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WATER TEMPERATURE MONITORING IN SELECTED THOMPSON RIVER TRIBUTARIES, B.C., 1996: IMPLICATIONS OF MEASURED TEMPERATURES FOR ANADROMOUS SALMONIDS

by

L. C. Walthers[1] and J. C. Nener[2]

Habitat and Enhancement Branch
Fisheries and Oceans Canada
555 West Hastings Street
Vancouver, British Columbia V6B 5G3

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[1] StreamLine Research
184 Black Powder Trail
Nanaimo, British Columbia V9S 5G9

[2] Land Use Planning Unit
Habitat and Enhancement Branch
Department of Fisheries and Oceans
Station 360, 555 West Hastings St.
Vancouver, British Columbia V6B 5G3

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ABSTRACT

Walthers, L. C., and J. C. Nener. 2000. Water temperature monitoring in selected Thompson River tributaries, B.C., 1996: implications of measured temperatures for anadromous salmonids. Can. Tech. Rep. Fish. Aquat. Sci. 2306: 69 p.

During the summer of 1996 the Department of Fisheries and Oceans (DFO) conducted a water temperature monitoring program in a number of important salmon-bearing tributaries in the Thompson River watershed. The Nicola, Coldwater, Bonaparte, Deadman, and Salmon Rivers, as well as Spius Creek, were suspected of being temperature sensitive systems. A warm summer climate and a land base used widely by both agricultural and forestry interests are thought to influence temperature regimes in these southern interior (British Columbia) systems. Data collected during the summer of 1996 indicated that these tributaries are vulnerable to warm climate trends, with maximum water temperatures at all sites exceeding 22°C. Daily maximum temperatures at all sites also frequently reached levels known to cause significant stress and mortality in salmon (>20°C). The warmest water temperatures were recorded in the Nicola River where maximums exceeded 25°C, the upper end of the lethal temperature threshold for Pacific anadromous salmon. High water temperatures are likely a limiting factor for populations of coho and chinook salmon in this region. Land uses have resulted in extensive losses of riparian vegetation and aggravated naturally elevated summer thermal regimes. Restoration of riparian vegetation throughout these systems would likely help to reduce maximum summer water temperatures.

RÉSUMÉ

Walthers, L. C. et J. C. Nener. 2000. Surveillance de la température de l'eau dans quelques affluents de la rivière Thomson (Colombie-Britannique), 1996; influence des températures mesurées sur les salmonidés anadromes. Canada. Tech. Rep. Fish. Aquat. Sci. 2306: 69 p.

Au cours de l'été 1996, le ministère des Pêches et des Océans (MPO) a conduit un programme de surveillance de la température dans un certain nombre d'importants cours d'eau salmonicoles du bassin de la rivière Thomson. On suspectait en effet les rivières Nicola, Coldwater, Bonaparte, Deadman, Salmon et Spius Creek d'être des systèmes sensibles du point de vue de la température. En particulier, on s'attendait à ce que les températures estivales généralement douces et l'utilisation des terres à des fins principalement agricoles ou forestières influencent le régime des températures de ces cours d'eau de l'intérieur méridional de la province. Les données recueillies au cours de l'été 1996 ont confirmé que les affluents en question sont sensibles aux périodes de réchauffement, la température maximum enregistrée sur les sites dépassant dans tous les cas 22 °C. De plus, sur tous les sites, les maxima quotidiens atteignaient fréquemment des niveaux connus pour causer du stress et une mortalité importante chez les saumons (T>20 °C). Les températures les plus élevées ont été enregistrées dans la rivière Nicola où le maximum dépassait 25 °C, seuil létal pour le saumon du Pacifique. Des températures d'eau élevées constituent probablement un facteur limitant pour les populations de saumons cohos et quinnats de la région. L'exploitation des terres s'est traduite par une disparition généralisée de la végétation riparienne et a aggravé l'effet des régimes de températures élevées qui caractérisent la saison estivale. La restauration de la végétation riparienne le long de ces cours d'eau contribuerait certainement à réduire la température maximum de l'eau de ces cours d'eau durant l'été.

1.0 INTRODUCTION

Results of temperature monitoring programs indicate that during hot, dry summers the Thompson River can exert a measurable warming effect on the Fraser River (Lauzier *et al.* 1995; Foreman *et al.* 1997) - a result which prompted interest in a more thorough examination of temperature conditions in the Thompson watershed. There was some concern that high summer water temperatures in the Thompson River basin could impact salmon populations, which utilize the system for spawning and/or rearing.

In 1994 a program was initiated to monitor temperatures in the Nicola River and results indicated that summer water temperatures frequently exceed lethal ranges for Pacific salmon (Walthers and Nener 1997a). Subsequent monitoring in 1995 on the Nicola and Salmon Rivers also suggested that Thompson River tributaries are extremely susceptible to warming during the summer months and can experience temperatures in excess of 21°C for extended periods of time (Walthers and Nener 1997b and 1998). Land uses in these tributary watersheds have altered natural thermal regimes and contributed to the high summer temperatures, which frequently exceed lethal ranges for salmonids. Subsequent concerns about water quality and salmon habitat prompted an examination of temperature conditions in several additional Thompson River tributaries that are influenced by similar land uses and climate conditions. During 1996 water temperature monitoring addressed the Nicola, Coldwater, Bonaparte, Deadman and Salmon Rivers, as well as Spius Creek.

Water temperature is one of the most important environmental factors affecting fish. Temperature regimes affect migrations, spawning, development, distribution, growth, behavior, metabolism, and resistance to diseases, parasites, and pollutants (Armour 1991). The survival and productivity of juvenile and adult salmonids is significantly affected by temperature. In the Thompson River watershed previous studies have suggested that high water temperatures are a constraint for salmon production (Kosakoski and Hamilton 1982; Walthers and Nener 1997a). Losses of riparian vegetation throughout this watershed due to logging, ranching, crop production, transportation routes and urban development have likely resulted in elevated summer thermal regimes due to direct solar heating. The destabilization of stream banks which accompanies losses of streamside vegetation further contributes to the problem as channels become wider, shallower and more susceptible to warming. Erosion of streambanks also elevates silt and sediment content, which elevates temperatures due to the considerable heat absorption of these particles (Reid and Wood 1989). In addition, water withdrawals for irrigation (and other uses) impose further temperature stresses on these aquatic systems by reducing flows and thereby contributing to more extreme daily water temperature fluctuations.

The Thompson River basin encompasses a large geographic area with numerous tributary systems, and a diversity of fish habitats. Individual tributaries may appear insignificant, yet collectively they are incredibly important and support a number of genetically distinct salmon populations. There is considerable evidence suggesting that adaptation to local environments is a major factor in maintaining and promoting genetic variation among populations (Taylor 1991). This tendency for interpopulation adaptive divergence has undoubtedly been important to the colonization of diverse habitats by each species and, hence, to their productivity and persistence (Thorpe *et al.* 1981; Lannan *et al.* 1989). The Thompson River tributaries addressed in this study are important chinook, coho and steelhead systems and contribute to the species genetic diversity and productivity of the

Thompson watershed. The Nicola, Bonaparte, Deadman and Salmon River drainages, and Spius Creek, all provide spawning and rearing habitats but are increasingly influenced by the cumulative impacts of regional climates as well as agricultural and forestry land uses.

The present study was undertaken to assess temperature conditions in these vulnerable Thompson tributaries. This report summarizes results of temperature monitoring during 1996 in Spius Creek, and the Nicola, Bonaparte, Deadman and Salmon Rivers. Information about diurnal water temperature fluctuations, and the duration of temperatures which exceed critical thresholds for salmonids has been included. Factors which influence water temperature are discussed in detail. In addition, the implications of thermal conditions found are discussed and summarized for the various salmonid life-stages.

2.0 STUDY AREA AND METHODS

2.1 Thompson Watershed and Tributaries

The Thompson River watershed is estimated to contribute almost 22% of the total Fraser River basin salmon production. Geographically it is the largest tributary system, with an area of 54,900 km^2, or 23.9% of the Fraser watershed (Northcote and Larkin 1989), and has by far the largest discharge of any Fraser tributary. The Thompson drains the Interior Plateau of British Columbia, and summer water temperatures reflect climate conditions of the area, which normally experiences hot, dry summers. Grasslands and open forests of pine and interior douglas fir dominate the natural landscape. Since the mid-1800's the grasslands have been widely developed by the cattle/beef industry (Pitt and Hooper 1994). Collectively, widespread agricultural development, livestock grazing, urban development and logging have significantly modified the landscape, impacting regional drainages and important salmon habitats.

The study area streams (Nicola, Bonaparte, Deadman and Salmon Rivers, and Spius Creek) are in the southern part of the Thompson sub-basin (Fig. 1a and 1b). All these systems have experienced significant losses of riparian vegetation. This, combined with regional climate conditions, makes these systems very vulnerable to high temperatures and poor water quality conditions. Degraded riparian structure, excessive water withdrawals for irrigation, seasonal low flows and warm, dry summer conditions significantly impact the quality of available spawning and rearing habitats.

The Interior Plateau of British Columbia experiences some of the warmest temperatures and driest conditions in the province. Daily maximum summer air temperatures often exceed 30°C and sometimes approach 40°C. Precipitation is low with annual accumulations of 250-500 mm (Hope *et al.* 1991a and 1991b; Pitt and Hooper 1994). Although climate conditions vary and are usually cooler and wetter in the headwaters, the lower reaches of all the study area systems are influenced by hot, dry summer conditions. Snow pack in some systems may play a critical role in moderating extreme temperatures, however, factors such as rate and timing of melt, and climate conditions undoubtedly influence the magnitude and timing of these events. All monitoring sites were located in the lower reaches of the study streams.

Table 1 provides a summary of the study area tributary characteristics. Most sites are located in the Ponderosa Pine/Bunchgrass biogeoclimatic zone, and experience very dry summer conditions. The Salmon River site is the exception; lower elevations of this watershed are in the Interior Douglas Fir zone where conditions are somewhat moister. The Salmon River is also the only system originating in the South Thompson drainage, whereas the other tributaries are part of the lower Thompson mainstem drainage. Spius Creek is a smaller system, but a significant tributary of the Nicola River. Each of the systems monitored in this study support several species of anadromous salmon, including runs which begin returning to their spawning streams between mid-July and early September.

Table 1. Summary of watershed characteristics for temperature monitoring sites, 1996.

	NICOLA	SPIUS	BONAPARTE	DEADMAN	SALMON
Drainage Area	7,227 km^2	780.2 km^2	5,390.4 km^2	1,497.3 km^2	1,510 km^2
Mainstem Length	212 km	48.6 km	178.1 km	113.6 km	148.7 km
Naturalized Mean Annual Flow *	22.7 m^3/s	9.5 m^3/s	4.5 m^3/s	2.9 m^3/s	4.6 m^3/s
Orientation of Flow	N and W	N	SW, S and SE	S	E and N
Biogeoclimatic zone LOW → HIGH ELEVATION	Ponderosa Pine / Bunch Grass → Interior Douglas Fir → Montane Spruce	Ponderosa Pine → Interior Douglas Fir → Montane Spruce	Ponderosa Pine / Bunch Grass → Interior Douglas Fir → Montane Spruce	Ponderosa Pine / Bunch Grass → Interior Douglas Fir → Montane Spruce	Interior Douglas Fir → Interior Cedar / Hemlock → Montane Spruce
Anadromous Salmonids	coho pink chinook steelhead	Coho Chinook Steelhead	coho pink chinook steelhead	coho pink chinook steelhead	coho chinook sockeye

*discharge information from Rood and Hamilton (1995), who calculated naturalized flows by adding licensed water withdrawals to flows measured at gauges.

As indicated in Table 1 the predominate biogeoclimatic zone at lower elevations is the Ponderosa Pine/Bunchgrass zone. It typically occupies the floors and lower slopes at lower elevations (250 to 800 m) along the river valleys. The Coast Mountains cast a pronounced rain shadow over the southern Interior Plateau making this the driest, and in summer the warmest zone in B.C. The mean July temperature is 17-22°C and the hot, dry summers result in large moisture deficits during the growing season (Hope *et al.* 1991b). Significant agricultural development including both crop production and cattle ranching is located in this zone. Riparian areas and expanses of flat land (fluvial/lacustrine terraces) have also been extensively modified for agricultural use.

The Interior Douglas Fir zone dominates the low to mid-elevation landscape and next to the Ponderosa Pine/Bunchgrass zone it is the warmest and driest zone in the province. Mean annual precipitation is 300-750 mm and substantial water deficits are common during the growing season. This area is utilized for agriculture, largely cattle grazing, and forestry. Logging activities are generally confined to the headwaters. Disruptions of flow regimes and increases in siltation associated with logging have been noted in the Spius Creek drainage (Rood and Hamilton 1995). Logging also occurs in the Bonaparte, Deadman, Coldwater, and Salmon systems.

2.2 Equipment and Installation

As in 1994 and 1995 (Walthers and Nener 1997a, 1998) the temperature monitoring program used a total of six Starlog 128 Kb data loggers (model 6004B). Temperatures were recorded at sites on the Nicola, Spius, Bonaparte, Deadman and Salmon drainages. Initially there was a Coldwater River site, however, vandalism of this data logger resulted in the retrieval of only limited data (Appendix 2). All data loggers were programmed to record the average temperature every hour, based on a 5 second scan rate. Two temperature probes on 10 m leads (model 6507A RED) were used per data logger, with one probe serving as a backup. Probes were protected in 1/2" conduit and checked using a calibrated total immersion thermometer.

Data loggers were placed in protective aluminum boxes and hidden amongst rocks, bushes and debris on stream banks. The exception was the Bonaparte data logger, which was placed on the fishway behind a locked fence. Thermistor temperature probes were positioned in well mixed, moving water with at least 5-7 meters of the probe lead in the water. Initiation of temperature monitoring was somewhat delayed due to a cool, wet spring and high water levels. Equipment was installed on June 25-26, 1996. The data loggers were removed between October 15 and October 26, 1996.

2.3 Site Descriptions

NIR56 (Canford Bridge): Nicola River site - 56 km upstream of the Thompson-Nicola confluence. This site was located on the south bank of the Nicola River approximately 0.5 km downstream of the bridge crossing and next to the Sunshine Valley Road. The data logger was hidden in the rip-rap along the bank. The stream flow was moderate and the bank slope was steep. The data logger measured the water temperature in the Nicola River downstream of Merritt and Guichon Creek, but upstream of Spius Creek.

NIR4 (Lower Nicola): Nicola River site - 4 km upstream of the Thompson-Nicola confluence. This site was located on the north bank of the Nicola River. The data logger was hidden in large boulders along a steep bank adjacent to Highway 8. Access was from Highway 8, 5 km from Spences Bridge.

SP2 (Spius Hatchery): Spuis Creek site - about 1-2 km upstream of the Nicola-Spius confluence. This site was located on the east bank of Spius Creek. The data logger was hidden in the rip-rap along the bank and next to the water intake structure, about 100 m upstream from the Spius Creek Hatchery buildings.

COR4B (Lower Coldwater): Coldwater River site - at the southeast corner of Merritt and approximately 4 km upstream from the confluence with the Nicola. The data logger was located in large boulders on the right bank below the washed out corner bank. The stream flow was moderate and the bank slope fairly steep. This data logger was vandalized and only 4 weeks of data were collected.

BPR3 (Bonaparte Fishway): Bonaparte River site - about 3 km upstream of the Bonaparte-Thompson confluence. This site was located on the west bank of the Bonaparte River. The data logger was locked on the Fishway and frequently monitored. The stream flow was moderate-fast and the bank steep.

