AN EMPIRICAL ANALYSIS OF WATER TEMPERATURE AND DISSOLVED OXYGEN CONDITIONS IN THE RED DEER RIVER

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OVERVIEW

Temperature and dissolved oxygen (DO) are important water quality variables which affect the viability of fish and other aquatic organisms. These variables can potentially be influenced by river flow. Understanding the effects of flow and other factors on these important variables is critical for river management, particularly in the face of increasing demands on river resources. In this report, simple empirical methods are used to investigate the relationships between water temperature, DO, air temperature, and flow at two locations in the Red Deer River.

Available water temperature, DO, discharge, and air temperature data were compiled for a number of sites along the Red Deer River. Compliance with water temperature and dissolved oxygen requirements for fish were evaluated at all sites using daily data. Non-compliance with acute and chronic temperature criteria occurred more frequently at stations located in the lower reaches of the river. Violations of oxygen criteria in the summer months were extremely rare; the lowest DO concentrations were recorded during winter months in the long-term monthly data sets.

An attempt was made to derive predictive equations for water temperature from air temperature at two of the sites for which there were daily measurements for portions of two years: Highway 2 near Normandeau and Nevis Bridge. There was a strong correlation between water temperature and air temperature at both sites. The correlation between water temperature and DO was also fairly strong; however, neither of these variables was well correlated with river flow. For both sites, maximum water temperature was best predicted by a linear combination of the previous day's mean air temperature and the current day's maximum and minimum air temperatures. The regression equations developed explained almost 90% of the variance in water temperature.

Using these equations, maximum water temperatures were generated for the period between May 15 and September 15, from 1989 through 1996. Acute temperature criteria were evaluated for the eight years of derived data. No violations were predicted to have occurred at Highway 2 near Normandeau, upstream of Red Deer. Occasionally, however, derived temperatures at the Nevis Bridge site farther downstream exceeded acute criteria for Mountain Whitefish fry and adults.

Based on site-specific data, flow appeared to have an insufficient effect on instream temperature and DO to define minimum flows needed to maintain compliance. More data need to be collected under warm, low flow conditions to address the question of minimum acceptable flows more completely. Experimental increases in flow during such conditions would further help to define river response.

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1.0 INTRODUCTION

1.1 BACKGROUND

The Red Deer River, a major tributary of the South Saskatchewan River, supports numerous industrial, municipal, and agricultural uses as well as providing important habitat for aquatic species. The Red Deer River Instream Needs/Instream Objectives (IN/IO) Committee and the Red Deer River Corridor Planning Study require that instream flows be specified for maintaining water quality in the Red Deer River. As a first step, water temperature and dissolved oxygen (DO) are examined in this report; other attributes of concern will be examined in future work.

A preliminary evaluation of water temperature and dissolved oxygen at various sites along the Red Deer River in the summer of 1992 indicated that these variables were not greatly influenced by flow conditions (Shaw 1992). These data were also used to calibrate a water quality model (DSSAMt) to define what discharge would be required to maintain conditions suitable for various fish in the Red Deer River. A preliminary estimated flow of 30 m^3/s (25 m^3/s, with a 5 m^3/s margin for safety) from the Dickson Dam was presented as the minimum needed to protect water quality during the open water season (AGRA *et al.* 1995).

Compared with long-term flow records for three hydrometric stations on the Red Deer River, flows in June, July, and August of 1992 were generally above average (Alberta Environmental Protection (AEP) unpublished data). As well, air temperatures at the Red Deer Airport were unusually cool from July to September that year (Sosiak and Trew 1996). Since only 1992 data were used in the DSSAMt simulations, it is possible that under conditions of warmer air temperatures and lower flows, problems may occur due to model calibration during an atypical year.

Temperature and DO data collected from the Red Deer River in 1996 have been added to the 1992 data to help resolve the relationships between flow, DO, and temperature. Recognizing that the DSSAMt model is not readily available for use, and that calibration of another model would require considerable time and effort, it was proposed that simpler empirical methods should be explored for defining the minimum flow required to maintain acceptable temperature and DO conditions.

1.2 OBJECTIVES

The main objective of this report is to use available data from the Red Deer River to determine the relationships between stream flow, air temperature, water temperature, and dissolved oxygen. The possibility of deriving simple predictive equations based on these relationships is examined. Also, the frequency of compliance with temperature and oxygen criteria for selected fish species is determined, based on actual data and derived data. This report is not meant to be an exhaustive analysis of habitat suitability; data manipulation is its focus.

2.0 METHODS

2.1 DATA COMPILATION

Water temperature and dissolved oxygen (DO) data were compiled for a number of sites along the length of the Red Deer River (Table 1). Monthly data were available on a year-round basis from three long-term sampling locations: at Highway 2 near Normandeau (AEP), at Morrin Bridge (AEP), and near Bindloss (Prairie Provinces Water Board (PPWB)). The rest of the data were in the form of hourly (or occasionally half-hourly) readings collected primarily during the open water season (May - October) by automatic data loggers (Hydrolab Datasonde). In the summer of 1992, data were collected at 11 sites, from immediately downstream of the Dickson Dam through to Bindloss near the Alberta-Saskatchewan border. Three sites were sampled during late summer and autumn in 1996, two of which, Highway 2 near Normandeau, upstream of Red Deer, and Nevis Bridge, downstream of Red Deer, had been sampled in 1992.

The hourly data were summarized as daily mean, maximum, and minimum values. Flow (average daily discharge) and air temperature (daily mean, maximum, and minimum) were also compiled for all of the data sets using stations as close to the water quality sites as possible (Table 1). The range of water temperature, DO, air temperature, and flow data for each datasonde site during the open water season and for each long-term site throughout the year is given in Table 2.

2.2 RELATIONSHIPS BETWEEN VARIABLES

2.2.1 Correlation

The relationships between temperature, oxygen, and flow were first investigated using correlation analysis (Microsoft Excel 7.0) at the Highway 2 (near Normandeau) and Nevis

Bridge sites. Correlation coefficients (r) were calculated for all the variables at each site. Because air temperature and water temperature at each site were strongly correlated, it was decided that the prediction of water temperature based on air temperature would be pursued in this exercise. Water temperatures have been predicted from air temperatures using simple linear regression for streams in the Mississippi River basin with some success (Stefan and Preud'homme 1993). As well, the principal predictor for water temperature used in the DSSAMt model for the Red Deer River was air temperature (AGRA *et al.* 1995).

2.2.2 Regression

The prediction of maximum water temperature is of particular interest because acute criteria for fish are based on maximums. Using a predictive equation based on available air temperature data, historic compliance for water temperature can be estimated. A regression analysis approach was used to derive such equations for both the Highway 2 and Nevis sites. Least squares linear regression equations (Microsoft Excel 7.0) for predicting maximum water temperature were first based on mean air temperature only, then different combinations of air temperature variables (mean, maximum, minimum) and flow were added. The calculations were repeated for different periods of time to determine if season had any bearing on the relationships between variables. Time-lagged air temperature data (temperatures from the previous day) were also incorporated into the regressions. The "success" of each regression was based on its r^2 value. In all cases, raw data were used, because the temperature data were reasonably normally distributed. The effect of serial correlation (where one observation is related to those near it in time) within each temperature variable was not tested.

2.3 COMPLIANCE WITH FISH CRITERIA

The temperature and oxygen criteria for the three fish species of concern in the Red Deer River appear in Tables 3 and 4. These criteria were taken from the report, "Temperature and Dissolved Oxygen Criteria for Alberta Fishes in Flowing Waters" (Taylor and Barton 1992), as recommended by A. Locke, Fisheries Management, AEP.

