cooper 2000. Riparian vegetation and channel change in response to river regulation: A comparative study of regulated and unregulated streams in the Green River Basin, USA. Regulated Rivers: Research and Management 16:543-564.

Meyer-Peter, E. and D.L. Frink 1948. Formula for bed-load transport. Proceedings of the International Association for Hydraulic Research, 2nd Meeting, Stockholm.

Michalsky, S.J., R.E. Rowell, and G.A. Yarranton 1991. Highwood River riparian vegetation study. Prepared for: Alberta Environment, Edmonton, AB.

Milhous, R.T. 1980. Effect of sediment transport and flow regulation on the ecology of gravel bed rivers. *in*: Gravel-bed Rivers, R.D. Hey, J.C. Bathurst and C.R. Thorne (eds.). John Wiley and Sons, Toronto. pp.819-842.

Milhous, R.T. 1990. The calculation of flushing flows for gravel and cobble bed rivers. *in:* Hydraulic engineering: Proceedings of the 1990 conference, Vol. 1, H.H. Chang and J.C. Hill (eds.). American Society of Civil Engineers, New York. pp.598-603.

Milhous, R.T. 1998. Numerical modelling of flushing flows in gravel-bed rivers. *in*: Gravel-bed Rivers in the Environment. Klingeman, Beschta, Komar and Bradley (eds.). John Wiley and Sons, Toronto. pp.579-609.

Milhous, R.T., M.A. Updike, and D.M. Schneider 1989. Physical habitat simulation system reference manual - Version II. U.S. Dept. of the Interior. Fish and Wildlife Service. Washington, DC. Instream Flow Information Paper No. 26.

Miller, J.R., T.T. Schulz, N.T. Hobbs, K.R. Wilson, D.L. Schrupp, and W.L Baker 1995. Changes in the landscape structure of a southeastern Wyoming riparian zone following shifts in stream dynamics. Biological Conservation 72:371-379.

Mitchell, P. 2001. Limnological assessment of the Oldman River Reservoir. Alberta Environment, Water Quality Section. Edmonton. 55p. +App.

Moore, K.M.S. and S.V. Gregory 1988. Summer habitat utilization and ecology of cutthroat trout fry (*Salmo clarkii*) in Cascade Mountain streams. Canadian Journal of Fisheries and Aquatic Sciences 45(11):1921-1930.

Mosley, M.P. 1981. Semi-determinate hydraulic geometry of river channels, South Island, New Zealand. Earth Surface Process and Landforms 6:127-137.

Muhar S., S. Schmutz, and M. Jungwirth 1995. River restoration concepts - Goals and perspectives. Hydrobiologia 303:183-194.

Muth, R.T., L.W. Crist, K.E. LaGory, J.W. Hayse, K.R. Bestgen, T.P. Ryan, J.K. Lyons, and R.A. Valdez 2000. Flow and temperature recommendations for endangered fishes in the Green

River downstream of Flaming Gorge dam. Upper Colorado River Endangered Fish Recovery Program Project FG-53. www.ead.anl.gov/pub/index.cfm

National Park Service 2001. Virgin River water right, 1996. Presented at Managing river flows for biodiversity conference, July 30 – August 2, 2001, Colorado State University. www.nature.nps.gov/wrd/wrnps.htm

National Research Council (NRC) 1992a. Restoration of aquatic systems: Science, technology and public policy. National Academy Press, Washington DC.

National Research Council (NRC) 1992b. Water transfers in the west: Efficiency, equity, and the environment. Committee on Western Water Management, Water Science and Technology Board, Commission on Engineering and Technical Systems, National Research Council, National Academic Press, Washington, D.C.

Nehring, R.B. and R.M. Anderson 1993. Determination of population-limiting critical salmonid habitats in Colorado streams using IFIM/PHABSIM. Rivers 4:1-19.

Neill, C.R. and E.K Yaremko 2001. Channel maintenance flow assessment Highwood River near High River. Northwest Hydraulic Consultants Ltd. Edmonton, Alberta. 29p.