DMR4 (Lower Deadman): Deadman River site - about 4 km upstream of the Deadman-Thompson confluence. This site was located on the east bank of the Deadman River. The data logger was hidden under sage brush near the stream bank. The stream flow was moderate-slow and the bank slope moderate.

SR6 (Lower Salmon): Salmon River site - about 5-6 km upstream from the river mouth at Salmon Arm. The data logger was located on the Vivian property on the west bank and under a private bridge structure, approximately 300 m downstream from Mouttell Creek. Access is via the Salmon River Road and 30th Avenue SW. The stream flow was moderate-slow and the bank steep.

2.4 Site Visits

Data loggers were checked weekly to ensure that equipment was operating properly and probes were in the water. Data was downloaded every 4-8 weeks. If necessary data loggers or probes were repositioned and new positions noted in the field books. Field notes included the date and time of visit, calibrated thermometer readings taken at the thermistor probe and the reading being recorded by each thermistor probe at the time of the visit.

2.5 Temperature Data Verification

Temperature data for both thermistor probes was graphed and examined for possible errors. Calibrated thermometer readings collected during site visits were used to assess the quality of the collected data, and to select the thermistor probe with the best data. Average differences between actual thermistor readings and calibrated thermometer readings were all less than ± 0.1, therefore no adjustments were made to the data sets.

3.0 RESULTS AND DISCUSSION

3.1 Statistical Analysis of Water Temperature Data

3.1.1 *Between-Site Comparisons*

Bonferroni (Dunn) T test was used to assess significant temperature trends between the tributary monitoring sites. Variables used for comparison were daily maximum, minimum and mean water temperatures. Values for these parameters are shown graphically for each site in Figs. 2a and 2b. Statistical comparisons between sites showed a number of similarities and differences. Distinct between-site trends appear only for the lower Nicola site (NIR4) which was significantly warmer than most sites for maximum, minimum and mean temperatures, and the Spius Creek site (SP2) which was the coolest site. Other comparisons between sites show no obvious trends or site associations.

The results of the temperature monitoring study have been summarized on a weekly basis in Appendix 1. Assessment of these results indicate that the warmest temperatures occurred in the Nicola River (NIR4 and NIR56) with the highest temperature peaks occurring at the Canford Bridge site (NIR56) and the warmest average temperatures occurring in the lower Nicola (NIR4). The next warmest sites were on the Deadman and Bonaparte Rivers. The Deadman is characterized by high temperature spikes and low minimum temperatures while the Bonaparte has more moderate temperatures, with lower maximums and higher minimums. The Salmon River (Shuswap) and Spius Creek were cooler than the other sites, with average temperatures in the Salmon higher than in Spius Creek, which reported greater temperature fluctuations.

Graphs of hourly temperature fluctuations (Figs. 3a and 3b) illustrate the magnitude of daily temperature fluctuations and the distinct differences between sites. The Lower Nicola (NIR4) site and the Bonaparte Fishway (BPR3) site experience modest temperature fluctuations in comparison with other sites included in this study. More extreme temperature fluctuations occurred at the Spius Hatchery (SP2) and the Lower Deadman (DMR4) sites.

3.2 Implications of Measured Temperatures for Pacific Salmonids

Inventory information for all study area tributaries indicate that chinook salmon return to spawn between mid-July and mid-September. Coho salmon begin returning to spawn in early fall. Juveniles of both species usually rear in small natal streams for a year or more prior to their seaward migration. Both species would thus be exposed to high summer water temperatures as adults and/or juveniles. Data were therefore analyzed and interpreted in the context of temperatures which are preferred and lethal to both adult and juvenile life stages of anadromous Pacific salmonids.

Thermal tolerance (LT_{50}) is defined as the temperature which is tolerated by 50% of a test population for a sustained period of time, usually between 8 to 24 hours. LT_{50} is also influenced by prior thermal history of the test fish, and numerous other stress-related factors. Acclimation temperature (temperature at which fish are held (or living) prior to the change in temperature) influences both the LT_{50} and the exposure time that results in death. The lower end of the thermal tolerance range for juvenile anadromous salmonids is 21°C and the upper end of the range is 25°C, meaning that 50% mortality of salmon populations would be expected somewhere in this temperature range. As discussed by Elliot (1981) significant disturbances in normal fish behavior (*i.e.* obvious signs of thermal stress) will likely occur within this range of critical temperatures. The lower value is often linked to "avoidance", "restlessness" and "disturbed" behavior types (Coutant 1977; Alabaster and Lloyd 1980). The highest value (25°C) is generally the maximum temperature at which the fish can survive for brief periods. The occurrence of thermal stress in these critical ranges is affected by several variables, the most important being the period of exposure and the acclimation temperature. In laboratory studies Brett (1952) found the upper lethal limit for adult chinook to be 25.1°C, while juvenile salmon were found not tolerant of temperatures exceeding 25.1°C for a 1 week period. Studies have documented values that are directly lethal to the various species of salmonids, and it is generally accepted that temperatures between 25°C and 30°C will lead directly to lethal physiological responses and death (Becker and Genoway 1979).

In nature, stressors (*i.e.* elevated temperatures) rarely occur in isolation. The complexity of habitat variables that occur in a "normal" environment constantly challenge survival. Poor water quality, competition, predation, and other potential stressors can act as part of a multiple-factor or synergistic stress (Servizi and Martens 1991; Fagerlund *et al.* 1995). Potentially fatal temperatures may therefore be lower in the natural environment compared with laboratory conditions where data defining lethal thresholds have been obtained. The critical temperatures referred to in this report (see Table 2) may be more typical of environmental or field values and are best estimates derived from documented research and available expert opinions, outlined in Levy (1992); see also (Brett 1952; Vernon 1958; Bell 1973; Smirnov 1975; Reiser and Bjornn 1979; Armour 1991; Heard 1991).

The preferred temperature range is described as the range within which fish are most frequently found when given choices along a thermal gradient. Variability in preferred temperature is often considerable and related to differences in acclimation temperature, age, size and physiological condition of the fish (Elliot 1981). Reiser and Bjornn (1979) suggested a preferred temperature range for juvenile coho of 11.8°C to 14.6°C and for juvenile chinook a preferred range of 7.9°C to 13.8°C.

Table 2. Temperature Preferences and Tolerances - species *Oncorhynchus.*

>25°C	UPPER RANGE of LT_{50} for SALMON
>21°C	LOWER RANGE of LT_{50} for SALMON
>16°C	CESSATION of SPAWNING INCREASE in DISEASE
8-15°C	PREFERENCE FOR REARING
5-15°C	PREFERENCE for SPAWNING MIGRATION
4-14°C	PREFERENCE for SPAWNING

3.3 Overviews of Temperature Data

Daily maximum, minimum and mean water temperatures are displayed in Figs. 2a and 2b, and show both the diurnal fluctuations and seasonal trends observed at each monitoring site. Significant temperature thresholds for anadromous salmon are delimited on the graphs at 25°C, 21°C and 16°C.

3.3.1 *Weekly Overviews*

Temperature data were summarized using 7-day increments for maximum, minimum, and mean daily temperatures at each site (Appendix 1). Results for each site were compared and ranked according to the hottest (1) and coolest (16) weeks (see lower right-hand corner of the site summary tables in Appendix 1).

3.3.1.1 The Hottest Weeks - Mid-Summer

Water temperatures at all sites exceeded the lower end of the thermal tolerance range for Pacific anadromous salmonids (21°C). Sites on the Nicola, Coldwater and Deadman Rivers were the hottest, and exceeded or approached the upper end of the thermal tolerance range (25°). The results of the limited data for the Coldwater River suggest it would have experienced the highest temperature peaks during the summer of 1996 compared with all other sites. A temperature monitoring study on the Coldwater and Nicola systems during 1994 and 1995 showed that this Coldwater River site also experienced higher maximums than the Nicola during the warmest weeks of summer. In 1996, weeks 4 through 7 (mid/late July to mid-August) were the warmest, with maximum water temperatures exceeding 20°C at all sites. Average 1996 temperatures were lower than reported in the Nicola in 1994 and 1995 (Walthers and Nener 1997a; 1998), however they still exceeded 16°C at all sites during weeks 4 through 7 at all sites. The Nicola drainage was the warmest system and average temperatures were >18°C for this same period. Maximum water temperatures occurred at all sites in late July (July 25-30), except the Bonaparte Fishway site which recorded it's maximum temperature on July 15, 1996.

Table 3 summarizes maximum water temperatures for all monitoring sites. While temperatures >21°C were recorded at all sites, overall temperature conditions reflect the cooler summer and higher water flows of 1996, compared with previous years. These results provide a measure of the problems within this region, when even during more favourable, cooler conditions, temperatures still frequently reach critical levels for salmonids.

Table 3. Summary of maximum recorded water temperatures for Thompson tributary monitoring sites in 1996.

	DATE	TIME	MAX°C
Canford Bridge (NIR56)	07/27/96	17:00	25.8
	07/27/96	18:00	25.8
	07/27/96	19:00	25.8
Lower Nicola (NIR4)	07/29/96	17:00	24.8
	07/29/96	18:00	24.8
	07/29/96	19:00	24.8
***Lower Coldwater (COR4B)**	07/23/96	17:00	24.1
	07/23/96	18:00	24.1
	07/23/96	19:00	24.1
Lower Deadman (DMR4)	07/28/96	17:00	24.1
	07/28/96	18:00	24.1
	07/30/96	16:00	24.1
	07/30/96	17:00	24.1
Lower Salmon (SR6)	07/25/96	17:00	23.2
	07/25/96	18:00	23.2
	07/27/96	18:00	23.2
	07/27/96	19:00	23.2
	07/28/96	17:00	23.2
	07/28/96	18:00	23.2
	08/29/96	17:00	23.2
Spius Hatchery (SP2)	07/29/96	17:00	23.2
	07/29/96	18:00	23.2
Bonaparte Fishway (BPR3)	07/15/96	19:00	22.6

*Data for the Coldwater site does not extend past July 24, 1996, which suggests that maximum temperatures may have been higher at this site during the warmest period.

3.3.1.2 Cooling Trends - Late Summer/Early Fall

By weeks 8 and 9 (08/19/96-09/01/96) there was a gradual cooling trend, with average water temperatures declining to a range of 16°C to 18.5°C. However, maximum temperatures were still in the lethal range (>21°C) at all sites. In week 11 (09/09/96-09/15/96) maximum temperatures were still fairly warm and ranged from 17.6°C (BPR3) to 19.6°C (NIR4). Significant reductions in maximum temperatures did not occur until week 12 (09/16/96-09/22/96), when recorded maximums were less than 16°C at all sites.

3.3.2 Implications of Daily Temperature Fluctuations

Water temperatures normally vary daily, seasonally, annually and spatially. In natural river ecosystems salmonids will experience daily temperature fluctuations. Some evidence even suggests that thermal tolerance and resistance increase with slightly fluctuating acclimation temperatures or with a brief exposure to sub-lethal high temperatures (Heath 1963; Hutchinson 1976). However, in some tributaries of the Thompson watershed, fluctuating water temperatures can be extreme, and lethal temperature events occur repeatedly. For example, during the summer of 1994 water temperatures in the Coldwater River increased from a low of 20.2°C to a high of 29.7°C in increments of 0.5°C to 2°C per hour over an 8 hour period (Walthers and Nener 1997a). Such temperature extremes are lethal to salmon and Thomas *et al.* (1986) suggested that even exposure to temporary (1-2 hour) high temperatures above lethal limits (*i.e.* >21°C-25°C) can be detrimental to health. Sudden changes in water temperature can be devastating in terms of survival (Fagerlund *et al.* 1995). During 1996 the frequency of extreme high temperatures was notably less than previous years, however temperatures between 21°C and 26°C still occurred during the warmest periods at all monitoring sites.

In 1996 a maximum daily fluctuation of 10.1°C (Aug-22) occurred at Spius Creek, with a peak temperature of 20.5°C reported. For August, when daily fluctuations were generally the greatest, average daily temperature fluctuations per site were: 3.3°C (Bonaparte Fishway-BPR3), 4.1°C (Lower Nicola-NIR4), 4.9°C (Lower Salmon-SR6), 5.6°C (Canford Bridge-NIR56), 6.0°C (Lower Deadman-DMR4) and 7.2°C (Spius Hatchery-SP2). Table 4 summarizes average maximum and minimum temperatures, and helps describe the characteristic temperature fluctuations for each system. Figures 4a to 4f describe average deviations from the daily mean per month and per site. This graphical report summarizes daily temperature patterns for each month and gives some evidence suggesting that both Nicola sites, and the Bonaparte and Salmon River sites may be prone to periods of prolonged sub-lethal/lethal temperatures. Comparatively extreme temperature fluctuations occurring at Spius Creek and the Deadman River likely result from lower flows and stronger solar influences. During very warm conditions these smaller systems would likely be prone to lethal temperature spikes.

Table 4. Average maximum and minimum temperatures (°C) per month per site for Thompson tributary sites, 1996.

		Canford Bridge NIR56	Lower Nicola NIR4	Spius Hatchery SP2	Bonaparte Fishway BPR3	Lower Deadman DMR4	Lower Salmon SR2
JULY	Avg. Max	21.2	21.3	17.9	20.1	20.7	19.4
	Avg. Min	16.2	16.8	11.7	16.6	14.1	15.6
AUGUST	Avg. Max	21.3	20.8	20.1	19.2	19.9	19.5
	Avg. Min	15.7	16.7	12.8	15.8	13.9	14.6
SEPTEMBER	Avg. Max	15.7	15.3	14.7	14.5	14.8	14.1
	Avg. Min	11.3	12.4	9.2	11.6	10.5	11.1

3.3.3 *Influence of Time and Temperature*

In field studies, Martin *et al.* (1986) showed a strong correlation between diel temperature fluctuation and summer mortality of juvenile coho. They suggested that as long as the temperature did not exceed 28°C, mortality was not a direct result of temperature, but rather the amount of time temperatures exceeded 25°C. While these observations may not translate directly to the Thompson tributaries they do imply that mortality is influenced by: (1) extreme temperature fluctuations and/or (2) sustained sub-lethal temperatures. The nature of temperature change is also important. In laboratory studies Dean (1973) found that a combination of a gradual increase to a sub-lethal situation with a subsequent gradual decrease could significantly impact survival. This implies salmon populations may be impacted in systems experiencing modest temperature fluctuations but sustained sub-lethal temperatures. These combinations of potentially lethal temperature situations and conditions were recorded in all the Thompson River tributaries monitored here. In the Fraser River, some evidence even suggests that thermal stress resulting from sub-lethal temperatures (*i.e.* >19°C) will compromise survival if prolonged (I.V. Williams, I.V. Williams Consulting Ltd., pers. comm.).

A summary of temperature events >21°C (Table 5) describe a number of critical time-temperature situations. Sustained "lethal" temperature events were assessed according to the frequency of temperature occurrences >21°C which exceeded 3 consecutive hours per day. Temperatures in excess of 21°C for greater than 3 consecutive hours occurred from early July through late August for all sites, which would have affected both rearing juveniles and returning spawners. Maximum consecutive temperatures >21°C for >3 consecutive hours occurred at all sites July 28th and July 30th. The Lower Nicola (NIR4) site experienced the longest period (43 hrs) of temperatures continuously >21°C, as well as a total of 351 hours of temperatures >21°C for the 1996 season.