In this evaluation, the criteria have been applied to all available data. In practice, however, only the adult walleye/sauger criteria apply to the entire river. Guidelines for walleye fry and mountain whitefish and brown trout adults are considered only upstream of the Content

Bridge on Highway 21 (Nevis). Fry of the latter two species are the priority for fisheries management between the Joffre Bridge on Highway 11 and the Dickson Dam (E. Vuori, Fisheries Management, AEP, pers. comm.).

Acute temperature and dissolved oxygen criteria for fish are based on daily maximum temperature and minimum DO, so can only be properly evaluated using the hourly (collapsed into daily) data. Chronic guidelines are based on 7-day averages of mean values and therefore can only be evaluated when daily means are available. The instantaneous monthly readings from the three long-term data sets technically do not allow for the evaluation of acute or chronic guidelines, because they are neither maximum nor mean values. However, these data can be used to illustrate year-round conditions over a number of years. If the acute criteria are not met by some of these monthly samples, then it is possible that non-compliance occurs more commonly.

The best regression equations for predicting maximum water temperature were used to generate historical temperature data for the Highway 2 and Nevis sites. Predictions were made for May 15 to September 15 for the past 8 years of climate data (1989 - 1996) which were easily accessible. Compliance with acute criteria was then determined. Because equations to predict mean water temperature were not developed in this report, compliance with chronic guidelines was not assessed.

3.0 RESULTS AND DISCUSSION

3.1 DATA RANGE

Water temperature in the Red Deer River tends to increase with distance downstream from the Dickson Dam (Table 2). The warmest temperature (26.1° C) noted in the available data occurred at the site near Jenner. Maximum water temperatures above 24° C occurred almost exclusively in the lower reaches of the river, and corresponded to very warm air temperatures (Table 5). High water temperatures were measured at a wide range of flows of between 29 and 121 m^3/s. Dissolved oxygen concentrations ranged from 6.8 to 8.5 mg/L at these high temperatures.

The lowest DO concentrations were recorded from the Morrin Bridge and Bindloss long-term sites (Table 6). At these sites, all DO values below 5 mg/L were recorded during ice-covered winter conditions of fairly cold temperatures and low flows. On only two occasions were DO concentrations below 5 mg/L recorded in the summer datasonde data. These low values did not occur at particularly low flows or at very warm water temperatures (Table 6).

3.2 RELATIONSHIPS BETWEEN VARIABLES

3.2.1 Correlation

For both the Highway 2 and Nevis sites, maximum water temperature correlated well with air temperature, particularly with mean air temperature (Table 7). Minimum DO was negatively correlated with air and water temperature; the strongest correlation for DO was with maximum water temperature. Flow was poorly correlated to both DO and water temperature at both sites. The highest correlation coefficients for flow occurred with minimum air temperature. This apparent correspondence is due to the seasonal nature of temperature and flow. In the fall, when temperatures are decreasing, flow decreases as well (Figures 1 and 2).

3.2.2 Regression

The linear relationship between air temperature and water temperature (Figures 1 and 2) suggests that regression could provide a reasonable way of developing predictive equations, particularly if the warmer and colder months are considered separately. Air temperature is not the only factor affecting water temperature; solar radiation, wind velocity, precipitation, and water depth, among others, can all have an influence. Accounting for these factors, however, is difficult. Water temperatures have been predicted fairly accurately from air temperatures for streams in the Mississippi River basin using simple linear regression (Stefan and Preud'homme 1993). The regressions calculated for these streams using daily data had r^2 values of between 0.67 and 0.90. Smaller streams tended to have smaller deviations between observed and predicted values than did larger, deeper rivers. In many cases, the relationships were improved by using time-lagged air data.

The relationship between minimum DO and maximum water temperature also appears to be explainable, for the most part, by a linear equation (Figures 1 and 2). It was decided, however, that the derivation of water temperature from air temperature should be attempted first. As expected from the poor correlation coefficients, flow did not make a large contribution to most of the regressions (Tables 8 and 9). The regressions using October data, however, were greatly improved by the addition of flow. Again, this good relationship does not indicate a stronger effect from flow; rather, it illustrates a seasonal phenomenon where declining discharge and temperature tend to coincide (Figures 1 and 2).

Using all three air temperature variables (mean, maximum, minimum) gave the best regressions for prediction of maximum water temperature at both sites for most time periods; these were improved further by lagging the mean temperature by one day (Tables 8 and 9). Using the max and min of the previous day with that day's mean also improved the regressions, but not as much. Two day lags (not shown), however, decreased the amount of variance explained. Data from the end of May (when the 1992 datasondes were deployed) to the end of September in the case of Normandeau at Highway 2, and to September 15 for Nevis Bridge provided the best equations for the "summer" time period, with r^2 values of 0.86 and 0.89, respectively. The regression statistics, residual ranges, and other information for these equations are presented in Appendices I and II.

The predictive equations developed for Hwy 2 and Nevis leave just over 10% of the total variance in water temperature unaccounted for. Shome (1996) developed a regression equation for water temperature prediction in the Highwood River at Aldersyde, based on four years of daily data, that explains over 99% of the variance. This equation, however, incorporates the maximum *water* temperature of the previous day, the overnight minimum *water* temperature, and depth of flow, as well as air temperature. The relative contribution of each variable to the regression is not reported. A regression equation based on air temperature alone would be appropriate for estimating the frequency of criteria exceedences in historic data where water temperature has not been measured regularly. Such an equation would also allow future predictions to be made that rely on fewer actual or derived measurements.

Actual and derived data for 1992 and 1996 are compared in Figure 3. For the Highway 2 site, the mean and standard deviation of the absolute residual values (|observed - predicted|) was $0.80 \pm 0.62°$ C; the biggest actual difference at this site was a prediction of 2.88° C higher than the actual water temperature. At Nevis, the largest difference was 3.44° C higher than the actual water temperature. At both sites, the largest difference occurred on August 21, 1992, following a sudden decrease in air temperature (snow storm). The absolute mean and standard deviation of the differences between actual and predicted values at this site was $0.85 \pm 0.70°$ C. Ideally, the predictions should be evaluated using an independent data set. More data will need to be collected in order to do this.

3.3 COMPLIANCE WITH FISH CRITERIA

3.3.1 Actual Data

Water temperatures were evaluated using the most sensitive of the available criteria first (Table 3). The acute (29° C) and chronic (24° C) temperature criteria for walleye were never exceeded. The acute temperature of 25° C for adult brown trout was exceeded at Jenner in 1992. Temperatures greater than 24° C occurred at all sites downstream of Morrin Bridge; the acute temperature for brown trout fry (23° C) was also exceeded farther upstream at Nevis Bridge. Chronic criteria were exceeded much more frequently and at sites farther upstream than were acute criteria (Table 10).

Dissolved oxygen concentrations were evaluated using all of the available criteria (Table 4). The acute value of 5 mg/L (all fry) was not met on two occasions for the datasonde data, once near Normandeau and once near Jenner (Table 11). Dissolved oxygen concentrations did not appear to fall below critical levels during episodes of very high water temperature, however. Concentrations were frequently below the guidelines for all species and both life stages at the long-term sites of Morrin Bridge and Bindloss. These low levels all occurred under winter conditions, and all of these incidents occurred before 1990 (Table 6). The monthly data could not be evaluated using the chronic guidelines; the available daily data complied with the chronic DO guidelines.

3.3.2 Derived Data

The regressions equations calculated in Section 3.2 were used to predict maximum water temperatures for the period May 15 to September 15 for Hwy 2 and Nevis from 1989 through 1996 (Figure 3). These eight years were chosen because the air temperature data were easily accessible. The predicted maximums were compared to the acute criteria for all three fish species (Table 12). No exceedences were predicted to have occurred at Hwy 2 over the eight year period. At Nevis, the mountain whitefish fry acute temperature of 24° C was predicted to have been exceeded twice; whitefish adult and brown trout fry criteria (22 and 23° C) were exceeded more frequently.

