POTENTIAL EFFECTS OF MOUNTAIN PINE BEETLE ON NECHAKO RIVER HYDROLOGY AND WHITE STURGEON

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1.0 INTRODUCTION

The Nechako River population of white sturgeon (*Acipenser transmontanus*) is a red-listed species in British Columbia (BC Conservation Data Centre 2005) and is classified as endangered by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC - November 2003). Genetic analysis indicates the Nechako River population is distinct from the Fraser River population, suggesting limited or no inter-breeding among the Nechako and Fraser stocks (Smith et al. 2002). Research also suggests the Nechako population is experiencing recruitment failure with the population dominated by larger, older fish and few juveniles (Nechako White Sturgeon Recovery Initiative (NWSRI) 2004). This situation is not unique to the Nechako River, as white sturgeon populations from the Kootenai and Columbia Rivers are undergoing similar failures. The role of abiotic factors such as temperature and flow on the life-history of white sturgeon has been the focus of extensive research in these systems since it has been shown that these factors influence the timing of spawning events, (Paragamian and Kruse 2001) egg survival and larvae dispersal (Koch 2004). Given the apparent importance of these factors on sturgeon spawning success, any event impacting the hydrology of the system, such as forced spills from reservoirs or increased run-off associated with forestry activities, could affect white sturgeon reproductive success. This report summarizes the potential effects of the mountain pine beetle (MPB) infestation on the hydrology of the Nechako River and associated effects on the Nechako white sturgeon population.

2.0 EFFECTS OF INCREASED PINE BEETLE INFESTATION ON NECHAKO HYDROLOGY

In order to gain an understanding of the potential hydrologic effects of the MPB infestation on the Nechako River, Dr. John Rex (Research Hydrologist, Ministry of Forests (MoF), Prince George) was contacted. Based on discussions with Dr. Rex and after reviewing documents pertaining to MPB and hydrology produced by MoF, the following summary was produced:

- Large scale infestations will affect hydrological processes including (but not limited to): canopy interception, transpiration, soil moisture storage, groundwater levels, snow melt, runoff and peak flow (magnitude and timing), flooding, stream bank stability, and erosion and sedimentation
- For un-logged, infested stands, the degree of hydrologic impact is substantially reduced at sites with a functioning understory
- Increased harvesting could result in increased magnitude of peak flows due to the potential for greater accumulations of snow and reduced transpiration, sublimation and soil moisture storage

- Peak flows may occur earlier in the year, doe to accelerated snowmelt
- Increased surface erosion resulting in sedimentation may occur due to increased road construction
- The Vanderhoof Forest District has reported the occurrence of a raised water table in MPB affected areas although the cause(s) for the changes in site conditions has not been confirmed.

The degree to which these potential effects will be observed within the Nechako River watershed is difficult to predict given the number of independent variables that must be taken into account. These include: soil composition, aspect, slope, precipitation, overstory and understory composition, riparian function, road development and equivalent clearcut area (ECA). Research on the effects of past beetle infestations on hydrology at the watershed level can provide some indications and are summarized below:

- In 1939 a severe windstorm in Colorado created ideal breeding conditions for the Engelmann spruce beetle. When the epidemic was over approximately 80% of the trees in the affected area were killed. Water yields 25 years after the outbreak were approximately 10% greater than expected yields. Watershed aspect was determined to be the primary factor influencing runoff (Bethlahamy 1975)
- A MPB outbreak in 1975-77 killed approximately 35% of total timber in a 133 km^2 drainage in southwestern Montana. Comparison of hydrology data 4 years prior to and 5 years post epidemic indicated a 15% increase in water yield, a 2-3 week advance in the annul hydrograph, a 10% increase in low flow levels but little increase in peak flows (Potts 1984)
- An outbreak of spruce bark beetle in Bowron Lakes Park in the 1970's led to substantial salvage logging resulting in a clearcut that covered approximately 30% of the upper Bowron watershed. An assessment was completed in 1994 to determine the potential cumulative impacts of the salvage operation. Results of the assessment showed that while only 14% of the sub-basins within the watershed were at risk for increased peak flows, the majority of the area showed signs of increased surface erosion due to roads. In addition, much of the watershed experienced riparian harvesting leading to bank de-stabilization (Beaudry 1997)
- Evidence from snow-dominated watersheds in the southern interior of BC indicates that stream flow generating processes can be altered due to logging. Research at Penticton Creek indicate that a watershed with a 75% ECA and no roads can expect a 30% increase in daily peak flows (Schnorbus et al. 2004). This could translate into 10 year flood events post-harvest having the magnitude of 100 year events pre-harvest

3.0 EFFECTS OF FLOW ON WHITE STURGEON

The potential effects of flow on the life-history of sturgeon are most obvious during the spawning period. The following sections focus on the role of flow during both the pre-spawning migration and post-spawning survival of eggs and larvae.

3.1 Pre-Spawning

The first potential influence of flow on white sturgeon spawning is associated with the timing of the spawning event. During the spawning period, adults will congregate together and have been known to surface, breach and roll (Perrin et al. 2003). Telemetry studies completed on the Nechako population since 1999 have shown that during the majority of the year, white sturgeon remain in deep habitats and in particular are sedentary throughout the winter (October to March). A migration to spawning habitat occurs in the spring when both flow and temperature are increasing and in general spawning has been observed to occur at or around the peak flows (Parsley et al. 1993; Miller and Beckman 1996; Paragamian and Kruse 2001; Paragamian et al. 2001; Paragamian et al. 2002). Paragamian and Kruse (2001) identified that male sturgeon typically migrate to spawning areas first and spend an average of 30 days in the vicinity. Females then follow approximately one to two weeks later and only remain in the vicinity of the spawning area for an average of 10 days. However, the length of the spawning period does appear to vary from one system to the next. Fraser River studies indicated shorter spawning periods of 1 to 8 days based on retrieval of eggs (Perrin et al. 2003). In the Nechako, the spawning window appears to be similarly short.

During the spawning event documented in 2004, a congregation of approximately 36 individuals arrived at the spawning area beginning on May 15th and were gone by May 20th. Observations of spawning behaviour (including pairing of individuals and release of gametes) occurred on May 18th. Therefore, fish spent a maximum of 80 hours in the vicinity of the spawning habitat with the majority of the spawning being completed in one 36-hour period (Liebe et al. 2004). Studies have shown that in some systems there is a positive relationship between increasing flow and spawning migrations with small increases stimulating a migration (ex. Schaffter 1997). However, in other systems, such as the lower Fraser River, studies have suggested that spawning may occur during the declining limb of the hydrograph (Perrin et al. 2000) and that it is the time since the peak of freshet flows that is important. The latter appears to be the situation in the Nechako River since the spawning event observed in 2004 occurred on the descending limb of the hydrograph (Liebe et al. 2004).

Despite the apparent importance of flow to white sturgeon spawning, research has shown that other abiotic factors such as increasing temperature and photoperiod, which coincide with increasing flow in the spring, are also likely involved in the process (Paragamian and Kruse 2001; Paragamian and Wakkinen 2002). Research in the Kootenai River found that a >0.8 C decrease in water temperature could disrupt white sturgeon spawning (Paragamian and Wakkinen 2002) while in the Columbia River temperature in considered the primary environmental variable that determines the beginning of the spawning period (Parsley et al. 1993).

One theory to explain this reliance on multiple environmental factors is that there are separate cues to control the onset of physiological (gamete production) and behavioural (migration) changes associated with spawning. For example lengthening photoperiod and warming temperatures may trigger an endocrine response to produce gametes while peak flows and accumulated thermal units (ATU) trigger the migration to the spawning area. In a situation such as this it is unclear what effect there might be if changes in the river occur such that the environmental cues are premature, delayed, or asynchronous. In a situation where freshet flows are both increased in magnitude and occur earlier, such as would result from increased harvesting and associated reduced transpiration, the fish may receive the cues to migrate before being physiologically ready to spawn resulting in reduced spawning success.

3.2 Post-Spawning

Flow plays an important role during spawning, incubation and larval stages. White sturgeon are broadcast spawners with male and female fish releasing milt and eggs while side-by-side and fertilization taking place in the water column. Spawning sites are most often associated with turbulent and turbid river sections upstream of floodplains (Parsley and Beckman 1993; Perrin et al. 2003; Coutant 2004). The eggs have an adhesive coating and descend to the substrate where they adhere. After a short incubation period (7-8 days at 14-16ºC; Conte et al. 1998) the eggs hatch into yolk-sac larvae, which burrow further into the substrate and absorb the yolk-sac. During this period both eggs and larvae require a continuous supply of oxygen and are therefore dependent on flow to prevent desiccation.

Flow also controls both the deposition and removal of fine substrates, which can smother eggs or larvae (Kock 2004) and potentially prevent adhesion. When the larvae re-emerge from the substrate (8-9 days at 16-20ºC; Conte et al. 1998) they begin to actively feed and disperse to new habitats by swimming up into the water column and allowing the current to push them downstream as they drift back down to the substrate. They will continue this swim-up dispersal routine until they encounter suitable rearing habitat (Conte et al. 1988; Coutant 2004). The duration of the swim-up phase has been shown to be negatively correlated with water velocity, typically lasting from 1 to 6 days (Brannon et al. 1985 and Deng et al. 2002 in Coutant 2004).

Based on this summary of the general reproductive strategy of white sturgeon it can be seen that both temperature, which determines incubation time, and flow, which controls egg and larval dispersal, are key components of the post-spawning process. However, since each river system differs in its flow and temperature regimes, it is likely that each individual population of white sturgeon has evolved to respond to a specific set of environmental cues that allow spawning to take place during the period where there will be the greatest potential for success.

Due to the observation of spawning congregations and collection of fertilized eggs from the Nechako River in recent years (Liebe et al. 2004), as well as the relatively high survival of sturgeon larvae after age one (Ireland et al. 2002), it is theorized that the primary cause of recruitment failure in the Nechako likely manifests within the first year post-spawning (McAdam et al. 2005). Investigations of the substrate needs of larval and juvenile white sturgeon suggest that sedimentation resulting in infilling of interstitial spaces in the substrate may have a substantial impact on survival post-spawning (McAdam et al. 2005). Loss of these spaces can lead to increased predation of eggs and larvae (McAdam et al. 2005), while lack of clean surfaces for eggs to adhere to can result in them being flushed from the system (Coutant 2004). Lastly, in the Kootenai River, sand movement has been observed to smother eggs although geomorphic assessments of the Nechako suggest sand movement is not rapid enough in that system to cause egg burial (NHC and McAdam 2003 in McAdam et al. 2005).

Based on these observations, processes that result in increased sedimentation within the river are assumed to have a negative influence on white sturgeon spawning. Another theory for decreased survival during this period is related to the amount of flooded vegetation habitat available immediately downstream of the spawning areas. Coutant (2004) suggested flooded riparian habitat with a mixture of rock and vegetation would provide both abundant surfaces for egg adhesion as well as interstitial spaces for larvae to hide. In addition, an abundance of invertebrates in this area would provide ample sources of food. This theory is based on observations of spawning events from the Columbia, lower Fraser and Snake River, which tended to be more successful in higher flow years and in locations immediately upstream of sections of flooded riparian vegetation (Coutant 2004).

A situation where peak flows are accelerated could result in a decrease in flows during the period when peak flows would historically have occurred. This could result in insufficient discharge to incubate eggs and disperse larvae and prevent access to flooded vegetation habitat. Lastly, early spawning that coincides with the accelerated peak flows could result in substantial increases in incubation times of eggs and larvae due to lower temperatures and potential increases in mortality.

3.3 Summary of potential effects

Based on the a review of the literature associated with the potential effects of MPB infestation on hydrology as well as the role of flow in the life history of white sturgeon, the following general conclusions are provided:

- An increase in water yield resulting in increased peak flows would likely not have a negative effect on white sturgeon spawning. Current management practices in several white sturgeon systems include flow supplementation during the spawning period (ex Kootenai River, Paragamian and Wakkinen 2002)

- Acceleration in the timing of peak flow events may result in a premature relocation response such that the behavioural and physiological changes necessary for successful reproduction no longer coincide

- Acceleration in peak flows could result in a subsequent decrease in flows during the time when the peak historically would have occurred resulting in insufficient flow conditions for incubating eggs and dispersal of larvae and limit access to areas of flooded vegetation

- An increase in sedimentation associated with increased runoff may lead to loss of spawning habitat, infilling of interstitial spaces, and smothering of eggs and larvae

- It is unclear what effect, if any, changes to the hydrology of the system might have on the temperature regime of the Nechako. However, since temperature has a substantial influence on all life stages of fish (including growth rate, incubation times, energy budget, swimming efficiency etc) and since all species have an upper and lower thermal threshold for survival, potential fluctuations in temperature as a result of hydrologic changes should also be considered

4.0 HYDROLOGY OF THE NECHAKO RIVER

River flows in the Nechako River have been regulated since the construction of Kenny dam in the early 1950's.Prior to the construction of Kenny dam, the peak discharge occurred in June and minimum flows occurred in winter. Since regulation and in particular since 1980 the flow releases from the reservoir for the protection of Chinook and sockeye salmon has dictated the shape of the annual hydrograph in the match at the river upstream from its confluence with the Stuart River.