Sustained temperatures in excess of 21°C are significantly stressful and problematic for fish that cannot move to cooler waters. Migration to cool water refuges such as outlets of cooler creeks and groundwater seepage sites is crucial during such situations, however these microhabitats must be abundant and available to fish if they are to be able to mitigate high ambient water temperatures. On the Nicola, during summer high temperatures, fish have been observed utilizing these cool water habitats (Levings *et al.* 1985). However, the actual quantity and quality of these refugia are poorly documented for the system. Utilization of such cool water microhabitats can only be speculated on for the other tributaries monitored here, but it is expected that during periods of warm temperatures such cool water habitats would be necessary for survival.

Table 5. Summary of recorded temperatures >21°C exceeding 3 consecutive hours.

>21°C	**Canford Bridge NIR56**	**Lower Nicola NIR4**	**Spius Hatchery SP2**	**Bonaparte Fishway BPR3**	**Lower Deadman DMR4**	**Lower Salmon SR6**
Dates (range)	07/12-08/30	07/08-08/30	07/23-08/29	07/13-08/29	07/08-08/29	07/23-08/29
Average time	16:00	14:30	17:30	14:30	18:00	18:00
# of total hours >21°C	324 hrs	351 hrs	78 hrs	139 hrs	157 hrs	104 hrs
# of days of >21°C for >3 consecutive hours	32 days	28 days	12 days	15 days	18 days	14 days
Avg # hours per day of >21°C for >3 consecutive hours	10 hrs	12.2 hrs	4.5 hrs	8.8 hrs	7.3 hrs	6.6 hrs
Date/time of max consecutive period >21°C	07/28,11:00 -07/29,06:00	07/28,12:00 -07/30,07:00	08/29,15:00 -08/29,21:00	07/29,16:00 -07/30,07:00	07/28,14:00 -07/28,23:00	07/29,14:00 -07/29,22:00
Max consecutive period >21°C	20 hrs	43 hrs	7 hrs	16 hrs	10 hrs	9 hrs

COR4B: data does not extend past 07/24/96; however during this period the average time of temperatures >21°C = 18:00 hours, and total hours of temperatures >21°C = 37 hours.

3.4 Factors Contributing to High Water Temperatures

3.4.1 *The Influence of Geographical Features on Water Temperature*

The influence of geographic features on thermal conditions in drainage systems is considerable. Water temperatures show geographical variations related to latitude and altitude. The proximity of features such as mountains and large water bodies can influence climate patterns which subsequently influence water temperatures. Local temperature conditions are also affected by aspect, topography, and other environmental variables such as riparian cover and ground water inputs. The Thompson River tributaries monitored in this study share many common features, but each system is uniquely affected by it's orientation, drainage area, elevation and gradient, the height and density of riparian vegetation, channel configuration, and cool water inputs.

In general the water temperature of drainage systems increases in the downstream direction (Gordon *et al.* 1992), in part because air temperatures decrease as elevation increases. The air at low elevations is denser and therefore absorbs more radiant energy than the air at higher elevations at the same latitude. Air temperature decreases at a rate of approximately 0.4°C per 100 m gain in elevation (Kimmins 1987). Weather conditions also change with increasing elevation and consequently result in lower temperatures at higher elevations. Small systems with high-elevation origins express these low temperatures diurnally. In the Thompson watershed, the Coldwater River (1994 and 1995), Spius Creek (1996), and the Deadman River (1996) showed large diurnal fluctuations (high daytime and low early morning temperatures) which are partly attributed to cool source waters and low flows. During the day small tributaries and shallow sections are heated directly through solar radiation, and through the transfer of heat from air and substrate to water (Wetzel 1975). At night when solar radiation is absent, moving (mixed) water with a relatively large surface area-to-volume ratio readily loses heat to the atmosphere. Cool source waters can thus influence downstream temperatures more profoundly during the night and early morning when solar radiation is absent. During July (1996) the lowest temperature in Spius Creek was 7.5°C, which was at least 4°C lower than all other monitoring sites. The very low temperatures in Spius Creek likely result from cool (high elevation) source waters and a relatively short mainstem length (48.6 km, see Table 1). The somewhat lower temperatures in the Deadman River site are likely due to a combination of factors including low flows and cooler source waters. Figures 5a to 5f show stream profiles for each system, which helps to describe some drainage system characteristics (gradient, elevation, length), as well as providing a geographic background for explaining some aspects of reported thermal regimes.

The Coast Mountains rain shadow effect is very pronounced and results in a significant moisture deficit in the summer in the Thompson Plateau, especially in the deeper valleys. In the southern Interior Plateau of British Columbia the combination of dry climate conditions and relatively intense solar radiation result in semi-arid type conditions. Favourable soils and climate conditions have encouraged widespread agricultural development. Water deficiencies and subsequent water withdrawals for irrigation have placed heavy demands on the water resources of the region, which are already limited during the summer months. Water withdrawals exacerbate natural low flow issues and contribute to further warming.

Solar radiation is the most important factor in the warming of streams and the amount of solar radiation received increases with increasing slope for S and SE/SW aspects, while decreasing with increasing slope for E/W, NE/NW and N aspects. The Bonaparte and Deadman Rivers both have southerly aspects (see Table 1) and would thus be most significantly influenced by solar radiation. Nevertheless, the Bonaparte River reported cooler temperatures with very modest fluctuations in comparison with the other sites. Several factors, including a large high elevation lake (Bonaparte Lake) likely act to modify temperature extremes downstream. The Bonaparte watershed is also in a more northerly latitude than the other systems studied here, with the headwaters very close to the North Thompson region where climate conditions are cooler. Unknown factors such as cooling groundwater inputs may also influence the thermal regime in the Bonaparte River.

The Nicola River system is probably the warmest major drainage in the Thompson watershed. Urban development, agricultural land uses, a large low elevation lake, summer water withdrawals and logging in the upper reaches likely contribute to the warm temperatures experienced in this system. Much of the mainstem length also occupies a warm, low elevation corridor which is defined by the driest and warmest (Ponderosa

Pine/Bunchgrass) biogeoclimatic zone in the province. Lack of riparian cover and low summer flows compound temperature problems in the system.

3.4.2 *Riparian Losses*

High water temperatures in the Thompson watershed are partly a result of climate and geography, however several factors including degraded riparian zones and low flows contribute to temperature problems in the region. Shade from riparian vegetation moderates stream temperatures, often preventing excessive summer temperatures that may be lethal to fish. In addition, riparian vegetation has a strong role in maintaining bank integrity. When it is removed, erosion often occurs, resulting in a wider channel and shallower stream which is more vulnerable to summer warming influences. These damaged riparian habitats not only contribute to temperature problems in the above systems, but also impact bank erosion, input of fine sediments, loss of fish food organisms, change in substrate composition and generally accompany a deterioration of habitat complexity, which is vital for thriving salmon stocks.

Numerous studies have demonstrated relationships between loss of riparian vegetation along a watercourse and increased water temperatures (Holtby 1988). Field studies have shown significant increases in summer water temperature and decreases in winter temperatures when shade is removed from small drainages. Brown and Krygier (1970) observed an 8°C increase in mean monthly maximum summer water temperatures in a small Oregon stream which was clear-cut. Meehan *et al.* (1969) also observed a 5°C increase in mean monthly maximums during the summer months in a clear-cut Alaskan stream. Studies on clear-cut watersheds show that when riparian buffer strips are used, stream temperatures remain essentially the same as in undisturbed watersheds (Brown and Krygier 1970; Graynoth 1979).

One study from Oregon State (Hall and Lantz 1969) examined effects of clear-cutting an entire 71 ha watershed which provided spawning and rearing habitat for coho. Before logging, the maximum summer water temperature was 16°C, and the diurnal temperature fluctuation was measured to be 1.5°C. After logging, the maximum water temperature was 30°C and diurnal fluctuations reached 16°C.

Studies in the Slim Creek watershed of B.C., located 80 km east of Prince George, showed an average water temperature increase of 1-3°C relative to unlogged sites upstream (Brownlee *et al.* 1988). The same study found diurnal temperature fluctuations to be at least twice as large at downstream sites that lacked riparian vegetation in comparison with upstream shaded reaches. Water temperatures downstream of logged areas fluctuated over 8°C in one 24 hour period, compared with 2°C at the upstream control site. The average water temperature increase reported by Brownlee is in the range of that predicted to accompany global warming in B.C., as discussed in Levy (1992).

While quantification of devegetated riparian areas for all Thompson watershed tributaries is lacking, observations and assessments of land use (*i.e.* grazing, urbanization, logging) imply significant losses of riparian vegetation and structure. A study recently completed by Beeson and Doyle (1995) identified the presence/absence of riparian vegetation along bends in reaches of the Bonaparte, Deadman and Salmon Rivers, and Chase Creek, all of which are tributaries to the Thompson River. The reaches studied ranged from 18 km to 36 km in length. The percent length of devegetated reaches ranged from 46% to 63%.

Additional studies by Miles (1995a, 1995b) have documented riparian damage and channel widening on the Deadman and Salmon Rivers. Miles (1995a) reports that within the Deadman study area 64 km (44%) of stream bank had no woody riparian vegetation and another 15 km (23%) has only a narrow fringe remaining. Where riparian vegetation is lacking channel widths have increased by an average of 330%. Similar findings are reported for the Salmon River, where 43 km (28 % of the 154 km of bank length in the study area) has no woody riparian vegetation and another 34 km has only a narrow fringe. Channel widths have increased by 11% to 211% where riparian vegetation is lacking (1995b)

It is reasonable to assume that loss of riparian vegetation along the Nicola River and its tributaries presents a similar problem. Preliminary results of a study commissioned by DFO-FRAP (Patterson, DFO, pers. comm.) indicate that bank erosion and slumping, substrate mobility, and channel instability are common in the Nicola and Coldwater River study areas (Dam outlet to confluence with Thompson, and Kingsvale to confluence with Nicola River, respectively).

Losses of riparian vegetation likely have significant impacts on water temperatures in Thompson River tributaries, and possibly also on the Thompson River itself. Water flowing into the Thompson from affected tributaries will be several degrees warmer than it would be if healthy riparian zones were present along most of the tributary lengths.

3.5 Water Temperature and Life Cycle Events during Freshwater Phases

As with most fish the body temperature of salmonids is always close to that of the water. Each species has a definite range of temperatures it can survive within. For salmonids that range is essentially from 0°C to 21°C. Individuals within the species, at various developmental stages, have an even more limited range than the species as a whole. For salmonids, incubation, juvenile rearing, ocean phase, adult migration and spawning all have distinct ranges of preferred and tolerated temperatures. Changes in season and accompanying temperature changes are often cues to changes in the life-cycle stage and subsequent changes in habitat. Generally, immature stages (embryo and alevin) are less tolerant of temperature extremes and fluctuations than are adults (Moyle 1993).

3.5.1 *Juvenile Rearing*

Coho and chinook juveniles rear in or near their natal stream or in other small systems for a year or more prior to seaward migration. They are therefore vulnerable to high water temperatures during the summer months. Moyle (1993) suggests that the water temperature requirement for growth is between 5°C and 17.5°C for juvenile Pacific salmon. While higher temperatures my not be directly lethal, they do cause metabolic rates to increase. Growth then decreases as most or all food is used for maintenance. A marked decrease in the feeding behavior of brown trout at temperatures >19°C and no feeding at 20°C (Elliot 1981) has been observed and may be indicative of other salmonids.

Bjornn and Reiser (1991) suggested that the preferred temperatures of both chinook and coho are between 12°C and 14°C. Brett (1971) indicated that the preferred temperature of sockeye (15°C) is also the temperature at which active metabolic rate, metabolic scope, sustained swimming speed and growth rate are optimized. Correspondence in preferred temperature and physiological optimum temperature is clearly adaptive (Brett 1971) and Levy (1992) suggests that physiological optimum temperatures for the other Fraser basin salmon species are likely in a similar range as for sockeye (15°C ± 2°C).

Reported mainstem water temperatures for the study area tributaries are not within the preferred or physiological optimum temperatures for sustained periods for much of the summer months. As discussed by Taylor and Taylor (1977), when the scale of environmental changes exceeds the animal's capacity to respond in situ, the general biological response to adversity - migration - comes into play (Thorpe 1994). In high-altitude desert streams rainbow trout selected habitats of relatively low productivity and food availability, in order to avoid nearby habitats where the temperatures were approaching their upper lethal limit (Li *et al.* 1994). Baltz *et al.* (1987) also suggested that stream fishes alter their microhabitat preferences as temperature changes. In the Nicola, juvenile salmon use cool water seepage sites, off-channel ponds, and cool creeks as refugia (Levings *et al.* 1985). During sampling of the mid-Nicola reaches in 1985 salmonids were found only within a 10-foot radius of the Clapperton Creek outflow into the Nicola River (O. Langer, DFO, pers. comm.). During the warm summer months appropriate habitat with a favourable thermal regime is clearly restricted to areas with cool inputs of surface or ground water (Walthers and Nener 1997a).

Fraser River coho juveniles, and the offspring of many chinook runs, rear primarily in small tributaries which are highly susceptible to the thermal and hydrological impacts associated with global warming. Levy (1992) suggested that coho and chinook stocks of the Thompson Region would be particularly susceptible to such effects. Temperature monitoring since 1994 in the Nicola, Salmon and recently in other significant Thompson tributaries indicate that thermal regimes even in cooler years reach critical levels. This should provide us with some forewarning of risks to salmon habitats if predicted global warming trends continue.

3.5.2 *Adult Spawning Migrations*

In the Thompson River watershed salmon spawning migrations occur at various times throughout the system, depending upon the species and stock. Maturation and migration schedules of particular stocks have evolved over time in adaptation to the specific environmental conditions in natal streams. Water levels and temperatures in the Fraser River are often cues to initiate upstream movements. Many Thompson River salmon stocks begin migrations in the summer/fall season and may therefore be vulnerable to elevated summer and early fall water temperatures. Water temperatures during spawning migrations are critical to adult survival and reproductive success. Elevated temperatures can lead to disease outbreaks, altered timing of migration, accelerated or retarded maturation, and accelerated use of limited energy reserves. Deviations from normal temperature conditions likely affect survival (Bjornn and Reiser 1991). Pearse and Larkin (1992) identified temperature induced stress as a contributing factor to pre-spawning mortalities in the Fraser River watershed. Temperature ranges and other requirements for each species during spawning migrations are summarized in Table 6. Generally it is suggested that temperatures in excess of 16°C are unfavourable for salmon during spawning migrations.

Table 6. Water temperatures (Bell 1986), depths and velocities (Thompson 1972) that enable upstream migration of adult salmon.

	TEMPERATURE RANGE (°C)	MINIMUM DEPTH (m)	MAXIMUM VELOCITY (m/s)
Fall chinook	10.6-19.4	0.24	2.44
Spring chinook	3.3-13.3	0.24	2.44
Summer chinook	13.9-20.0	0.24	2.44
Coho	7.2-15.6	0.18	2.44
Pink	7.2-15.6	0.18	2.13
Sockeye	7.2-15.6	0.18	2.13

Adapted from Bjornn and Reiser (1991)

As with juvenile salmon, adults make use of cool water refugia during upstream spawning migrations. Berman and Quinn (1991) examined patterns of behavioral thermoregulation, habitat preference, and movements of fish during spawning migrations. Adult spring chinook salmon were tagged with temperature-sensitive radio transmitters and released back to the natural environment. During a four-month tracking period it was discovered that tagged fish maintained an internal body temperature 2-5°C less than ambient river temperature by utilizing cool thermal refuges. Observations in the Fraser River basin suggest that many stocks utilize the outflow of cool tributaries during migrations upstream (R. Lauzier, DFO, pers. comm.). While many of these small cool systems are not significant salmon producers they undoubtedly play a critical role as cool water refugia. Data records indicate that preferred spawning migration temperatures in the Fraser and Thompson Rivers are often exceeded, and hence could critically affect survival if thermal refuges are limited or unavailable during upstream movements. In 1994 mainstem summer temperatures in the Fraser and Thompson River were often >19°C (Lauzier *et al.* 1995), and while temperatures in 1996 were less, they still exceeded 17°C for prolonged periods (Barnes and Walthers 1997). Elevated and fluctuating temperatures in natal streams may also impact reproductive success. Thompson River tributaries are often subject to temperature extremes and it is expected that prolonged periods of sub-lethal and lethal temperatures during migrations and at the spawning grounds would negatively impact egg viability and survival.