Nilsson, C., A. Ekblad, M. Gardfjell, and B. Carlberg 1991. Long-term effects of river regulation on river margin vegetation. Journal of Applied Ecology 28:963-987.

OMRWQI (Oldman River Basin Water Quality Initiative) 2000. Oldman River Basin water quality initiative summary report 2000. Alberta Environment, Lethbridge. 24p.

OMRWQI (Oldman River Basin Water Quality Initiative) 2001. Oldman River Basin water quality initiative 2000/2001 Annual Report: Partnering for the future. Alberta Environment, Lethbridge.

Orth, D.J. 1987. Ecological considerations in the development and application of instream flow-habitat models. Regulated Rivers: Research and Management 1:171-181.

Orth, D.J. 1995. Food web influences on fish population responses to instream flow. Bulletin Francais et de la Peche de la Pisciculture 337/338/339:317-328. Osborne, L.L. and D.A. Kovacic 1993. Riparian vegetated buffer strips in water quality restoration and stream management. Freshwater Biology 29:243-258.

Petts, G.E. 1987. Time-scales for ecological change in regulated rivers. *in:* Regulated streams: Advances in ecology, J.F. Craig and J.B. Kemper (eds.). Plenum Press, New York, NY. Pp257-266.

Petts, G.E. 1986. Water Allocation to Protect River Systems. Regulated Rivers: Research and Management 12:353-365.

Petts, G.E. and I. Foster 1985. Rivers and Landscapes. Edward Arnold, London.

Petts, G.E. and I. Maddock 1996. Flow allocation for in-river needs. *in:* River Restoration, G. Petts and P. Calow (eds.). Blackwell Science. London. pp. 60-79.

Petts, G.E., I. Maddock, M. Bickerton, and A.J.D. Ferguson 1995. Linking hydrology and ecology: The scientific basis for river management. *in:* The ecological basis for river management, D.M. Harper and A.J.D. Ferguson (eds.). John Wiley and Sons, Toronto. pp. 1-16.

Pianka, E.R. 1974. Niche overlap and diffuse competition. Proceedings of the National Academy of Sciences, USA 71(5):2141-2145.

Poff, N.L. and J.V. Ward 1990. Physical habitat template of lotic systems: Recovery in the context of historical pattern of spatiotemporal heterogeneity. Environmental Management 14(5):629-645.

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

Postel, S.L. 2000. Entering an era of water scarcity: The challenges ahead. Ecological Applications 10(4):941-948.

Potyondy J.P. and E.D. Andrews 1999. Channel maintenance considerations in hydropower relicensing. Stream Systems Technology Center, Rocky Mountain Research Station. Stream Notes, April 1999.

Power, G., R. Cunjak, J. Flannagan, and C. Katapodis 1993. Biological effects of river ice. *in*: Environmental Aspects of River Ice, T.D. Prowse and N.C. Gridey (eds.). Environment Canada, National Hydrology Research Institute, Saskatoon, SK. NHRI Science Report No. 5, pp. 97-119.

Prowse, T.D. 2001. River-ice ecology II: Biological aspects. Journal of Cold Regions Engineering 15(1):17-33.

R.L. & L. Environmental Services Ltd. 1994. Management of lake sturgeon (*Acipenser fulvescens)* sport fisheries in Alberta. Prepared for World Wildlife Fund/Prairie For Tomorrow, and Alberta Fish and Wildlife Division. 38p.

R.L. & L. Environmental Services Ltd. 1996. Fisheries and fish habitat inventories of the lower Bow, lower Oldman, and South Saskatchewan rivers, fall 1995. Prepared for Alberta Environmental Protection, Natural Resources Service, Fisheries Management Division. R.L. & L. Report No. 478F. 71p. +App.

