FLOWS REQUIRED TO PROTECT WATER QUALITY IN THE LITTLE BOW RIVER AND MOSQUITO CREEK

Alberta Environment

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April 2002

W0203

Pub No. T/655
ISBN: 07785-2161-3 (Printed Edition)
ISBN: 07785-2111-7 (On-line Edition)
Web Site: http://www3.gov.ab.ca/env/info/infocentre/publist.cfm

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SUMMARY

The Alberta government will construct the Little Bow River Reservoir at the confluence of the Little Bow River and Mosquito Creek. The Joint Review Panel convened by the Natural Resources Conservation Board and the Canadian Environmental Assessment Agency (NRCB/CEAA Joint Review Panel) has approved this project subject to certain requirements and recommendations. These included the development of a Highwood River Basin Water Management Plan, and a Little Bow River Reservoir Water Quality Protection Plan.

To assist the development of plans for the Highwood and Little Bow River watersheds, the Science and Standards Division, Alberta Environment (AENV) was asked to examine the relationship between flow and water quality in the Little Bow River and Mosquito Creek. This report presents an evaluation of the effects of flow on water quality. Equations were developed to predict the relationship between flow and dissolved oxygen in the Little Bow River, and the relationship between flow and total suspended solids in Mosquito Creek. These equations were used to estimate flows that should ensure suitable water quality.

Dissolved oxygen levels in the Little Bow River at Highway 533 were predicted to remain above 5 and 4 mg/L at minimum flows of 3.20 m^3/s (113 ft^3/s) and 1.80 m^3/s (63.6 ft^3/s), respectively. Lower flows would maintain lower levels of dissolved oxygen. The equation developed to predict minimum dissolved oxygen at this site might not provide accurate predictions at flows outside the range used in the analysis, namely 0.35 m^3/s to 3.46 m^3/s (12.36 - 122.19 ft^3/s).

This analysis does not evaluate the impact on water quality of increasing flows in the Little Bow River to a maximum of 8.50 m^3/s (300 ft^3/s) during the spring to fill the Little Bow River Reservoir. Similarly, this study used data collected during the open water season (March – September) and can not be used to evaluate the effects of flow on water quality during the winter.

Total suspended solids (TSS) in Mosquito Creek downstream of Nanton near Range Road 281 was predicted to remain below the CCME guideline at mean monthly flows ranging from 1.258 to 1.615 m^3/s (44.43 - 57.03 ft^3/s), in August and July, respectively. TSS would remain below the guideline at much lower flows during the early spring and fall. The equation developed to predict TSS at this site might not provide accurate predictions at flows outside the range used in the analysis, namely 0.223 - 2.091 m^3/s (7.87 - 73.84 ft^3/s).

Reductions in TSS loading to Mosquito Creek or reduced biomass of aquatic plants in the Little Bow River may change the flow requirements to maintain water quality. It was not possible to develop flow requirements to maintain other water quality variables at other locations in either watershed.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGMENTS

We thank all technical and professional staff of Alberta Environment who assisted in the monitoring of the Little Bow River and Mosquito Creek. Bridgette Halbig assisted in data compilation and report preparation. Dave Trew provided review comments on the draft report.

1.0 INTRODUCTION

The Alberta government will construct the Little Bow River Reservoir at the confluence of the Little Bow River and Mosquito Creek. The Joint Review Panel convened by the Natural Resources Conservation Board and the Canadian Environmental Assessment Agency (NRCB/CEAA Joint Review Panel) (Application #9601) has approved this project subject to certain requirements and recommendations (NRCB 1998). These requirements include the development of a Highwood River Basin Water Management Plan. There was also a recommendation that a Little Bow River Reservoir Water Quality Protection Plan should be developed.

Under the Highwood Diversion Plan (APWSS 1995) that was evaluated by the Joint Review Panel, diversion from the Highwood River to the Little Bow Canal would range from 0.28 m^3/s (10 ft^3/s) to a maximum of 8.50 m^3/s (300 ft^3/s) during the open water season. Diversion would remain at 0.57 m^3/s (20 ft^3/s) during the winter months (October 15-April 15). Diversion to Women's Coulee (then called Squaw Coulee) would range between 0.28 - 1.70 m^3/s (10 – 60 ft^3/s) during the open water season. Diversion to both Women's Coulee and the Little Bow Canal would be subject to meeting Instream Flow Needs in the Highwood River.