If daily mean water temperatures were predicted using essentially the same regression method used to predict maximum water temperatures, chronic criteria could also be tested. This work was not completed for this report, but all the necessary data are available.

4.0 CONCLUSIONS

Using simple regression techniques, reasonable equations for predicting maximum water temperature from air temperature at two sites in the Red Deer River were developed. The predictive power of these equations would likely improve with additional years of daily data. It would also be useful to have an independent data set that was not used for model development in order to test the equations.

There is a good correlation between DO and water temperature at individual sites during the summer months. It is possible, therefore, that minimum DO could be predicted from maximum water temperature (ultimately from air temperature) using a similar approach to that developed for temperature prediction. To date, however, summer DO conditions have not been of great concern; it is in winter during cold temperatures and very low flows that DO most often falls below critical levels. More daily data need to be collected during winter to address this issue.

Maximum water temperatures appear to increase with distance downstream of the Dickson Dam. Fairly frequent violations of temperature criteria for mountain whitefish and brown trout in the lower Red Deer River are not a concern, because only walleye are a priority for fisheries management in these warmer reaches. Occasional warm temperatures at the Nevis Bridge site, however, may exceed acute criteria for these species. Chronic temperatures were also occasionally above the guidelines for brown trout fry and for both life-stages of whitefish upstream of Nevis. Nevis, therefore, may represent the practical limit for these two species in the Red Deer River.

The data sets examined indicated that flow accounted for a relatively small fraction of the variability in temperature and DO. Minimum flows to maintain desirable levels of temperature and DO in the Red Deer River could not be defined from this analysis. It is important to stress that these results do *not* imply that hypolimnetic releases from the Glennifer Reservoir could not be used to cool the upper reaches of the river during periods of hot weather, nor that lowered summer flows due to irrigation and other demands would have no effect on instream temperature in the lower reaches. Shaw and Anderson (1994) reported that hypolimnetic discharge from the Dickson Dam noticeably decreased seasonal temperature fluctuations, but only for a distance of about 20 km below the dam. Modelling conducted by AGRA *et al.* (1995) indicated that increasing flows from 20 to 40 m^3/s (in a cool year) would cool the river by 1.8° C at Nevis and 0.6° C at Drumheller, at the most. However, neither of these studies dealt with actual or simulated conditions of prolonged low flows and high temperatures followed by continued high temperature and increasing flow.

To improve our understanding of the relationship between flow and temperature in the Red Deer River, more daily data are needed, particularly during low flows and high temperatures. If such extreme conditions were to occur, the feasibility of experimental flow increases to define river responses should be considered. These data would be of great benefit to future modelling exercises.

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6.0 TABLES, FIGURES, AND APPENDICES

TABLE 1. Monthly and daily data available for the Red Deer River.

Water Quality Station	*Code 00AL-*	*Dates for DO and Temperature data*	*Flows*	*Air Temperatures*
Long-term (Monthly)				
at Hwy 2	05CC0004	Nov 1977 - Oct 1995	at Red Deer (05CC002)	Red Deer A (3025480)
at Morrin Bridge* *(*Drumheller CE0001 to 1986)*	05CE0002	Nov 1977 - Oct 1995	at Drumheller (05CE001)	Craigmyle (3021940)** ***missing Oct 79 - Apr 85*
near Bindloss	05CK0001	Jan 1978 - Dec 1995	near Bindloss (05CK004)	Empress (3022400)
1996 (Daily)				
at Haynes		Sept 13 - Oct 22	at Red Deer (05CC002)	Red Deer A (3025480)
at Hwy 2 near Normadeau	05CC1802	Aug 22 - Oct 22	at Red Deer (05CC002)	Red Deer A (3025480)
at Nevis Bridge	05CD1212	Aug 22 - Oct 21	at Red Deer (05CC002)	Stettler North (3024572)
1993 (Daily)				
at Nevis Bridge	05CD1212	Feb 11 - Feb 19	at Red Deer (05CC002)	**** using RDA for analysis* Stettler North (3016119)
1992 (Daily)				
d/s Dickson Dam	05CC1002	July 8-21, Sept 1-14	Dickson Dam (05CB007)	Dickson Dam (3022078)
u/s Innisfail	05CC1702	July 7-21, Sept 1-14	Dickson Dam (05CB007)	Dickson Dam (3022078)
at Hwy 2 near Normadeau	05CC1802	May 28 - Sept 14	at Red Deer (05CC002)	Red Deer A (3025480)
at Joffre Bridge	05CD1001	Aug 26 - Sept 15 *(Temp only)*	at Red Deer (05CC002)	Red Deer A (3025480)
at Nevis Bridge	05CD1212	Jan 15-30, May 28 - Oct 29	at Red Deer (05CC002)	Stettler North (3016119)
near Big Valley at Hwy 590	05CD1252	July 8-21, Sept 1-14	at Red Deer (05CC002)	**** using RDA for analysis* Stettler North (3016119)
at Morrin Bridge	05CE0003	Aug 27 - Oct 13 *(Temp only)*	at Drumheller (05CE001)	Craigmyle (3021940)
u/s Drumheller at Hwy 56	05CE1302	July 23 - Aug 4	at Drumheller (05CE001)	Craigmyle (3021940)
at Finnigan Ferry	05CG2002	July 23 - Aug 4	at Drumheller (05CE001)	Craigmyle (3021940)
near Jenner	05CJ3012	May 28 - Oct 29	near Bindloss (05CK004)	Jenner (3023560)
near Bindloss	05CK2102	July 23 - Aug 5	near Bindloss (05CK004)	Empress (3022400)

TABLE 2. Ranges for water and air temperature, dissolved oxygen, and discharge.

Site (Red Deer River)	Dates	Water Temperature Maximum (°C)	Water Temperature Minimum (°C)	Dissolved Oxygen Maximum (mg/L)	Dissolved Oxygen Minimum (mg/L)	Air Temperature Maximum (°C)	Air Temperature Minimum (°C)	Discharge Maximum (m^3/s)	Discharge Minimum (m^3/s)
	1992								
d/s Dickson Dam	July 8-21, Sept 1-14	17.8	11.7	10.5	8.1	24.0	-1.0	30.4	24.0
u/s Innisfail	July 7-21, Sept 1-14	17.5	10.4	10.6	8.6	24.0	-1.0	30.4	24.0
at Hwy 2 near Normandeau	May 28 - Sept 14	20.9	9.4	10.3	4.5	29.4	-5.1	298.0	26.4
at Joffre Bridge	Aug 26 - Sept 15	19.0	7.8	-	-	23.5	-4.2	39.9	26.4
at Nevis Bridge	May 28 - Oct 29	24.0	0.4	14.2	6.0	32.0	-13.0	298.0	20.1
near Big Valley at Hwy 590	July 8-21, Sept 1-14	19.8	8.5	11.5	8.2	25.5	-2.5	244.0	26.4
at Morrin Bridge	Aug 27 - Oct 13	16.7	5.6	-	-	29.5	-5.5	43.9	26.0
u/s Drumheller at Hwy 56	July 23 - Aug 4	24.3	19.0	9.0	7.8	27.0	7.0	85.1	64.6
at Finnigan Ferry	July 23 - Aug 4	24.8	18.8	8.8	7.7	27.0	7.0	85.1	64.6
near Jenner	May 28 - Oct 29	26.1	0.0	14.6	4.6	34.5	-12.0	292.0	28.7
near Bindloss	July 23 - Aug 5	24.5	18.8	8.5	7.4	30.0	9.0	104.0	74.3
	1996								
near Haynes	Sept 13 - Oct 22	18.4	1.9	14.3	7.4	26.3	-8.7	26.3	21.8
at Hwy 2 near Normandeau	Aug 22 - Oct 22	21.9	3.5	11.5	7.4	32.3	-8.7	29.0	21.8
at Nevis Bridge	Aug 22 - Oct 20	24.2	2.6	14.4	6.7	32.3	-8.6	29.0	22.0
	Long-term								
at Hwy 2 near Normandeau	Nov 1977 - Oct 1995	21.5	-0.3	14.2	7.0	31.1	-34.3	382.0	4.1
at Morrin Bridge	Nov 1977 - Oct 1995	23.4	-0.3	17.6	0.4	34.4	-35.5	490.0	4.4
near Bindloss	Jan 1978 - Dec 1995	25.0	-0.4	16.2	0.9	36.0	-40.0	620.0	2.9

TABLE 3. Water temperature criteria for three fish species in the Red Deer River.