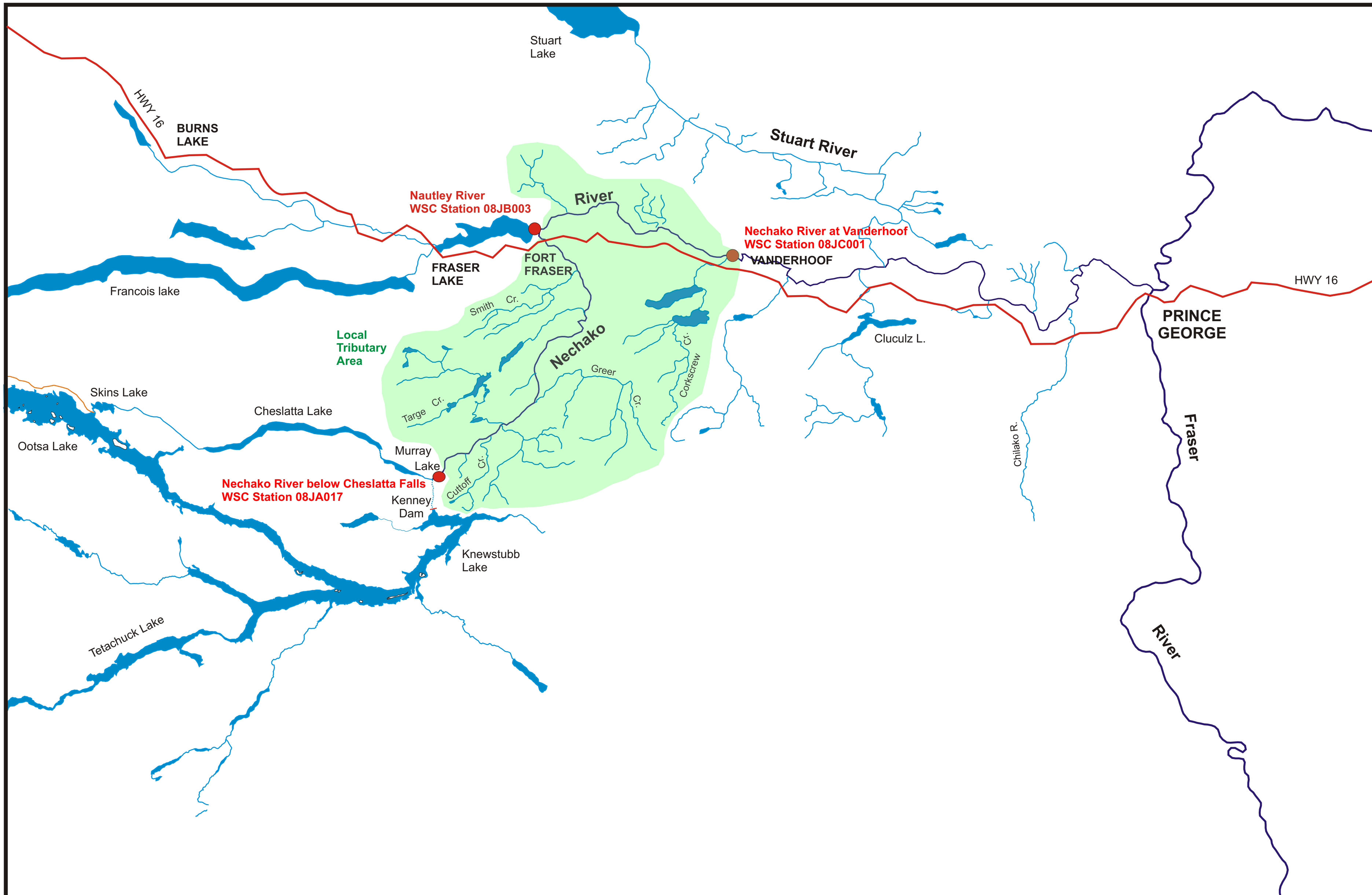
Since the early 1950's flows in the Nechako River have been measured by the Water Survey of Canada at town of Vanderhoof (WSC Station 08JC001). Flows contributing to the Nechako River from the Francois Lake drainage have been measured in the Nautley River, immediately above its confluence with the Nechako River (WSC 08JB003). In 1980, another water survey of Canada gauging station was established in the Nechako River below Cheslatta Falls (WSC 08JA017) (Figure 1).

As the releases from the Nechako Reservoir at the Skins Lake spillway have remained relatively constant over periods from three to seven months during each year since 1980, the variation in river flow downstream from Cheslatta Falls in all months except July and August is due to the local runoff, and especially during April, May and June. Further, snowmelt dominates the timing and volume of the runoff to this section of the river each spring. During the remainder of the year runoff in local drainages will be dominated by local rain events and river flows can vary substantially between months and between local drainages as storms are typically quite localized. Therefore in order to examine whether the timing of the runoff during sturgeon spawning (in early June) has been an affected by the infestation of the mountain pine beetle and associated loss of forest cover, the examination of basin hydrology basin focused on the river between Cheslatta falls and Vanderhoof, where sturgeon spawning was documented (Triton, 2004).

To examine the effect of the infestation of the mountain pine beetle on the river flows and specifically the timing of the tributary inflows, the local runoff was determined by subtracting the river flows recorded in the Nechako River below Cheslatta Falls and from the Nautley River from the recorded flows in the Nechako River at Vanderhoof. Appropriate adjustments were made to allow for the timing of flow between the gauging stations and the remainder represents the estimated inflow of water from the local drainages. An example of the runoff pattern during the spring period is shown in Figure 2 and annual estimates of this runoff for the years 1981 to 2004 are presented graphically in Appendix 1A.

To examine the differences in the inflow that might result from differences in inter-annual snowpack, the snowpack records (snow water equivalent) for the Skins Lake Spillway recording station were obtained from the Ministry of Environment (MOE) Hydrology Section. As experience has shown that the April 1 snow pack provides the most reliable estimate of the volume of snowmelt runoff to be expected in any year only the records for April 1 were used for comparison. Further, as the snow melt runoff would occur entirely during the period from April 1 to the end of June, and as sturgeon spawning has been recorded as occurring typically in June (Triton, 2004) only flow records between April 1 and June 30 were analyzed. In addition, a scatter plot of snow water equivalent data and unit runoff was produced to determine if there was a strong or weak relationship between the snow pack data and unit runoff.

Finally, a review of preliminary water temperature data from the Nechako River below Cheslatta Falls WSC gauging station (1987 to 2004) and the Vanderhoof WSC gauging station (2000 to 2004) was also conducted to identify potential decreases in water temperature during May and June.



Nechako Hydrology Review

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FIGURE 1. Water Survey of Canada hydrometric stations and local tributary area in the Nechako River watershed

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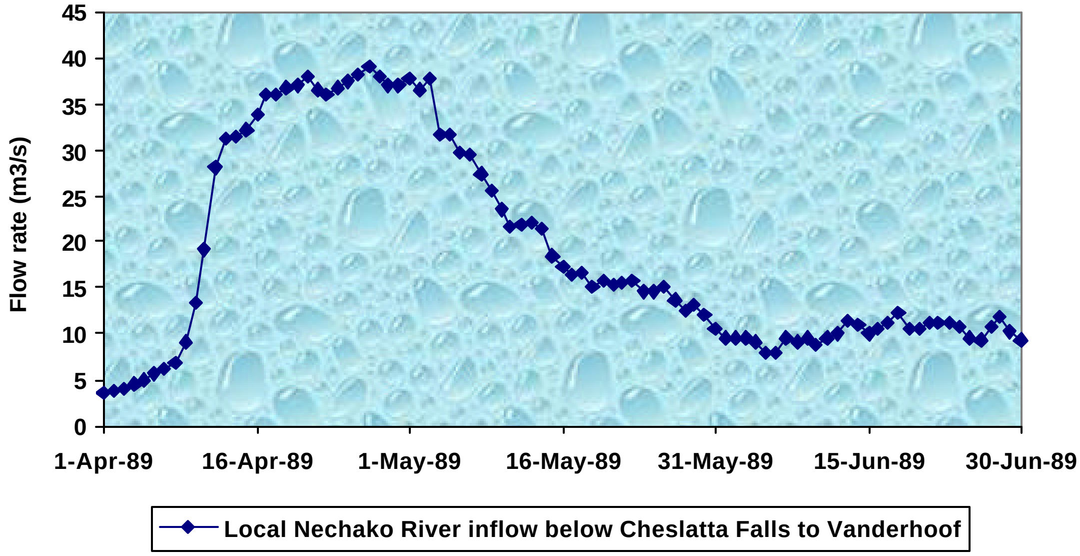
Figure 2. Local Nechako River inflow below Cheslatta Falls to Vanderhoof (m3/s) from April through June, 1989



5.0 RESULTS AND DISCUSSION

5.1 Runoff timing and rate

The examination of the data presented in Appendix 1 shows that local runoff starts to increase in early April, rising to a peak from mid April through mid May and receding to a minimum in late June. This response is consistent with the melt of the low elevation snow pack in the watershed.

There appears to be no distinct difference between the hydrographs for the period from 1981 to 1999 and 2000 to 2004 (the latter period being when the MPB infestation extended into this section of the watershed). As noted earlier, the peak local runoff can occur as early as the second week of April or as late as the third week of May and there was no difference between the two time periods. As well, the lowest peak inflow rates (<28.5 m^3/s) occurred in 1981, 1988, 1990, 1993 and 1995 and in 2000, 2001, 2003 and 2004. The highest peak inflow rates occurred in 2002 and 1997, reaching 89m^3/s and 129 m^3/s respectively. The remaining peak inflow for the period of record ranged from >30 m^3/s to <80 m^3/s. No increase in peak flow rate was observed between 2000 and 2004.

5.1.1 Local volume

The monthly total local runoff volume (in dam^3) between 1982 and 1999 ranged from 52,139 dam^3 in April to a high of 65,156 dam^3 in May. The average local volumes between 2000 and 2004 ranged from 41,420 dam^3 in April to 72,700 dam^3 in May. Both the May and June average local volumes were higher between 2000 and 2004 than those between 1982 and 1999, with a difference of 7,544 dam^3 between the May volumes and an 18,738 dam^3 difference between the June volumes (Appendix 1B). The greater local runoff volume in 2002 may have been an indication of an effect of the MPB infestation. However, this is not consistent with the unit runoff data presented below.

5.2 Runoff relationship to snow pack

The comparison of the snow pack data and local inflows revealed no obvious differences between April snow water equivalent and April runoff (m^3/km^2) values between 1982 to 1999 and 2000 to 2004 (Figure 3). The April snow water equivalent data from 2000 through 2004 ranged from 0 to 92 mm, below the average snow water equivalent of 95 mm between 1981 and 1999 (Appendix 1C). The associated unit runoff in m^3/km^2 between 2000 and 2004 averaged 11.94 dam^3/km^2, also below the average unit runoff of 15.03 dam^3/km^2 between 1981 and 1999.

The scatter plot indicated a weak relationship between the snow water equivalent and unit runoff data, with an R^2 value of 0.0417 (Figure 4). This weak relationship shows the spring snow pack is only responsible for part of the local runoff, or the Skins Lake snow course data are not representative of the general snow pack conditions in the basin. The uncontrolled portion of the runoff relationship is linked to local spring rain events.

5.3 Water temperature

The average water temperatures between 1987 and 1999 below Cheslatta Falls in May and June were 8.2 °C and 13.2°. Between 2000 and 2003, the average water temperatures were slightly lower and included averages of 7.33 °C in May and 13.09 °C in June. Between 2000 and 2004 the water temperatures at Vanderhoof indicate increasing average water temperatures for the months of May and June, as follows:

- **May-00** *7.4°C*
- **Jun-00** *12.9°C*
- **May-01** *9.3°C*
- **Jun-01** *14.26°C*
- **May-02** *8.4°C*
- **Jun-02** *14.11°C*
- **May-03** *10.2°C*
- **Jun-03** *16.2°C*
- **May-04** *12.0°C*
- **Jun-04** *17.6°C*

Water temperature data collected at the Vanderhoof WSC station from May and June from 2000 to 2004 are shown in Figure 5. Mean daily water temperatures for May and June at this station are summarized in Appendix 1D.

Figure 3. Comparison of SWE and Unit runoff (dam^3/km^2) from 1981 to 2004

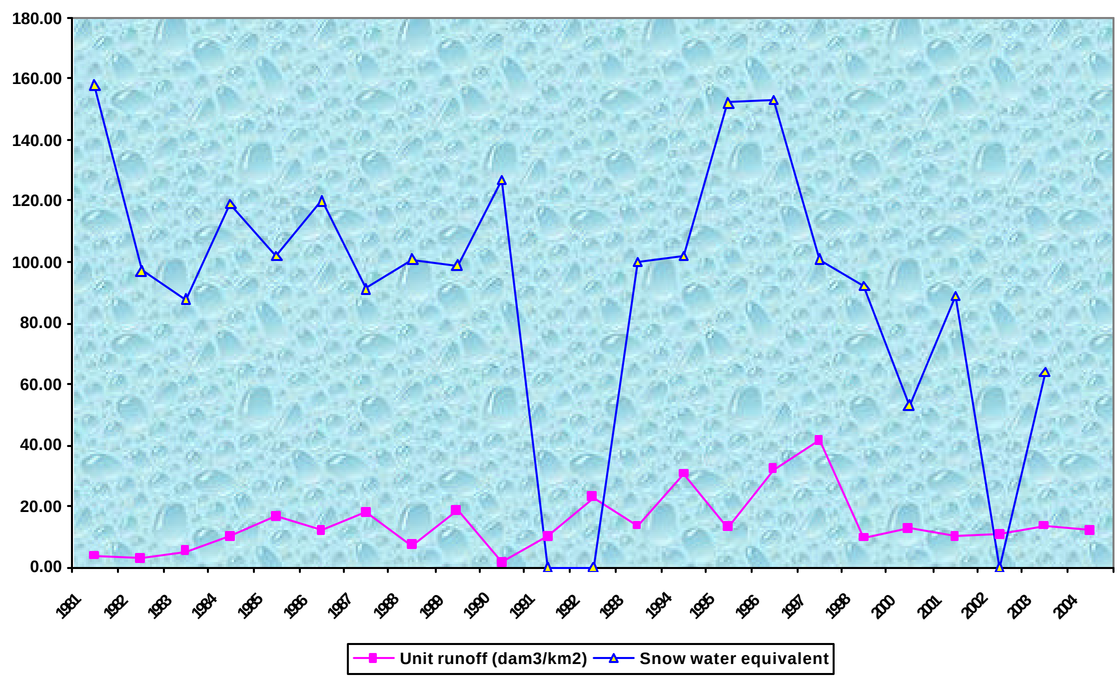


Figure 4. Comparison of snow water equivalent data (mm) and unit runoff (dam3/km2) from 1981 to 2004

