

TABLE OF CONTENTS

Acknowledgements.....	i
Executive Summary	iii
Fish Habitat.....	iv
Water Quality	v
Riparian Vegetation	vi
Channel Maintenance	vii
One Ecosystem IFN Determination from Four Riverine Components.....	viii
Table of Contents	xi
1.0 Introduction	1
2.0 South Saskatchewan River Basin Water Management Plan	3
2.1 Instream Flow Needs Technical Team	4
2.2 Purpose of the SSRB IFN Report	5
3.0 Overview of the SSRB Aquatic Resources	7
3.1 Study Area	7
3.2 Background of Water Management in the SSRB.....	12
3.3 Red Deer River Basin.....	15
3.3.1 Fisheries Resources.....	16
3.3.2 Riparian Resources	16
3.3.3 Water Quality.....	18
3.3.4 Geomorphology	20
3.4 Bow River Basin	22
3.4.1 Fisheries Resources.....	22
3.4.2 Riparian Resources	23
3.4.3 Water Quality.....	24
3.4.4 Geomorphology	25
3.5 Oldman River Basin.....	25
3.5.1 Fisheries Resources.....	25
3.5.2 Riparian Resources	27
3.5.3 Water Quality.....	28
3.5.4 Geomorphology	29
3.6 Southern Tributaries	31
3.6.1 Fisheries Resources.....	32

3.6.2	Riparian Resources	32
3.6.3	Water Quality	36
3.6.4	Geomorphology	38
3.7	South Saskatchewan River Basin	41
3.7.1	Fisheries Resources.....	41
3.7.2	Riparian Resources	41
3.7.3	Water Quality	43
3.7.4	Geomorphology	43
4.0	Ecological Basis of Flow Regimes for Aquatic Resources.....	45
4.1	The Aquatic Ecosystem and Biological Diversity.....	45
4.2	Instream Flows in the Context of Riverine Ecology	45
4.2.1	Ecological Principles.....	46
4.2.2	Physical Processes.....	47
4.2.3	Biological Processes.....	48
4.2.4	Interconnectivity of the Riverine Ecosystem.....	50
4.3	Current Methods and Research for Ecosystem IFN Studies	51
4.3.1	Use of Natural Flow as a Benchmark Condition.....	52
4.4	Technical Team Approach to Defining an Aquatic Ecosystem IFN.....	54
5.0	Fish Habitat Instream Flow Needs	57
5.1	General Process.....	57
5.1.1	Physical Habitat Modelling	58
5.2	Site-specific Fish Habitat IFN Data for the SSRB.....	61
5.2.1	River Reach Delineation	61
5.2.2	Study Site Selection	61
5.2.3	Hydraulic Modelling	62
5.2.4	Selection of Target Species and Life Stages	64
5.2.5	Species and Life Stage Periodicities	65
5.2.6	Habitat Suitability Criteria	70
5.2.7	WUA Results for Each Reach.....	71
5.3	Fish Habitat IFN Determination Method	73
5.3.1	Background	73
5.3.2	Step 1: Percent Reduction in Flow from Natural	75
5.3.3	Step 2: Defining The Ecosystem Base Flow.....	75
5.3.4	Step 3: Determining Flows for Fish Habitat-Time Series Analysis	77
5.3.5	Step 4: Conducting Habitat Time Series	77
5.3.6	Step 5: Reviewing Evaluation Metrics	78
5.3.7	Summary of the Final Approach.....	79
5.3.8	Modification for the South Saskatchewan River Basin	81
5.4	Fish Habitat IFN Results and Discussion.....	82
5.4.1	Winter Ice-Covered IFN for Fish Habitat	85
5.4.2	Red Deer River Fish Habitat IFN Results	85
5.4.3	Bow River Fish Habitat IFN Results.....	93
5.4.4	Oldman River Fish Habitat IFN Results	98
5.4.5	Southern Tributaries Fish Habitat IFN Results.....	108
5.4.6	South Saskatchewan River	116