Species	*Acute Fry*	*Adult Acute*	*Chronic Fry (upper limit)*	*Chronic Adult (upper limit)*
Mountain Whitefish	24 °C	22 °C	18 °C	18 °C
Brown Trout	23 °C	25 °C	15 °C	20 °C
Walleye/Sauger	29 °C	29 °C	24 °C	24 °C

Acute = Maximum water temperature
Chronic = 7-day average

TABLE 4. Dissolved oxygen criteria for three fish species in the Red Deer River.

Species	*Acute Fry*	*Adult Acute*	*Chronic Fry*	*Chronic Adult*
Mountain Whitefish	5 mg/L	4 mg/L	6.5 mg/L	6.5 mg/L
Brown Trout	5 mg/L	4 mg/L	6.5 mg/L	6 mg/L
Walleye/Sauger	5 mg/L	3 mg/L	6 mg/L	5 mg/L

Acute = Minimum dissolved oxygen concentration
Chronic = 7-day average

Source: Taylor, B.R. and B.A. Barton. 1992. Temperature and Dissolved Oxygen Criteria for Alberta Fishes in Flowing Water. Prep. For Fish and Wildlife Division, AEP. Edmonton, AB. 72 pp.

TABLE 5. Incidents with water temperatures greater than 24 °C.

Site (Red Deer River)	*Dates*	*WT Max* °C	*AT Max* °C	*AT Min* °C	*AT Mean* °C	*Flow* m^3/s	*DO Min* mg/L
u/s Drumheller at Hwy 56	August 1, 1992	24.3	25.0	13.0	19.0	64.6	7.8
at Finnigan Ferry	July 31, 1992	24.8	26.5	11.0	18.7	66.0	7.8
	August 1, 1992	24.8	25.0	13.0	19.0	64.6	7.7
near Jenner	June 26, 1992	24.4	33.0	10.0	21.5	121.0	7.3
	June 27, 1992	24.7	29.0	15.0	22.0	112.0	6.9
	July 31, 1992	24.7	30.0	12.0	21.0	85.2	7.9
	August 1, 1992	24.8	27.0			83.2	7.7
	August 2, 1992	24.4	27.0	14.0	20.5	84.0	7.8
	August 4, 1992	24.1	27.0	10.0	18.5	74.3	8.2
	August 14, 1992	24.0	34.0	12.0	23.0	76.9	8.1
	August 15, 1992	26.1	33.5	15.0	24.2	73.5	7.6
	August 16, 1992	25.7	28.0	14.5	21.2	69.2	7.8
	August 17, 1992	25.6	31.0	9.0	20.0	65.0	7.9
	August 18, 1992	24.9	34.5	13.0	23.7	61.0	7.9
	August 19, 1992	25.1	28.0	15.0	21.5	57.0	7.8
near Bindloss	July 31, 1992	24.5	30.0	13.0	21.5	85.2	7.4
	August 1, 1992	24.4	29.0	13.0	21.0	83.2	7.4
	August 2, 1992	24.4	28.0	13.0	20.5	84.0	7.4
at Nevis Bridge	August 30, 1996	24.2	31.4	12.9	22.2	29.0	6.8
near Bindloss (**Long-term**)	July 17, 1979	24.5	32.0	10.0	21.0	59.5	8.0
	August 21, 1979	25.0	27.0	16.0	21.5	32.5	7.9
	July 9, 1985	24.5	35.0	15.0	25.0	31.9	7.9
	July 25, 1988	24.9	36.0	13.0	24.5	45.3	8.4
	July 24, 1989	24.2	31.0	15.0	23.0	70.6	8.5

WT = water temperature AT = air temperature DO = dissolved oxygen

TABLE 6. Incidents with dissolved oxygen concentrations less than 5 mg/L.

Site (Red Deer River)	*Dates*	*DO min mg/L*	*WT Max °C*	*AT Max °C*	*AT Min °C*	*AT Mean °C*	*Flow m^3/s*
at Hwy 2 near Normandeau	June 9, 1992	4.5	17.6	29.3	9.7	19.5	53.6
near Jenner	June 19, 1992	4.6	19.9	26.0	7.0	16.5	262.0
at Morrin Bridge (**Long-term**)	January 27, 1977	2.6	0.5	-14.4	-26.1	-20.3	9.5
	January 22, 1979	3.4	0.5	-9.0	-28.0	-18.5	6.9
	February 20, 1979	2.5	0.5	-8.0	-17.5	-12.8	5.4
(all winter conditions)	January 16, 1980	0.8	1.0				6.1
	February 13, 1980	2.7	0.5				5.6
	March 12, 1980	2.4	1.0				5.2
	January 19, 1981	1.8	0.5				12.0
	January 18, 1982	0.4	0.0				7.3
	February 8, 1982	0.5	0.0				4.4
	January 11, 1989	3.9	0.0				16.0
	February 7, 1989	4.8	0.4				14.9
near Bindloss (**Long-term**)	January 10, 1978	0.9	0.0	-18.0	-29.0	-23.5	6.6
	February 14, 1978	1.6	0.0	-11.5	-21.0	-16.3	5.9
	January 23, 1979	3.8	0.0	-12.0	-27.0	-19.5	4.2
	February 14, 1979	2.1	0.0	-21.0	-28.0	-24.5	3.9
(all winter conditions)	March 18, 1980	3.3	1.0	5.0	-7.0	-1.0	5.0
	January 20, 1981	3.1	0.0	8.0	-10.0	-1.0	9.5
	January 19, 1982	1.5	0.0	-24.0	-39.0	-31.5	2.9
	February 9, 1982	1.2	0.0	-16.0	-32.5	-24.3	4.2
	January 24, 1984	3.8	0.0	-4.0	-8.0	-6.0	14.5
	January 15, 1985	2.6	0.5	0.0	-6.0	-3.0	13.1
	February 12, 1985	4.1	0.0	-12.0	-22.0	-17.0	12.0
	January 16, 1989	2.1	0.0	3.0	-20.0	-8.5	13.4
	February 16, 1989	3.8	-0.4	-21.0	-27.0	-24.0	13.4

WT = water temperature AT = air temperature DO = dissolved oxygen

TABLE 7. Correlation coefficients (r) for major variables using daily data from 1992 and 1996 for two sites in the Red Deer River.