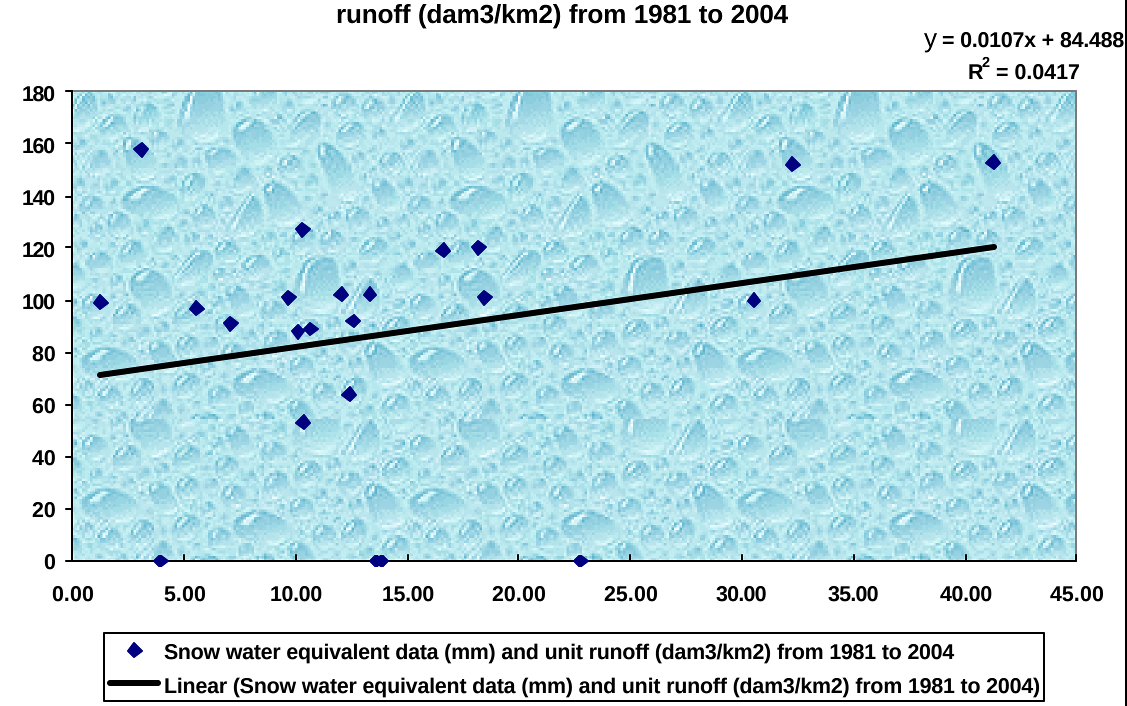
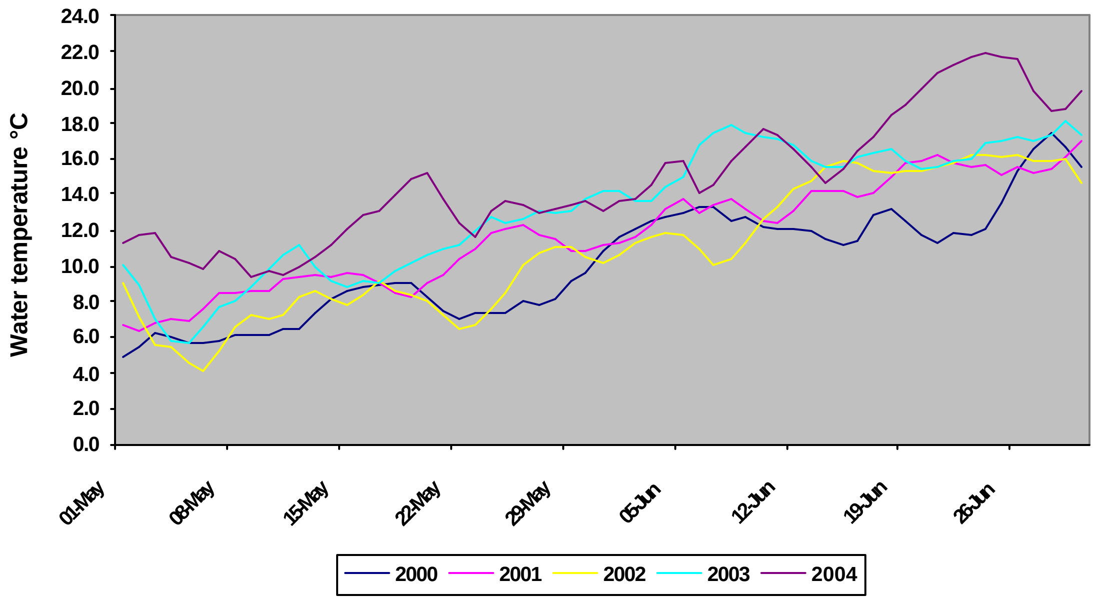


Figure 5. May and June daily average water temperatures (°C) in the Nechako River at Vanderhoof between 2000 and 2004.



6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

No obvious shift in runoff timing, change in water temperature or increase in flow rate that could be linked to the MBP infestation was observed in the local flow dataset, although increases in May and June monthly flow volumes and mean daily water temperatures were observed between 2000 and 2004. The average April snowpack data (snow water equivalent data) and associated flow volumes from 2000 and 2004 are slightly lower than those from 1982 through 1999, but otherwise show little variation.

6.2 Recommendations

Routing effects associated with regulation may be resulting in significant error in the estimates of local runoff that could mask changes in runoff timing. The method of subtracting flows between gauging stations may introduce errors in the data due to flow times between stations. Our model allowed for a one-day lag between the Nechako River below Cheslatta Falls and Vanderhoof. A more refined model allowing for part days lag times may be more accurate. An alternative approach to identifying the potential impacts of the current MPB infestation on hydrology in the Nechako watershed would be to review flow data from Van Tine Creek (WSC 08JA014). Van Tine Creek is located in the upper Nechako watershed and has been gauged since 1974, well before the beginning of the current outbreak. It is unaffected by regulation and does not have significant storage, making it a suitable candidate for studies of potential changes in the hydrological regime resulting from the MPB infestation.

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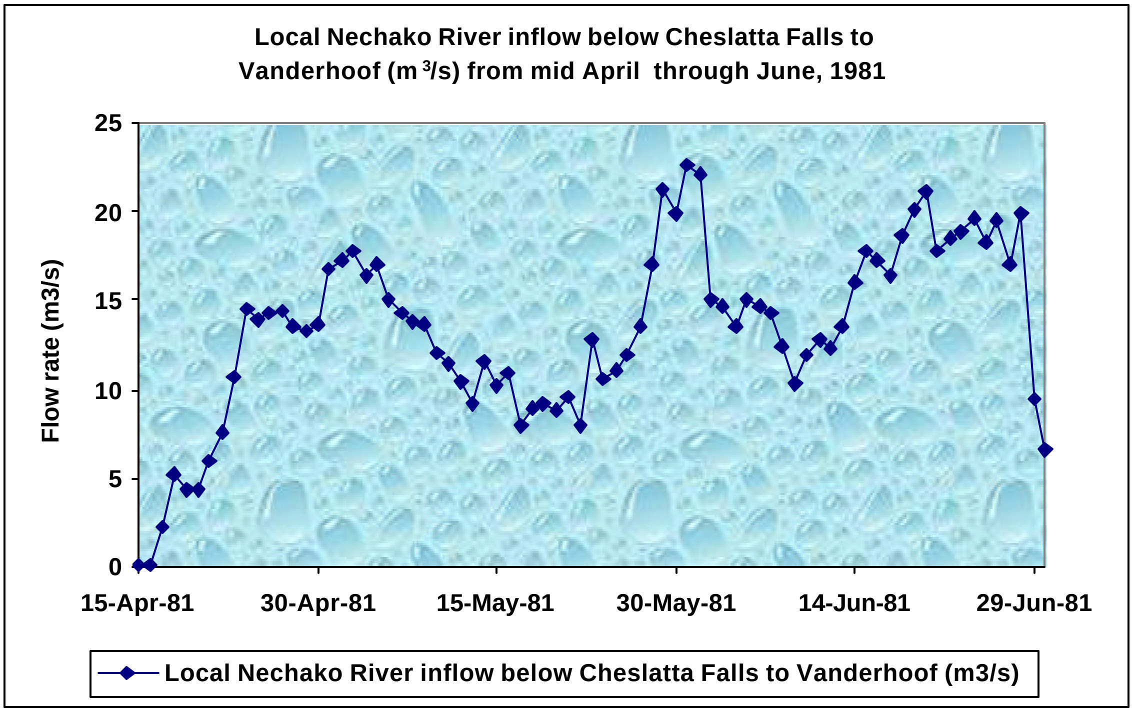
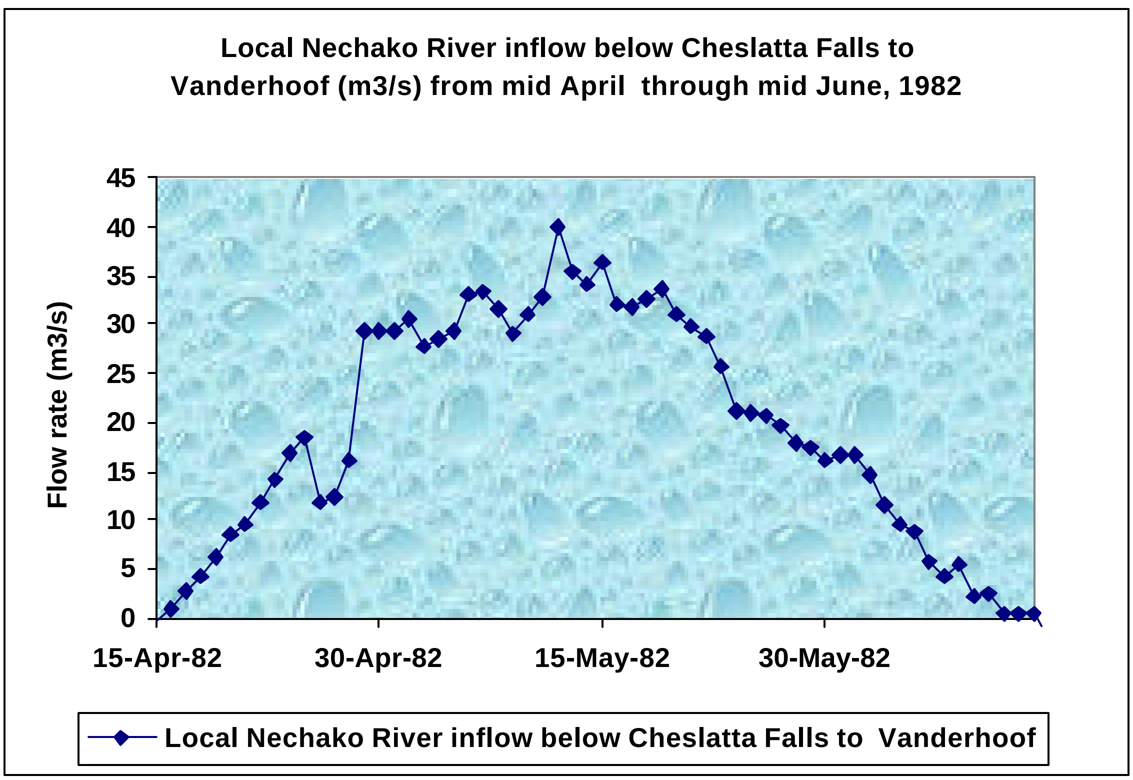
APPENDIX 1A: HYDROGRAPHS OF LOCAL FLOW AT VANDERHOOF FROM 1981 TO 2004





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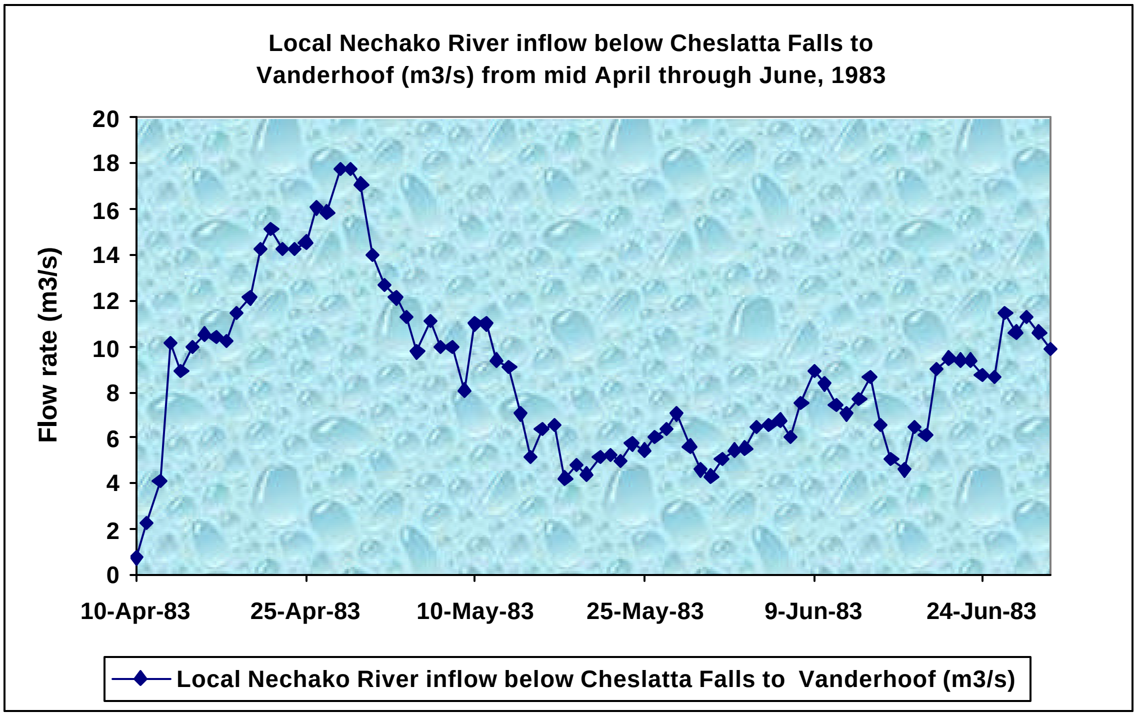