3.5.3 *Spawning*

Appropriate temperature ranges for spawning are even narrower than for migration. While salmonids have been observed to spawn between 1.0°C and 20.0°C (Bjornn and Reiser 1991) the actual reproductive success is questionable at extremely low and high temperatures. Estimated spawning temperature requirements for each species are summarized in Table 7. As discussed by Bjornn and Reiser (1991) the distinct range of time and temperatures for spawning for each stock has resulted from evolution and adaptation to natural conditions in the natal stream that will maximize survival of offspring in the undisturbed system. Extended and stressful migrations have been observed to result in pre-spawning mortality, especially when temperatures are also excessive at the spawning grounds. Average minimum and maximum temperatures for the study area tributaries usually ranged between 10°C and 15.5°C for September (1996), which is slightly greater than Bell (1986) has recommended for spawning.

Table 7. Recommended temperatures for spawning and incubation of salmonids (Bell 1986). Adapted from Bjornn and Reiser (1991).

	TEMPERATURE (°C)	
	Spawning	**Incubation**
Fall chinook	5.6-13.9	5.0-14.4
Spring chinook	5.6-13.9	5.0-14.4
Summer chinook	5.6-13.9	5.0-14.4
Coho	4.4-9.4	4.4-13.3
Pink	7.2-12.8	4.4-13.3
Sockeye	10.6-12.2	4.4-13.3

Also, selection by some species of spawning areas associated with upwelling groundwater flow may mitigate unfavourable environmental conditions in the system.

3.6 Fish Presence and Timing of Life Cycle Events

Life cycle information for salmonids in the study area tributaries (Nicola, Spius, Bonaparte, Deadman and Salmon) indicate that both juveniles and adult spawners of some salmonid species are likely to experience high water temperatures. Information available from DFO Stream Information Summary System catalogues (Department of Fisheries and Oceans 1992) pertaining to the presence of juveniles and spawning seasons for each tributary included in the study has been summarized below.

NICOLA & COLDWATER RIVERS, SPIUS CREEK

Coho salmon ***(Oncorhynchus kisutch)***

Coho salmon spawn throughout the Nicola River with the heaviest spawning between Spius Creek and Merritt (DFO, 1992). Spawning occurs between late September and early November, when water temperatures are declining. While adult spawners may not be impacted by high water temperatures due to timing, resident juvenile populations would be particularly susceptible to high summer water temperatures as they rear in small streams for at least one year prior to their seaward migration. Rearing habitat is believed to be limited by temperature conditions, as an August field sampling program in the Nicola found juvenile coho to be clustered in areas which are influenced by cool water inputs (Levings *et al.* 1985).

Coho spawn in the Coldwater River between late October and late November, after water temperatures have declined to the sub-lethal range. Rearing juveniles are likely impacted by water temperatures during the summer months. Results of an August field survey showed that coho fry were mostly restricted to areas with cool water inputs (Levings *et al.* 1985).

In Spius Creek coho spawn between late September and mid-late November, so returning spawners would not be impacted by warm water temperatures. Rearing juveniles which utilize the system throughout the year may be impacted by warm summer water temperatures.

Pink salmon ***(Oncorhynchus gorbuscha)***
Pink salmon spawn in the lower 25 km of the mainstem Nicola, generally between Spius Creek and Spences Bridge. Spawning occurs on odd years from early September to mid October, when water temperatures are declining. The young migrate to sea immediately after emergence, hence pink salmon are less likely than other salmonids to be impacted by high summer water temperatures.

Chinook salmon ***(Oncorhynchus tshawytscha)***
Chinook salmon spawn throughout the Nicola system, with most spawning between Spius Creek and Merritt. Chinook have been observed spawning upstream and downstream from Douglas Lake. Spawning occurs between mid-July and mid-September, making this species extremely vulnerable to the high summer water temperatures. Water temperature data collected immediately upstream of Nicola Lake in the summer of 1995 during June to mid-July showed water at this reach to be hotter in comparison with all sites monitored in the 1994 study (Walthers and Nener 1997a; 1998). Chinook attempting to spawn upstream of Nicola Lake are likely strongly impacted by high water temperatures.

Chinook runs vary widely in terms of how long juveniles remain in their natal streams following emergence, prior to seaward migration. Some juveniles make use of cold water refuges in the Nicola River mainstem, while others pass down into the Thompson River. Sebastian (1982) suggested that as fish increase in size they likely move into deep water habitats found in larger systems downstream.

Chinook salmon return to the Coldwater River in June, and spawn between July and mid-September. Returning spawners would be exposed to the highest water temperatures of the year.

Results of field studies show that juvenile chinook salmon generally start leaving the Coldwater system by March or April (Scott and Olmsted 1985). Some are believed to rear in the Nicola (which also experiences high summer temperatures) and some in the Thompson River.

Chinook salmon in Spius Creek are reported to spawn between late July through to mid-September, and would likely encounter unfavourable water temperatures during most years.

BONAPARTE RIVER

Coho salmon ***(Oncorhynchus kisutch)***
Coho are known to spawn in the lower 3.3 km of the Bonaparte River. Spawning occurs October through November when water temperatures are cool. Rearing juveniles would still be impacted by high water temperatures during the summer months.

Chinook salmon ***(Oncorhynchus tshawytscha)***
Chinook salmon in the Bonaparte River start spawning during August and continue through September. Elevated water temperatures in late summer would impact these populations, although temperatures are generally declining at this time. Juveniles rearing in the Bonaparte would be vulnerable to warm summer water temperatures.

DEADMAN RIVER

Coho salmon *(Oncorhynchus kisutch)*

Coho salmon spawn in the Deadman River in October and November, after warm summer water temperatures have declined. Spawning occurs throughout to the confluence of Tobacco Creek. While spawners are not exposed to extremely high temperatures, rearing juveniles would still be negatively affected.

Chinook salmon *(Oncorhynchus tshawytscha)*

In the Deadman River chinook salmon spawn from mid-July through September and would therefore be impacted by high water temperatures. Spawning occurs throughout to the confluence of Tobacco Creek with an upstream limit about 4 km below Mowich Lake. In 1996 the hottest temperatures (up to 24.1°C) occurred during late July which would have impacted returning spawners. Rearing juveniles would also be vulnerable to the warm summer temperatures which occur in the Deadman River.

Pink salmon *(Oncorhynchus gorbuscha)*

Pink salmon spawn in the Deadman River up to Criss Creek from early September to mid October during odd years. The young migrate to sea immediately after emergence. Due to their life-cycle and the timing of spawning they are unlikely to be impacted by high summer water temperatures.

Sockeye salmon *(Oncorhynchus nerka)*

A small late run sockeye population started spawning in the Deadman River during October-November, 1986. These individuals are thought to be "spill-over" from the Adams River run. The spawners appear when water temperatures are declining and therefore would not be impacted by high water temperatures.

SALMON RIVER

Coho salmon *(Oncorhynchus kisutch)*

Coho salmon enter the Salmon River in October and spawn from October through December, so spawning would not be affected by summer water temperatures. However, juveniles utilize the system year round and are directly impacted by warm summer temperatures. Rearing habitat is thought to be limited in the Salmon River.

Chinook salmon *(Oncorhynchus tshawytscha)*

Chinook salmon begin to appear in the system in July and August, with spawning occurring in September, so their reproductive success may be affected by summer water temperatures, particularly in hot years. Chinook juveniles utilize the system year round and are therefore vulnerable to warm summer temperatures.

Sockeye salmon *(Oncorhynchus nerka)*

A small late run sockeye population spawns throughout the lower half of the Salmon River from September through November. These spawners appear when water temperatures are declining and therefore would not be impacted by high water temperatures. Juvenile sockeye migrate to Shuswap Lake following emergence and would therefore be unaffected by summer water temperatures in the Salmon River.

4.0 CONCLUSIONS AND RECOMMENDATIONS

Results of the 1996 temperature monitoring program indicate that water temperatures in Thompson River tributaries are at times problematic for salmonids during the summer months. Previous monitoring efforts in the Nicola and Salmon River drainages during 1994 and 1995 (Walthers and Nener 1997a; 1997b; 1998) also indicate that high water temperatures are a constraint for salmon production in most years. The very high water temperatures observed in the Nicola mainstem in 1994, 1995 and 1996 contributes to the effective loss of habitat available to rearing salmon and migrating spawners. All systems including the Nicola, Deadman, Bonaparte, Coldwater, Spius and Salmon drainages experienced temperatures in the lethal range during the summer of 1996. Regional climate conditions and lack of riparian cover contribute largely to the temperature problems in these systems.

4.1 Protection of Cool Water Refugia

As previously suggested the protection of cool water refugia in these Thompson River tributaries is important. Rearing juveniles may be confined to areas where cool water inputs from springs and small groundwater-fed streams provide thermal refuges during hot summer months. As yet there is little information available which would clearly identify and protect these areas. Many small non-natal streams are also important habitat components and must be identified as such. In the Fraser River many smaller tributaries provide cool water refuge for fish during their upstream spawning migration. Many tributaries are also believed to provide important seasonal habitat for some juveniles. It is expected that similar observations would apply to the Thompson River and its tributaries. These cool groundwater inputs and cool water streams must be identified, mapped, and protected. Without safeguarding these areas further declines in salmon populations can be expected.

4.2 Restoration of Riparian Vegetation

Restoring degraded riparian areas within the Thompson River watershed is an important step in improving the quality of salmon habitat throughout the region. Shade from riparian vegetation is important in moderating stream temperatures and preventing the damaging effects of streamside erosion. Lack of riparian structure is clearly linked to high summer water temperatures and habitat loss. Studies documenting the changes which have occurred in the last half of this century for a number of Thompson River tributaries (*i.e.* Deadman and Salmon Rivers) (Miles 1995a and 1995b) are both alarming and important in describing factors which have contributed to the deterioration of once vital salmon stocks. In the Deadman River average increases in unvegetated channel widths of 330% and a streambank length of 64 km (44%) with no woody riparian vegetation have been reported by Miles (1995a). These conditions are clearly detrimental to salmon stocks in the system. Riparian restoration efforts in various watersheds including the Deadman and Salmon Rivers have been initiated, however successful efforts are contingent on the contributions of landowners who are both educated and understanding of the long term value and importance of a healthy watershed and ecosystem. While forestry practices are being modified to accommodate water quality and fisheries habitat issues, so too must all activities which negatively impact valuable watershed ecosystems.

4.3 Climate Change

Some predictions suggest that the average temperature of the Earth's surface could increase anywhere from 2°C to 5°C during the next century (Hansen *et al.* 1988; Houghton *et al.* 1990). Estimations of salmonid habitat loss in Wyoming streams for increases between 1°C and 5°C is between 16.2% and 68% (Keleher and Rahel 1996). Stefan *et al.* (1992) also examined the effects of global warming on Minnesota's coldwater fishes and determined that predicted increases in temperatures could limit available habitat to the northern portion of the state, where adequate shading by riparian vegetation would inhibit stream warming. Comparisons between these regions and the Thompson watershed are obviously difficult, however the underlying theme of global change should prompt us to carefully assess potential risks to habitat throughout the Thompson and Fraser River systems. Clearly climate warming poses a significant threat to the Thompson watershed. Existing habitat problems and already stressed and limited environments are at critical stages and further impacts would undoubtedly endanger salmon populations and the limited water resources of this region.

Water temperature is a critical habitat component, which may profoundly affect the future of Thompson River salmon stocks. Riparian vegetation has been eliminated throughout many areas of the watershed and formerly significant salmon-producing systems have been significantly degraded. Restoration efforts in these systems will be an important step towards sustaining salmon populations. Global warming is a distinct possibility and the temperatures reported in the Thompson watershed suggest the system is vulnerable and at risk. All efforts made to enhance Thompson River stocks would be undermined should we fail to continue to diligently pursue the restoration and protection of all critical habitat components.

ACKNOWLEDGEMENTS

Many thanks again to all the individuals who contributed to monitoring efforts and the completion of this report. We are indebted to Barney Stirling (Nicola Valley Tribal Council) for his continued efforts on the Nicola River. Thanks to the Shuswap Nation; the Bonaparte Indian Band for assistance on the Bonaparte River; Don Ignace and the Skeetchestn Indian Band for work on the Deadman River; and Mike Wallis for his help on the Salmon River. Thanks also to FACET systems Inc. for generation of our stream profiles and Glen Langford for his assistance with our maps. This work was funded through the Fraser River Action Plan.

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FIGURES

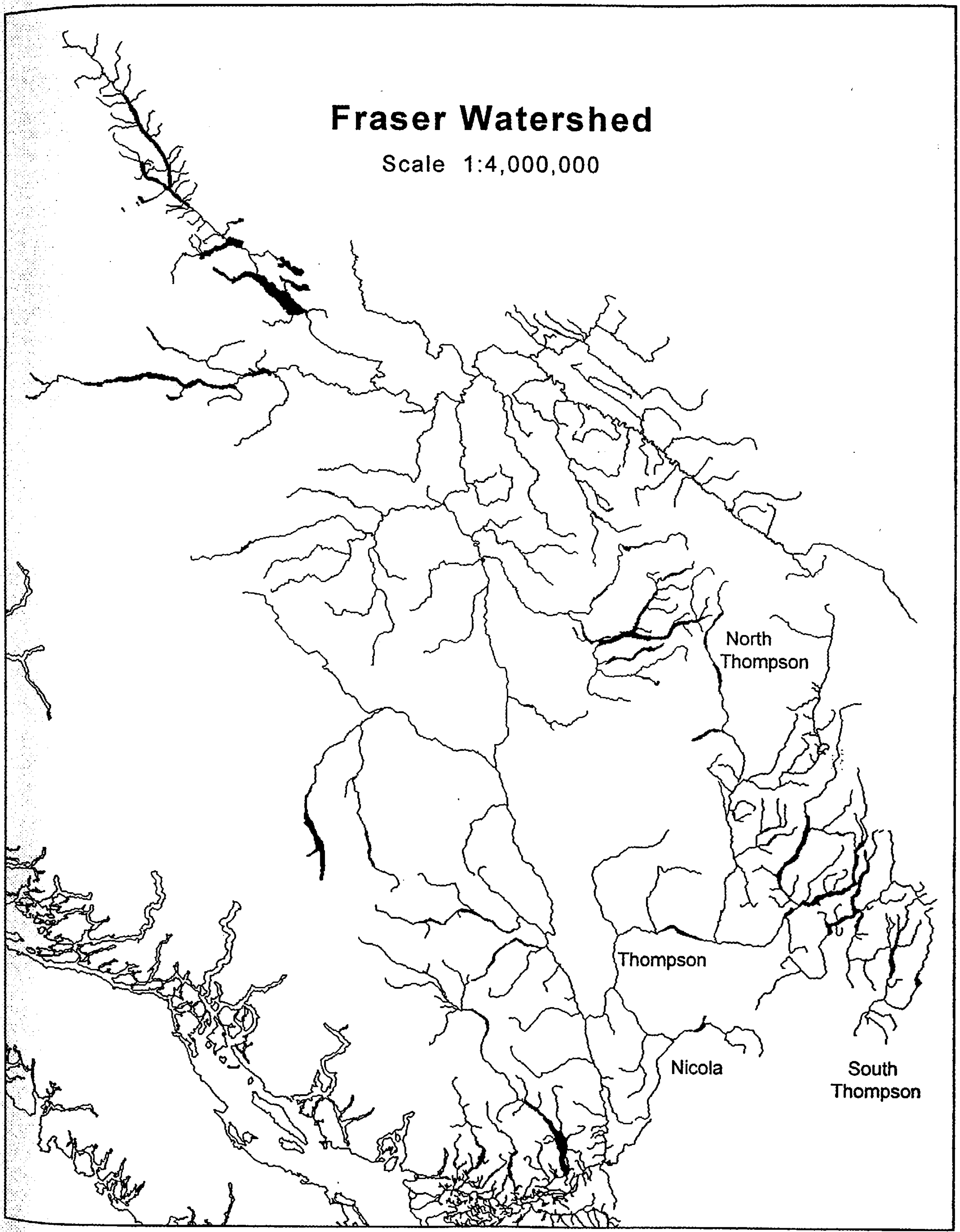


Fig. 1a. Fraser River basin and Thompson watershed, British Columbia.