		MIN DO *mg/L*	*MAX WT* *°C*	*FLOW* *m^3/s*	*MEAN AT* *°C*	*MAX AT* *°C*	*MIN AT* *°C*
Highway 2 at Normandeau	n = 170						
Minimum Dissolved Oxygen (MIN DO)		1					
Maximum Water Temperature (MAX WT)		-0.662	1				
Flow		-0.100	0.322	1			
Mean Air Temperature (MEAN AT)		-0.646	**0.879**	0.346	1		
Maximum Air Temperature (MAX AT)		-0.586	0.816	0.238	0.940	1	
Minimum Air Temperature (MIN AT)		-0.595	0.784	0.430	0.871	0.652	1
Nevis Bridge	n = 212						
Minimum Dissolved Oxygen (MIN DO)		1					
Maximum Water Temperature (MAX WT)		-0.841	1				
Flow		-0.250	0.391	1			
Mean Air Temperature (MEAN AT)		-0.740	**0.870**	0.371	1		
Maximum Air Temperature (MAX AT)		-0.619	0.766	0.263	0.946	1	
Minimum Air Temperature (MIN AT)		-0.780	0.859	0.454	0.898	0.708	1

TABLE 8. Red Deer River at Highway 2 near Normandeau: r^2 values from various regressions (linear) using daily data from 1992 and 1996 combined.

Time Period	*n*	[1] *Variables...* *Mn*	*Mn, Q*	*Mn, Ma-Mi*	*Mi, Ma*	*Mn, Mi, Ma*	*Mn-1, Mi-1, Ma-1*	*Mn-1, Mi, Ma*	*Mn, Mi-1, Ma-1*
May 29 - Oct 22	170	0.773	0.773	0.774	0.776	0.799	0.738	0.816	0.817
May 29 - Sept 30[2]	148	0.787	0.790	0.803	0.804	0.809	0.733	**0.862**	0.828
May 29 - Sept 15	133	0.725	0.736	0.751	0.751	0.751	0.678	0.819	0.777
May 29 - July 31	64	0.597	0.597	0.613	0.614	0.619			
Aug 1 -Sept 30	84	0.844	0.850	0.850	0.851	0.862			
May 29 - June 30	33	0.673	0.685	0.673	0.675	0.708			
July 1 - 31	31	0.677	0.683	0.734	0.734	0.734			
Aug 1 - 31	41	0.815	0.816	0.832	0.832	0.833			
Sept 1 - 30	43	0.751	0.763	0.753	0.754	0.758			
Oct 1 - 22	22	0.767	0.926	0.804	0.805	0.816			

[1]Variables:

Mn = Mean Air Temperature (current day)
Mi = Minimum Air Temperature (current day)
Ma = Maximum Air Temperature (current day)
Q = Flow
Ma-Mi = Maximum - Minimum Air Temperature
Mn - 1 = Mean Air Temperature (previous day)
Mi - 1 = Minimum Air Temperature (previous day)
Ma - 1 Maximum Air Temperature (previous day)

[2]Best Predictive Equation:

Max Water Temp = 0.269 (Mn-1) + 0.244 (Ma) - 0.0164 (Mn) + 8.422

TABLE 9. Red Deer River at Nevis Bridge: r^2 values from various regressions using daily data from 1992 and 1996 combined.

Time Period	*n*	[1] *Variables... Mn*	*Mn, Q*	*Mn, Ma-Mi*	*Mi, Ma*	*Mn, Mi, Ma*	*Mn-1, Mi-1, Ma-1*	*Mn-1, Mi, Ma*	*Mn, Mi-1, Ma-1*
May 29 - Oct 28	212	0.756	0.762	0.787	0.788	0.794	0.801	0.836	0.849
May 29 - Sept 30	164	0.724	0.724	0.736	0.737	0.744	0.794	0.835	0.836
May 29 - Sept 15[2]	134	0.777	0.789	0.777	0.778	0.782	0.837	**0.889**	0.880
May 29 - July 31	64	0.598	0.700	0.599	0.600	0.621			
Aug 1 -Sept 30	100	0.711	0.725	0.725	0.726	0.732			
May 29 - June 30	33	0.554	0.726	0.560	0.564	0.647			
July 1 - 31	31	0.718	0.739	0.729	0.727	0.734			
Aug 1 - 31	41	0.742	0.742	0.742	0.743	0.751			
Sept 1 - 30	59	0.471	0.510	0.525	0.525	0.526			
Oct 1 - 28	48	0.627	0.746	0.664	0.664	0.664			

[1] *Variables:*

Mn = Mean Air Temperature (current day)
Mi = Minimum Air Temperature (current day)
Ma = Maximum Air Temperature (current day)
Q = Flow
Ma-Mi = Maximum - Minimum Air Temperature
Mn - 1 = Mean Air Temperature (previous day)
Mi - 1 = Minimum Air Temperature (previous day)
Ma - 1 Maximum Air Temperature (previous day)

[2] *Best Predictive Equation:*

Max Water Temp = 0.490 (Mn-1) + 0.206 (Ma) - 0.0148 (Mn) + 7.330

TABLE 10. Evaluation of most sensitive water temperature criteria for all available data.

		Exceedances						
Site (Red Deer River)	*Dates*	*Adult Acute* ***> 22 °C***	*Fry Acute* ***> 23 °C***	*Fry Acute* ***> 24 °C***	*Adult Acute* ***> 25 °C***	*Fry Chronic** ***> 15 °C***	*F&A Chronic** ***> 18 °C***	*Adult Chronic** ***>20 °C***
	1992							
d/s Dickson Dam	July 8-21, Sept 1-14	0/24	0/24	0/24	0/24	**5/12 45%**	0/12	0/12
u/s Innisfail	July 7-21, Sept 1-14	0/24	0/24	0/24	0/24	**6/12 50%**	0/12	0/12
at Hwy 2 near Normandeau	May 28 - Sept 14	0/108	0/108	0/108	0/108	**64/102 63%**	**6/102 6%**	0/102
at Joffre Bridge	Aug 26 - Sept 15	0/19	0/19	0/19	0/19	0/13	0/13	0/13
at Nevis Bridge	May 28 - Oct 29	**8/153 5%**	**4/153 3%**	0/153	0/153	**84/147 57%**	**40/147 27%**	**8/147 5%**
near Big Valley at Hwy 590	July 8-21, Sept 1-14	0/24	0/24	0/24	0/24	**6/12 50%**	0/12	0/12
at Morrin Bridge	Aug 27 - Oct 13	0/46	0/46	0/46	0/46	0/40	0/40	0/40
u/s Drumheller at Hwy 56	July 23 - Aug 4	**8/11 73%**	**4/11 36%**	**1/11 9%**	0/11	**5/5 100%**	**5/5 100%**	**5/5 100%**
at Finnigan Ferry	July 23 - Aug 4	**9/11 82%**	**4/11 36%**	**2/11 18%**	0/11	**5/5 100%**	**5/5 100%**	**5/5 100%**
near Jenner	May 28 - Oct 29	**33/153 22%**	**21/153 14%**	**12/153 8%**	**4/153 3%**	**88/147 60%**	**66/147 45%**	**36/147 24%**
near Bindloss	July 23 - Aug 5	**8/12 67%**	**5/12 42%**	**3/12 25%**	0/12	**6/6 100%**	**6/6 100%**	**6/6 100%**
	1996							
near Haynes	Sept 13 - Oct 22	0/40	0/40	0/40	0/40	0/34	0/34	0/34
at Hwy 2 near Normandeau	Aug 22 - Oct 22	0/62	0/62	0/62	0/62	**13/56 13%**	**6/56 11%**	0/56
at Nevis Bridge	Aug 22 - Oct 20	**8/59 14%**	**2/59 3%**	**1/59 2%**	0/59	**15/54 28%**	**8/54 15%**	**6/54 11%**
	Long-term							
at Hwy 2 near Normandeau	Nov 1977 - Oct 1995	0/210	0/210	0/210	0/210			
at Morrin Bridge	Nov 1977 - Oct 1995	**2/219 1%**	**1/219 0.5%**	0/219	0/219			
Near Bindloss	Jan 1978 - Dec 1995	**8/216 4%**	**6/216 3%**	**5/216 2%**	0/216			

**Chronic guidelines are evaluated against 7 day average values*

TABLE 11. Evaluation of dissolved oxygen criteria for all available data.