R.L. & L. Environmental Services Ltd. 1997. Fisheries inventories of the lower Bow, lower Oldman and South Saskatchewan rivers, 1995-1996. Prepared for Alberta Environmental Protection, Natural Resources Service. R.L.& L. Report No. 516F. 90p. +App.

R.L. & L. Environmental Services Ltd. 2000a. Oldman River dam project fisheries evaluation program: 1995 annual report - Downstream Oldman River. Prepared for Alberta Public Works, Supply and Services. R.L. & L. Report No. 457AF. 55p. +App.

R.L. & L. Environmental Services Ltd. 2000b. Oldman River dam project fisheries evaluation program: 1996 annual report - Downstream Oldman River. Prepared for Alberta Public Works, Supply and Services. R.L. & L. Report No. 510F. 47p. +App.

Rabeni, C.F. and R.B. Jacobson 1993. The importance of fluvial hydraulics to fish-habitat restoration in low-gradient alluvial streams. Freshwater Biology 29:211-220.

Rader, R.B. and T.A. Belish 1999. Influence of mild to severe flow alterations on invertebrates in three mountain streams. Regulated Rivers: Research and Management 15:353-363.

Railsback, S.F., R.F. Blackett, and N.D. Pottinger 1993. Evaluation of the fisheries impact assessment and monitoring program for the Terror Lake hydroelectric project. Rivers 4(4):312-327. Railsback, S. F., H. B. Stauffer, and B. C. Harvey. (*In press*) What can habitat preference models tell us? Tests using a virtual trout population. Ecological Applications. Prepublication copy available at, http://math.humboldt.edu/~simsys/Products.html

Rasmussen, J.L. 1996. Floodplain management: AFS position statement. Fisheries 21(4):6-10.

Reese, C.D. and B.C. Harvey 2002. Temperature-dependent interactions between juvenile steelhead and Sacramento pike minnow in laboratory streams. Transactions of the American Fisheries Society 131:599-606.

Reid Crowther and Partners Ltd. and Stanley Associates Engineering Ltd. 1990. City of Calgary wastewater treatment master plan. 1990 to 2050. Final Report – Volumes I, II and III.

Reid, D.E. 1991. Cottonwood mortality assessment at Police Point Park, Alberta. *in:* Proceedings of the Biology and Management of Southern Alberta's Cottonwoods Conference, S.B. Rood and J.M. Mahoney (eds.). University of Lethbridge, AB. pp. 43-46.

Reid, D.E., L. Zilm, J.M. Mahoney, and S.B. Rood 1992. Riparian vegetation of the St. Mary, Belly and Waterton River valleys, Alberta. Submitted by Hardy BBT Limited and the University of Lethbridge, AB. Report #CE01190

Reiser, D.W., G. Lewis, and P. DeVries 1988. Feasibility study fisheries habitat enhancement project East Fork Salmon River, Idaho. Report to Shoshone-Bannock Tribes, Fort Hall, ID.

Reiser, D.W., M.P. Ramey, and T.R. Lambert 1987. Considerations in assessing flushing flow needs in regulated stream systems. *in*: Regulated Streams: Advances in Ecology, J.F. Craig and J.B. Kemper (eds.). Plenum Press, New York, NY. pp. 45-57.

Reiser, D.W., M.P. Ramey, S. Beck, T.R. Lambert, and R.E. Geary 1989a. Flushing flow recommendations for maintenance of salmonid spawning gravels in a steep regulated stream. Regulated Rivers: Research and Management 3:267-275.

Reiser, D.W., T.A. Wesche, and C. Estes 1989b. Status of instream flow litigation and practices in North America. Fisheries 14(2):22-29.

Richards, K. 1982. Rivers: Form and process in alluvial channels. Methuen & Company, London.

Richter, B.D. and H.E. Richter 2000. Prescribing flood regimes to sustain riparian ecosystems along meandering rivers. Conservation Biology 14(5):1467-1478.

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

Roell, M.J. and D.J. Orth. 1994. Trophic basis of production of stream-dwelling smallmouth bass, rock bass, and flathead catfish in relation to invertebrate bait harvest. Transactions of the American Fisheries Society 122:46-62.