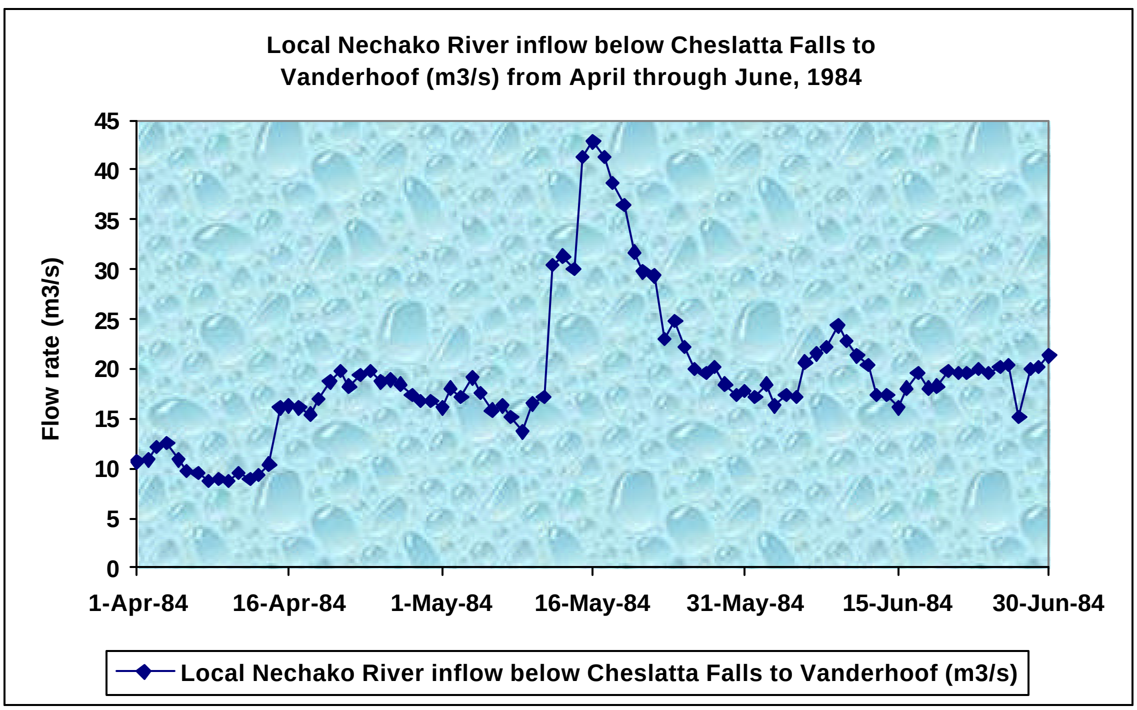

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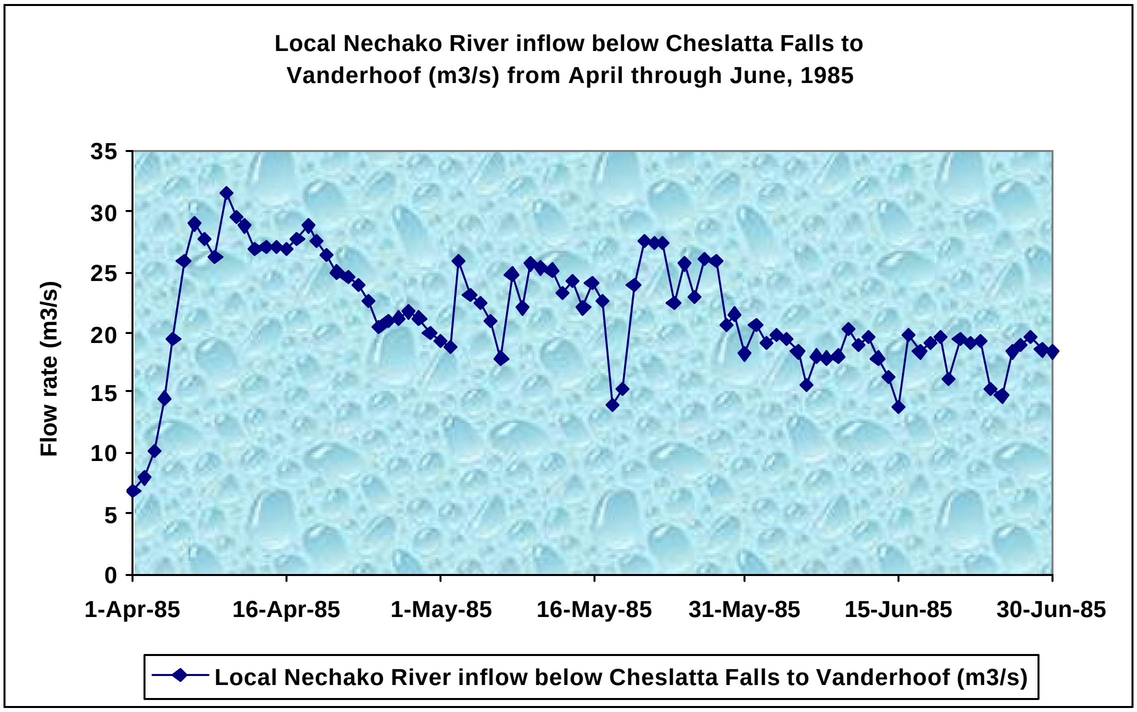

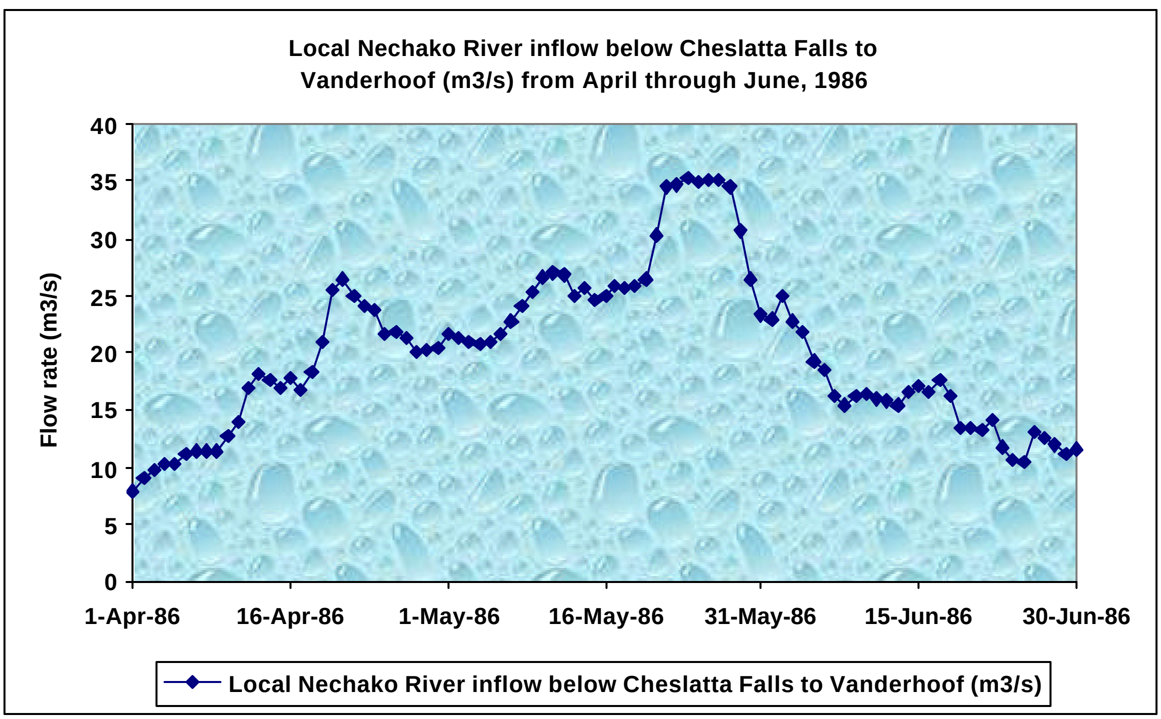

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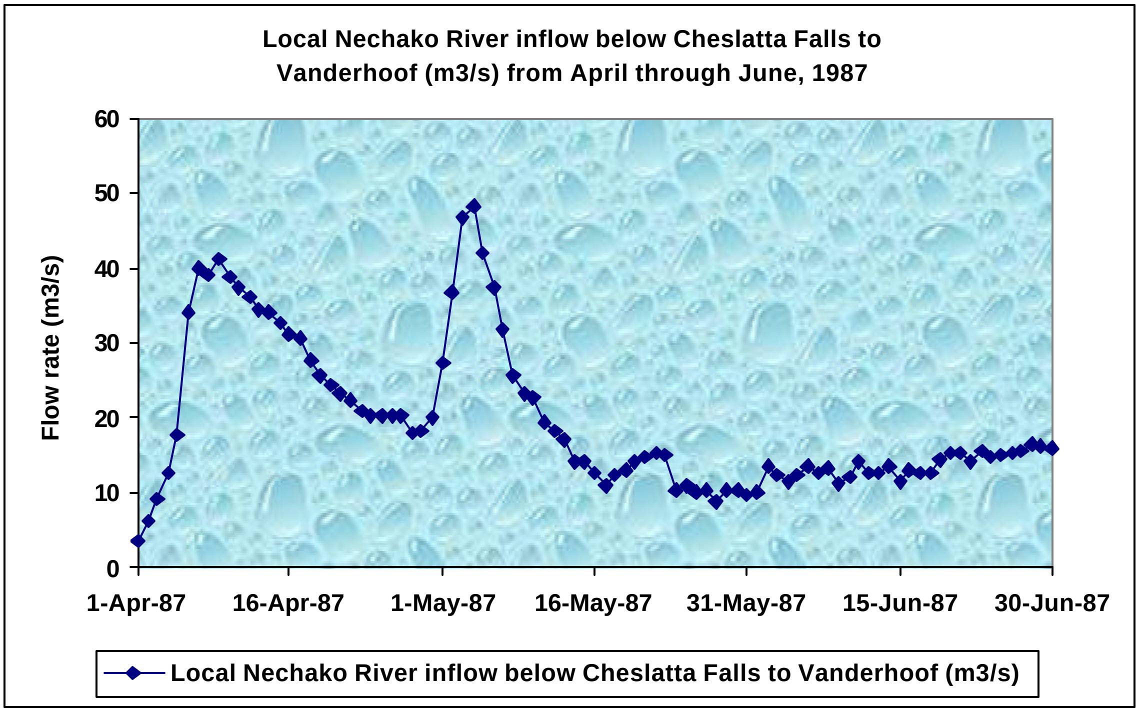
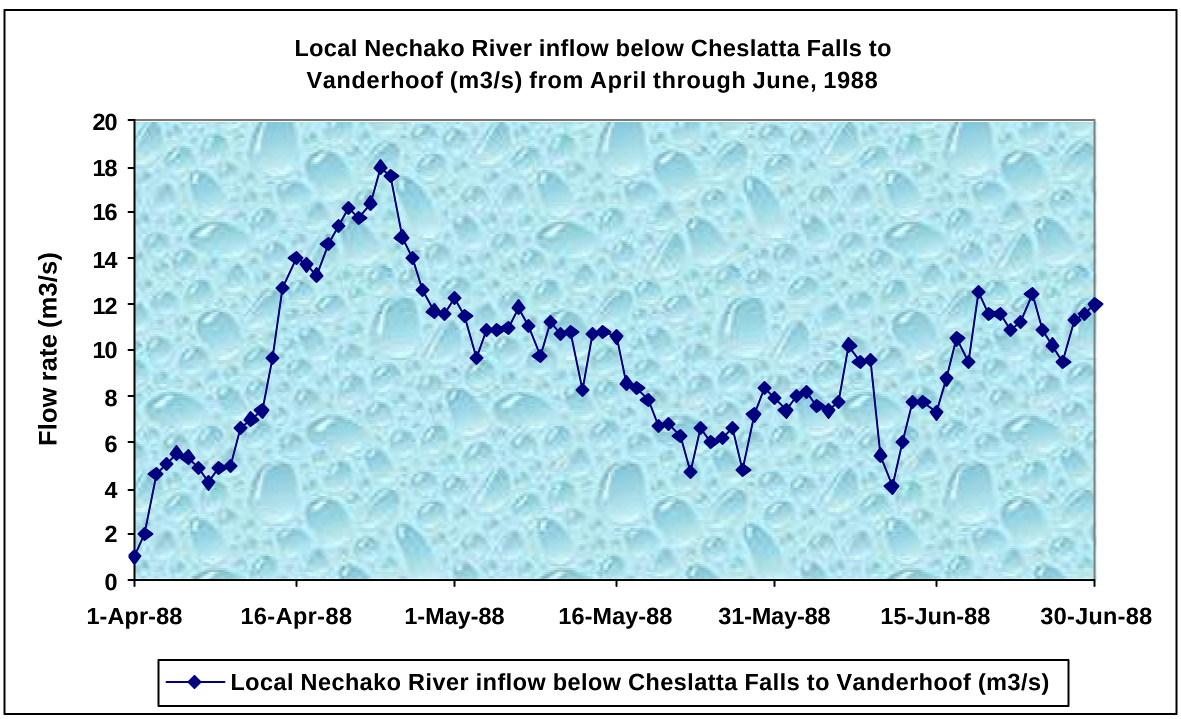
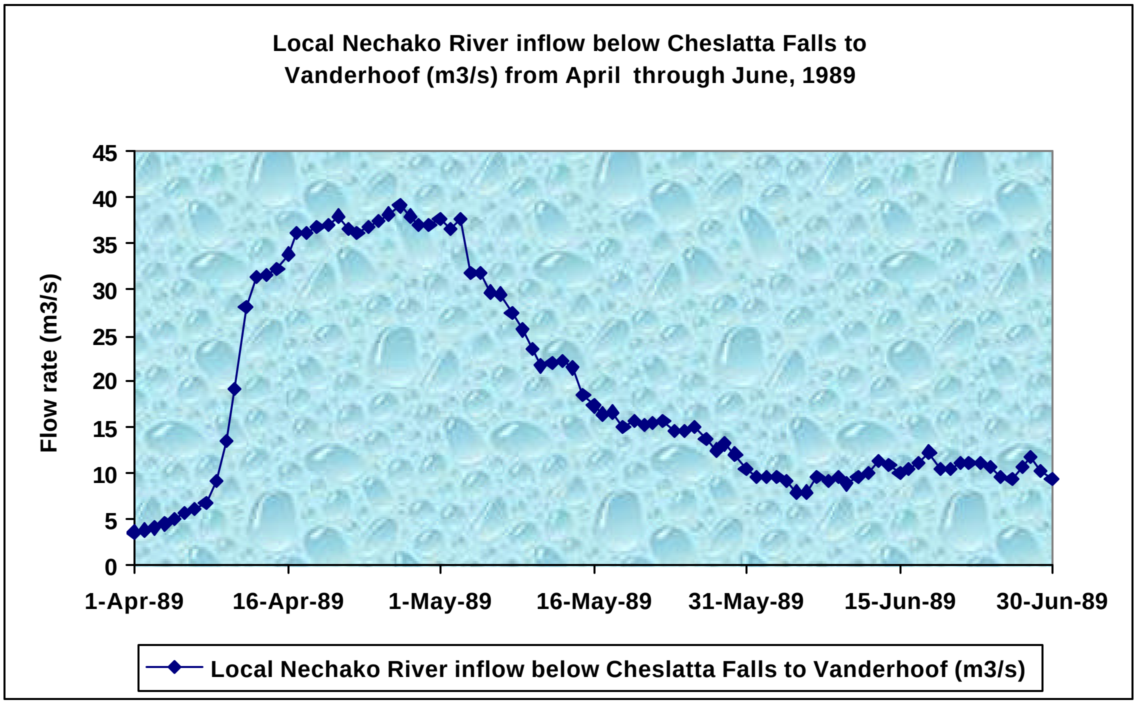
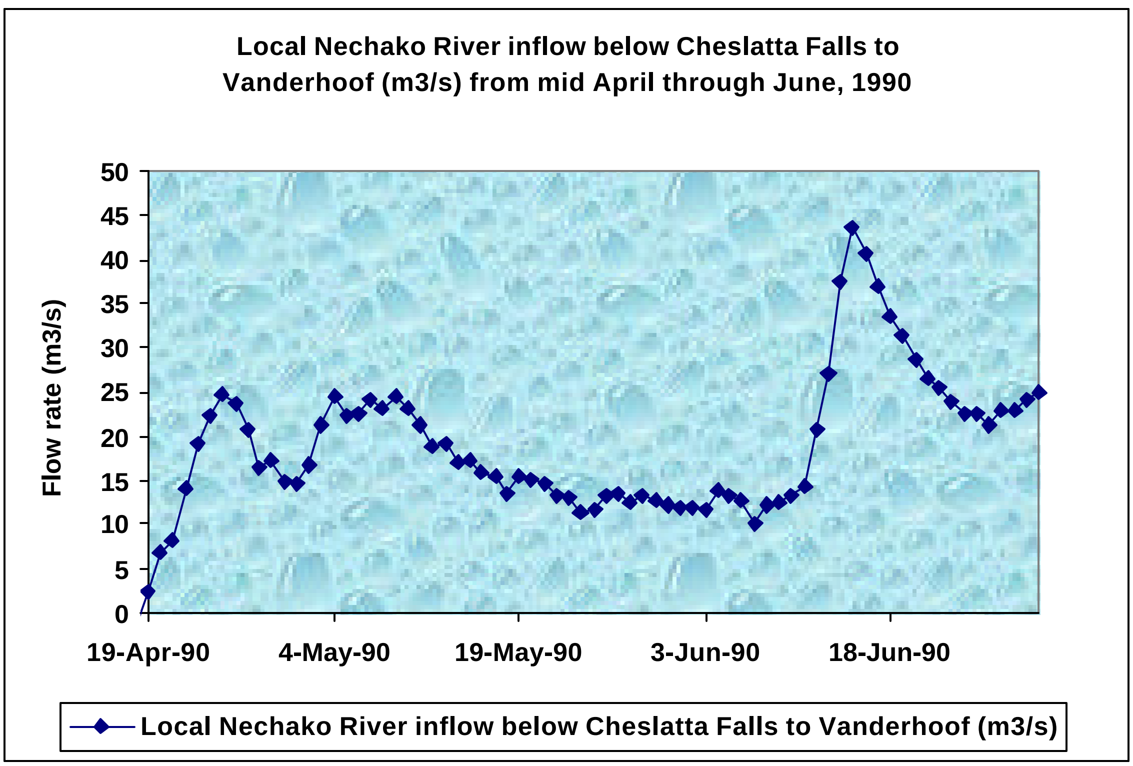