Site (Red Deer River)	*Dates*	*Adult Acute* **<3 mg/L**	*F&A Acute* **<4 mg/L**	*F&A Acute* **<5 mg/L**	*Adult Chronic** **<5 mg/L**	*F&A Chronic** **<6 mg/L**	*F&A Chronic** **<6.5 mg/L**
	1992						
d/s Dickson Dam	July 8-21, Sept 1-14	0/24	0/24	0/24	0/12	0/12	0/12
u/s Innisfail	July 7-21, Sept 1-14	0/24	0/24	0/24	0/12	0/12	0/12
at Hwy 2 near Normandeau	May 28 - Sept 14	0/108	0/108	**1/108 1%**	0/102	0/102	0/102
at Joffre Bridge	Aug 26 - Sept 15	Temperature data only					
at Nevis Bridge	May 28 - Oct 29	0/141	0/141	0/141	0/129	0/129	0/129
near Big Valley at Hwy 590	July 8-21, Sept 1-14	0/24	0/24	0/24	0/12	0/12	0/12
at Morrin Bridge	Aug 27 - Oct 13	Temperature data only					
u/s Drumheller at Hwy 56	July 23 - Aug 4	0/11	0/11	0/11	0/5	0/5	0/5
at Finnigan Ferry	July 23 - Aug 4	0/11	0/11	0/11	0/5	0/5	0/5
near Jenner	May 28 - Oct 29	0/149	0/149	**1/149 1%**	0/137	0/137	0/137
near Bindloss	July 23 - Aug 5	0/12	0/12	0/12	0/6	0/6	0/6
	1996						
near Haynes	Sept 13 - Oct 22	0/40	0/40	0/40	0/34	0/34	0/34
at Hwy 2 near Normandeau	Aug 22 - Oct 22	0/62	0/62	0/62	0/56	0/56	0/56
at Nevis Bridge	Aug 22 - Oct 20	0/59	0/59	0/59	0/54	0/54	0/54
	Long-term						
at Hwy 2 near Normandeau	Nov 1977 - Oct 1995	0/195	0/195	0/195			
at Morrin Bridge	Nov 1977 - Oct 1995	**8/201 4%**	**10/201 5%**	**11/201 5%**			
near Bindloss	Jan 1978 - Dec 1995	**7/209 3%**	**12/209 6%**	**13/209 6%**			

**Chronic guidelines are evaluated against 7 day average values*

TABLE 12. Highest predicted maximum water temperature and compliance with acute criteria for three fish species in the Red Deer River, 1989 - 1996. (between May 15 and June 15; total number of days = 123).

Year	*Site*	*Max Water Temp °C*	*Mountain Whitefish*		*Brown Trout*		*Walleye/ Sauger*	
			Fry >24	*Adult > 22*	*Fry > 23*	*Adult > 25*	*Fry > 29*	*Adult >29*
1989	Hwy 2	20.8	0	0	0	0	0	0
	Nevis	23.9	0	**12** **10%**	**2** **2%**	0	0	0
1990	Hwy 2	21.6	0	0	0	0	0	0
	Nevis	24.0	**1** **1%**	**12** **10%**	**4** **3%**	0	0	0
1991	Hwy 2	21.5	0	0	0	0	0	0
	Nevis	24.0	0	**14** **11%**	**5** **4%**	0	0	0
1992	Hwy 2	20.8	0	0	0	0	0	0
	Nevis	23.6	0	**9** **7%**	**1** **1%**	0	0	0
1993	Hwy 2	19.3	0	0	0	0	0	0
	Nevis	21.7	0	0	0	0	0	0
1994	Hwy 2	21.1	0	0	0	0	0	0
	Nevis	24.0	0	**18** **15%**	**10** **8%**	0	0	0
1995	Hwy 2	20.6	0	0	0	0	0	0
	Nevis	22.7	0	**1** **1%**	0	0	0	0
1996	Hwy 2	21.7	0	0	0	0	0	0
	Nevis	24.7	**1** **1%**	**9** **7%**	**3** **2%**	0	0	0
84 - 95	Hwy 2 Long term data (n = 48)	20.8	0	0	0	0	0	0

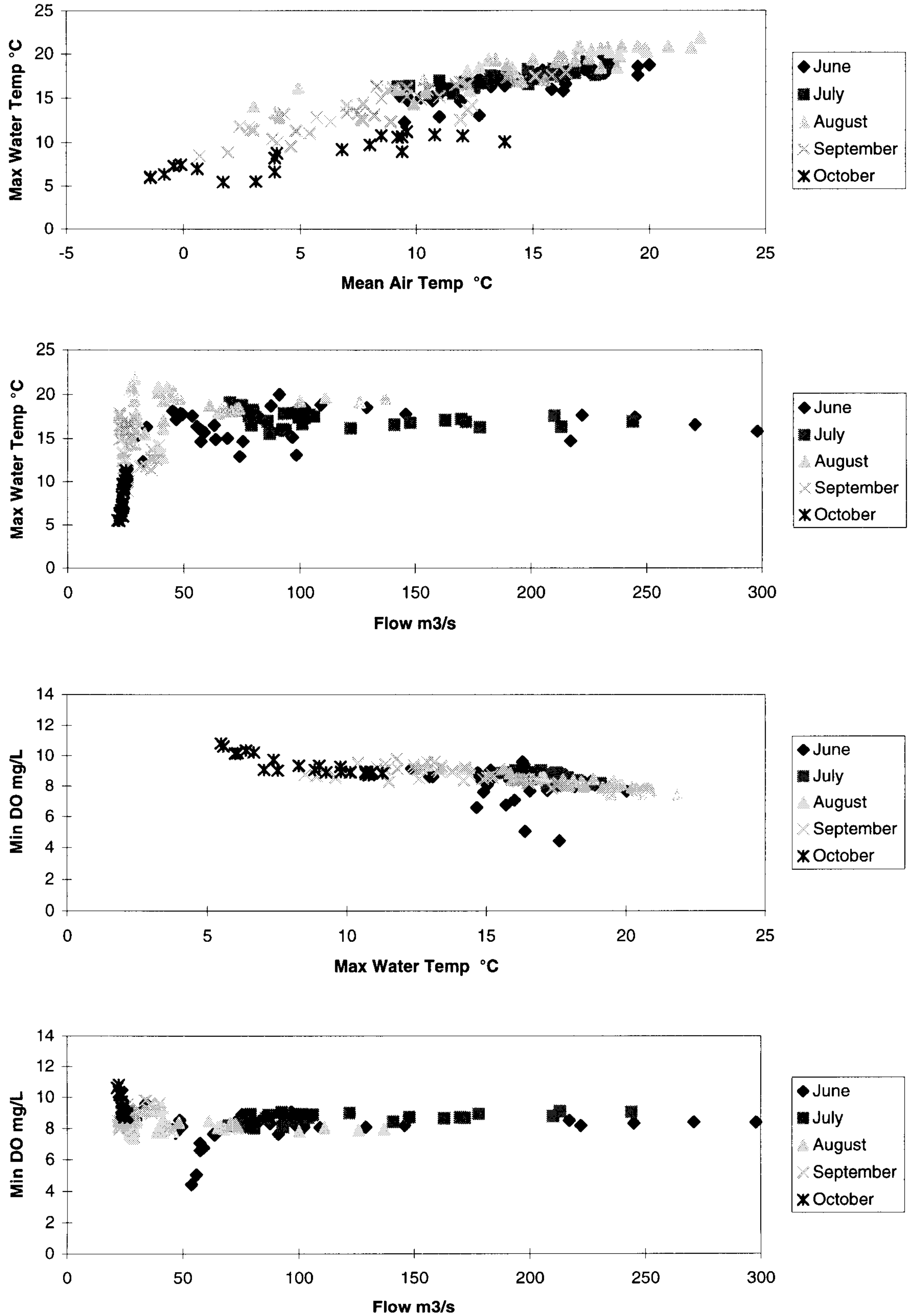

FIGURE 1. Relationships between variables in the Red Deer River at Highway 2 near Normandeau, using all daily data for 1992 and 1996.

