4.0 ECOLOGICAL BASIS OF FLOW REGIMES FOR AQUATIC RESOURCES

4.1 The Aquatic Ecosystem and Biological Diversity

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

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

Goldstein (1999) states that ecological integrity

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

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

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

4.2 Instream Flows in the Context of Riverine Ecology

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

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

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

4.2.1 Ecological Principles

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

Poff et al. (1997) state that

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

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

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

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

Annear et al. (2002) conducted a detailed review of the most common methods for developing instream needs by IFN practitioners from across the United States and Canada and concluded that the predominance of single-flow recommendations has not succeeded in protecting the integrity of aquatic ecosystems. Although the acceptance of the ecological principles behind the Natural Flow Paradigm is widespread and can be supported by a large body of knowledge (Poff et al. 1997, Bunn and Arthington 2002), incorporating these ecosystem principles into river management practice is a challenge (Richter et al. 1997). Annear et al. (2002) suggest that five interrelated riverine components should be considered in the setting of aquatic ecosystem objectives: hydrology, geomorphology, biology, water quality, and connectivity.

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

4.2.2 Physical Processes

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

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

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

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

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

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

4.2.3 Biological Processes

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

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

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

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

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

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

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

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

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

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

4.2.4 Interconnectivity of the Riverine Ecosystem

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

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

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

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

4.3 Current Methods and Research for Ecosystem IFN Studies

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

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

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

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

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

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

4.3.1 Use of Natural Flow as a Benchmark Condition

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

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

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

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

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

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

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

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

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

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

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

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

1. The primary objective of determining instream flow needs is to provide a description of flow requirements for achieving a high level of protection of the riverine ecosystem, to the extent that can be achieved by instream flows alone.

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

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

4.4 Technical Team Approach to Defining an Aquatic Ecosystem IFN

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

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

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

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

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

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

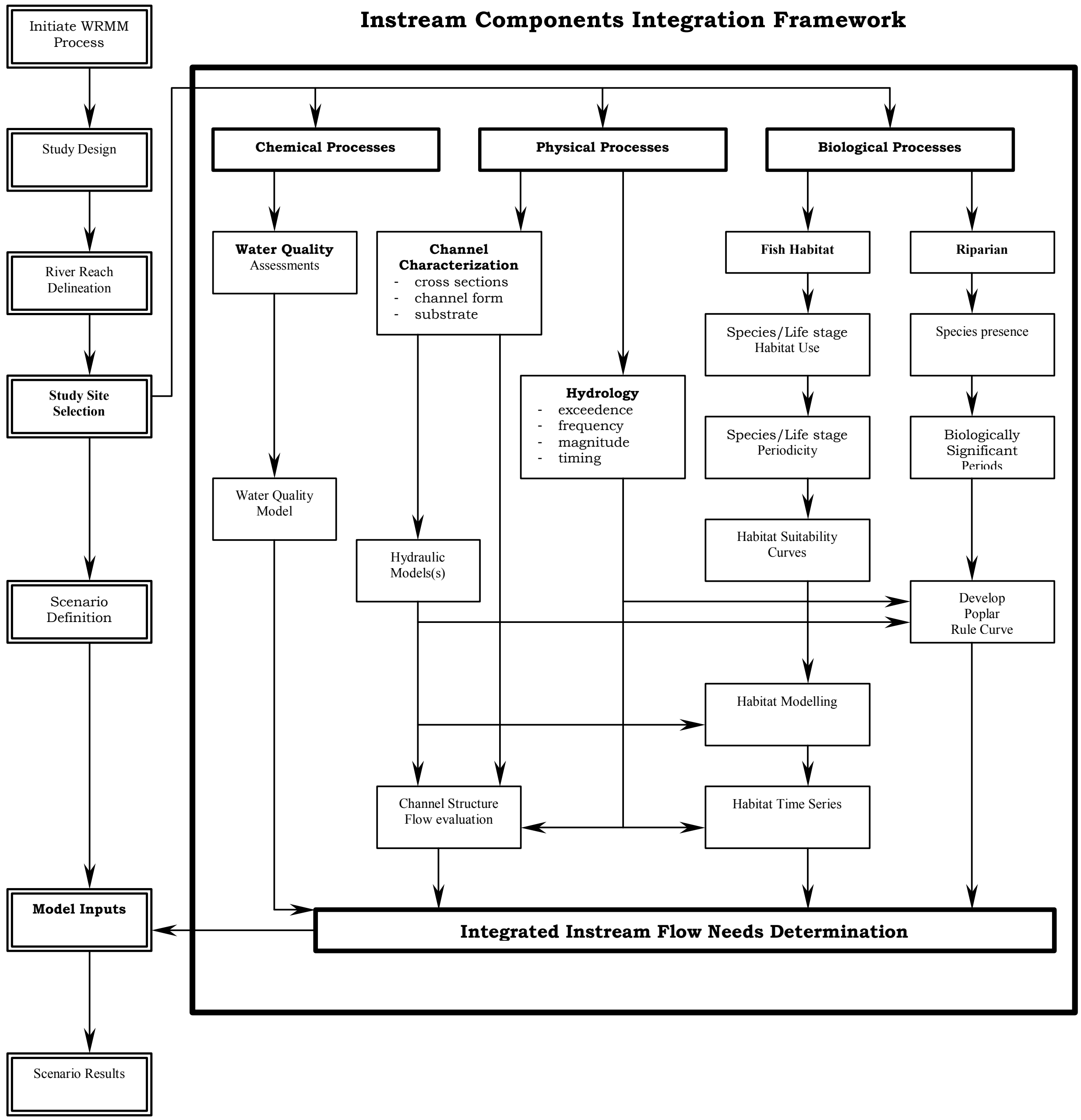

Figure 4.1. Multi-disciplinary assessment framework applied for the SSRB WMP, to determine the ecosystem IFN (adapted from Hardy and Addley 2001).