Concerns were expressed at the hearings for the Little Bow Project/Highwood Diversion Plan that summer flows of 0.28 m^3/s would adversely affect water quality in the upper Little Bow River. The Joint Review Panel requested a revised diversion plan. The Panel directed that the plan should include increased conveyance flows in the upper Little Bow River of about 0.85 - 1.13 m^3/s (30 - 40 ft^3/s) in summer, and flows in the lower Mosquito Creek of 0.57 - 0.85 m^3/s (20 - 30 ft^3/s)(p. 4-55, NRCB 1998). The panel did not specify whether 0.85 - 1.13 m^3/s should be maintained everywhere throughout the Little Bow River upstream from the reservoir, but AENV has assumed this is the case in the development of the Highwood Management Plan. It has also been assumed in this report that conveyance flows are minimum flows that must be maintained.

To assist the development of plans for the Highwood and Little Bow River watersheds, Alberta Transportation asked the Science and Standards Division, Alberta Environment (AENV) to examine the relationship between flow and water quality in the Little Bow River and Mosquito Creek, and determine flows that would protect water quality. This report presents a statistical evaluation of the effects of flow on water quality, and equations that can be used to predict the relationship between flow and dissolved oxygen in the Little Bow River, and total suspended solids (TSS) in Mosquito Creek. Flows that should ensure suitable water quality are also presented.

2.0 METHODS

Flows and water quality data collected during intensive sampling programs during the open water season in 1999 (March 24-September 1), and 2000 were used in the analysis. Sites along the Little Bow River from 168 Street downstream to Reservoir FSL were sampled April 6-September 1, 2000, but otherwise 2000 results were from March 31-September 1. Total phosphorus (TP) was sampled daily using automated samplers (N = 250 - 309) as indicated in Table 1, but otherwise variables were measured on grab samples or metered (dissolved oxygen and temperature) during site visits (N = 10 downstream from the reservoir, otherwise N = 25 – 50). The analysis also used hourly water temperature and dissolved oxygen concentration that was measured using datasondes. These data were regularly confirmed using certified thermometers and Winkler titration. Datasondes were installed at Mosquito Creek at Highway 529, Little Bow River at Highway 533, and Little Bow River downstream from the reservoir, during all or part of June 17-September 1, 1999, June 13-September 7, 2000 and June 6-September 4, 2001.

To determine which water quality variables were significantly influenced by flow, all data were first tested for statistically significant correlation (? = 0.05) with mean daily flow using Spearman Rho Rank Order Correlation. Representative sites with sufficient data in each reach were selected for correlation analysis. Maximum daily water temperatures and minimum dissolved oxygen concentrations were correlated with flow, where these were available from datasondes. Otherwise measurements of these variables during visits to the other sites (N = 18 – 46) were used in the analysis. TP and TSS measurements from the Little Bow River alone during the early spring (March, April) were excluded from the correlation analysis, because these variables were very high during low flows at the onset of diversion from Highwood River.

To eliminate spurious correlation due to significant mutual correlation among three variables, Partial Spearman Rank Correlation Coefficients between flow and chemical variables were calculated as required. Dissolved oxygen was adjusted for correlation between flow and water temperature, and water temperature was adjusted for correlation between flow and air temperature. These adjustments were required because dissolved oxygen concentrations sometimes declined with increasing flows, due to increasing water temperature. The adjusted correlation for dissolved oxygen mainly reflects the effects of aquatic plants on dissolved oxygen, with the effects of temperature removed. Similarly, water temperature tended to increase over the season as air temperatures increased along with flow (e.g., Rho = 0.498, $P < 0.001$ at Mosquito Creek downstream from Nanton near Range Road 281).

Of the different variables that were significantly correlated with flow, minimum flows were only developed to maintain adequate dissolved oxygen in the Little Bow River at Highway 533 east of Nanton (WDS Station AB05AC0100). Similarly, although different variables were correlated with flow in Mosquito Creek, maximum flows were developed to prevent increased total suspended solids due to scouring at high flows in Mosquito Creek downstream from Nanton near Range Road 281 (WDS Station AB05AC0150). TSS increased greatly in Mosquito Creek with increasing flow downstream from Women's Coulee. Bank erosion in Women's Coulee (Sosiak 2000) and resuspension of shoreline sediments during high flows in the open water season in Mosquito Creek were assumed to be important sources of sediment.

Table 1 Correlation between flow and biological, physical and chemical variables in the Little Bow River and Mosquito Creek during the open water seasons in 1999 - 2001. Statistically significant correlations (? = 0.05) are in bold italics.