5.4.7 Summary of Fish Habitat Results 117

6.0 Water Quality Instream Flow Needs 121

6.1 Background..... 121

6.1.1 Instream temperature and dissolved oxygen 121

6.1.2 Assimilation of Wastes..... 123

6.1.3 Scouring Flows..... 124

6.2 Recommended Flows for Water Quality Instream Flow Needs 125

6.2.1 Red Deer River 125

6.2.2 Bow River 132

6.2.3 Oldman River 134

6.2.4 The Southern Tributaries of the Oldman River 135

6.2.5 South Saskatchewan River sub-basin 137

6.3 Conclusion 138

6.3.1 Further Work 138

7.0 Riparian Ecosystem Instream Flow Needs 141

7.1 Introduction 141

7.2 Links Between Cottonwood Biology and Hydrology..... 142

7.3 Impacts of Damming and Diversions..... 143

7.4 Targeting Flows to Sustain Riparian Forests 145

7.4.1 Base flows for forest survival and maintenance 146

7.4.2 Moderate flows for tree health and growth 146

7.4.3 Peak flows for seedling establishment..... 147

7.4.4 Flow-ramping and moderate flows for seedling survival 148

7.5 Drafting the ‘Poplar Rule Curve’..... 148

7.6 Applying the PRC within the South Saskatchewan River Basin 156

7.6.1 Flow modifications that affect riparian cottonwoods 157

7.6.2 PRC flows for test reaches in the Oldman River Basin 160

Evaluating PRC flows along test reaches..... 162

7.7 Evaluating the PRC Criteria..... 174

7.7.1 Relative contribution of each PRC criterion..... 174

7.7.2 PRC criterion 1: Naturalized flow 178

7.7.3 PRC criterion 2: Naturalized 90% exceedence flow 180

7.7.4 PRC criterion 3: 65% of naturalized flow..... 183

7.7.5 PRC criterion 4: 50% return interval-shifted naturalized flow 185

7.7.6 PRC criterion 5: 125% bankfull flow 187

7.7.7 Summary of evaluation of PRC criteria 188

7.8 Applicability of PRC flows for other systems:..... 189

8.0 Channel Maintenance Instream Flow Needs 193

8.1 Background - Channel Maintenance Flows 193

8.2 Review of Methods 196

8.3 Calculating a Channel Maintenance Flow (CMF), Shields Method.... 198

8.4 Summary of Channel Maintenance Flows for SSRB Reaches 202

 8.4.1 Overbank Flows Needed for Geomorphic Activity 202

8.5 Conclusion and Recommendations 205

9.0 Integrated Aquatic Ecosystem IFN..... 207

 9.1 Background..... 207

 9.2 IFN Integration Method..... 207

 9.3 Integrated Ecosystem IFN Determinations 214

10.0 Summary and Conclusions..... 225

 10.1 Summary of the IFN Process for the SSRB WMP 227

 10.1.1 Fish Habitat 227

 10.1.2 Water Quality..... 230

 10.1.3 Riparian Vegetation..... 232

 10.1.4 Channel Maintenance Flows..... 236

 10.1.5 Integration of the Four IFN Components..... 237

 10.2 Application of the Ecosystem IFN in the SSRB WMP 238

11.0 Literature Cited 243

Glossary 261

Appendix A – Fisheries Management Objectives..... 271

Appendix B –Historical Distribution of Riparian Forest (Dawson 1885) 271

Appendix C – Hydraulic Calibration and Simulation Results for Fish Habitat Modelling
..... 271

Appendix D – Weighted Useable Area (WUA) Curves..... 271

Appendix E – Fish Habitat Evaluation Results..... 271

Appendix F – Channel maintenance Flow Calculations 271

Appendix G – Integrated Ecosystem IFN Determinations..... 271

LIST OF FIGURES

Figure 3.1. Major flow regulating structures on the mainstem reaches of the Red Deer, Bow, Oldman, St. Mary, Belly, and Waterton Rivers. 8

Figure 3.2. Location of the IFN reach boundaries for the Red Deer, Bow, Oldman, St. Mary, Belly, Waterton, and South Saskatchewan Rivers..... 9

Figure 3.3. The natural and recorded flow downstream of the St. Mary River Dam and the Oldman River Dam. 13

Figure 3.4. The natural and recorded flow for the Bow River at Calgary and downstream of the Bassano Dam..... 14

Figure 3.5. The natural and recorded flow downstream of the Dickson Dam for the Red Deer River at Drumheller..... 15

Figure 3.6. Geographic ranges of the cottonwood species that occur in the SSRB. 17