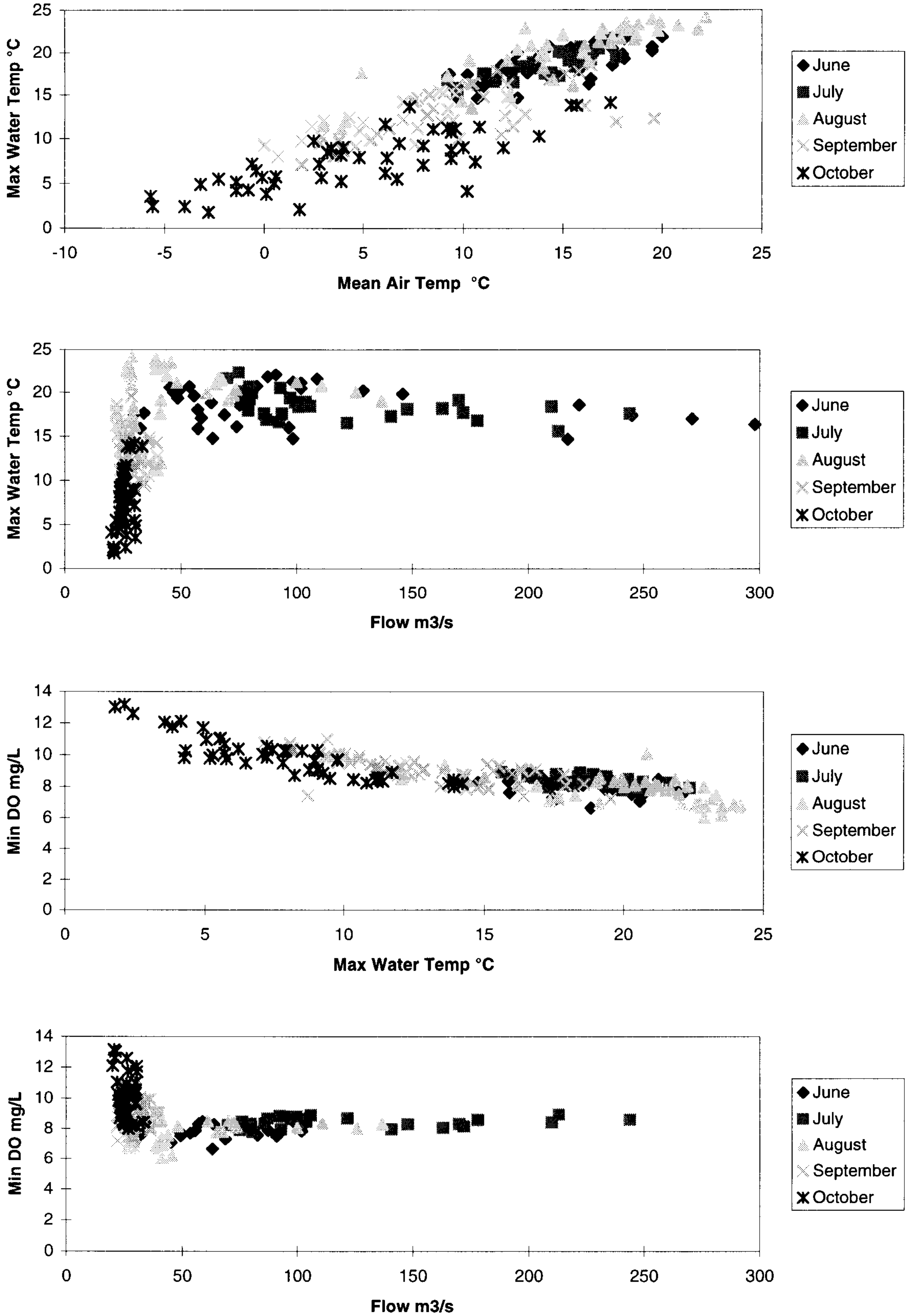

FIGURE 2. Relationships between variables in the Red Deer River at Nevis Bridge, using all daily data for 1992 and 1996 (air temperature from Red Deer Airport).