APPENDIX 1A: HYDROGRAPHS OF LOCAL FLOW AT VANDERHOOF FROM 1981 TO 2004





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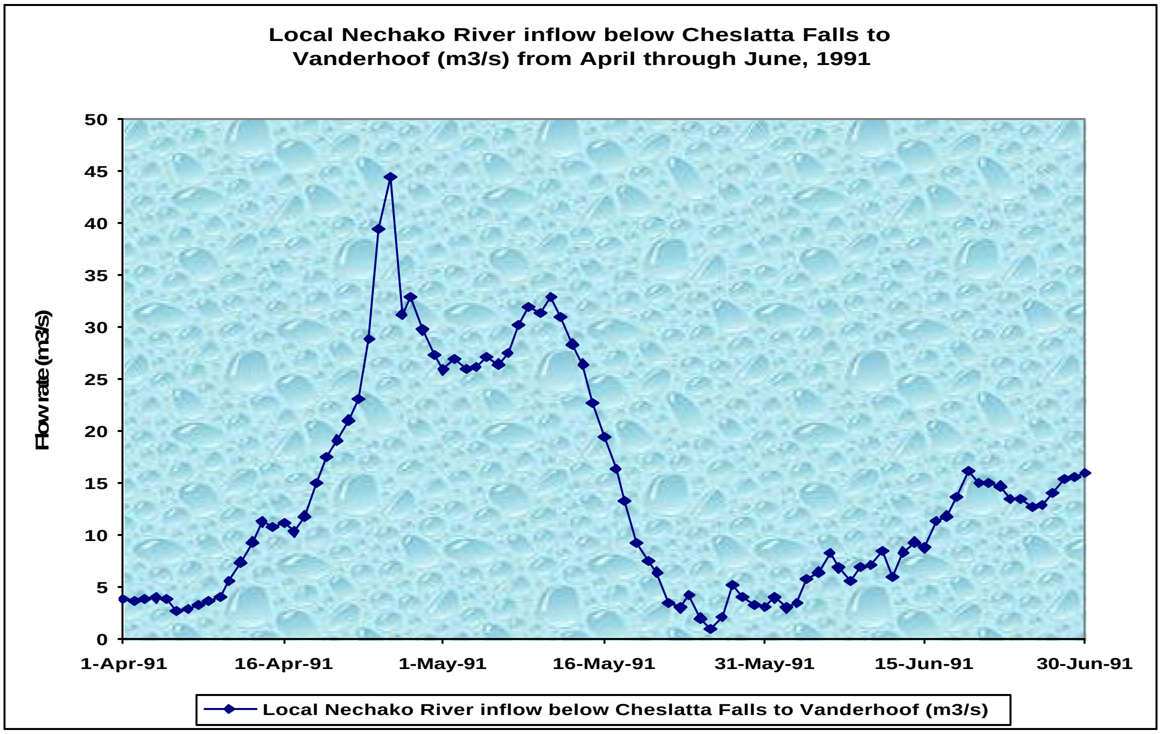

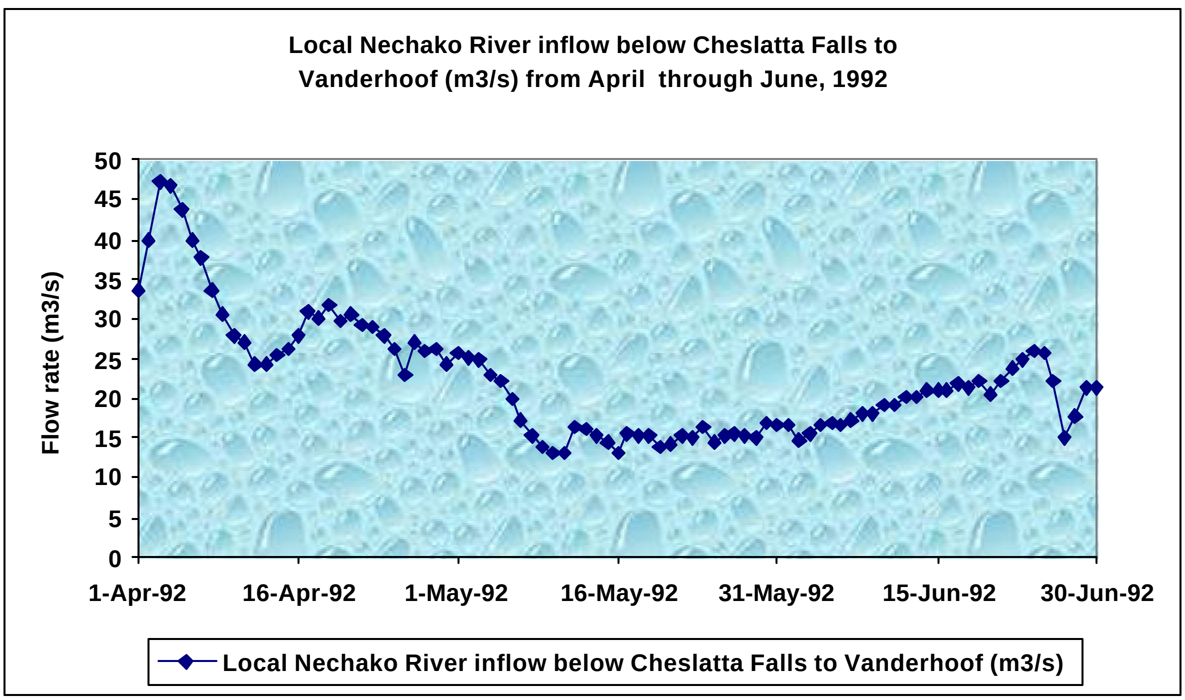

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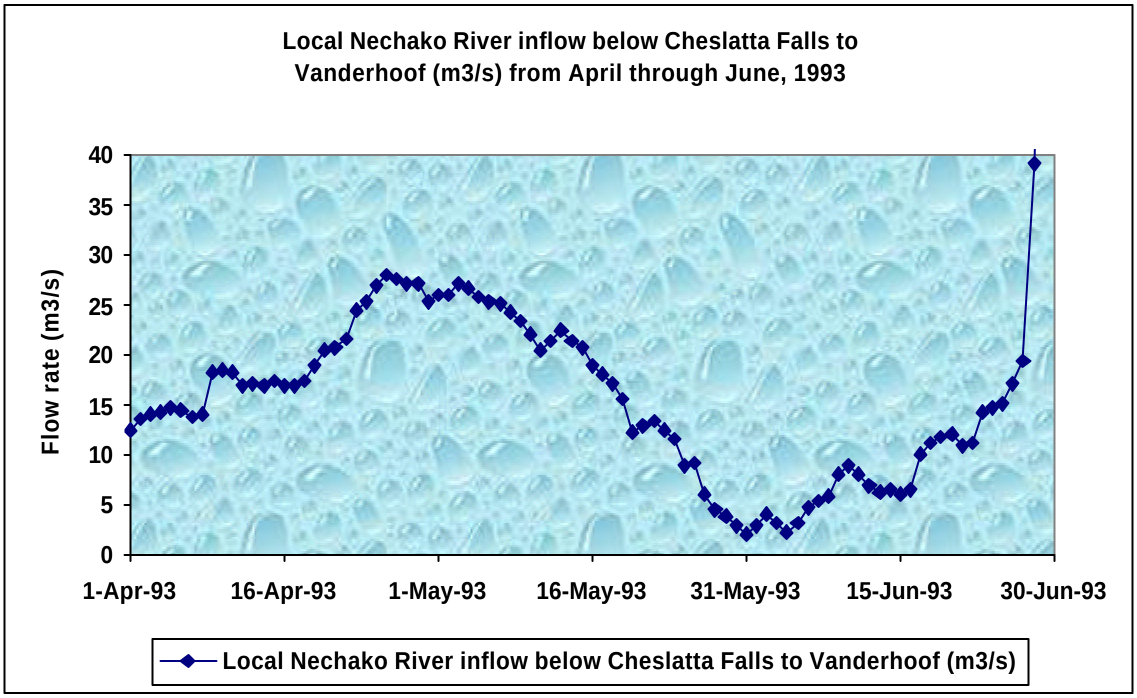