Sampling Sites	Spearman Rank Correlation (Rho)' between Flow and Other Variables[a]									
	TP	TDP	TSS	NO_2+ NO_3	NH_3	TN	DO [b]	Water Temp [b]	*Ecoli*	Fcoli
Mosquito Ck. d/s Cross Ck.	***0.537***	0.203	***0.614***	***0.785***	***0.477***	0.351	***0.650***	***-0.522***	-0.055	0.202
Mosquito Ck. d/s of Cayley Colony	***-0.300***	***-0.462***	0.180	***0.572***	0.005	0.023	0.110	***-0.482***	0.107	0.037
Women's Coulee near Cayley	***0.591***	-0.376	***0.647***	0.006	***-0.529***	***-0.612***	0.102	***0.535***	***0.710***	***0.564***
Mosquito Ck. d/s Hwy 534	-0.130	***-0.522***	***0.671***	-0.298	***-0.546***	-0.314	-0.341	0.352	0.008	-0.272
Nanton Ck. near Mouth	***-0.175***	-0.084	***0.449***	***0.602***	0.085	-0.124	***-0.388***	-0.264	-0.089	0.108
Mosquito Ck. d/s Nanton	***0.123***	***-0.316***	***0.749***	-0.116	0.216	-0.021	***-0.725***	0.231	0.167	0.080
Mosquito Ck. at Hwy 529	***0.216***	0.041	***0.388***	0.275	0.181	-0.111	***0.333***	***-0.421***	***0.598***	***0.669***
Mosquito Ck. near FSL	-0.179	-0.087	0.008	-0.130	0.025	***-0.385***	***-0.580***	***0.638***	***0.598***	***0.573***
Little Bow R. at Highwood R.	***0.295***	0.245	0.306	***-0.455***	0.086	0.120	-0.183	0.024	***0.516***	***0.421***
Little Bow R. at Highway 2	0.071	***0.435***	0.281	***-0.359***	***-0.319***	-0.155	0.042	-0.002	***0.571***	***0.545***
Little Bow R. at 168 St.	0.092	0.067	-0.013	***-0.773***	***-0.726***	***-0.687***	-0.156	0.321	***0.509***	***0.478***
Little Bow R. at 658 Avenue	***0.287***	-0.036	0.092	***-0.622***	***-0.511***	***-0.447***	-0.195	0.072	0.271	0.249
Little Bow R. at Hwy 534	-0.112	0.185	-0.404	***-0.686***	***-0.693***	***-0.688***	***0.491***	-0.075	0.158	0.172
Little Bow R. at Hwy 533	***0.131***	-0.170	-0.161	***-0.462***	-0.315	-0.313	***0.545***	***-0.132***	0.270	***0.501***
Little Bow R. at Reservoir FSL	-0.314	-0.240	-0.025	***-0.604***	***-0.437***	***-0.641***	0.038	-0.113	0.268	0.263
Little Bow R. d/s of Reservoir	0.119	0.377	NA	0.084	0.197	-0.268	***0.341***	***-0.318***	NA	NA

[a] Abbreviations: TP (total phosphorus), TDP (total dissolved phosphorus), TSS (total suspended solids, as nonfilterable residue), NH_3 (total ammonia), NO_2+NO_3 (nitrite+nitrate), TN (total nitrogen), *E. coli* (*Escherichia coli*), F. coli (fecal coliforms), u/s (upstream), d/s (downstream), NA (insufficient data for analysis)

[b] Partial Spearman Rank Correlation used to eliminate spurious correlation where flow, the tested variable, and a third variable were all significantly correlated. DO corrected for correlation between flow and water temperature, and water temperature corrected for correlation between flow and air temperature.

Unlike the headwater sites on Mosquito Creek, these two locations are in regulated parts of the watershed where it would be possible to maintain protective flows. Other variables either lacked suitable guidelines (e.g., nitrite+nitrate, TP), or increased slightly with flow and would not be protected by maintaining a minimum flow.

Following an initial review of the data relative to water quality guidelines, and correlation analysis, the analysis of datasonde results was restricted to July and August when the lowest dissolved oxygen levels were recorded, due to nocturnal respiration by aquatic plants. This review used the following water quality guidelines:

maximum water temperature of 28?C (acute guideline)
minimum dissolved oxygen of 5 mg/L (acute guideline)
7-d mean dissolved oxygen of 6.5 mg/L (chronic guideline)

The first two guidelines were developed for the environmental impact assessment for the Pine Coulee Reservoir Project, to protect pike and walleye in Willow Creek (AENV 1992). The dissolved oxygen guidelines are also Alberta guidelines (AENV 1999). The NRCB concluded both pike and walleye could live in the Little Bow River Reservoir if reservoir water quality is improved through a water quality protection plan (NRCB 1998). Accordingly the guidelines developed for Willow Creek are appropriate for the current exercise.