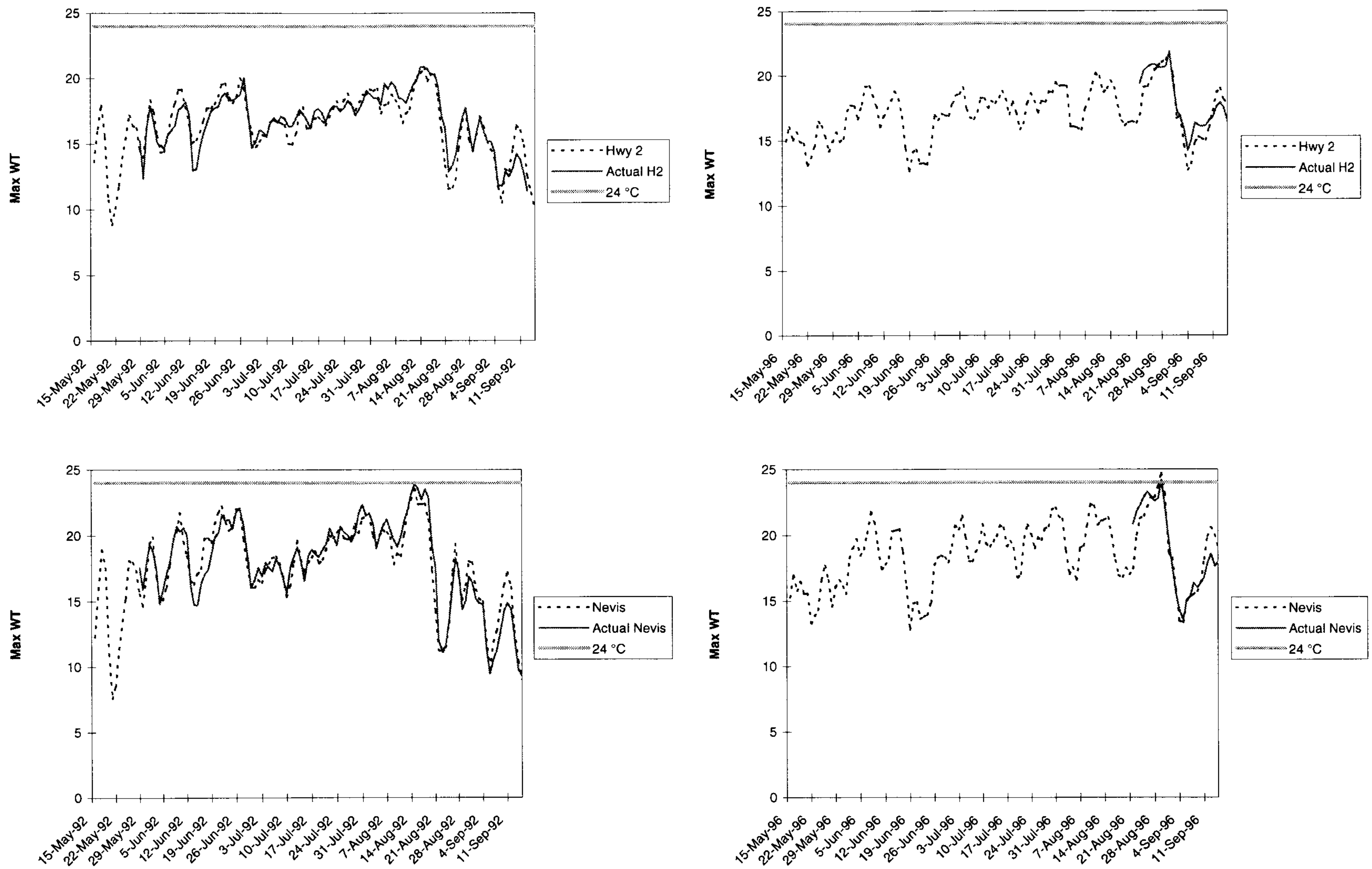

FIGURE 3. Actual and predicted maximum water temperatures in the Red Deer River at Highway 2 near Normandeau and at Nevis Bridge for 1992 and 1996.

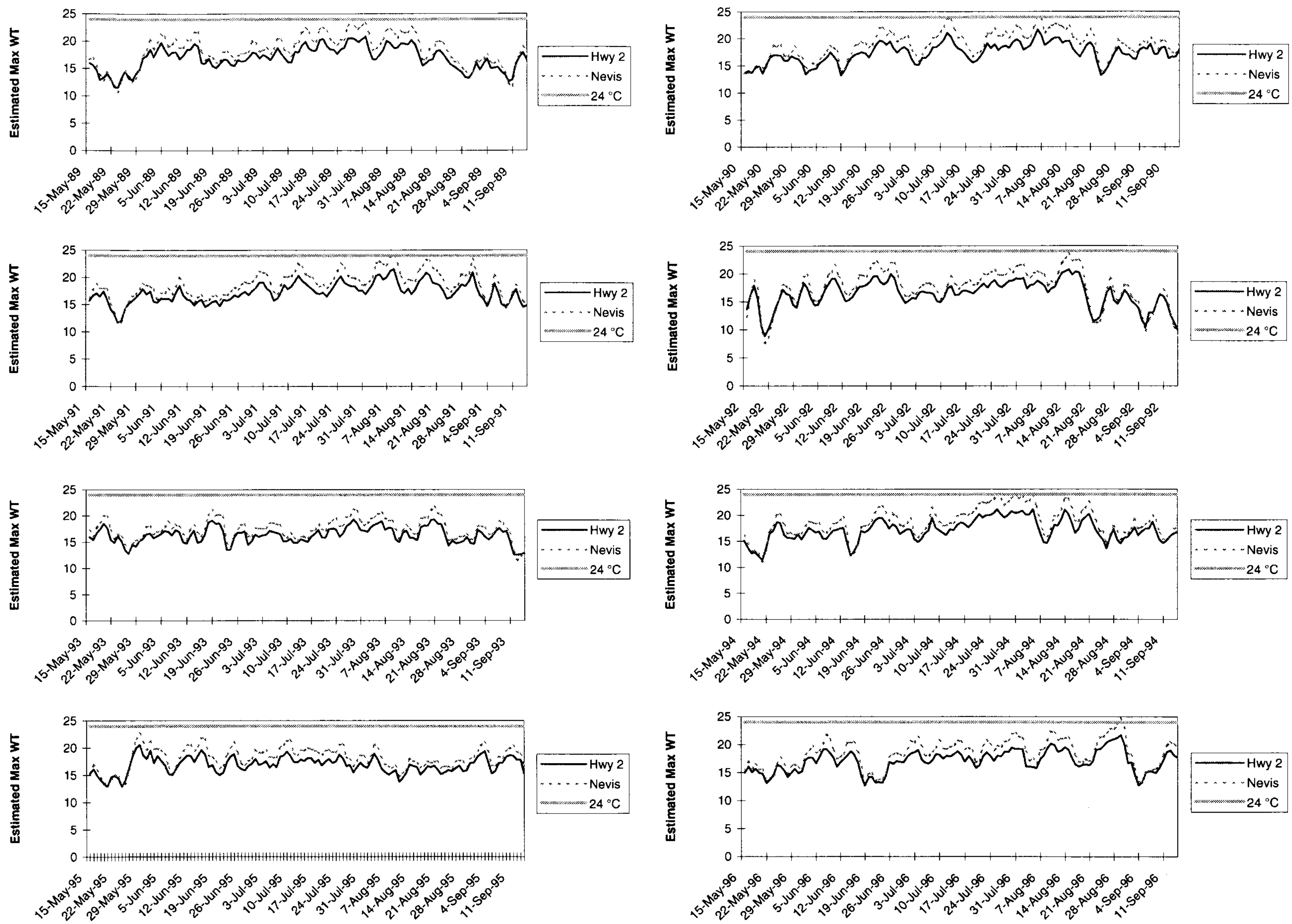

FIGURE 4. Maximum water temperatures predicted from air temperature for two sites in the Red Deer River, May 15 - September 15, 1989 - 1996.

APPENDIX I. Regression statistics for the Red Deer River at Highway 2 near Normandeau using previous day's mean and current day's minimum and maximum air temperatures.

Regression Statistics	
Multiple R	0.928
R Square	0.862
Adjusted R Square	0.859
Standard Error	1.025
Observations	148

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	943.458	314.486	299.532	1.1202E-61
Residual	144	151.189	1.050		
Total	147	1094.647			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*STEYX*
Intercept	8.422	0.301	27.942	5.088E-60	7.826	9.018	
MN AT - 1D (X1)	0.269	0.035	7.765	1.388E-12	0.200	0.337	1.520
MAX AT (X2)	0.244	0.018	13.303	7.661E-27	0.208	0.280	1.323
MIN AT (X3)	-0.016	0.034	-0.483	0.630	-0.083	0.051	2.032

STEYX = standard error of the predicted y-value for each x in the regression; it measures the amount of in the prediction of y from an individual x

EQUATION FOR PREDICTIONS: Y = 0.269 (X1) + 0.244(X2) - 0.0164(X3) + 8.422

Residuals Range: 2.88 - -2.43 ºC

Absolute Value of Observed - Predicted

Mean	0.80 ºC
SD	0.62
Max	2.88
Min	0.01

APPENDIX II. Regression statistics for the Red Deer River at Nevis Bridge using previous day's mean and current day's minimum and maximum air temperatures.

Regression Statistics	
Multiple R	0.943
R Square	0.889
Adjusted R Square	0.887
Standard Error	1.118
Observations	134

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	1306.965	435.655	348.503	5.99739E-62
Residual	130	162.510	1.250		
Total	133	1469.475			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*STEYX*
Intercept	7.330	0.383	19.118	1.37133E-39	6.572	8.089	
MN AT - 1D (X1)	0.490	0.043	11.439	2.14113E-21	0.405	0.575	1.439
MAX AT (X2)	0.206	0.022	9.402	2.46035E-16	0.163	0.249	1.939
MIN AT (X3)	0.015	0.041	0.364	0.716	-0.066	0.095	2.267

STEYX = standard error of the predicted y-value for each x in the regression; it measures the amount of in the prediction of y from an individual x

EQUATION FOR PREDICTIONS: Y = 0.490 (X1) + 0.206 (X2) - 0.0148 (X3) + 7.330

Residuals Range: 3.44 - -2.78 ºC

Absolute Value of Observed - Predicted

Mean	0.85 ºC
SD	0.70
Max	3.44
Min	0.00