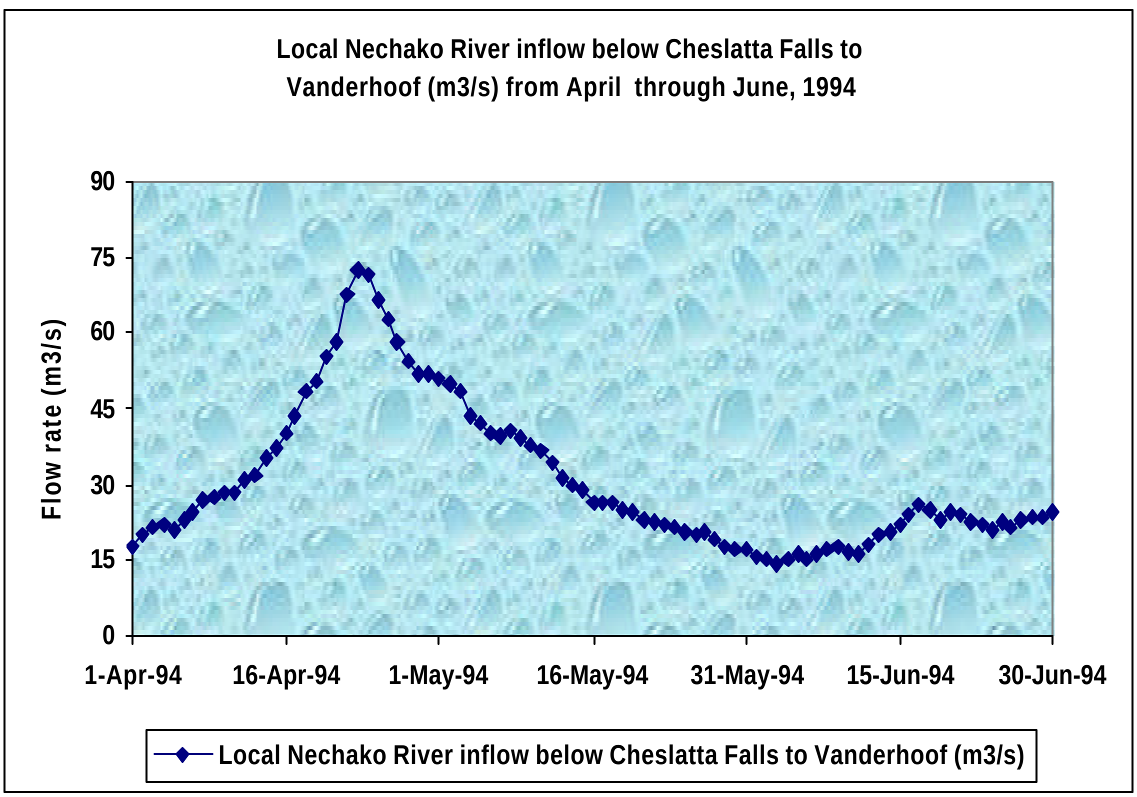

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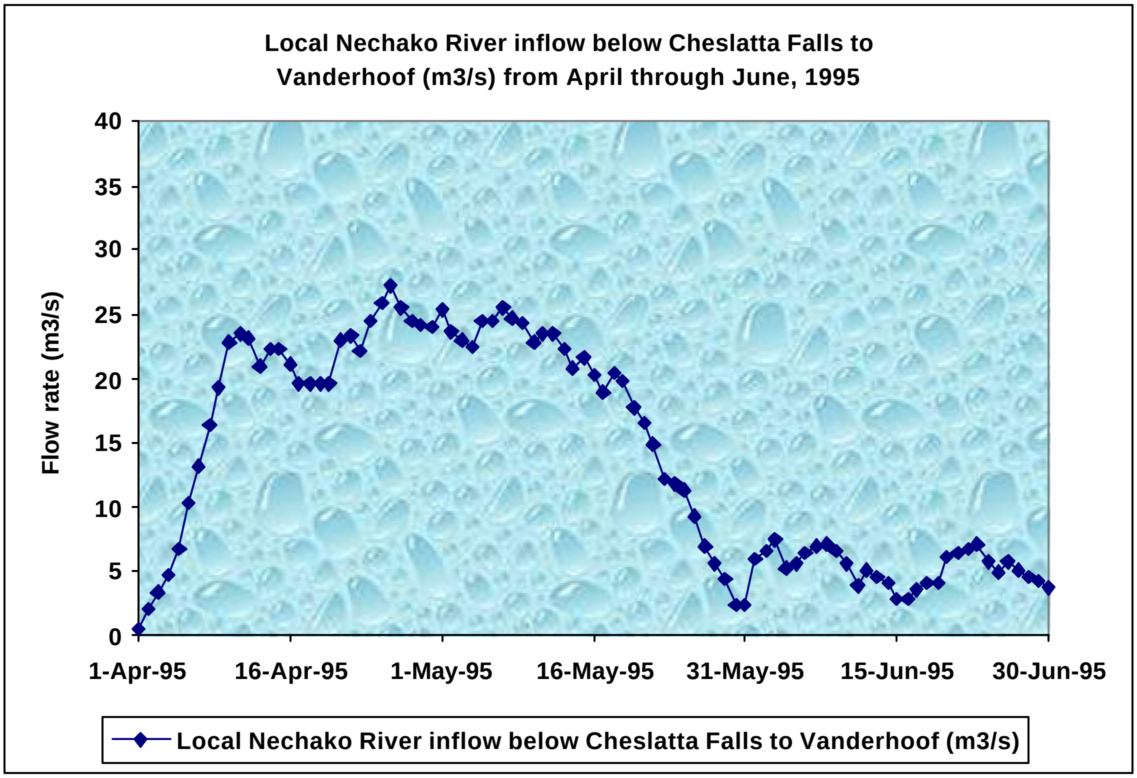

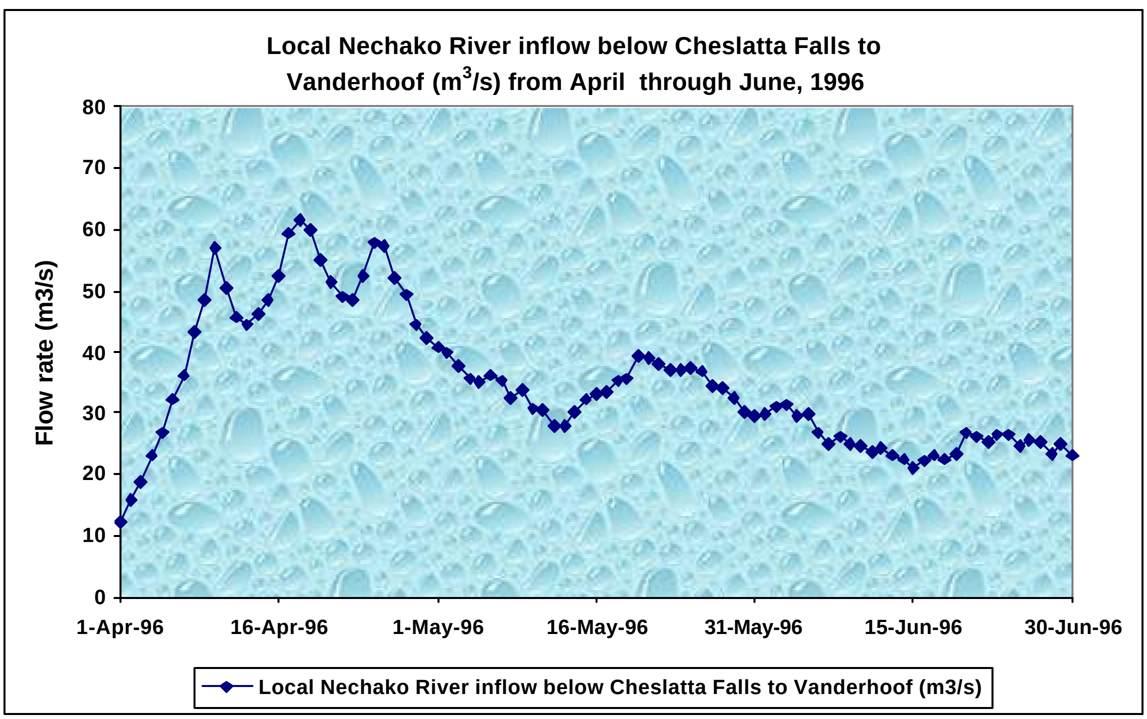

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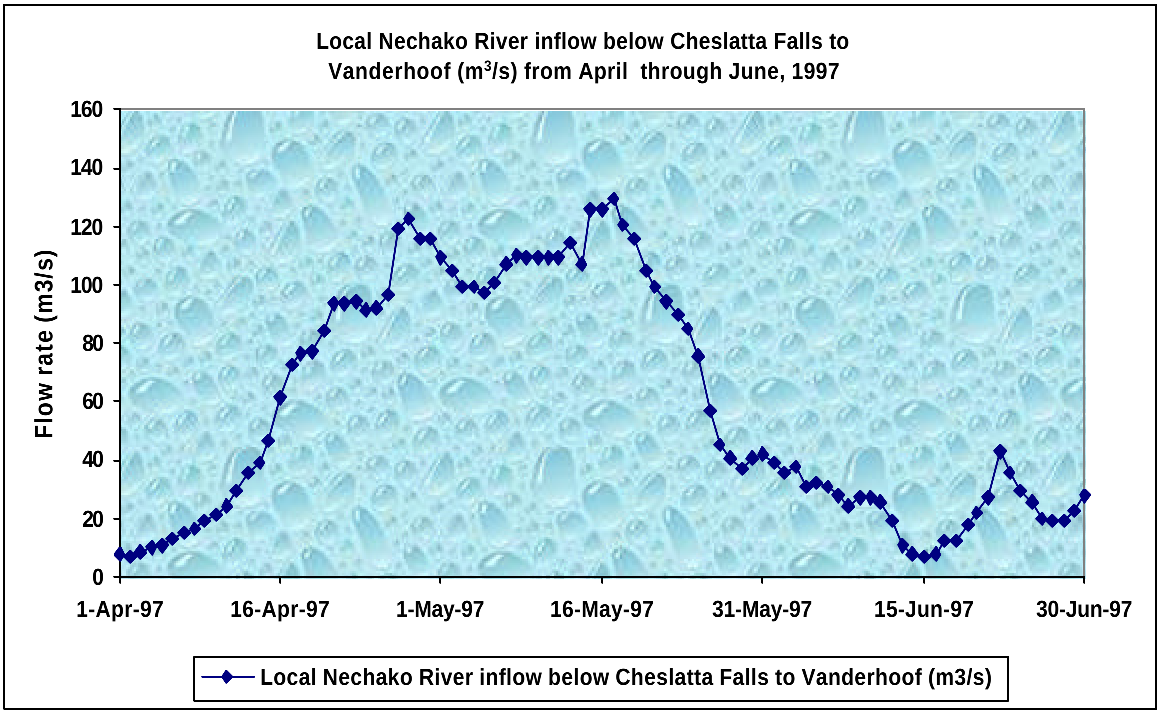
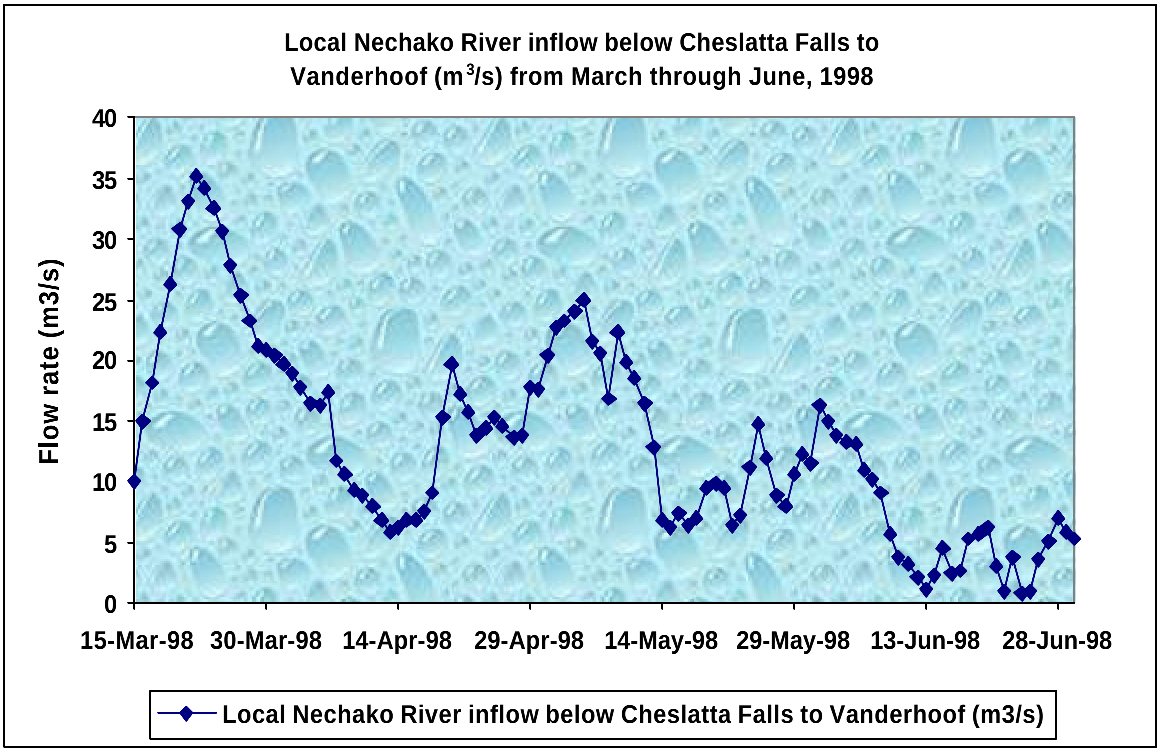
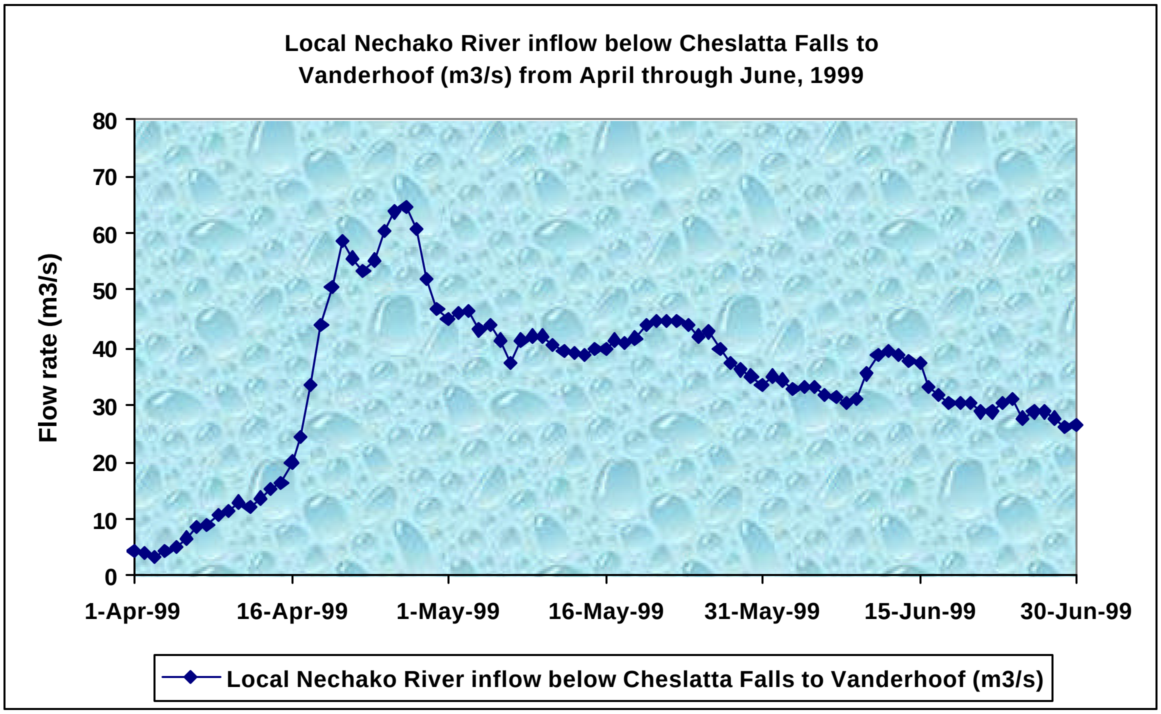
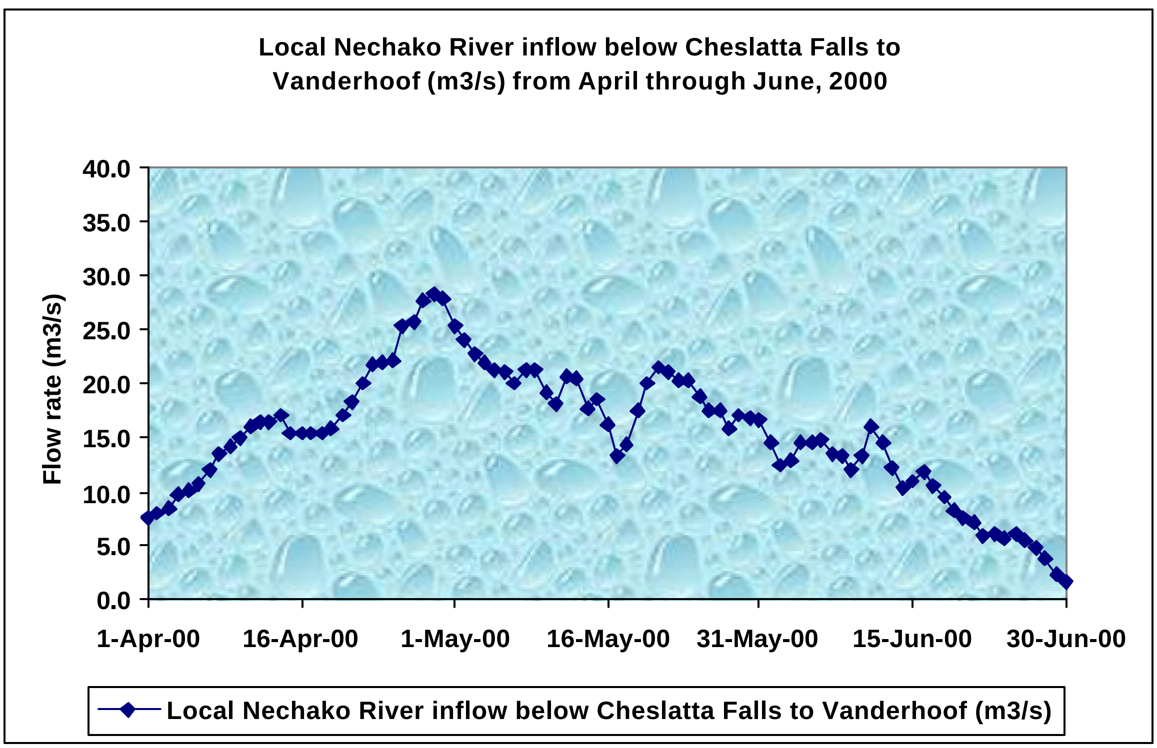