Water temperature did not rise above the guideline at the datasonde sites. Accordingly, protective flows were only developed for dissolved oxygen. Furthermore, protective flows were only developed for the Little Bow River at Highway 533, because daily dissolved oxygen measurements were only available at this site on the Little Bow River (Table 1). Flows measured at Highway 533 (WDS station AB05AC930) in 1999 and 2000 were used in the analysis. The Hydrology Branch, AENV, provided estimates of 2001 flows for this location, based on area gauges. It was not possible to investigate relationships between flow and water quality during the winter and fall, because flows were not available for most sites, and sites were only sampled monthly. Further details on the 1999 sampling locations, methods, and results are provided in Sosiak (2000).

To develop a flow to protect dissolved oxygen, the relationship between dissolved oxygen and flow was investigated. The difference between daily minimum dissolved oxygen levels and equilibrium dissolved oxygen levels at corresponding water temperatures and station elevations (Benson and Krause, 1980) was regressed against daily mean flow using least squares linear regression. It was assumed that the temperature-adjusted flow-dissolved oxygen relationship was approximately linear over the observed range of flows. Equilibrium dissolved oxygen levels are temperature dependent, and therefore fluctuate substantially with changes in water temperature. Subtracting equilibrium dissolved oxygen levels is intended to remove the influence of water temperature on recorded dissolved oxygen minima. With the effects of temperature removed, decreases in dissolved oxygen are mainly due to the effects of biological oxygen consumption from aquatic plants.

To estimate the flow at which dissolved oxygen fell below the 5-mg/L guideline level, the lowest equilibrium dissolved oxygen concentration that occurred concurrently with the lowest recorded dissolved oxygen concentration was determined using the 1999, 2000, and 2001 data. This was necessary because minimum equilibrium dissolved oxygen levels typically occur each day during mid- to late-afternoon while the lowest recorded dissolved oxygen levels occur prior to sunrise. The lowest equilibrium dissolved oxygen level to occur at the same time as lowest recorded dissolved oxygen concentration was determined to be 7.87 mg/L (2:00 July 13, 1999). The difference between this value (7.87 mg/L, 1999) and 5 mg/L (guideline concentration) was substituted into the regression equation for the term DO_{eq} - DO_{min}, in effect replacing this term with the worst case equilibrium dissolved oxygen level for DO_{eq}, and replacing the 5mg/L guideline level for DO_{min}. The corresponding flow was determined by rearrangement of the equation.

To evaluate the degree of protection provided by various flows, the frequency that dissolved oxygen was predicted to fall below the guideline was also determined using the regression equation. The difference between 5 mg/L and the daily equilibrium dissolved oxygen level that was concurrent with a dissolved oxygen minimum was determined for each monitoring date in July and August, 1999-2001. The n^{th} percentiles for these values were then calculated, and substituted into the regression equation (Table 2). For example, the tenth percentile for all differences (1999-2001) between equilibrium and guideline (5 mg/L) dissolved oxygen levels was 3.12 mg/L. Substituted into the regression equation, this results in a flow of 2.84 m^3/s. This flow will provide protection 90% of the time against dissolved oxygen levels that fall below the 5 mg/L guideline. Because some sport fish can tolerate lower levels of dissolved oxygen, and other guidelines may be considered, estimates of the frequency of dissolved oxygen falling below 4.5 mg/L, 4 mg/L, and 3.5 mg/L were also prepared. Since dissolved oxygen did not fall to 3 mg/L, 3.5 mg/L was the lowest minimum evaluated.

Total ammonia and TSS (dependent variables) were each separately regressed against flow (independent variable) for sites where the correlation with flow was strongest. The 13 linear and non-linear regression models available in the water quality statistics package WQHYDRO (Aroner 2000) were evaluated. Only those models that were statistically significant were refined using a robust regression procedure, which minimizes the effects of data with large residuals. The models with lower standard errors were then compared to measured data, and the model which best matched the observed data in each case was selected.