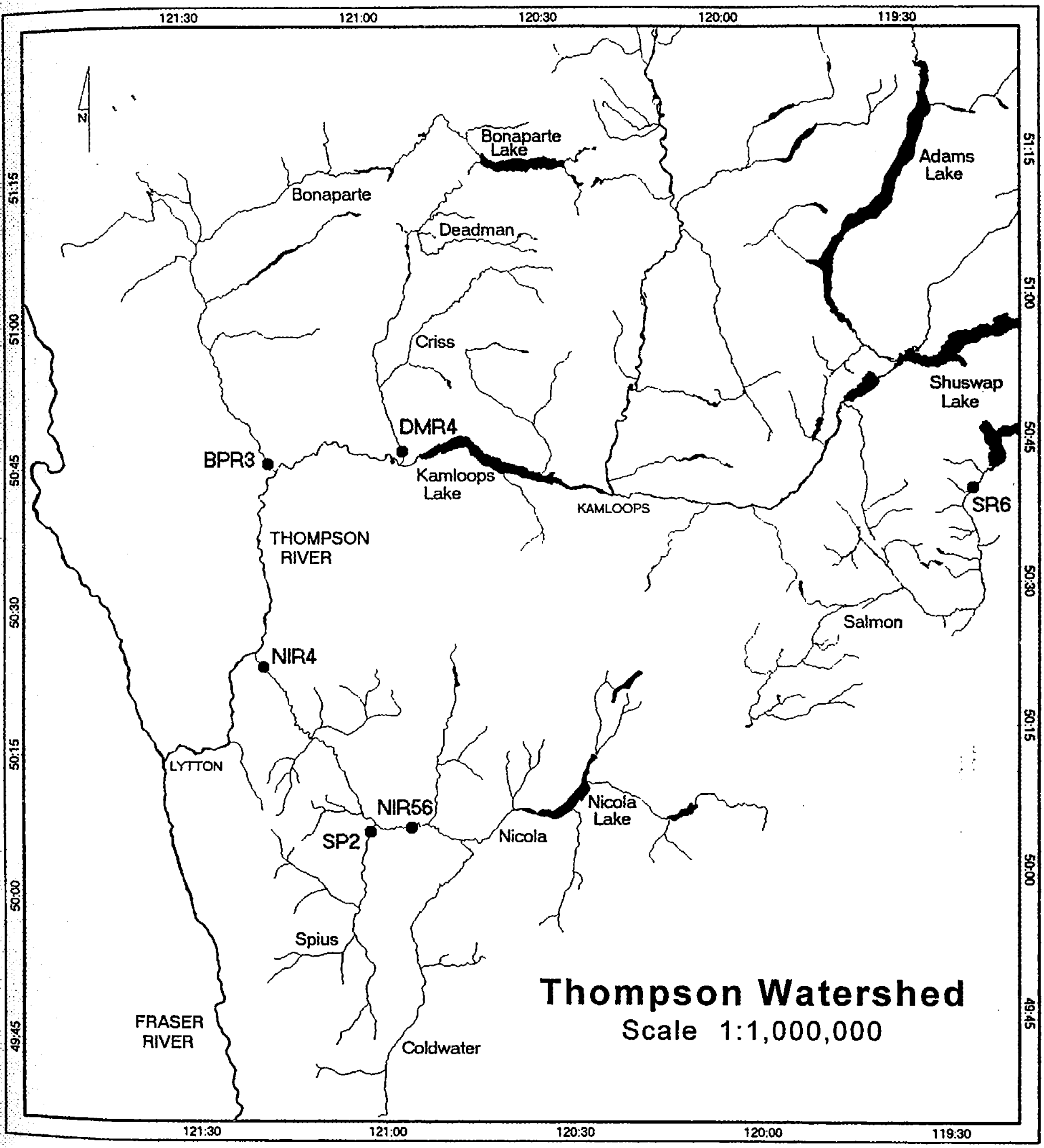


Fig 1b. Location of water temperature monitoring sites, 1996.

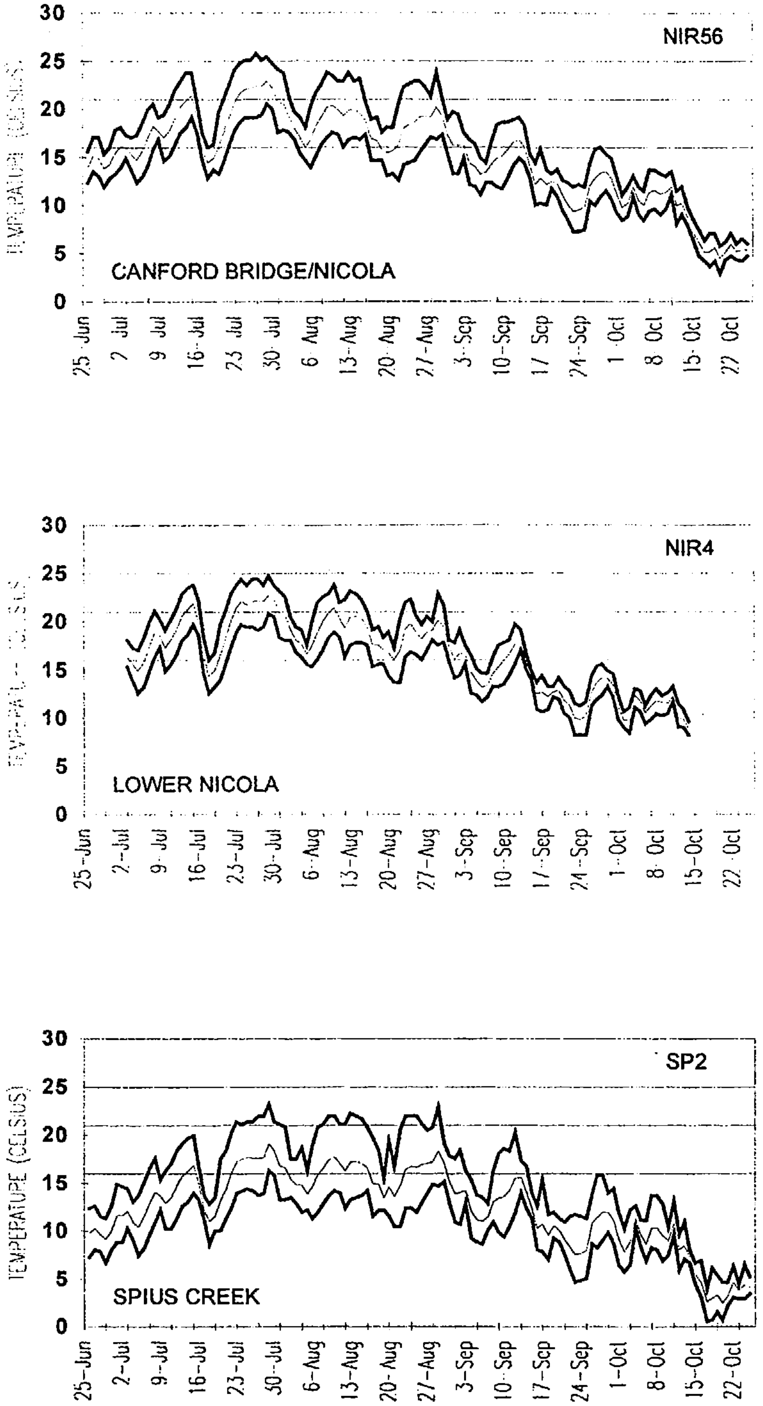


Fig. 2a. Daily maximum, minimum and mean water temperatures for all Thompson watershed sites, 1996. Lines at 16°C, 21°C and 25°C correspond with (a) maximum preferred spawning migration temperature, (b) lower limit of LT_{50}, and (c) upper limit of LT_{50}, respectively.

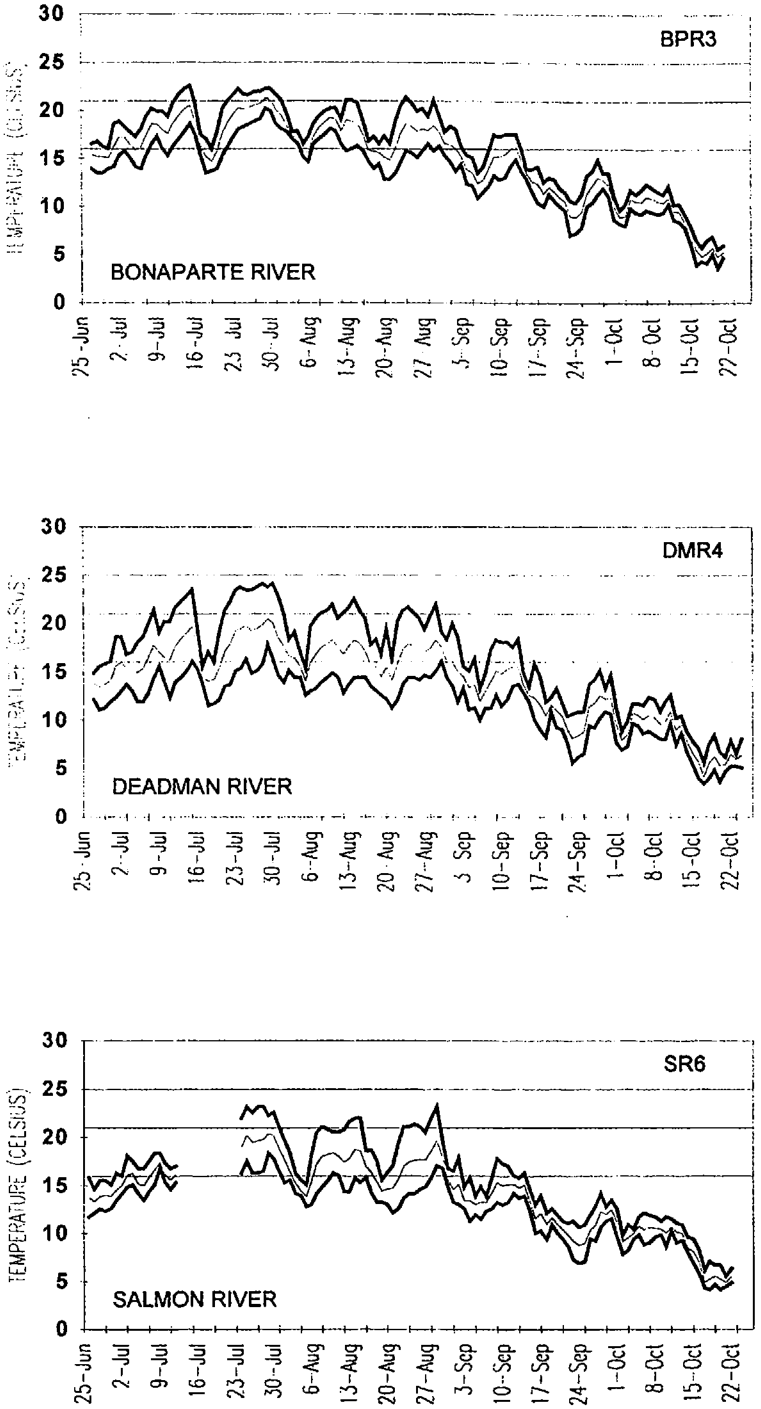


Fig. 2b. Daily maximum, minimum and mean water temperatures for all Thompson watershed sites, 1996. Lines at 16°C, 21°C and 25°C correspond with (a) maximum preferred spawning migration temperature, (b) lower limit of LT_{50}, and (c) upper limit LT_{50}, respectively.

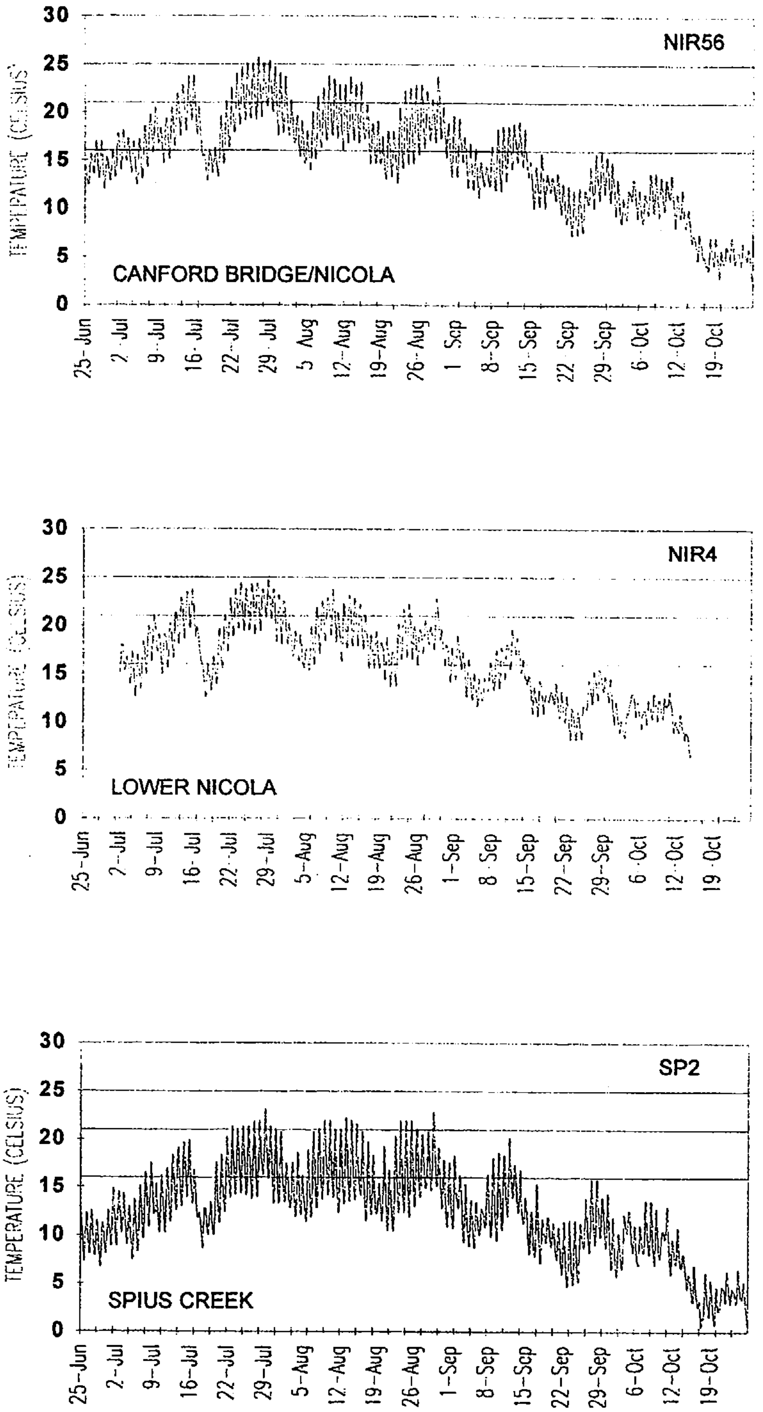


Fig. 3a. Hourly water temperatures for all Thompson watershed sites, 1996. Lines at 16°C, 21°C and 25°C correspond with (a) maximum preferred spawning migration temperature, (b) lower limit of LT_{50}, and (c) upper limit of LT_{50}, respectively.