APPENDIX 1A: HYDROGRAPHS OF LOCAL FLOW AT VANDERHOOF FROM 1981 TO 2004





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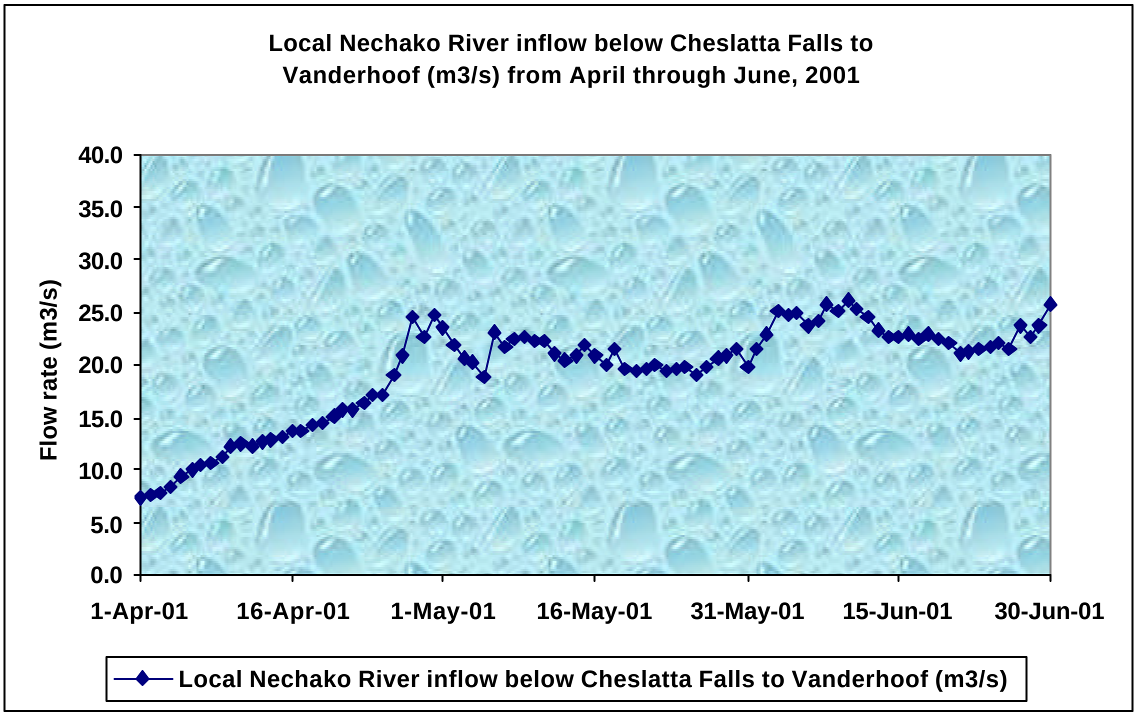

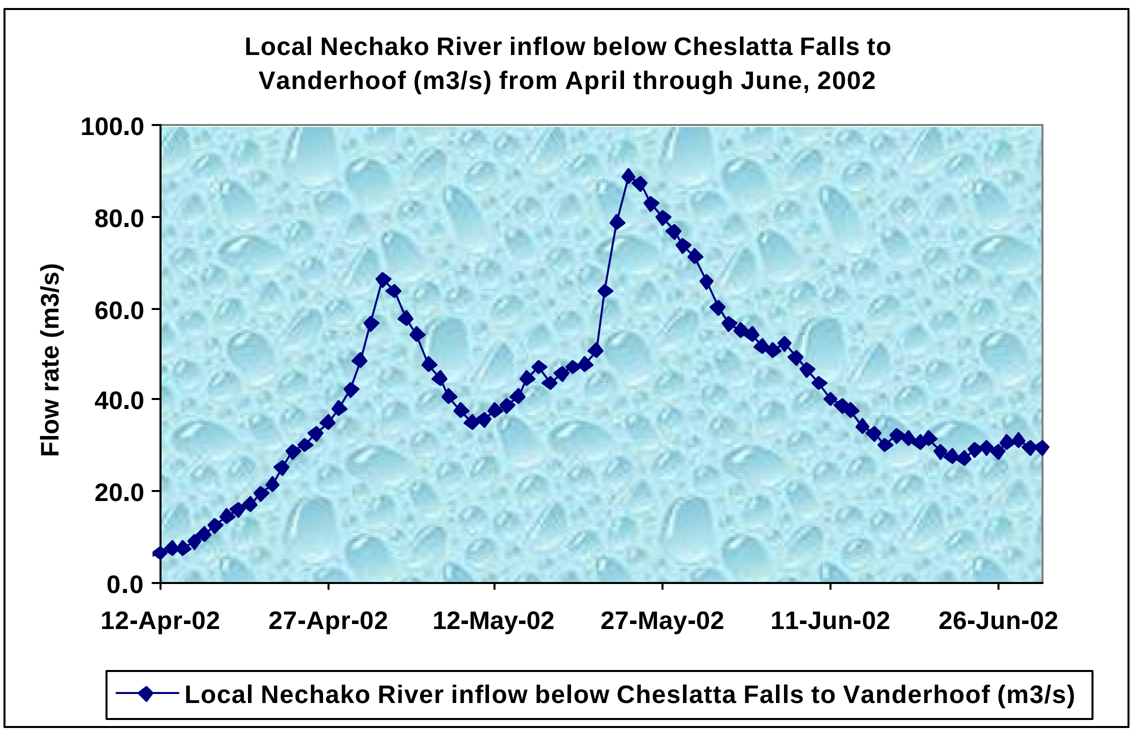

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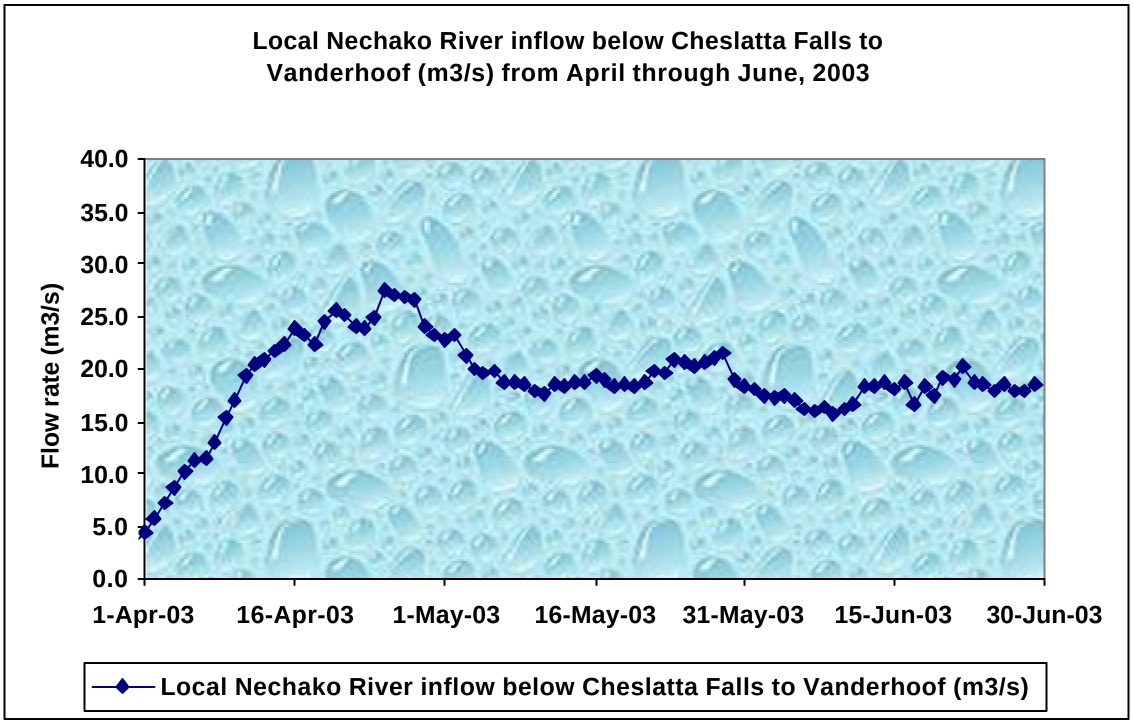