Table 2 Flows at which dissolved oxygen falls below minimum levels estimated for various percent frequencies in the Little Bow River at Highway 533, 1999-2001

Dissolved Oxygen	Flow (m^3/s) at which dissolved oxygen will fall below a given concentration and frequency (%)																			
	0%	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%	75%	80%	85%	90%	95%
5 $mg \cdot L^{-1}$	3.20	2.96	2.84	2.71	2.65	2.56	2.46	2.41	2.35	2.30	2.25	2.19	2.11	2.01	1.95	1.86	1.74	1.55	1.46	1.25
4.5 $mg \cdot L^{-1}$	2.50	2.26	2.14	2.01	1.95	1.86	1.77	1.71	1.65	1.60	1.55	1.50	1.42	1.31	1.25	1.16	1.04	0.85	0.76	0.55
4 $mg \cdot L^{-1}$	1.80	1.56	1.44	1.31	1.25	1.17	1.07	1.02	0.95	0.90	0.86	0.80	0.72	0.61	0.55	0.47				
3.5 $mg \cdot L^{-1}$	1.11	0.86	0.74	0.61	0.55	0.47	0.37													

To estimate an acceptable maximum flow in Mosquito Creek, background levels of TSS were first estimated. The TSS corresponding to the long-term average flows (1982-1999) at Mosquito Creek downstream from Nanton near Range Road 281 were estimated using the best regression model. Flows in Mosquito Creek at Highway 529 (WDS site AB05AC0160) were multiplied by a ratio of watershed areas at the two sampling sites (ratio = 805.1/962.7), to estimate long-term average flows downstream from Nanton. The maximum allowable increase in TSS of either 5 mg/L for clear flow (where TSS $\leq$ 25 mg/L), or 25 mg/L during high flow (where TSS > 25 mg/L)(CCME 1999) were then added to the monthly background levels of TSS. Mean flows corresponding to the new maximum TSS concentration were then determined from the regression equation using an iterative procedure in Excel 7.0.

3.0 RESULTS AND DISCUSSION

Results of the correlation and regression analysis between flow and various water quality variables are presented in Table 1, and Figures 1 to 3. Results of the regression analysis designed to determine flows to maintain suitable levels of dissolved oxygen are in Tables 2 and 3, and Figure 4. Results of the analysis designed to determine flows to maintain TSS levels are in Tables 3 and 4.

3.1 Effects of Flow on Water Quality

The correlation analysis found that water temperature declined with increasing flow in the headwaters of Mosquito Creek, in Mosquito Creek at Highway 529 (Table 1), and the lower Little Bow River. However, water temperature did not increase above the 28?C guideline during hourly monitoring at any of the datasonde sites over three years. A significant positive correlation between flow and dissolved oxygen was found in the Little Bow River at Highway 533, and dissolved oxygen well below 5 mg/L ($\geq$ 3.11 mg/L) was measured at this site. Accordingly, a flow designed to maintain acceptable levels of dissolved oxygen was developed for that site (Section 3.2).

The correlation analysis also found a strong positive correlation between flow and TSS at most sites along Mosquito Creek, but no correlation between these variables along the Little Bow River (Table 1). Previous work (Sosiak 2000) determined that erosion along Women's Coulee is the probable source of elevated levels of TSS in Mosquito Creek. TSS greatly increased at relatively low flows in Women's Coulee, then increased at a lower rate as flows continued to rise (Figure 1). In contrast, TSS levels in Mosquito Creek downstream from Nanton near Range Road 281 were relatively low up to about 1.0 m^3/s, and continued to increase at higher flows (Figure 2). Accordingly, a flow designed to prevent an unacceptable increase in TSS was estimated (Section 3.3).

Resuspension of creek sediments during increasing flows, TSS from diffuse runoff, and bank erosion along Women’s Coulee may account for the different relationship between flow and TSS in Mosquito Creek. Although areas of bank erosion have been found along the Little Bow River (Sosiak 2000) between Highway 2 and 168 Street, the current analysis does not provide evidence that TSS can be expected to increase in the Little Bow River with increasing flow within the range of flows used in this analysis namely 0.35 m^3/s to 3.46 m^3/s (12.36 - 122.19 ft^3/s). This analysis does not evaluate the impact on water quality of increasing flows in the Little Bow River to a maximum of 8.50 m^3/s (300 ft^3/s) during the spring to fill the Little Bow River Reservoir. Similarly, this study used data collected during the open water season (March – September) and can not be used to evaluate the effects of flow on water quality during the winter.

Significant inverse correlation between flow and both total ammonia and nitrite+nitrate was detected at sites from Highway 2 to 658 Avenue along the Little Bow River (Table 1). This relationship suggests that these variables will be higher at lower flows. However, none of the ammonia measurements at these sites were greater than the CCME guideline for this variable (CCME 1999) at any flow. Furthermore, total ammonia levels declined greatly at higher flows.

