6.0 WATER QUALITY INSTREAM FLOW NEEDS

6.1 Background

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

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

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

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

6.1.1 Instream temperature and dissolved oxygen

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

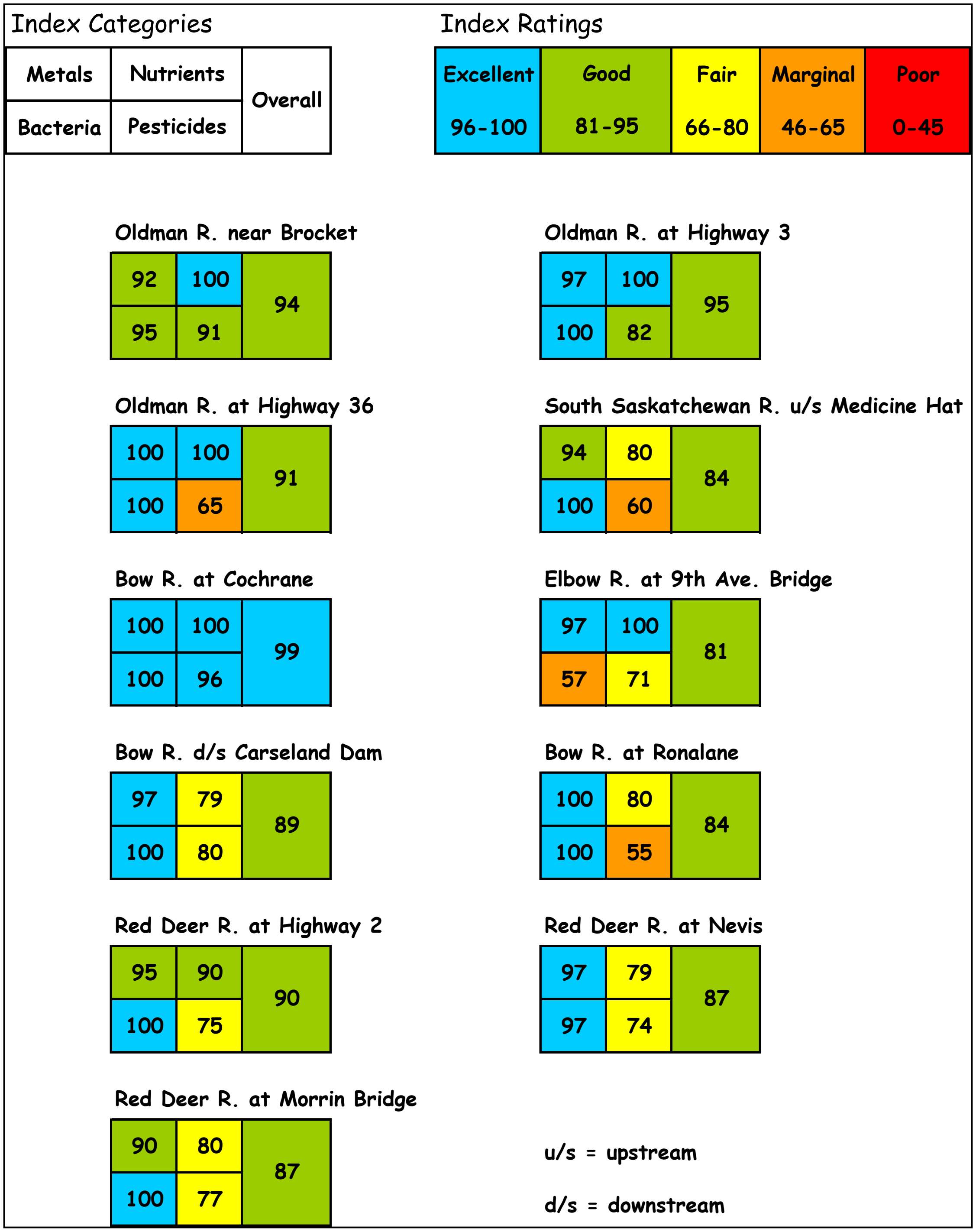

Figure 6.1. Alberta surface water quality index for southern rivers, 2000-2001.

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

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

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

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

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

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

6.1.2 Assimilation of Wastes

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

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

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

6.1.3 Scouring Flows

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

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

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

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

6.2 Recommended Flows for Water Quality Instream Flow Needs

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

6.2.1 Red Deer River

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

Table 6.1. Red Deer River water quality IFN determinations.