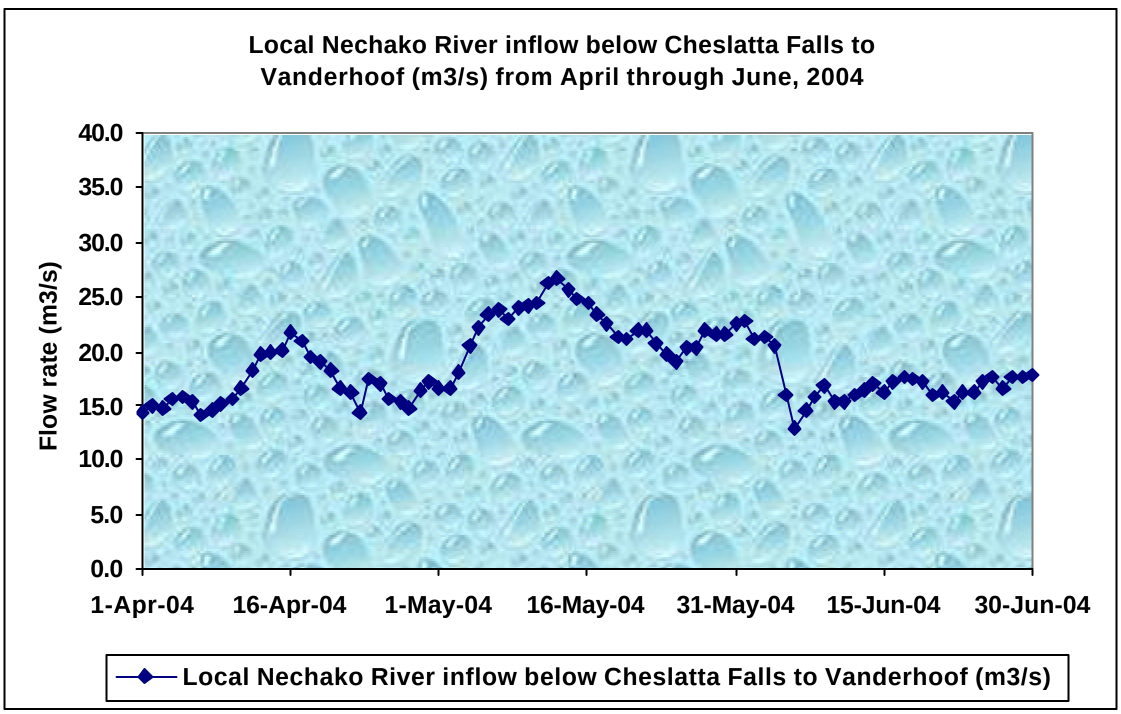

APPENDIX 1B: ESTIMATES OF LOCAL AREA VOLUMES IN DAM^3

Year	VANDERHOOF VOLUME (DAM^3)			NAUTLEY VOLUME (DAM^3)			BELOW CHESLATTA VOLUME (DAM^3)			LOCAL AREA VOLUME (DAM^3)		
	Apr	May	Jun	Apr	May	Jun	Apr	May	Jun	Apr	May	Jun
1981	204,000	394,000	463,000	39,300	152,000	207,000	151,000	201,000	213,000	13,700	41,000	43,000
1982	192,000	406,000	423,000	24,200	153,000	258,000	157,000	176,000	158,000	10,800	77,000	7,000
1983	155,000	245,000	247,000	24,800	84,400	81,000	111,000	140,000	147,000	19,200	20,600	19,000
1984	211,000	354,000	338,000	40,900	115,000	136,000	135,000	174,000	151,000	35,100	65,000	51,000
1985	217,000	357,000	398,000	32,300	121,000	187,000	127,000	175,000	162,000	57,700	61,000	49,000
1986	192,000	300,000	340,000	27,200	68,800	146,000	123,000	159,000	153,000	41,800	72,200	41,000
1987	232,000	415,000	340,000	46,800	168,000	147,000	122,000	194,000	158,000	63,200	53,000	35,000
1988	177,000	279,000	327,000	33,400	115,000	156,000	119,000	139,000	147,000	24,600	25,000	24,000
1989	190,000	373,000	289,000	36,900	174,000	136,000	89,000	142,000	126,000	64,100	57,000	27,000
1990	441,000	524,000	375,000	63,700	163,000	170,000	373,000	297,000	146,000	4,300	64,000	59,000
1991	279,000	432,000	312,000	39,200	189,000	147,000	204,000	194,000	138,000	35,800	49,000	27,000
1992	318,000	386,000	325,000	134,000	212,000	146,000	105,000	129,000	130,000	79,000	45,000	49,000
1993	191,000	361,000	365,000	38,900	148,000	162,000	104,000	167,000	163,000	48,100	46,000	40,000
1994	360,000	515,000	366,000	118,000	271,000	175,000	136,000	161,000	138,000	106,000	83,000	53,000
1995	222,000	428,000	322,000	52,700	217,000	176,000	123,000	163,000	131,000	46,300	48,000	15,000
1996	347,000	598,000	520,000	104,000	317,000	293,000	131,000	188,000	162,000	112,000	93,000	65,000
1997	419,000	1,240,000	1,270,000	91,800	598,000	493,000	184,000	399,000	728,000	143,200	243,000	49,000
1998	221,000	394,000	306,000	43,400	182,000	146,000	144,000	175,000	143,000	33,600	37,000	17,000
2000	171,000	300,000	276,000	34,000	91,800	106,000	93,300	158,000	144,000	43,700	50,200	26,000
2001	153,000	285,000	343,000	22,800	79,500	130,000	94,300	151,000	153,000	35,900	54,500	60,000
2002	165,000	580,000	690,000	38,600	242,000	403,000	89,300	190,000	185,000	37,100	148,000	102,000
2003	167,000	281,000	280,000	33,400	95,200	98,700	86,300	134,000	134,000	47,300	51,800	47,300
2004	195,000	331,000	282,000	46,900	122,000	97,500	105,000	150,000	140,000	43,100	59,000	44,500

APPENDIX 1C: UNIT RUNOFF CALCULATIONS FOR LOCAL INFLOW AND SNOW WATER EQUIVALENT DATA.

Year	Nechako River at Vanderhoof			Nautley River			Nechako River below Cheslatta Falls			Local inflow dam^3			Unit runoff dam^3 / km^2			Snow water equivalent data		
	Apr	May	Jun	Apr	May	Jun	Apr	May	Jun	Apr	May	Jun	dam^3/km^2	dam^3/km^2	dam^3/km^2	April	May	June
1981	204000	394000	463000	39300	152000	207000	151000	208000	213000	13,700	34,000	43,000	3.95	9.80	12.39	0	0	0
1982	192,000	406,000	423,000	24,200	153,000	258,000	157,000	176,000	158000	10,800	77,000	7,000	3.11	22.19	2.02	158	100	0
1983	155,000	245,000	247,000	24,800	84,400	81,000	111,000	140,000	147000	19,200	20,600	19,000	5.53	5.94	5.48	97	0	0
1984	211,000	354,000	338,000	40,900	115,000	136,000	135,000	174,000	151000	35,100	65,000	51,000	10.12	18.73	14.70	88	0	0
1985	217,000	357,000	398,000	32,300	121,000	187,000	127,000	175,000	162000	57,700	61,000	49,000	16.63	17.58	14.12	119	0	0
1986	192,000	300,000	340,000	27,200	68,800	146,000	123,000	159,000	153000	41,800	72,200	41,000	12.05	20.81	11.82	102	0	0
1987	232,000	415,000	340,000	46,800	168,000	147,000	122,000	194,000	158000	63,200	53,000	35,000	18.21	15.27	10.09	120	0	0
1988	177,000	279,000	327,000	33,400	115,000	156,000	119,000	139,000	147000	24,600	25,000	24,000	7.09	7.20	6.92	91	0	0
1989	190,000	373,000	289,000	36,900	174,000	136,000	89,000	142,000	126000	64,100	57,000	27,000	18.47	16.43	7.78	101	0	0
1990	441,000	524,000	375,000	63,700	163,000	170,000	373,000	297,000	146000	4,300	64,000	59,000	1.24	18.44	17.00	99	0	0
1991	279,000	432,000	312,000	39,200	189,000	147,000	204,000	194,000	138000	35,800	49,000	27,000	10.32	14.12	7.78	127	0	0
1992	318,000	386,000	325,000	134,000	212,000	146,000	105,000	129,000	130000	79,000	45,000	49,000	22.77	12.97	14.12	0	0	0
1993	191,000	361,000	365,000	38,900	148,000	162,000	104,000	167,000	163000	48,100	46,000	40,000	13.86	13.26	11.53	0	0	0
1994	360,000	515,000	366,000	118,000	271,000	175,000	136,000	161,000	138000	106,000	83,000	53,000	30.55	23.92	15.27	100	0	0
1995	222,000	428,000	322,000	52,700	217,000	176,000	123,000	163,000	131000	46,300	48,000	15,000	13.34	13.83	4.32	102	0	0
1996	347,000	598,000	520,000	104,000	317,000	293,000	131,000	188,000	162000	112,000	93,000	65,000	32.28	26.80	18.73	152	0	0
1997	419,000	1,240,000	1,270,000	91,800	598,000	493,000	184,000	399,000	728000	143,200	243,000	49,000	41.27	70.03	14.12	153	0	0

APPENDIX 1C: UNIT RUNOFF CALCULATIONS FOR LOCAL INFLOW AND SNOW WATER EQUIVALENT DATA.

Year	Nechako River at Vanderhoof			Nautley River			Nechako River below Cheslatta Falls			Local inflow dam^3			Unit runoff dam^3 / km^2			Snow water equivalent data		
	Apr	May	Jun	Apr	May	Jun	Apr	May	Jun	Apr	May	Jun	dam^3/km^2	dam^3/km^2	dam^3/km^2	April	May	June
1998	221,000	394,000	306,000	43,400	182,000	146,000	144,000	175,000	143000	33,600	37,000	17,000	9.68	10.66	4.90	101	0	0
2000	171,000	300,000	276,000	34,000	91,800	106,000	93,300	158,000	144000	43,700	50,200	26,000	12.59	14.47	7.49	92	0	0
2001	153,000	285,000	343,000	22,800	79,500	130,000	94,300	151,000	153000	35,900	54,500	60,000	10.35	15.71	17.29	53	0	0
2002	165,000	580,000	690,000	38,600	242,000	403,000	89,300	190,000	185000	37,100	148,000	102,000	10.69	42.65	29.39	89	0	0
2003	167,000	281,000	280,000	33,400	95,200	98,700	86,300	134,000	134000	47,300	51,800	47,300	13.63	14.93	13.63	0	0	0
2004	195,000	331,000	282,000	46,900	122,000	97,500	105,000	150,000	140000	43,100	59,000	44,500	12.42	17.00	12.82	64	0	0

APPENDIX 1D: MEAN DAILY WATER TEMPERATURES IN THE NECHAKO RIVER AT VANDERHOOF, 2000 THROUGH 2004.

Date	2000	2001	2002	2003	2004	Date	2000	2001	2002	2003	2004
01-May	4.9	6.7	9.0	10.1	11.3	01-Jun	11.7	11.3	10.6	14.1	13.6
02-May	5.4	6.3	7.1	8.9	11.7	02-Jun	12.0	11.7	11.3	13.6	13.7
03-May	6.2	6.7	5.5	7.1	11.8	03-Jun	12.4	12.2	11.6	13.6	14.6
04-May	6.0	7.0	5.4	5.9	10.5	04-Jun	12.8	13.2	11.9	14.4	15.8
05-May	5.8	6.8	4.5	5.7	10.2	05-Jun	13.0	13.7	11.8	14.9	15.9
06-May	5.7	7.6	4.1	6.5	9.9	06-Jun	13.3	13.0	10.9	16.7	14.1
07-May	5.8	8.4	5.2	7.7	10.8	07-Jun	13.3	13.4	10.1	17.5	14.5
08-May	6.1	8.5	6.5	8.0	10.4	08-Jun	12.4	13.7	10.4	17.8	15.9
09-May	6.1	8.6	7.3	8.9	9.3	09-Jun	12.8	13.2	11.3	17.5	16.6
10-May	6.2	8.6	7.1	9.7	9.6	10-Jun	12.1	12.5	12.6	17.3	17.6
11-May	6.4	9.2	7.2	10.6	9.5	11-Jun	12.0	12.4	13.3	17.2	17.3
12-May	6.5	9.4	8.3	11.2	10.0	12-Jun	12.0	13.1	14.4	16.8	16.6
13-May	7.4	9.4	8.6	10.0	10.5	13-Jun	12.0	14.3	14.8	15.9	15.6
14-May	8.2	9.4	8.1	9.2	11.1	14-Jun	11.5	14.2	15.6	15.5	14.7
15-May	8.6	9.6	7.8	8.9	12.1	15-Jun	11.2	14.2	15.9	15.5	15.4
16-May	8.8	9.5	8.3	9.1	12.8	16-Jun	11.4	13.8	15.8	16.1	16.4
17-May	8.9	9.1	9.1	9.0	13.1	17-Jun	12.8	14.0	15.3	16.3	17.3
18-May	9.0	8.4	8.6	9.7	13.9	18-Jun	13.2	14.9	15.2	16.5	18.4
19-May	9.1	8.2	8.3	10.2	14.9	19-Jun	12.5	15.8	15.2	15.9	19.0
20-May	8.2	9.0	8.0	10.6	15.2	20-Jun	11.8	15.9	15.3	15.4	20.0
21-May	7.4	9.5	7.3	10.9	13.7	21-Jun	11.3	16.2	15.5	15.5	20.8
22-May	7.0	10.4	6.5	11.1	12.3	22-Jun	11.8	15.8	15.8	15.9	21.2
23-May	7.4	10.9	6.6	12.0	11.6	23-Jun	11.7	15.4	16.2	16.0	21.7
24-May	7.4	11.9	7.6	12.6	13.1	24-Jun	12.1	15.7	16.2	16.9	22.0
25-May	7.4	12.1	8.5	12.4	13.6	25-Jun	13.5	15.1	16.1	16.9	21.7
26-May	8.0	12.3	10.1	12.5	13.4	26-Jun	15.3	15.5	16.3	17.2	21.6

APPENDIX 1D: MEAN DAILY WATER TEMPERATURES IN THE NECHAKO RIVER AT VANDERHOOF, 2000 THROUGH 2004.

Date	2000	2001	2002	2003	2004	Date	2000	2001	2002	2003	2004
27-May	7.8	11.8	10.7	13.1	13.0	27-Jun	16.5	15.2	15.9	16.9	19.7
28-May	8.1	11.5	11.1	13.0	13.2	28-Jun	17.5	15.4	15.9	17.4	18.7
29-May	9.1	10.8	11.0	13.1	13.4	29-Jun	16.6	16.1	16.0	18.1	18.8
30-May	9.5	10.8	10.5	13.7	13.6	30-Jun	15.5	17.0	14.7	17.4	19.7
31-May	10.8	11.1	10.2	14.2	13.1	*Preliminary temperature provided by Environment Canada*					