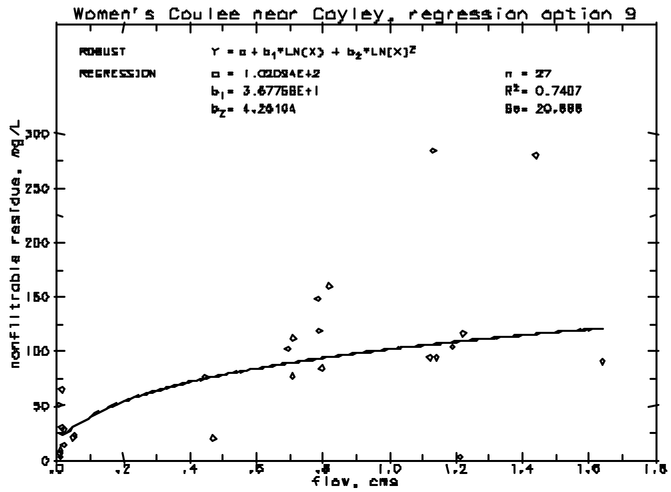

Figure 1 **Regression between total suspended solids (as nonfilterable residue) and flow in Women's Coulee near Cayley**

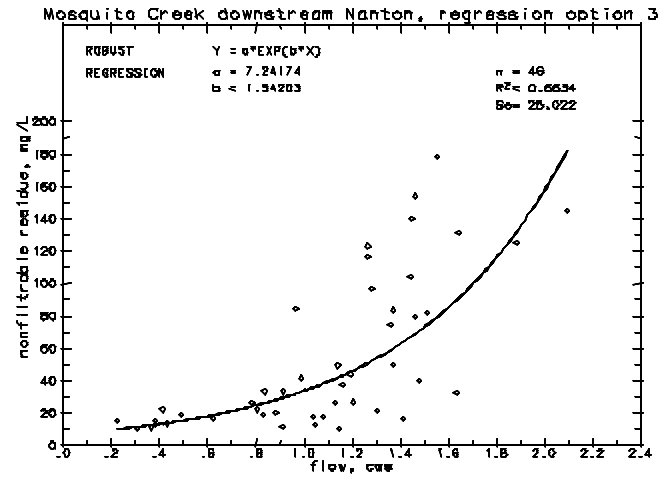

Figure 2 **Regression between total suspended solids (as nonfilterable residue) and flow in Mosquito Creek downstream from Nanton near Range Road 281**

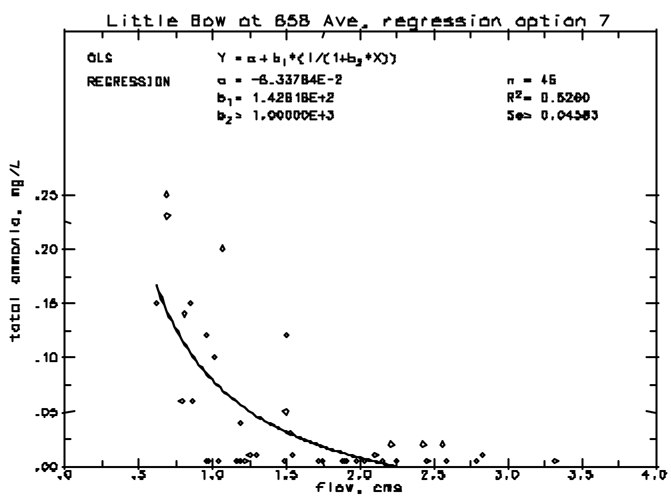

Figure 3 **Regression between total ammonia and flow in the Little Bow River at 658 Avenue**

Table 3 Regression equations for dissolved oxygen (DO) and total suspended solids (TSS) as functions of flow (Q) in the Little Bow River and Mosquito Creek during the open water season

Site	Predictive Equation	r^2	SE	*N*
Little Bow River at Highway 533	$(DO_{eq} - DO_{min})^a = -0.71587373(Q) + 5.1564666$	0.526	0.425	158
Mosquito Creek downstream from Nanton near Range Road 281	TSS = 7.24174*(EXP(1.54203*Q)	0.663	25.02	46

[a] other abbreviations: DO_{eq} = equilibrium dissolved oxygen (calculated) at DO_{min}; DO_{min} = daily minimum dissolved oxygen