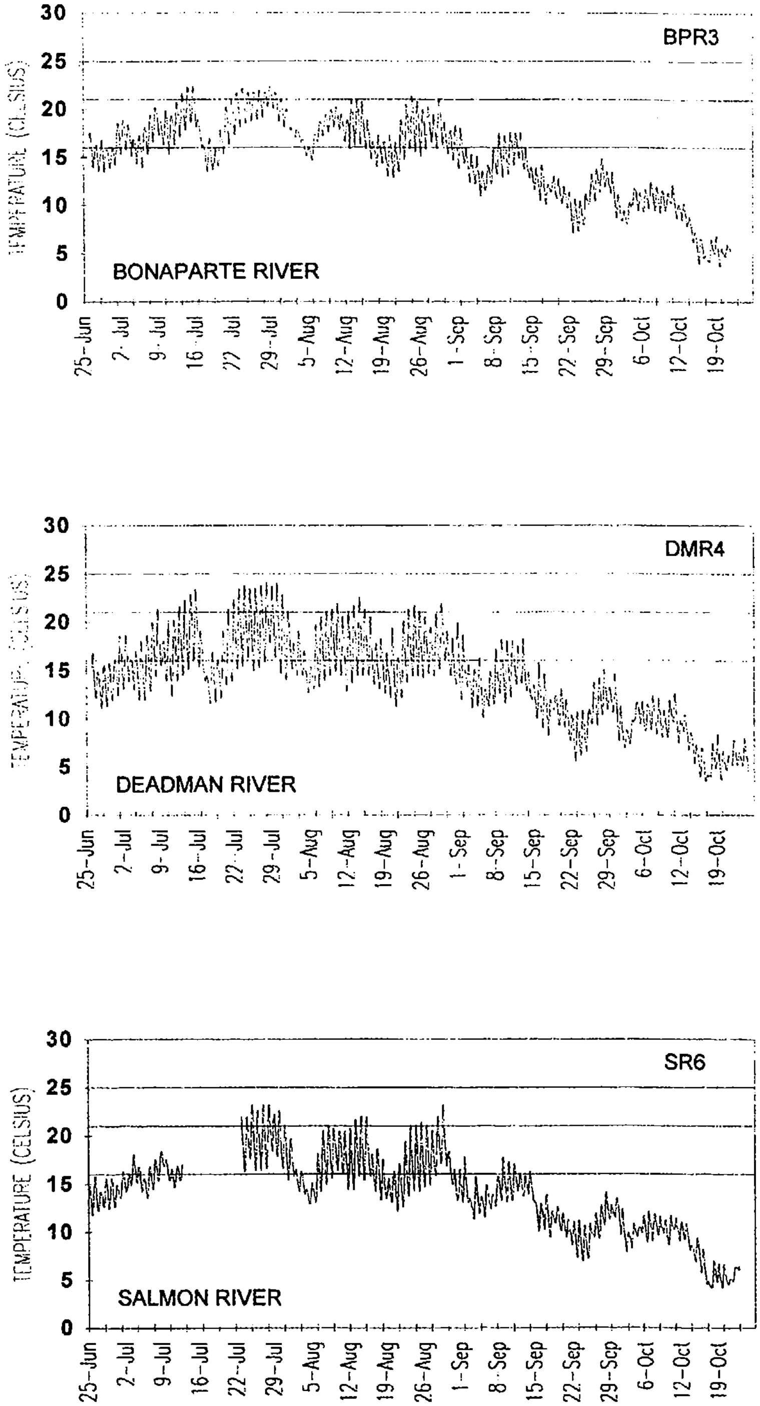


Fig. 3b. Hourly water temperatures for all Thompson watershed sites, 1996. Lines at 16°C, 21°C and 25°C correspond with (a) maximum preferred spawning migration temperature, (b) lower limit of LT_{50}, and (c) upper limit of LT_{50}, respectively.

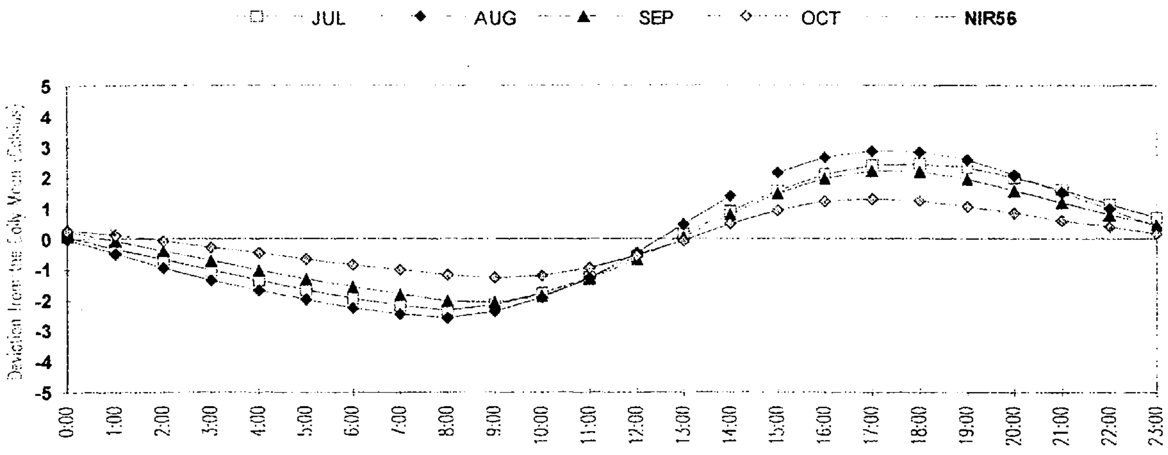


Fig. 4a. Average hourly deviations from the daily mean per month for the Nicola River at NIR56, 1996.

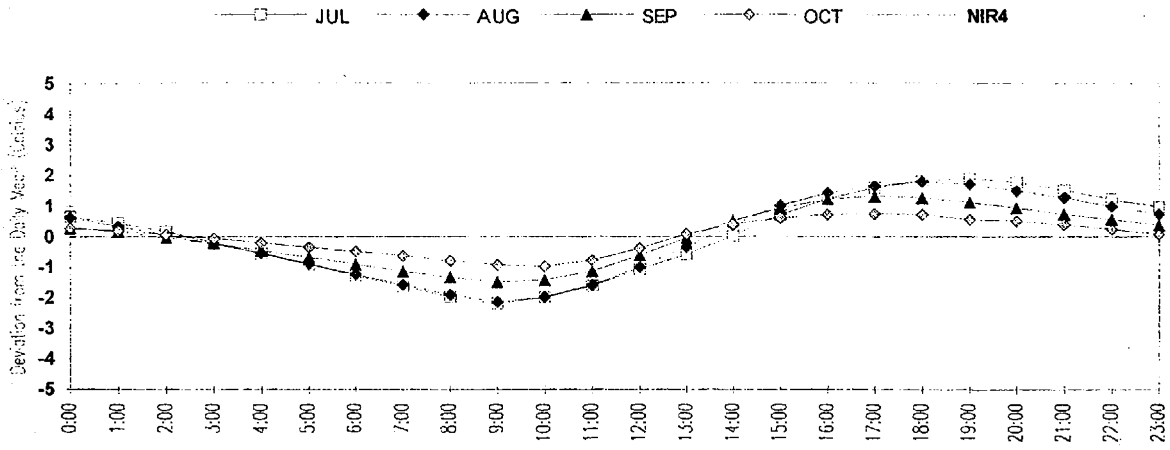


Fig. 4b. Average hourly deviations from the daily mean per month for the Nicola River at NIR4, 1996.

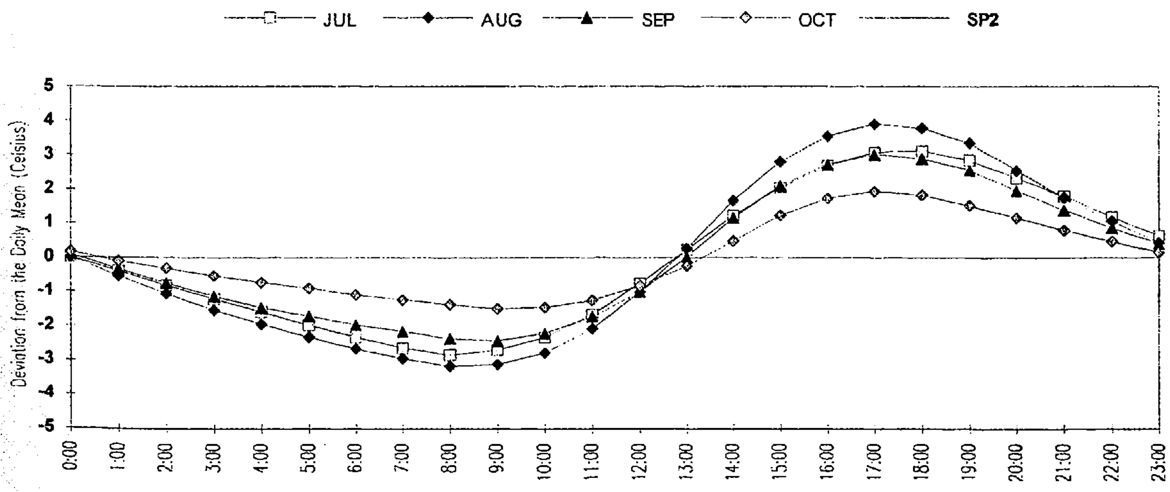


Fig. 4c. Average hourly deviations from the daily mean per month for Spius Creek at SP2, 1996.

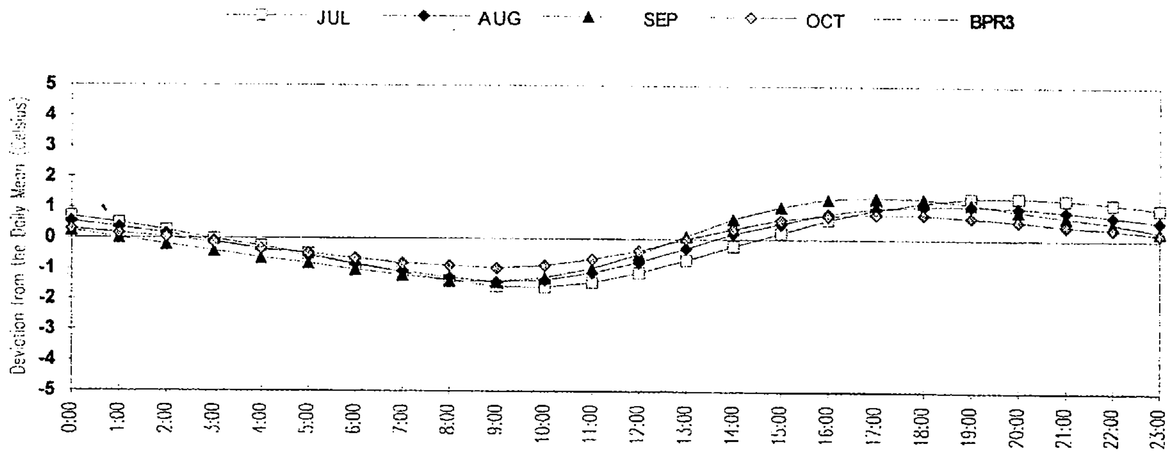


Fig. 4d. Average hourly deviations from the daily mean per month for the Bonaparte River at BPR3, 1996.

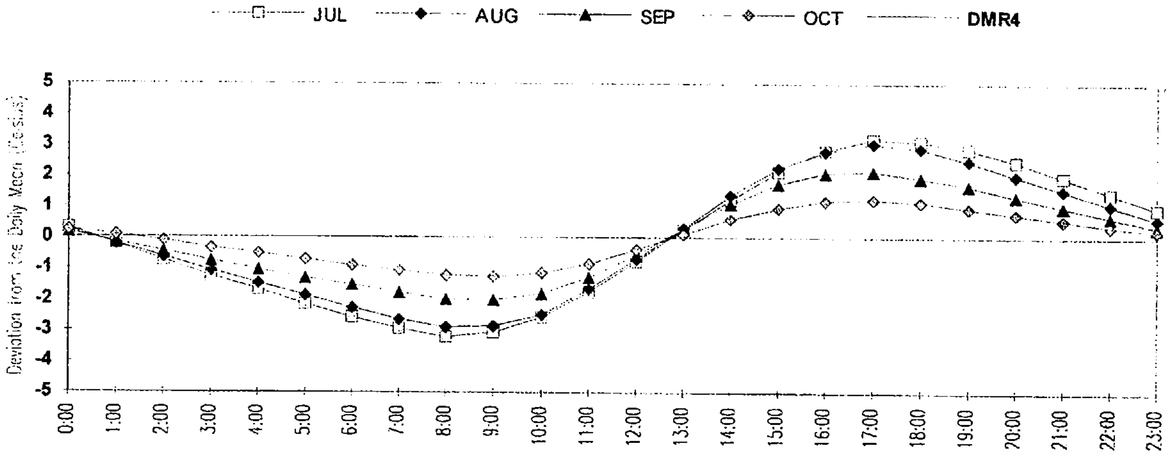


Fig. 4e. Average hourly deviations from the daily mean per month for the Deadman River at DMR4, 1996.

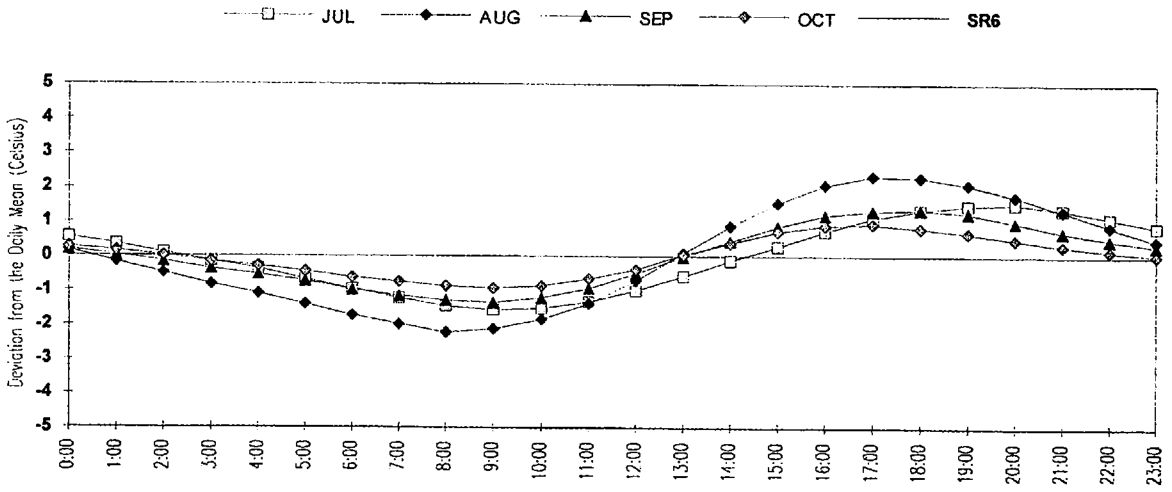


Fig. 4f. Average hourly deviations from the daily mean per month for the Salmon River at SR6, 1996.