Figure 3.7. Changes in density of poplar communities from 1951 to 1990. 35

Figure 4.1. Multi-disciplinary assessment framework applied for the SSRB WMP to determine the ecosystem IFN. 56

Figure 5.1. Conceptual representation of a stream reach by computational cells, with attributes of depth, velocity, and channel index, used in habitat modelling. 59

Figure 5.2. Calculation of component suitability index values for the depth, velocity and channel index that generates the WUA versus discharge function. 60

Figure 5.3. Species periodicity charts for the Bow River..... 66

Figure 5.4. Species periodicity charts for the Red Deer River. 67

Figure 5.5. Species periodicity charts for the Oldman River. 68

Figure 5.6. Species periodicity charts for the St. Mary, Belly, and Waterton Rivers.... 69

Figure 5.7. Oldman River Reach 6 WUA curves for all target management species and life stages. 73

Figure 5.8. Example of the 80% habitat exceedence procedure for defining the EBF from the Oldman River Reach 6. 76

Figure 5.9. Availability of site-specific fish habitat IFN (PHABSIM) study sites used to develop the fish habitat IFN determination for the SSRB WMP. 84

Figure 5.10. The weekly Ecosystem Base Flows for the Red Deer River Reach 1 using the maximum value between the 80% habitat duration analysis for goldeye adult and the 95% flow exceedence..... 86

Figure 5.11. The weekly Ecosystem Base Flows for the Red Deer River Reach 3 using the maximum value between the 80% habitat duration analysis for goldeye adult and the 95% flow exceedence..... 88

Figure 5.12. The weekly Ecosystem Base Flows for the Red Deer River Reach 5 using the maximum value between the 80% habitat duration analysis for goldeye adult and walleye spawning and the 95% flow exceedence. 90

Figure 5.13. The weekly Ecosystem Base Flows for the Red Deer River Reach 6 using the maximum value between the 80% habitat duration analysis for mountain whitefish and the 95% flow exceedence..... 91

Figure 5.14. The weekly Ecosystem Base Flows for the Red Deer River Reach 7 using the maximum value between the 80% habitat duration analysis for mountain whitefish juvenile and the 95% flow exceedence. 92

Figure 5.15. The weekly Ecosystem Base Flows for the Bow River Reach 1 using the Tessmann calculation..... 93

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

Figure 5.17. The weekly Ecosystem Base Flows for the Bow River Reach 3 using the maximum value between the 80% habitat duration analysis for mountain whitefish juvenile and the 95% flow exceedence. 96

Figure 5.18. The weekly Ecosystem Base Flows for the Bow River Reach 4 using the maximum value between the 80% habitat duration analysis for mountain whitefish adult and the 95% flow exceedence. 98

Figure 5.19. The weekly Ecosystem Base Flows for the Oldman River Reach 1 using the Tessmann calculation. 99

Figure 5.20. The weekly Ecosystem Base Flows for the Oldman River Reach 2 using the maximum value between the 80% habitat duration analysis for mountain whitefish adult and the 95% flow exceedence. 100

Figure 5.21. The weekly Ecosystem Base Flows for the Oldman River Reach 3 using the maximum value between the 80% habitat duration analysis for mountain whitefish adult and the 95% flow exceedence. 102

Figure 5.22. The weekly Ecosystem Base Flows for the Oldman River Reach 4 using the maximum value between the 80% habitat duration analysis for mountain whitefish adult and the 95% flow exceedence. 103

Figure 5.23. The weekly Ecosystem Base Flows for the Oldman River Reach 5 using the maximum value between the 80% habitat duration analysis for mountain whitefish juvenile and the 95% flow exceedence. 105

Figure 5.24. The weekly Ecosystem Base Flows for the Oldman River Reach 6 using the maximum value between the 80% habitat duration analysis for mountain whitefish juvenile and the 95% flow exceedence. 106

Figure 5.25. The weekly Ecosystem Base Flows for the Oldman River Reach 7 using the maximum value between the 80% habitat duration analysis for mountain whitefish juvenile and the 95% flow exceedence. 108

Figure 5.26. The weekly Ecosystem Base Flows for the Belly River Reach 1 using the maximum value between the 80% habitat duration analysis for mountain whitefish adult and the 95% flow exceedence. 109