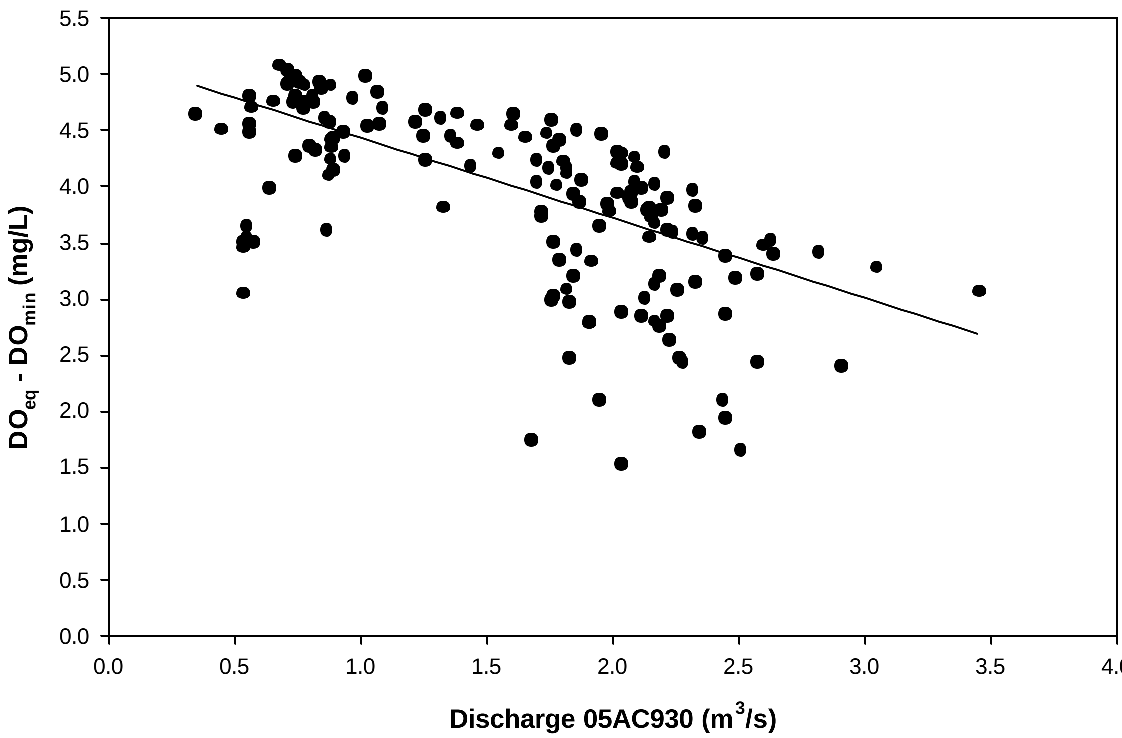

Figure 4 Flow versus minimum dissolved oxygen in the Little Bow River at Highway 533 with the effects of water temperature removed

Table 4 Flows that are predicted to prevent TSS from increasing to levels above the CCME guideline in Mosquito Creek downstream from Nanton near Range Road 281 during the open water season

Variable	March	April	May	June	July	Aug	Sept	Oct
Historic Mean Flows at this Site, m^3/s	0.550	0.416	0.895	1.363	1.397	0.813	0.669	0.343
Guideline Used	+5 mg/L	+5 mg/L	+25 mg/L	+25 mg/L	+25 mg/L	+25 mg/L	+5 mg/L	+5 mg/L
Allowable Maximum TSS, mg/L	21.9	18.7	53.8	84.3	87.4	50.4	25.3	17.3
Maximum Mean Monthly Flow, m^3/s	0.718	0.617	1.300	1.591	1.615	1.258	0.812	0.564
Allowable % Increase in Flow	16.8	20.1	40.5	22.8	21.9	44.5	14.3	22.1

At the site with the strongest correlation, Little Bow River at 658 Avenue, ammonia levels were below 0.05 mg/L at flows above 1.5 m^3/s (Figure 3).

The significant increase in coliform levels and TDP with increasing flow at some sites (Table 1) could be caused by diffuse runoff from unidentified sources upstream from the sampling sites.

3.2 Flows Required to Protect Dissolved Oxygen

This analysis suggests that dissolved oxygen in the Little Bow River at Highway 533 will always be greater than the 5 mg/L guideline, and all other dissolved oxygen levels evaluated, when flows at this location are $\geq$ 3.20 m^3/s (113 ft^3/s)(Table 2) during July and August. This flow is probably well above long-term average flows for this site. This site has no long-term gauge, but a gauge was operated in 1999 and 2000 and the average flows in July were 2.023 and 1.348 m^3/s, respectively. The fact that flows were typically below 3.20 m^3/s during 1999 to 2001 would explain why dissolved oxygen regularly fell below 5 mg/ L in those years.