Rood, S.B. 1997 Instream flows and riparian cottonwoods along the Red Deer River, Alberta. Prepared for Alberta Environmental Protection, Edmonton, AB.

Rood, S.B. and C.E. Bradley 1993. Assessment of riparian cottonwoods along the Bow River downstream from Calgary, Alberta. University of Lethbridge, Lethbridge, AB.

Rood, S.B. and Heinze-Milne 1989. Abrupt downstream forest decline following river damming in southern Alberta. Canadian Journal of Botany 67:1744-1749.

Rood, S.B. and A. Kalischuk 2003. Instream flow regulation, riparian vegetation and cottonwood seedling recruitment along the South Saskatchewan River, Alberta. Prepared for Alberta Environment, Edmonton and the City of Medicine Hat. 60p.

Rood, S.B. and J.M. Mahoney 1990. Collapse of riparian poplar forests downstream from dams in western prairies: Probable causes and prospects for mitigation. Environmental Management 14(4):451-464.

Rood, S.B. and J.M. Mahoney 1991a. The biology of riparian cottonwood forests in the Oldman River Basin: Oldman River Dam Mitigation Program Downstream Vegetation Project Report - Volume I. Prepared for Alberta Public Works, Supply and Services, Edmonton.

Rood, S.B. and J.M. Mahoney 1991b. The importance and extent of cottonwood forest decline downstream from dams. *in*: The biology and management of southern Alberta's cottonwoods. S.B. Rood & J.M. Mahoney (eds.). University of Lethbridge, AB. pp. 1-9.

Rood, S.B. and J.M. Mahoney 1995. River damming and riparian cottonwoods along the Marias River, Montana. Rivers 5(3):195-207.

Rood, S.B. and J.M. Mahoney 2000. Revised instream flow regulation enables cottonwood recruitment along the St. Mary River, Alberta, Canada. Rivers 7(2):109-125.

Rood, S.B., J. Campbell, and T. Despins 1986. Natural poplar hybrids from southern Alberta: I. Continuous variation for foliar characteristics. Canadian Journal of Botany 64:1382-1388.

Rood S.B., A.R. Kalischuk, and J.M. Mahoney 1998. Initial cottonwood seedling recruitment following the flood of the century of the Oldman River, Alberta, Canada. Wetlands 8(4):557-570.

Rood, S.B., J.M. Mahoney, D.E. Reid, and L. Zilm 1995. Instream flows and the decline of riparian cottonwoods along the St. Mary River, Alberta. Canadian Journal of Botany 73:1250-1260.

Rood, S.B., K. Taboulchanas, C.E. Bradley, and A.R. Kalischuk 1999. Influence of flow regulation on channel dynamics and riparian cottonwoods along the Bow River, Alberta. Rivers 7(1):33-48.

Rosgen, D.L. 1994. A classification of natural rivers. Catena 22:169-199.

Rosgen, D.L. 1996. Applied river morphology. Wildland Hydrology, Pagosa Springs, CO.

Rosgen, D.L., H.L. Silvey, and J.P. Potyondy 1986. The use of channel maintenance flow concepts in the Forest Service. Hydrological Science and Technology 2(1):19-26.

Ryan, S.E. 1996. Bedload transport patterns in coarse-grained channels under varying conditions of flow. *in:* Proceedings of the 6th Inter-agency sedimentation conference, Las Vegas, Nevada. pp. VI-22 to VI-27b.

Saffran, K.A. and A. Anderson 1997. An empirical analysis of water temperature and dissolved oxygen conditions in the Red Deer River. Prepared for Water Sciences Branch, Alberta Environmental Protection, Edmonton, Alberta. 25p.

Saffran, K.A. and A. Anderson. 1999. Development and use of water quality indices: The Alberta experience. Technical Bureau Supplement, Newsletter of the Canadian Water Resources Association. Water News 18(4):i-xii.