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

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

Previous work

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

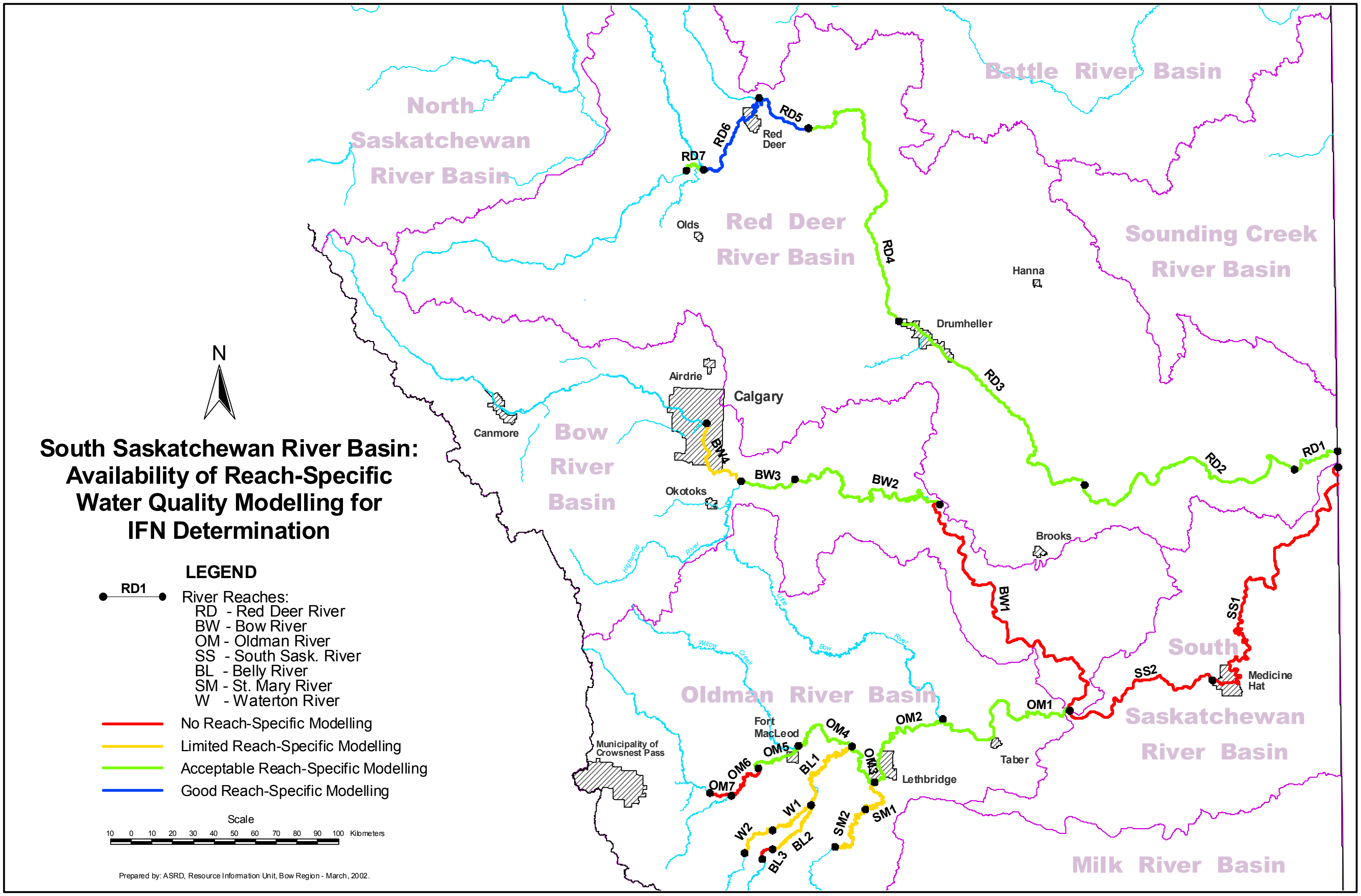

Figure 6.2. Availability of reach-specific water quality modelling for IFN determinations within the SSRB WMP.

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

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

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

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

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

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

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

Temperature IFN

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

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

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

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

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

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

Scenario Evaluation for DO

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

Un-ionized Ammonia

AGRA et al. (1995) states that

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

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

Caveats to Modelling Results

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

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

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

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

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

Winter IFN

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

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

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

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

Current Water Quality Modelling Work for the Red Deer River

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

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

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

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

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

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

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

6.2.2 Bow River

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

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

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

Reach Boundaries	Reach Code	Water Quality IFN (m^3/s)			
		Winter	Spring	Summer	Fall
WID weir to u/s Highwood Confluence	BW4	20 – 40*	N/A	100	N/A
Highwood R. confluence to u/s Carseland weir	BW3	30	N/A	100	N/A
Carseland weir to u/s of Bassano Dam	BW2	35 - 40	N/A	90	N/A
Bassano Dam to Mouth	BW1	35 – 40*	N/A	N/A	N/A

Notes
**** -** Estimate only**,** provided due to more recent ammonia concerns that may not have been addressed in the modelling. For Reach BW4 in winter, Golder/WER recommended 20 m^3/s. "Estimate" refers to an IFN based largely on professional opinion and additional water quality data, and not on modelling results (for example, the value for Reach BW1 in winter.)*
***N/A –** IFN values are not available. Modelling has not been carried out for this period.*
The IFN in Reach BW2 in summer is provided by Sosiak (1996). Golder/W-E-R (1994) recommended 100 m^3/s.

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

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

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

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

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

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

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

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

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

6.2.3 Oldman River

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

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

Table 6.3. Oldman River water quality IFN determinations.

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

Notes:
***Water quality IFNs** are based on minimum flows for protection of aquatic life, specifically on fish species actually present per reach.*
***Historic flows** - where WQ IFNs have not yet been determined, (recently recorded) historic flows are recommended based on existing water quality monitoring data that indicates few exceedences of guidelines, i.e. good water quality being present.*
***Target fish species** for management below Lethbridge are walleye and sauger.*

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

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

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

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

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

6.2.4 The Southern Tributaries of the Oldman River

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

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

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

Table 6.4. Oldman Tributaries water quality IFN determinations.

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

Notes
Water quality IFNs *are based on minimum flows for protection of aquatic life, specifically on fish species actually present per reach.*
Historic flows *- where WQ IFNs have not yet been determined, recently recorded historic flows are recommended based on existing water quality monitoring data indicating few exceedences of guidelines, i.e. good water quality being present.*

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

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

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

Interim flow recommendations

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

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

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

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

6.2.5 South Saskatchewan River sub-basin

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

Table 6.5. South Saskatchewan River water quality IFN determinations.

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

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

6.3 Conclusion

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

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

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

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

6.3.1 Further Work

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

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

Additional recommendations for water quality IFN development include the following:

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

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