Lower flows would maintain lower levels of dissolved oxygen. For example, if 4 mg/L is acceptable for the target sport fish species in the Little Bow River, then this analysis suggests that this concentration would be maintained if flows are above 1.80 m^3/s (63.6 ft^3/s) at this location (Table 2). Taylor and Barton (1992) recommended daily minimum dissolved oxygen of 4 mg/L to protect trout and whitefish, and 3 mg/L for non-salmonid fish. This recommendation suggests that dissolved oxygen would be suitable for both cold water species like trout, and coolwater species like pike and walleye, if flows at this location are maintained above 1.80 m^3/s in summer. This flow (1.80 m^3/s) is well above the minimum flows for this reach in summer included in the initial Highwood Diversion Plan (0.28 m^3/s) and recommended in the decision report of the Joint Review Panel (0.85 - 1.13 m^3/s).

Lower flows could also be maintained if dissolved oxygen might occasionally fall below the guideline. For example, the 5-mg/L guideline would be exceeded just 10% of the time at a flow of 2.84 m^3/s (100.3 ft^3/s). Presumably, the flows that protect a given level of dissolved oxygen would decrease if aquatic plant growth in the study reach were to decrease. Therefore, this value can be adjusted based on future monitoring data. Note that the model may not provide meaningful predictions for flows below 0.35 m^3/s or above 3.46 m^3/s (Figure 4). Furthermore, these flows were developed to maintain suitable dissolved oxygen and at a specific location in the Little Bow and Mosquito Creek basins, and do not apply to the entire watershed.

3.3 Flows Required to Protect Total Suspended Solids

The analysis predicted that mean monthly flows could increase to 1.615 m^3/s (57.03 ft^3/s) in July, an increase in mean monthly flow of 21.9%, without causing TSS to exceed the CCME guideline (Table 4). Flow could increase more in May and August, by 40.5 and 44.5% respectively, but since historic flows and background TSS were lower, the allowable maximum flows were somewhat lower than in June and July. The summer flows in Table 4 are all below the maximum diversion flow to Women's Coulee included in the initial Highwood Diversion Plan of 1.70 m^3/s.

If TSS loading to Women's Coulee and Mosquito Creek could be reduced, peak flows could perhaps increase without causing unacceptable TSS concentrations in Mosquito Creek. Following the identification of areas of bank erosion in Women's Coulee (Sosiak 2000), stream banks were stabilized near the Old Women's Buffalo Jump during the winter of 2000-2001. There has not yet been sufficient monitoring to evaluate the impacts of this project on TSS concentrations in Women's Coulee.

The procedure used in this analysis assumes that flow is the best predictor of TSS at this site. This appears to be a reasonable assumption since none of the other significant physical and chemical variables (rho $\leq$ 0.470) were as highly correlated with TSS as flow (rho = 0.749) at this site. Impacts of flow in Mosquito Creek downstream from Nanton near Range Road 281 were evaluated using TSS collected over flows ranging from 0.223 to 2.091 m^3/s (7.875 - 73.843 ft^3/s). The equation and procedure used in this analysis may not be valid at flows above or below this range.

4.0 CONCLUSIONS

The main conclusions of this analysis are as follows:

1. Dissolved oxygen levels in the Little Bow River at Highway 533 are predicted to remain above 5 and 4 mg/L at minimum flows of 3.20 m^3/s (113 ft^3/s) and 1.80 m^3/s (63.6 ft^3/s), respectively. Lower flows would maintain lower levels of dissolved oxygen.

2. Impacts of flow on water quality in the Little Bow River at Highway 533 were evaluated using DO collected over the range 0.35 to 3.46 m^3/s during the open water season. The equation developed in this analysis may not be valid at flows above or below this range.

3. The results of this analysis can not be used to evaluate the impact on water quality of increasing flows in the Little Bow River to a maximum of 8.50 m^3/s (300 ft^3/s) during the spring, or the effects of flow on water quality in either stream during the winter.

4. TSS in Mosquito Creek downstream of Nanton near Range Road 281 was predicted to remain below the CCME guideline at mean monthly flows ranging from 1.258 to 1.615 m^3/s (44.43 - 57.03 ft^3/s), in May to August. TSS would remain below the guideline at much lower flows during the early spring and fall.

5. Impacts of flow in Mosquito Creek downstream from Nanton near Range Road 281 were evaluated using TSS collected over the range 0.223 - 2.091 m^3/s (7.87 - 73.84 ft^3/s). The equation developed in this analysis may not be valid at flows above or below this range.

6. Reductions in TSS loading to Mosquito Creek, or reduced biomass of aquatic plants in the Little Bow River may change the flow requirements to maintain water quality.

7. It was not possible to develop flow requirements to maintain other water quality variables at other locations in either watershed.

5.0 LITERATURE CITED

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