Saffran, K.A., K. Cash, K. Hallard, B. Neary, and C.R. Wright 2001. CCME Water Quality Index 1.0, User's manual. *in:* Canadian Environmental Quality Guidelines, 2001. Prepared for the Canadian Council of Ministers of the Environment Water Quality Index Technical subcommittee, Winnipeg. 5p.

Sale, M.J., S.F. Railsback, and E.E. Herricks 1981. Frequency analysis of aquatic habitat: A procedure for determining instream flow needs. *in:* Acquisition and utilization of aquatic habitat inventory information: Proceedings of a symposium of the western division of the American Fisheries Society, Portland, OR. October 28-30, 1981. pp. 340-346.

Schumm, S.A. 1969. River metamorphosis. American Society of Civil Engineers, Journal of Hydraulics Division HY1:255-273.

Scott M.L., G.C. Lines, and G.T. Auble 2000. Channel incision and patterns of cottonwood stress and mortality along the Mojave River, California. Journal of Arid Environments 44:399-414

Scott, M.L., G.T. Auble, and J.M. Friedman 1997. Flood dependency of cottonwood establishment along the Missouri River, Montana, USA. Ecological Applications 7(2):677-690.

Scott, M.L., G.T. Auble, J.M. Friedman, L.S. Ischinger, E.D. Eggleston, M.A. Wondzell, P.B. Shafroth, J.T. Back, and M.S. Jordan 1993. Flow recommendations for maintaining riparian vegetation along the Upper Missouri River, Montana. National Biological Survey, National Ecology Research Center, Fort Collins, CO. 36p.

Scott, M.L., P.B. Shafroth, and G.T. Auble 1999. Responses of riparian cottonwoods to alluvial water table declines. Environmental Management 23(3):347-358.

Shafroth, P., J. Stromberg, and D. Patten 2000. Response of riparian vegetation to different alluvial ground water regimes. Western North American Naturalist 60:66-76.

Shafroth, P., J. Stromberg, and D. Patten 2002. Riparian vegetation response to altered disturbance and stress regimes. Ecological Applications 12(1):107-123.

Shaw, J. 1994. Southern tributaries instream flow needs study: Water quality component (draft). Prepared for Environmental Planning Division, Alberta Environmental Protection, Calgary. 26p. +App.

Shaw, J. and R. Kellerhals 1982. The composition of recent alluvial gravels in Alberta river beds. Alberta Research Council, Edmonton, AB. Bulletin 41. 151p.

Shaw, R.D. and A.M. Anderson 1994. The effect of the Dickson Dam on water quality and zoobenthos of the Red Deer River. Water Sciences Branch, Alberta Environmental Protection. 125p.

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

Simonson, T.D. and W.A. Swenson 1990. Critical stream velocities for young-of-year smallmouth bass in relation to habitat use. Transactions of the American Fisheries Society 119:902-909.

Smith, G., 2003. Personal Communication, June 2003, California.

Snyder, W.D. and G.C. Miller 1991. Changes in plains cottonwoods along the Arkansas and South Platte Rivers, eastern Colorado. Prairie Naturalist 23(3):165-176.

Snyder, W.D. and G.C. Miller 1992. Changes in riparian vegetation along the Colorado River and Rio Grande, Colorado. Great Basin Naturalist 52:357-363.

Sosiak, A.J. 1996 Evaluation of temperature and oxygen objective exceedence for the Bow River between Carseland and Bassano. Memo from A. Sosiak, Alberta Environmental Protection, Water Management Division, to L.G. Fahner, Controller of Water Resources, AEP, May 10, 1996. 7p.

Sosiak, A.J. 2002 Long-term response of periphyton and macrophytes to reduced municipal nutrient loading to the Bow River Alberta, Canada. Canadian Journal of Fisheries and Aquatic Sciences 59:987-1001.

