Nechako River Geomorphic Assessment

Phase I: Historical Analysis of Lower Nechako River

Final Report, May 2003

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EXECUTIVE SUMMARY

The Kenney Dam and Nechako Reservoir have regulated flows in the Nechako River since 1952. A number of studies have examined the consequences of reduced annual flows, reduced annual peak flows, and increased sediment supply from the 1961 Cheslatta River avulsion on the morphology of the Nechako River. These previous studies have usually focused on the upper Nechako River – from Cheslatta Falls to Vanderhoof – and have emphasized chinook salmon as the species of concern.

White sturgeon in the Nechako River are endangered and attention has recently been focused on planning for their recovery. White sturgeon are now primarily found in the river between Vanderhoof and the Stuart River confluence, but are occasionally found as far upstream as Fort Fraser. Subsequent analysis has clearly identified that this population is undergoing a recruitment failure which began in the mid-1960's, or about a decade after the closure of the Kenney Dam. In this report, we extend the assessment of geomorphic changes to the lower Nechako River – from Vanderhoof to the Isle de Pierre Rapids – emphasizing changes that may have affected white sturgeon life stages and contributed to the observed recruitment failure.

Based on historical aerial photography and field reconnaissance, we found evidence that sand bedload deposition started in the Hulatt/Finmoore area in the 1964 freshet – the first significant flood event following the Cheslatta avulsion – and is ongoing to the present day. The sand deposition probably covered coarser gravel substrate, possibly reducing sturgeon spawning success. We infer that the 1964 freshet may also have started the process of pool infilling in the meandering river reach between Vanderhoof and Hulatt Rapids, possibly reducing sturgeon overwintering success. The timing of these changes coincides closely with the sturgeon recruitment failure.

Water Survey of Canada gauging records and field reconnaissance suggest that a wave of sand and granule bedload passed the Vanderhoof gauge site between the late 1960's and the early 1990's. The bedload wave probably consisted of Cheslatta-derived material slightly coarser than

the material that passed through in 1964 without affecting channel morphology. The wave appears to have passed now, and the ongoing sand deposition in the Hulatt/Finmoore area will likely cease within the coming decade or so. The riverbed will then downcut somewhat in response to reduced sediment supply, but the substrate will not return to its pre-regulation character because of the reduced flow conditions. Similarly, infilled pools in the meandering reach between Vanderhoof and Hulatt Rapids will not reform to their pre-regulation depths because the reduced flows no longer produce the same scour velocities that they once did.

We found no evidence of geomorphic changes downstream of the Stuart River confluence, apart from localized growth of bars within the first 2.5 km caused by bed adjustments in the lower Stuart River as Nechako water levels dropped. Stuart River flows moderate the influence of regulation on Nechako River flows downstream of the confluence, and coarse sediment inputs from the Stuart River control substrate character in this section. The wave of sand and granule bedload travelling downriver may have altered the substrate composition by filling cobble-gravel voids, as opposed to covering the existing substrate, but we had no way of examining this.

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Nechako River Geomorphic Assessment

Phase I: Historical Analysis of Lower Nechako River

Final Report, May 2003

1. Introduction

The Kenney Dam and Nechako Reservoir have regulated flows in the Nechako River since 1952. The project has been controversial and a number of studies have examined the consequences of reduced annual flows, reduced annual peak flows, and increased sediment supply from the 1961 Cheslatta River avulsion on the morphology of the Nechako River (e.g. Kellerhals et al. 1979; Rood and Neill 1987; Rood 1998a, 1998b, 1998c; **nhc** 2002, **nhc** and McAdam 2003). These previous studies of the Nechako River have usually focused on the upper Nechako River – from Cheslatta Falls to Vanderhoof – and have emphasized chinook salmon as the species of concern.

Previous studies of the morphology of the upper Nechako River have been based on both field investigations and analysis of historical air photos. These studies concluded that regulation of the Nechako River has resulted in a narrower channel through encroachment of riparian vegetation and abandonment of secondary channels (Rood and Neill 1987). Sediment has also been deposited along the upper Nechako River in response to lower annual peak flows. Cobble and gravel fans have grown at the mouths of tributaries; sand and fine gravel deposits on the channel bed appear to be gradually spreading over gravel substrate; fine sand and silt are deposited on bar surfaces and banks. Substrate sampling shows that fine sand is gradually accumulating in undisturbed substrate in chinook spawning areas (**nhc** 2002).