Figure 5.27. The weekly Ecosystem Base Flows for the Belly River Reach 2 using the maximum value between the 80% habitat duration analysis for mountain whitefish juvenile and the 95% flow exceedence. 110

Figure 5.28. The weekly Ecosystem Base Flows for the Belly River Reach 3 usinr the Tessmann calculation. 111

Figure 5.29. The weekly Ecosystem Base Flows for the St. Mary River Reach 1 using the maximum value between the 80% habitat duration analysis for mountain whitefish juvenile and the 95% flow exceedence. 112

Figure 5.30. The weekly Ecosystem Base Flows for the St. Mary River Reach 2 using the Tessmann calculation. 113

Figure 5.31. The weekly Ecosystem Base Flows for the Waterton River Reach 1 using the maximum value between the 80% habitat duration analysis for mountain whitefish adult and the 95% flow exceedence. 114

Figure 5.32. The weekly Ecosystem Base Flows for the Waterton River Reach 2 using the maximum value between the 80% habitat duration analysis for mountain whitefish adult and the 95% flow exceedence. 115

Figure 5.33. The weekly Ecosystem Base Flows for the South Saskatchewan River Reach 1 using the Tessmann calculation. 116

Figure 5.34. The weekly Ecosystem Base Flows for the South Saskatchewan River Reach 2 using the Tessmann calculation. 117

Figure 6.1. Alberta surface water quality index for southern rivers, 2000-2001..... 122

Figure 6.2. Availability of reach-specific water quality modelling for IFN determinations within the SSRB WMP. 126

Figure 7.1. Cross-section of a streambank showing the extent of moistened substrates and the suitability of zones for cottonwood seedling establishment..... 143

Figure 7.2. Generalized flows required by cottonwoods along the Oldman River..... 151

Figure 7.3. Exceedence curve for naturalized streamflows along the Oldman River. 152

Figure 7.4. Threshold-based streamflow requirements for cottonwoods in relation to the exceedence curve for naturalized streamflow along the Oldman River. 153

Figure 7.5. Three exceedence-based curves that each satisfy a portion of the streamflow requirements of cottonwoods along the Oldman River..... 154

Figure 7.6. PRC for cottonwoods in relation to the exceedence curve for naturalized streamflow along the Oldman River. 154

Figure 7.7. Major flow-regulatory structures and PRC study reaches in the SSRB... 157

Figure 7.8. Flow-chart of criteria-based decisions for calculating PRC flows..... 162

Figure 7.9. Actual vs. PRC weekly flows during a high flow year, a low flow year, and two average flow years along the upper and lower reaches of the Belly River..... 165

Figure 7.10. Naturalized vs. actual weekly flows during a high flow year, a low flow year, and two average flow years along the upper and lower reaches of the Belly River. 166

Figure 7.11. Actual vs. PRC weekly flows during a high flow year, a low flow year, and two average flow years along the upper and lower reaches of the Waterton River. 168

Figure 7.12. Naturalized vs. actual weekly flows during a high flow year, a low flow year, and two average flow years along the upper and lower reaches of the Waterton River. 169

Figure 7.13. Actual vs. PRC weekly flows during a high flow year, a low flow year, and two average flow years along the upper and lower reaches of the St. Mary River. 171

Figure 7.14. Naturalized vs. actual weekly flows during a high flow year, a low flow year, and two average flow years along the upper and lower reaches of the St. Mary River. 172

Figure 7.15. a) Example of a weekly PRC vs. a naturalized exceedence curve for flows along the St. Mary River near Lethbridge, and b) individual exceedence curves for each criterion of the PRC. 176

Figure 7.16. Ranges of naturalized flow affected by each PRC criterion. 177

Figure 7.17. a) Average change from naturalized to actual weekly flows for a series of flow-regulated years, and b) summary of changes to flows affected by PRC criterion 1. 179

Figure 7.18. a) Average actual weekly flows relative to naturalized 90% exceedence flows during the growing season for a series of flow-regulated years, and b) averages of actual weekly flows affected by PRC criterion 2. 182

Figure 7.19. a) Average change from naturalized to actual weekly flows during the growing season for a series of flow-regulated years, and b) summary of changes to flows affected by PRC criterion 3..... 184