Stalnaker, C.B. 1990 Minimum flow is a myth. *in:* Ecology and assessment of warmwater streams: workshop synopsis, M.B. Bain (ed.). U.S. Fish and Wildlife Service, Washington, DC. Biological Report 90(5). pp. 31-33.

Stalnaker, C.B. 1994 Evolution of instream flow modelling. *in:* River Handbook, Volume II. P. Calow and G.E. Petts (eds.). Blackwell Scientific Publications, Oxford. pp. 276-286.

Stalnaker, C., B.L. Lamb, J. Henriksen, K. Bovee, and J. Bartholow 1995. The instream flow incremental methodology: A primer for IFIM. U.S. Department of the Interior, National Biological Service, Washington, D.C. Biological Report 29.

Stanford, J.A. 1994. Instream flows to assist the recovery of endangered fishes of the upper Colorado River basin. National Biological Survey Biological Report 24. 47p.

Stanford, J.A., and J.V. Ward 1993. An ecosystem perspective of alluvial rivers: Connectivity and the hyporheic corridor. Journal of the North American Benthological Society 12:391-413.

Stanford, J.A., J.V. Ward, W.J. Liss, C.A. Frissell, R.N. Williams, J.A. Lichatowich, and C.C. Coutant 1996. A general protocol for restoration of regulated rivers. Regulated Rivers: Research and Management 12:391-413.

Statzner, B. 1988. Growth and Reynolds number of lotic macroinvertebrates: A problem for adaptation of shape to drag. Oikos 51:84-87.

Statzner, B., F. Kohman, and A.G. Hildrew 1991. Calibration of FST-hemispheres against bottom shear stress in a laboratory flume. Freshwater Biology 26:227-231.

Stromberg, J.C. 1993. Instream flow models for mixed deciduous riparian vegetation within a semiarid region. Regulated Rivers: Research and Management 8:225-235.

Stromberg, J.C. and D.T. Patten 1990. Riparian vegetation instream flow requirements: A case study from a diverted stream in the eastern Sierra Nevada, California, USA. Environmental Management 14(2):185-194.

Stromberg, J.C. and D.T. Patten 1991. Instream flow requirements for cottonwoods at Bishop Creek, Inyo County, California. Rivers 2(1):1-11.

Stromberg, J.C. and D.T. Patten 1996. Instream flow and cottonwood growth in the eastern Sierra Nevada of California, USA. Regulated Rivers: Research and Management 12:1-12.

Stromberg, J.C. and R. Tiller 1996. Effects of groundwater decline on riparian vegetation of semiarid regions: The San Pedro, Arizona. Ecological Applications 6(1):113-131.

Stromberg, J.C., D.T. Patten, and B.D. Richter 1991. Flood flows and dynamics of Sonoran riparian forests. Rivers 2(3):221-235.

Stromberg, J.C., B.D. Richter, D.T. Patten, and L.G. Wolden 1993. Response of a Sonoran riparian forest to a 10-year return flood. Great Basin Naturalist 53(2):118-130.

Studley, T.K. and nine other authors 1995. Response of fish populations to altered flows project. Volume 1: Predicting trout populations from stream flow and habitat variables. Pacific Gas and Electric Company, San Ramon, CA 94583.

Summit Environmental Consultants 1998. Guidebook for processes for instream flow assessment: Draft report. Vernon, BC. Project 630.

Taylor, B.R. and B.A. Barton 1992. Temperature and dissolved oxygen criteria for Alberta fishes in flowing waters. Prepared for Alberta Fish and Wildlife Division, Edmonton, AB. 72p.

Taylor, C.M. and R.J. Miller 1990. Reproductive ecology and population structure of the plains minnow, *Hybognathus placitus* (*Pisces: Cyprinidae*), in Central Oklahoma. American Midland Naturalist 123:32-39.

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

Tesaker, E. 2000. Under ice habitat: Report from a working group. 15th IAHR International Symposium, Gdansk, Poland. 12p.