White sturgeon in the Nechako River are endangered and attention has recently been focused on planning for their recovery. White sturgeon are now primarily found in the river between Vanderhoof and the Stuart River confluence, but are occasionally found as far upstream as Fort Fraser (RL&L 2000). Subsequent analysis has clearly identified that this population is undergoing a recruitment failure which began in the mid-1960's (Korman and Walters 2001), or about a decade after the closure of the Kenney Dam. Post-regulation hydrologic and geomorphic changes along the Nechako River – such as shallower flows, loss of secondary channels and sedimentation in the main channel – may be one of the causes of this failure. The reason for the delay in the population response is not known, but it may be related to a lag in the morphologic response along the Nechako to regulation or to sediment transport and deposition following the Cheslatta Falls avulsion.

The overall objective of this study is to identify geomorphic changes along the Nechako River, emphasizing those that may have affected white sturgeon life stages and contributed to the observed recruitment failure. Previous analysis (Rood and Neill 1987) identified geomorphic changes between Cheslatta Falls and Vanderhoof. Therefore, Phase I of this study extends the geomorphic analysis of Nechako River from Vanderhoof downstream to the Isle de Pierre Rapids, using hydrologic and hydraulic analyses, air photo analysis, and field reconnaissance. Phase II (see **nhc** and McAdam 2003) involved a more detailed investigation of channel changes at selected sites in the upper and lower portions of the river (i.e. Cheslatta Falls to the Isle de Pierre Rapids) and the assessment of potential relevance to white sturgeon.

2. Nechako River Hydrology and Regulation

2.1 Overview

The Nechako River drains approximately 47,000 km^2 of the Interior Plateau in west-central British Columbia (Figure 1). Prior to regulation, the river flowed through a series of large lakes on the lee side of the Coast Mountain Range, then flowed northeast and east to join the Fraser River at Prince George. The annual hydrograph was dominated by spring snowmelt, especially by the melt of large snowpacks at the west end of the watershed.

The Nechako Reservoir was created in 1952 by the construction of Kenney Dam in Nechako Canyon, approximately 290 km upstream of Prince George and 150 km upstream of Vanderhoof. The reservoir consists of a series of previously existing lakes whose level was raised by impoundment behind Kenney Dam and nine saddle dams constructed at low points along the north rim of the reservoir. A spillway was constructed 75 km to the west which directed outflow into Skins Lake, then down Cheslatta River, through Cheslatta and Murray Lakes, and into Nechako River at Cheslatta Falls, 9 km downstream of Kenney Dam (Figure 1). Flow through Nechako Canyon was eliminated, except for small tributary inflows and seepage from the dam. At the western end of the reservoir, another outlet was constructed: a tunnel through the Coast Mountains that diverts water to the Kemano River near the Pacific Ocean for hydroelectric generation.

Kenney Dam was completed in 1952 and the Nechako Reservoir began to fill. Diversions to the Kemano powerhouse began in 1954 and increased through the 1960's and 1970's. During this period, average annual flows released to Nechako River via the Skins Lake Spillway steadily declined. In 1980, a new flow regime was adopted for the benefit of salmon. The Nechako Fisheries Conservation Program (NFCP), through the Nechako Technical Committee, now manages flow releases from the Nechako Reservoir for the benefit of chinook salmon and carries out technical studies and monitoring of the upper river. By releasing flow at the Skins Lake Spillway, specified minimum flows are to be maintained at a Water Survey of Canada (WSC) gauge in the upper Nechako River from September through June. Furthermore, sufficient water is released in July and August to maintain water temperatures at or below a specified maximum temperature in the lower Nechako River at the Stuart River confluence. Under this flow management regime, the summer cooling flows typically generate the highest flows of the year, except in the occasional high snowpack year when some reservoir water is pre-spilled for flood management on the Fraser River.

2.2 Watershed Areas and Tributaries

The catchment areas at various points along the Nechako River are presented below:

- Nechako Reservoir: 14,000 km^2.
- Fort Fraser (WSC 08JA001): 17,700 km^2.
- Vanderhoof (WSC 08JC001): 25,100 km^2.
- Isle Pierre (WSC 08JC002): 42,500 km^2.
- Prince George (mouth): 47,000 km^2.

The largest tributaries to the Nechako River are the Stuart River (15,800 km^2), which joins the Nechako between Vanderhoof and Isle Pierre; and the Nautley River (6,030 km^2), which joins the Nechako shortly downstream of Fort Fraser. Neither tributary is regulated. Other smaller tributaries to the Nechako River drain moderately dry, low-relief plateau terrain and contribute relatively little runoff. Therefore, the Nechako River can be divided into three main hydrologic sections of relatively uniform discharge, with decreasing impact of flow regulation in the downstream direction as tributary inflows are added.

- Cheslatta Falls to Nautley River: Nechako River discharge almost entirely controlled by releases at the Skins Lake spillway. Flows represented by WSC Gauge 08JA017 (Nechako River below Cheslatta Falls); flow records start in 1980.