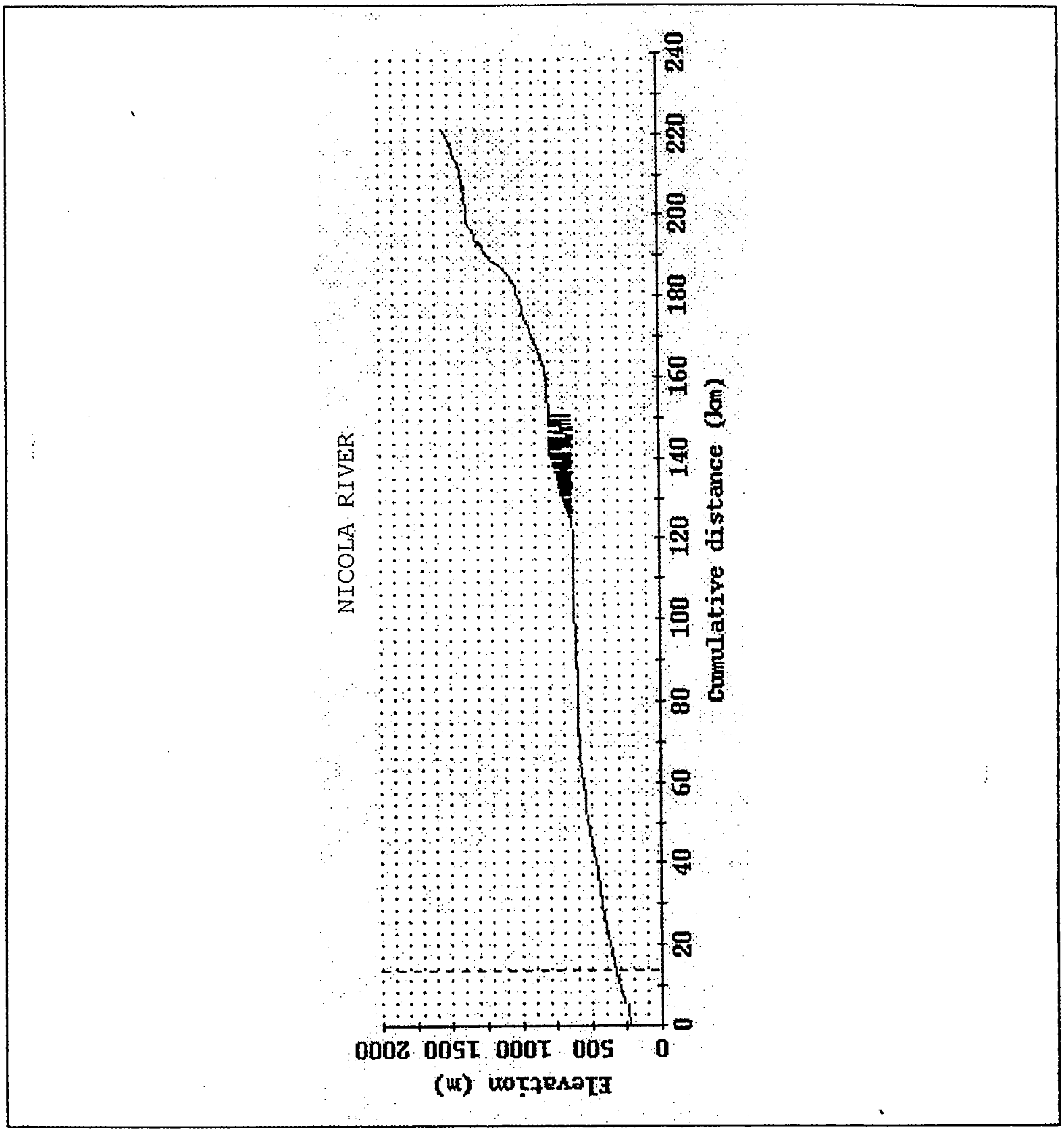


Fig. 5a. Stream elevation profile for the Nicola River.

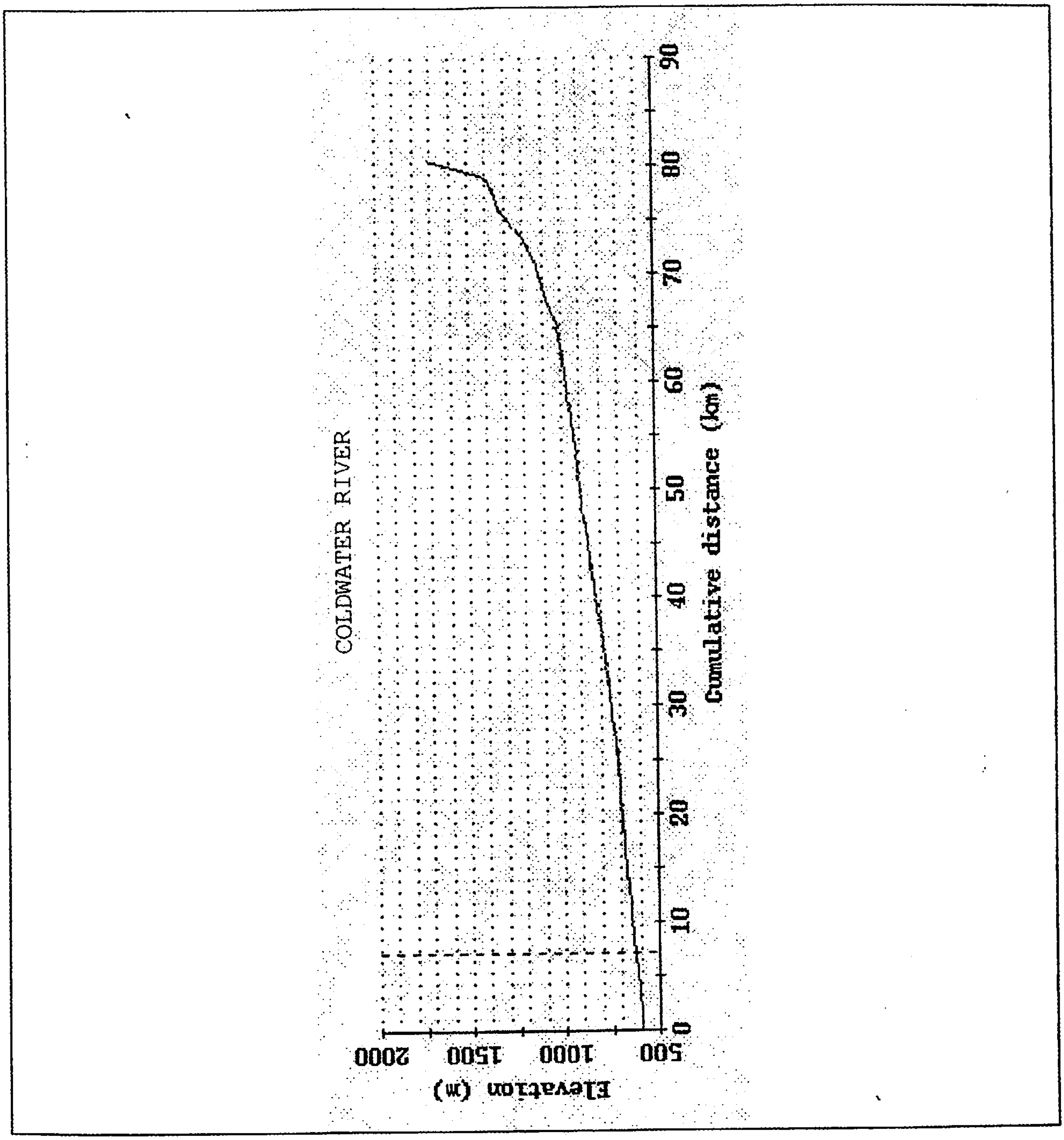
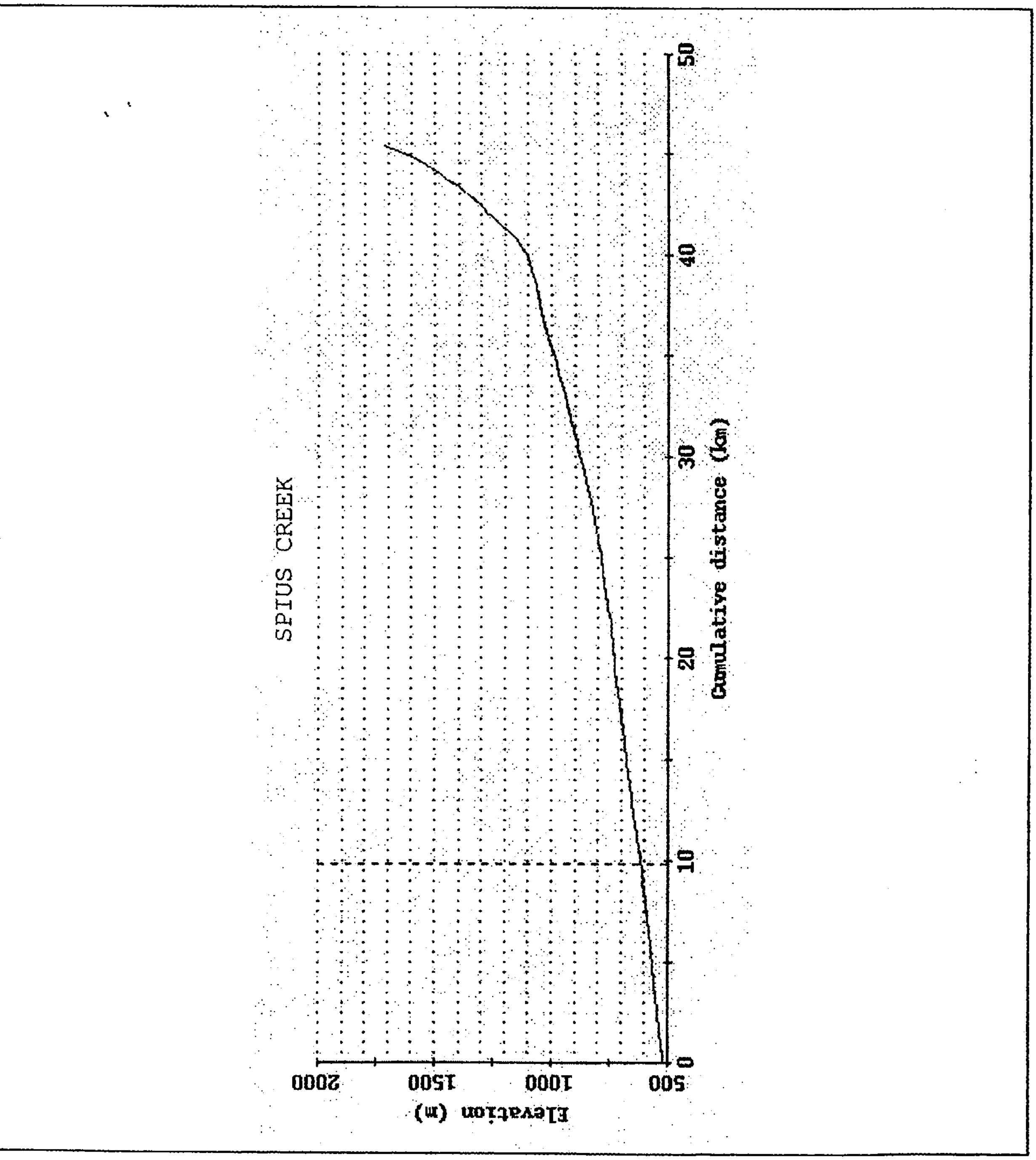


Fig. 5b. Stream elevation profile for the Coldwater River.



g. 5c. Stream elevation profile for Spius Creek.

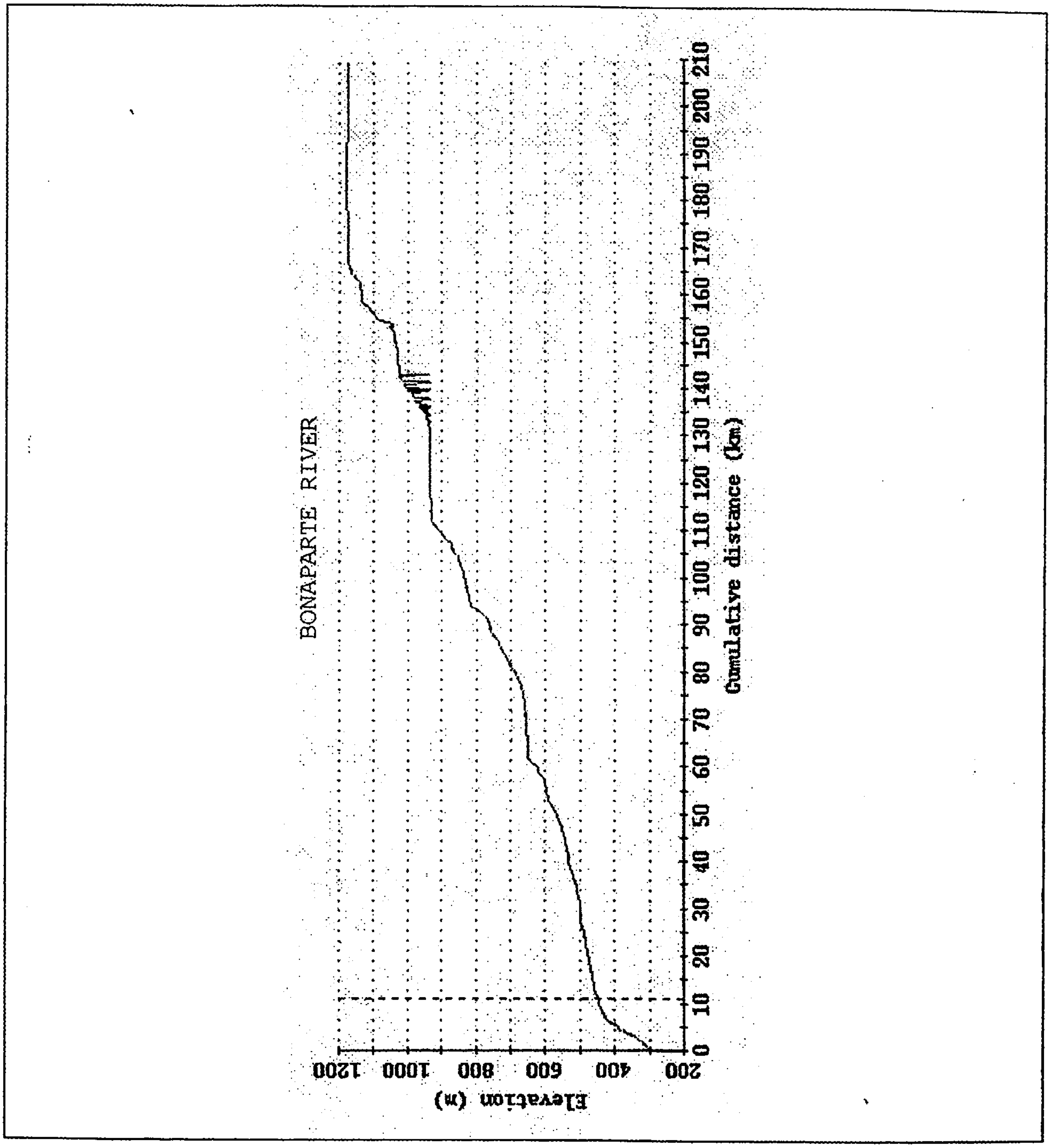


Fig. 5d. Stream elevation profile for the Bonaparte River.