Figure 7.20. a) Average return interval shifts from actual to naturalized weekly flows during the growing season, and b) summary of changes to flows affected by PRC criterion 4. 186

Figure 7.21. Comparison of naturalized weekly flows greater than 125% bankfull with their corresponding actual weekly flows. 188

Figure 7.22. Availability of site-specific data required to develop a PRC for every reach in the SSRB WMP. 190

Figure 8.1. Example of channel maintenance instream flow needs, determined using the modified Wyoming Model. 198

Figure 8.2. Shields number versus discharge relationship for the Red Deer River. .. 200

Figure 8.3. Shields number versus discharge relationship for the Bow River. 200

Figure 8.4. Shields number versus discharge relationship for the Oldman River. 201

Figure 8.5. Shields number versus discharge relationship for the South Saskatchewan River. 201

Figure 8.6. Availability of site-specific data required for the Shield’s equation to calculate the channel maintenance flows. 204

Figure 9.1. Illustration of how each ecosystem component was integrated into the final ecosystem IFN curve for the Belly River near Standoff. 209

Figure 9.2. Illustration of the seasonality of each ecosystem component for a drier than average water year and the resulting integrated ecosystem IFN. 210

Figure 9.3. An illustration of the seasonality of the naturalized hydrograph and the resulting integrated ecosystem IFN for the Red Deer River. 211

Figure 9.4. An illustration of inter-annual flow variability for the Oldman River near Monarch and the associated flow duration curves illustrating the variable ecosystem IFN determination. 213

Figure 9.5. Summary of the combined reach-specific data required for a detailed integrated ecosystem IFN throughout the SSRB. 215

Figure 9.6. The Red Deer River at Drumheller integrated ecosystem IFN. 217

Figure 9.7. The Bow River below the Carseland weir integrated ecosystem IFN. 218

Figure 9.8. The Oldman River at Lethbridge integrated ecosystem IFN. 219

Figure 9.9. The Belly River near Standoff integrated ecosystem IFN. 220

Figure 9.10. The Waterton River near Standoff integrated ecosystem IFN. 221

Figure 9.11. The St. Mary River near Lethbridge integrated ecosystem IFN. 222

Figure 9.12. The South Saskatchewan River at Medicine Hat integrated ecosystem IFN. 223

Figure 10.1. Example of inter-annual and intra-annual flow variability of the ecosystem IFN determination for the Oldman River. 239

LIST OF TABLES

Table 3.1. Red Deer River reach boundaries and gauging stations. 10

Table 3.2. Bow River reach boundaries and gauging stations..... 10

Table 3.3. South Saskatchewan River reach boundaries and gauging stations. 10

Table 3.4. Oldman River reach boundaries and gauging stations. 11

Table 3.5. Belly, St. Mary and Waterton river reach boundaries and gauging stations.
..... 11

Table 3.6. Assessments of riparian forest abundances along the Red Deer River in the
1880s, 1950s, 1980s, and late 1990s. 18

Table 3.7. Geographic characteristics of the Red Deer River and river valley. 21

Table 3.8. Assessments of riparian forest abundances along the Bow River in the
1880s, 1950s, 1980s, and late 1990s. 24

Table 3.9. Geographic characteristics of the Bow River and river valley..... 26

Table 3.10. Assessment of riparian forest abundance along the Oldman River in the
1880s, 1950s, 1980s, and late 1990s. 28

Table 3.11. Geographic characteristics of the Oldman River and river valley. 30

Table 3.12. Assessment of riparian forest abundance along the southern tributaries in
the 1880s, 1950s, 1980s, and late 1990s..... 33

Table 3.13. A) Changes to cottonwood abundance in the Oldman River Basin from the
1950s to the 1980s. B) Summary of magnitude of changes in cottonwood
abundance using ranked categories. 34

Table 3.14. Geographic characteristics of the southern tributaries of the Oldman
River. 40

Table 3.15. Assessments of riparian forest abundances along the South Saskatchewan
River in the 1880s, 1950s, 1980s, and late 1990s..... 43

Table 5.1. Habitat evaluation metrics for a 20% reduction from the natural flow with
the added constraint of the EBF for Red Deer River Reach 1. 85