- Nautley River to Stuart River: Nechako River discharge controlled mainly by releases at the Skins Lake spillway, augmented by Nautley River inflows. Flows represented by WSC Gauge 08JC001 (Nechako River at Vanderhoof); flow records at Vanderhoof start in 1948, flows prior to that estimated from WSC Gauge 08JA001 (Nechako River at Fort Fraser) for the period 1930-48.

- Stuart River to Isle Pierre: Flows represented by WSC Gauge 08JC002 (Nechako River at Isle Pierre). Nechako River flows at Isle Pierre consist of Nechako River flows at Vanderhoof, plus Stuart River flows near Fort St. James (WSC Gauge 08JE001), plus contributions from other small tributaries. The latter component makes up only 3% of the average annual flow at Isle Pierre. Flow records at Isle Pierre start in 1950; records for Stuart River start in 1928.

2.3 Flow-Regime Characteristics

Prior to regulation, the annual spring snowmelt freshet dominated the Nechako River hydrograph at Vanderhoof. The highest flows typically occurred in June, followed by receding flows through the summer (Figure 2a). Frontal rainstorms would stabilize the receding flows in the autumn months, and would cause occasional minor flood events. Minimum flows would occur in the winter and early spring.

Following regulation and diversion in the 1950's through the 1970's, mean monthly spring freshet flows at Vanderhoof were reduced by about half compared to the pre-regulation condition (Figure 2a). However, mean monthly autumn and winter flows in this period remained similar to the pre-regulation values. The mean annual maximum daily discharge dropped from 658 m^3/s prior to regulation to 426 m^3/s in this first post-regulation flow regime (Figure 3). The largest floods occurred in 1958, 1960, 1964, 1967, and 1972 (around 550 to 600 m^3/s), followed by the largest flood of the period in 1976 (745 m^3/s), the only flood to exceed the pre-regulation mean annual flood.

The flow management regime adopted in 1980 resulted in further reduction of spring flows, with the complete elimination of a regular spring freshet. The peak flow period shifted to July and August, resulting from spillway releases to meet temperature objectives, but these summer flows were still lower than summer flows in the pre-regulation and first post-regulation periods. Furthermore, autumn, winter and early spring flows were significantly reduced from the first post-regulation period (Figure 2a); these flow reductions actually started in 1978. The mean annual maximum daily discharge in this second post-regulation flow regime, as of 2001, was only 327 m^3/s (Figure 3). Only one significant flood event has occurred, in 1997, when water was spilled from the Nechako Reservoir during the spring freshet resulting in a maximum daily discharge of 532 m^3/s at Vanderhoof.

Mean annual discharge at Vanderhoof dropped to 76% of the pre-regulation value in the period 1957 to 1979, then to 41% of pre-regulation after 1980 (Table 1). Mean annual discharge at Isle Pierre showed a parallel, but less severe, reduction of flows with 93% and 63% of pre-regulation flow in the same two periods. The flows at Isle Pierre were buffered by Stuart River inflows that were not only unregulated, but actually increased after 1952 due to regional climatic trends (Figure 2b).

2.4 Changes in Water Level

The changes in water level associated with the various flow regimes cannot be directly determined because morphologic channel changes alter the stage-discharge relation at a gauging station over time. However, by selecting a single point in time at a given gauging station, we can examine the effect that changes in discharge would have had on water levels, independent from channel changes. We have used the 1952 channel geometry and rating tables from the WSC gauges at Vanderhoof and Isle Pierre to examine the change in water level associated with various flow regimes (Table 2, Figures 4 and 5).

In the first post-regulation period (1957-1979), the drop in mean monthly discharge during the spring and summer months would have resulted in a water level reduction of about 0.8 to 1.0 m at Vanderhoof, and about 0.3 to 0.4 m at Isle Pierre. In the autumn and winter, flows and water levels did not change significantly.

In the second post-regulation period (1980 onward), the further decline in spring flows would have resulted in a water level reduction of 1.8 m at Vanderhoof and 1.1 m at Isle Pierre, compared to the pre-regulation period. Despite the release of cooling flows, summer water levels would have dropped to 1.1m and 0.6 m below pre-regulation at Vanderhoof and Isle Pierre, respectively. Autumn and winter flows declined significantly after 1980, and would have resulted in water level drops of 1.0 m (autumn) and 0.5 m (winter) at Vanderhoof, and 0.8 m (autumn) and 0.3 m (winter) at Isle Pierre.