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

Thomas, J.A. and K.D. Bovee 1993. Application and testing of a procedure to evaluate transferability of habitat suitability criteria. Regulated Rivers: Research and Management 8:285-294.

Thompson, W and P. Hansen, 2002. Classification and management of riparian wetland sites of the Alberta grassland natural region and adjacent sub regions. Prepared for Alberta Riparian Habitat Management Program - Cows and Fish, Lethbridge. 416p.

Trimbee, A., A.G.H. Locke, J. Englert, R. Middleton, and J. Barlishen 1993. Oldman River instream flow needs summary. Planning Division, Water Resources Service, Alberta Environmental Protection, Edmonton, AB 15p.

Trush B. and S. McBain 2000. Alluvial river ecosystem attributes. Stream Systems Technology Center, USDA Forest Service. Stream Notes Jan. 2000. pp. 1-3.

Tyree, M.T., K.J. Kolb, S.B. Rood, and S. Patino, 1994. Vulnerability to drought-induced cavitation of riparian cottonwoods in Alberta: A possible factor in the decline of an ecosystem? Tree Physiology 14:455-466.

U.S. Army Corps of Engineers, Hydraulic Engineering Center 2001a. HEC-6, scour and deposition in rivers and reservoirs. Users manual accessed on internet site www.hec.usace.army.mil/publications/pubs_distrib/hec-6/hec6 Sept 2001.

U.S. Army Corps of Engineers, Hydraulic Engineering Center 2001b. HEC-RAS user's manual. www.hec.usace.army.mil/publications/pubs_distrib/hec-ras/user/user

U.S. Forest Service (USFS) 1994. Instream flow water right application for the Clarks Fork River, Wyoming. Wyoming State Engineer's Office.

U.S. Forest Service (USFS) 1995. A guide to field identification of bankfull stage in the Western United States. U.S. Forest Service, Stream Systems Technology Center, Fort Collins CO. 31-minute video.

U.S. Forest Service (USFS) 1997. An approach for quantifying channel maintenance instream flows in gravel-bed streams (Draft). Boise Adjudication Team, Boise, ID. 98p.

U.S. Fish and Wildlife Service (USFWS) 1993. Service Manual. Legal Series, Part 403 (Water Rights), Authorities and Definitions. refuges.fws.gov/manual/ser000-900.html

U.S. Fish and Wildlife Service (USFWS) and Hoopa Valley Tribe 1999. Trinity River flow evaluation: Final report. Prepared for U.S. Department of the Interior, Washington D.C. 308p. +App.

Usher, R. and W. Strong 1994. Ecological land classification for the proposed Suffield national wildlife area. Prepared for Environment Canada Conservation and Protection. 25p.

Walker, B., S. Carpenter, J. Anderies, N. Abel, G. Cumming, M. Janssen, L. Lebel, J. Norberg, G.D. Peterson, and R. Pritchard 2002. Resilience management in social-ecological systems: A working hypothesis for a participatory approach. Conservation Ecology 6(1):14. http://www.consecol.org/vol6/iss1/art14

Ward, J.V. 1998. Riverine landscapes: Biodiversity patterns, disturbance regimes, and aquatic conservation. Biological Conservation 83(3):269-278.

Ward, J.V. and K. Tockner 2001. Biodiversity: Towards a unifying theme for river ecology. Freshwater Biology 46:807-819.

Ward, J.V., K. Tockner, and F. Schiemer 1999. Biodiversity of floodplain river ecosystems: Ecotones and connectivity. Regulated Rivers: Research and Management 15:125-139.

Ward, J.V., K. Tockner, U. Uehlinger, and F. Malard 2001. Understanding natural patterns and processes in river corridors as the basis for effective river restoration. Regulated Rivers: Research and Management 17:311-323.

Webster's New Collegiate Dictionary 1976. Thomas Allen & Son Ltd., Toronto, ON.Weisberg, S.B. and W.H. Burton 1993. Enhancement of fish feeding and growth following an increase in minimum flow below the Comowingo Dam. North American Journal of Fisheries Management 13:103-109.