Table 5.2. Habitat evaluation metrics for a 20% reduction from the natural flow with
the added constraint of the EBF for Red Deer River Reach 3. 87

Table 5.3. Habitat evaluation metrics for a 25% reduction from the natural flow with
the added constraint of the EBF for Red Deer River Reach 5. 88

Table 5.4. Habitat evaluation metrics for a 20% reduction from the natural flow with
the added constraint of the EBF for Red Deer River Reach 6. 90

Table 5.5. Habitat evaluation metrics for a 25% reduction from the natural flow with
the added constraint of the EBF for Red Deer River Reach 7. 92

Table 5.6. Habitat evaluation metrics for a 25% reduction from the natural flow with
the added constraint of the EBF for Bow River Reach 2..... 93

Table 5.7. Habitat evaluation metrics for flows constrained only by the EBF for Bow
River Reach 3. 95

Table 5.8. Habitat evaluation metrics for a 55% reduction from the natural flow with
the added constraint of the EBF for Bow River Reach 4..... 97

Table 5.9. Habitat evaluation metrics for a 40% reduction from the natural flow with
the added constraint of the EBF for Oldman River Reach 2. 100

Table 5.10. Habitat evaluation metrics for a 30% reduction from the natural flow with
the added constraint of the EBF for Oldman River Reach 3. 101

Table 5.11. Habitat evaluation metrics for a 15% reduction from the natural flow with
the added constraint of the EBF for Oldman River Reach 4. 103

Table 5.12. Habitat evaluation metrics for a 30% reduction from the natural flow with the added constraint of the EBF for Oldman River Reach 5. 104

Table 5.13. Habitat evaluation metrics for a 20% reduction from the natural flow with the added constraint of the EBF for Oldman River Reach 6. 105

Table 5.14. Habitat evaluation metrics for a 20% reduction from the natural flow with the added constraint of the EBF for Oldman River Reach 7. 107

Table 5.15. Habitat evaluation metrics for a 30% reduction from the natural flow with the added constraint of the EBF for Belly River Reach 1. 109

Table 5.16. Habitat evaluation metrics for a 20% reduction from the natural flow with the added constraint of the EBF for Belly River Reach 2. 110

Table 5.17. Habitat evaluation metrics for a 40% reduction from the natural flow with the added constraint of the EBF for St. Mary River Reach 1. 112

Table 5.18. Habitat evaluation metrics for a 25% reduction from the natural flow with the added constraint of the EBF for Waterton River Reach 1. 114

Table 5.19. Habitat evaluation metrics for a 20% reduction from the natural flow with the added constraint of the EBF for Waterton River Reach 2. 115

Table 5.20. Summary of fish habitat IFN determinations to be incorporated into the ecosystem IFN. 119

Table 6.1. Red Deer River water quality IFN determinations. 125

Table 6.2. Bow River water quality IFN determinations. 132

Table 6.3. Oldman River water quality IFN determinations. 134

Table 6.4. Oldman Tributaries water quality IFN determinations. 136

Table 6.5. South Saskatchewan River water quality IFN determinations. 137

Table 7.1. Documented examples of riparian cottonwood declines associated with flow regulation along streams in North America. 144

Table 7.2. Riparian cottonwood phenology along the Oldman River at Lethbridge. .. 149

Table 7.3. Weekly flow requirements of riparian cottonwoods along the Oldman River at Lethbridge. 150

Table 7.4. Criteria for calculating PRC flows during a given week of the year. 155

Table 7.5. Weekly and bankfull flows used to calculate the PRC along test reaches in the Oldman River Basin. 161

Table 7.6. Average naturalized flow exceedences of 125% bankfull flow during peak flow weeks. 164

Table 7.7. A) Documented changes to cottonwood abundances from the 1950s to the 1980s along reaches upstream and downstream from the Belly River Diversion Weir, Waterton River Dam, and St. Mary River Dam. B) Summary of the magnitude of changes in cottonwood abundance. 173

Table 7.8. The ranges of flow affected by each PRC criterion. 175

Table 7.9. Summary comparing recorded flows to flows required by individual PRC criterion. 175

Table 7.10. Assessments of riparian forest abundances along various tributaries of the SSRB in the 1880s, 1950s, 1980s, and late 1990s. 180

Table 8.1. Recommended channel maintenance flows. 203