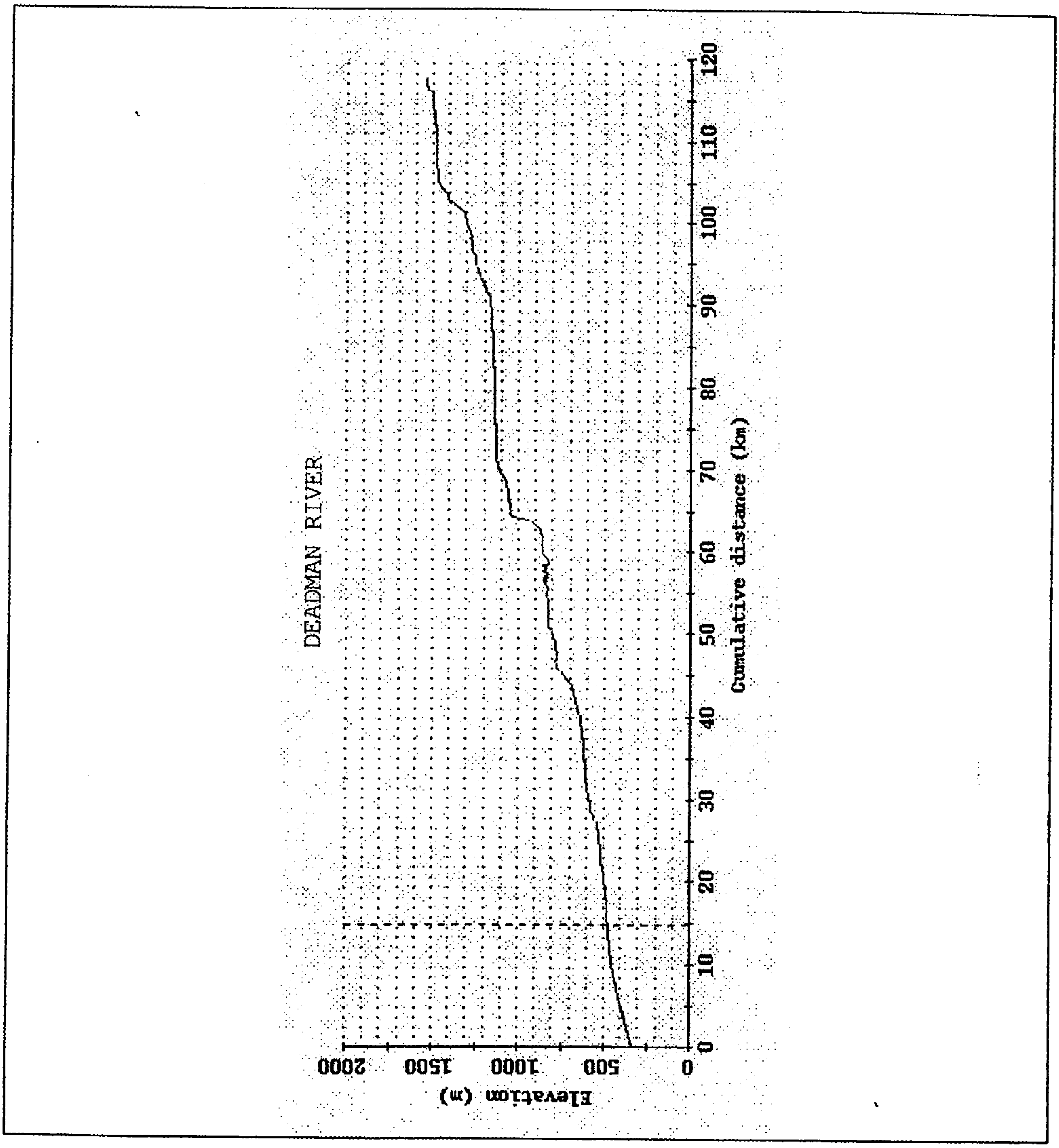
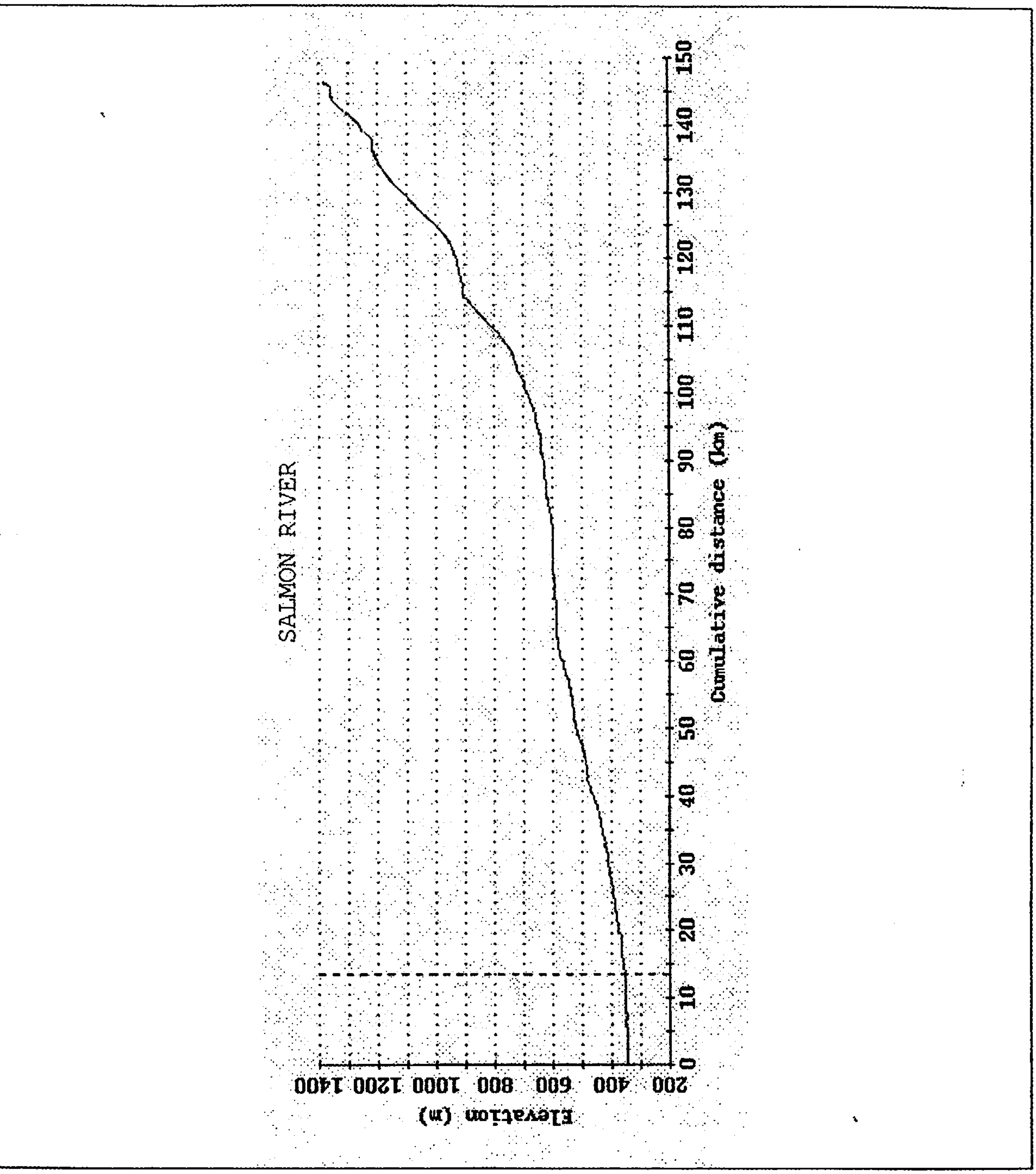


Fig. 5e. Stream elevation profile for the Deadman River.



g. 5f. Stream elevation profile for the Salmon River (Shuswap).

APPENDIX 1

ppendix 1. Site summaries by week for Thompson watershed sites. N is number of available mperature records used in determining averages. Max. and min. are defined as the highest and west temperature peaks recorded during each week per site. Temperatures are in °C. (1996)

WEEK 1	**NIR56**	**NIR4**	**SP2**	**BPR3**	**DMR4**	**SR6**
N	168	132	168	168	168	168
AVG	15.75	16.14	11.58	16.68	15.54	15.42
MAX	19.96	19.96	16.55	19.41	19.96	18.08
MIN	12.37	12.59	7.46	16.68	11.93	13.48

WATERSHED MAX 19.96
MIN 7.46 SP2
(07/01/96-07/07/96)
10

WEEK 2	**NIR56**	**NIR4**	**SP2**	**BPR3**	**DMR4**	**SR6**
N	168	168	168	168	168	168
AVG	18.67	19.11	14.41	18.72	17.49	16.39
MAX	23.79	23.48	19.68	22.26	22.86	18.34
MIN	14.63	14.86	10.24	15.34	12.37	14.63

WATERSHED MAX 23.79 NIR56
MIN 10.24 SP2
(07/08/96-07/14/96)
6

WEEK 3	**NIR56**	**NIR4**	**SP2**	**BPR3**	**DMR4**	**SR6**
N	168	168	168	168	168	N/A
AVG	17.04	17.47	13.45	16.99	16.02	N/A
MAX	23.79	23.79	19.96	22.56	23.48	N/A
MIN	12.81	12.59	8.63	13.48	11.50	N/A

WATERSHED MAX 23.79
MIN 8.63 SP2
(07/15/96-07/21/96)
7

WEEK 4	**NIR56**	**NIR4**	**SP2**	**BPR3**	**DMR4**	**SR6**
N	168	168	168	168	168	127
AVG	21.50	21.67	17.32	20.07	19.26	19.70
MAX	25.75	24.43	21.96	22.26	24.11	23.17
MIN	16.31	17.31	12.37	16.31	13.71	16.31

WATERSHED MAX 25.75 NIR56
MIN 12.37 SP2
(07/22/96-07/28/96)

1

WEEK 5	**NIR56**	**NIR4**	**SP2**	**BPR3**	**DMR4**	**SR6**
N	168	168	168	168	168	168
AVG	20.07	20.24	16.55	19.25	17.90	17.59
MAX	25.41	24.75	23.17	22.26	24.11	22.56
MIN	15.34	16.31	11.93	16.55	13.93	13.93

WATERSHED MAX 25.41 NIR56
MIN 11.93 SP2
(07/29/96-08/04/96)

2

WEEK 6	**NIR56**	**NIR4**	**SP2**	**BPR3**	**DMR4**	**SR6**
N	168	168	168	168	168	168
AVG	18.65	19.36	16.17	17.70	16.85	17.01
MAX	23.79	23.79	21.96	20.24	21.96	21.09
MIN	13.93	15.34	11.29	14.63	12.59	12.81

WATERSHED MAX 23.79
MIN 11.29 SP2
(08/05/96-08/11/96)

4

WEEK 7	NIR56	NIR4	SP2	BPR3	DMR4	SR6
N	168	168	168	168	168	168
AVG	18.70	19.32	16.30	17.61	16.99	17.32
MAX	23.79	23.17	22.26	21.09	22.56	21.96
MIN	14.63	15.34	11.50	13.93	12.81	13.25

WATERSHED MAX 23.79 NIR56
MIN 11.50 SP2
(08/12/96-08/18/96)

3

WEEK 8	NIR56	NIR4	SP2	BPR3	DMR4	SR6
N	168	168	168	168	168	168
AVG	16.84	17.77	15.14	16.59	16.10	15.94
MAX	22.86	22.26	21.96	21.37	21.67	21.37
MIN	12.59	13.71	10.45	12.81	11.29	12.15

WATERSHED MAX 22.86 NIR56
MIN 10.45 SP2
(08/19/96-08/25/96)

8

WEEK 9	NIR56	NIR4	SP2	BPR3	DMR4	SR6
N	168	168	168	168	168	168
AVG	18.62	18.44	16.51	17.58	17.09	17.39
MAX	23.79	22.86	22.86	21.09	21.96	23.17
MIN	13.25	14.16	10.87	14.63	13.48	13.25

WATERSHED MAX 23.79 NIR56
MIN 10.87 SP2
(08/26/96-09/01/96)

5

WEEK 10	**NIR56**	**NIR4**	**SP2**	**BPR3**	**DMR4**	**SR6**
N	168	168	168	168	168	168
AVG	14.51	14.73	12.40	13.98	13.65	13.69
MAX	19.41	19.14	18.34	18.08	18.60	17.82
MIN	11.08	11.72	8.63	10.87	10.04	11.29

WATERSHED MAX 19.41 NIR56
MIN 8.63 SP2
(09/02/96-09/08/96)
11

WEEK 11	**NIR56**	**NIR4**	**SP2**	**BPR3**	**DMR4**	**SR6**
N	168	168	168	168	168	168
AVG	15.60	16.24	14.11	15.18	14.62	14.83
MAX	19.14	19.68	20.24	17.56	18.34	17.82
MIN	11.72	13.25	9.43	12.81	11.50	12.37

WATERSHED MAX 20.24 SP2
MIN 9.43 SP2
(09/09/96-09/15/96)
9

WEEK 12	**NIR56**	**NIR4**	**SP2**	**BPR3**	**DMR4**	**SR6**
N	168	168	168	168	168	168
AVG	11.85	12.29	9.78	11.66	10.95	11.08
MAX	15.82	14.39	15.34	14.16	15.82	13.93
MIN	8.43	10.04	5.95	9.63	7.65	8.63

WATERSHED MAX 15.82 NIR56
MIN 5.95 SP2
(09/16/96-09/22/96)
13

WEEK 13	**NIR56**	**NIR4**	**SP2**	**BPR3**	**DMR4**	**SR6**
N	168	168	168	168	168	168
AVG	11.50	12.09	9.91	10.96	10.46	10.35
MAX	16.06	15.58	15.82	14.86	15.10	14.16
MIN	7.27	8.23	4.68	7.08	5.58	6.89

WATERSHED MAX 16.06 NIR56
MIN 4.48 SP2
09/23/96-09/29/96)

12

WEEK 14	**NIR56**	**NIR4**	**SP2**	**BPR3**	**DMR4**	**SR6**
N	168	168	168	168	168	168
AVG	10.92	11.25	9.49	10.28	9.94	10.50
MAX	14.86	14.63	14.39	13.48	14.63	13.48
MIN	8.43	8.43	5.77	8.04	6.89	7.85

WATERSHED MAX 14.86 NIR56
MIN 5.77 SP2
(09/30/96-10/06/96)

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WEEK 15	**NIR56**	**NIR4**	**SP2**	**BPR3**	**DMR4**	**SR6**
N	168	168	168	168	168	168
AVG	11.08	11.19	9.49	10.38	9.94	10.36
MAX	13.71	13.25	13.71	12.37	12.59	11.93
MIN	8.04	9.03	5.95	8.43	7.46	8.63

WATERSHED MAX 13.71
MIN 5.95 SP2
(10/07/96-10/13/96)

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WEEK 16	**NIR56**	**NIR4**	**SP2**	**BPR3**	**DMR4**	**SR6**
N	168	N/A	168	168	168	168
AVG	6.08	N/A	4.12	5.91	5.89	6.37
MAX	10.04	N/A	8.04	9.23	8.83	9.63
MIN	2.91	N/A	0.54	3.61	3.43	4.14

WATERSHED MAX 10.04 NIR56
MIN 0.54 SP2
(10/14/96-10/20/96)

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