Weisberg, S.B., A.J. Janicki, J. Gerritsen, and H.T. Wilson 1990. Enhancement of benthic macroinvertebrates by minimum flow from a hydroelectric dam. Regulated Rivers: Research and Management 5:265-277.

Wells, S.A. 1997. Theoretical basis for the CE-QUAL-W2 river basin model. Department of Civil Engineering, Portland State University Portland, OR. Technical Report EWR-6-97.

Wells, S.A. 1999. River basin modeling using CE-QUAL-W2 Version 3. Proceedings of the ASCE International Water Resources Engineering Technical Conference, Seattle, WA.

Wesche, T.A., V.R. Hasfurther, W.A. Hubert, and Q.D Skinner 1987. Assessment of flushing flow needs in a steep, rough, regulated tributary. *in:* Regulated Streams: Advances in Ecology, J.F. Craig and J.B. Kemper (eds.). Plenum Press, New York and London. pp. 59-70.

Whalen, K.G., D.L. Parrish, and M.E. Mather 1999. Effect of ice formation on selection of habitats and winter distribution of post-young-of-the-year Atlantic salmon parr. Canadian Journal of Fisheries and Aquatic Sciences 56:87-96.

Whiting, P.J. 1998. Floodplain maintenance flows. Rivers 6:160-170.

Wieliczko, J., K. Rees, and V.G. Buchwald 1992. Brown trout spawning in the Red Deer River downstream of the Dickson Dam, 1991. Alberta Forestry, Lands and Wildlife, Fish and Wildlife Division, Red Deer, AB.

Williams, G.P. and M.G. Wolman 1984. Downstream effects of dams on alluvial rivers. Geological Survey Professional Paper 1286. U.S. Government Printing Office, Washington, DC. 83p. Williams, J. G. 1996. Lost in space: minimum confidence intervals for idealized PHABSIM studies. Transactions of the American Fisheries Society 125:458-465.

Willms, J., S.B. Rood, W. Willms, and M. Tyree 1998. Branch growth of riparian cottonwoods: A hydrologically sensitive dendrochronological tool. Trees 12:215-223.

Winter, T.C., J.W. Harvey, O.L. Frankle, and W.M. Alley 1998. Groundwater and surface water: A single resource. U.S. Geological Survey, Branch of Information Services. 79p.

Wolman M.G. and J.P. Miller 1960. Magnitude and frequency of forces in geomorphic processes. Journal of Geology, 68:54-74.

WQA (Water Quality Associates Ltd.) 1989. Water quality study of the St. Mary, Belly, and Waterton rivers of southern Alberta. Prepared for Fish and Wildlife Division, Alberta Forestry Lands and Wildlife, Edmonton, AB. 68p. +App.

Wright, C.R., K.A. Saffran, A. Anderson, R.D. Neilson, N.D. MacAlpine, and S.E. Cooke 1999. A water quality index for agricultural streams in Alberta: The Alberta Agricultural Water Quality Index (AAWQI). Alberta Environmentally Sustainable Agriculture Program, Alberta Agriculture, Food and Rural Development, Edmonton. 35p.

Wristen, K.G. 1999. The National Sewage Report Card (Number Two). Sierra Legal Defence Fund, Vancouver. 64p.

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.

APPENDIX A – FISHERIES MANAGEMENT OBJECTIVES

APPENDIX B –HISTORICAL DISTRIBUTION OF RIPARIAN FOREST (DAWSON 1885)

APPENDIX C – HYDRAULIC CALIBRATION AND SIMULATION RESULTS FOR FISH HABITAT MODELLING

APPENDIX D – WEIGHTED USEABLE AREA (WUA) CURVES

APPENDIX E – FISH HABITAT EVALUATION RESULTS

APPENDIX F – CHANNEL MAINTENANCE FLOW CALCULATIONS

APPENDIX G – INTEGRATED ECOSYSTEM IFN DETERMINATIONS