These changes in seasonal water levels were based on assumed stable cross-sections at two WSC gauging stations on the Nechako River. As will be shown in Section 6, the cross-section at the Vanderhoof gauge, in particular, has not been stable over time, so the actual changes in water level will have been augmented in some periods and muted in others due to changes in river bed elevation. It is even more complicated to extend the observations of changes in seasonal water levels to other sites along the Nechako River, due to variations in channel stability and hydraulic geometry (the relation between discharge and depth, width and velocity at a site). However, the water level changes described above are at least indicative of the relative changes in the different seasons over time in the Nechako River.

3. Nechako River Geomorphology

3.1 Upper Nechako River

The upper Nechako River used to start at the lake outlet that is now blocked by Kenney Dam. From there, the river ran for several kilometres through a bedrock canyon called Nechako Canyon. The Cheslatta River plunges over Cheslatta Falls and into the Nechako River near the downstream end of the canyon, approximately 9 km downstream from the dam. The Cheslatta River confluence, usually referred to as Cheslatta Falls, is now the effective start of the Nechako River (Photos 10 and 13).

The Nechako River is mainly gravel-bedded between Cheslatta Falls and Vanderhoof. The river is incised into the Nechako Plateau and is often bounded by glaciofluvial and glaciolacustrine terraces. In some sections, broad floodplains have developed along the river channel, while in other sections the river channel is confined between terrace scarps. The Nechako River has always been lake-headed, so sediments have been derived solely from tributary inputs and erosion of floodplain and terrace deposits. The overall trend since regulation has been a reduction in erosion and transport potential, resulting in less active erosion of bed, banks, terrace scarps, and reduced transport of sediment from tributaries.

Rood and Neill (1987) identified a number of post-regulation geomorphic trends in the upper Nechako River. The river channel has been remarkably stable in planform. All channel changes have occurred in the form of vegetation encroachment and sediment deposition within the original channel boundaries. Sand and fine granules are covering cobble gravel substrate in some sections. In other sections, fine sand is gradually accumulating within the pores of cobble substrate (**nhc** 2002). Many secondary channels have been abandoned due to vegetation encroachment, sediment deposition and lowered water levels. Fans have grown at the mouths of tributaries due to reduced transport competence and capacity of the river.

The reduction and seasonal shift in flood flows has allowed colonizing plant species to become established at lower elevations along the channel margin. In the first post-regulation period

(1950's to 1970's), vegetation colonized the elevation band between the pre- and post-regulation annual high-water marks. The vegetation consisted of grasses and sedges, followed by various deciduous species such as alder, willow and cottonwood. In the second post-regulation period (1980's), vegetation encroached even lower, below the new annual high-water mark. Rood and Neill (1987) suggested that vegetation was colonizing the channel margin as low as the average spring water level. The vegetation would get a burst of growth in the spring and then would survive the period of inundation during the summer cooling flows. Under the previous flow regimes with a spring hydrograph peak, vegetation could not get established below the annual high-water mark because the spring freshet would last until July when it was too late for vegetation to get established. Rood and Neill made their observations in the mid-1980's when the early stages of vegetation, mostly grasses and sedges, were responding to the 1980 chinook-management flow regime.

3.2 Lower Nechako River

Today, the Nechako River bed consists of pebbles and granules for a short distance downstream of Vanderhoof, then the river is mainly sand-bedded for most of the distance downstream to the Stuart River confluence. However, occasional exposures of cobble and pebble gravel showing through silt and sand-covered bars suggest that the river was probably gravel-bedded all the way to the Stuart River confluence prior to regulation (e.g. Photos 23, 43, and 68). Downstream of the Stuart River, the Nechako River is still cobble-bedded due to flow and sediment inputs from the large tributary (e.g. Photos 59 and 60). Sand is only found in isolated pockets high on gravel bars. Bedrock is exposed in the channel at the Hulatt Rapids and at the Isle de Pierre Rapids (Photos 63 and 67), about 31 km and 73 km downstream of Vanderhoof, respectively.

The lower Nechako River flows between glaciolacustrine terrace scarps along most of its length between Vanderhoof and Isle Pierre. For the first 30 km downstream of Vanderhoof, there is a nearly continuous floodplain, but the river meanders widely through the floodplain and impinges against the terrace scarps at most outer bends. Much of this old floodplain is now essentially a low terrace because the reduced flood flows no longer overtop the banks and inundate the floodplain. Further downstream, the floodplain becomes discontinuous, and there is essentially no floodplain downstream of the Stuart River confluence (44 km downstream of Vanderhoof).

3.3 The Cheslatta River Avulsion

A large increase in sediment supply resulted from a major channel avulsion in Cheslatta River in 1961. The river shifted course upstream of Cheslatta Falls and ran down a formerly dry gully, eroding approximately 0.9×10^6 m^3 of sandy glaciofluvial sediment and carrying it into the abandoned Nechako River channel about 1 km upstream of the former confluence (Rood and Neill 1987). About half of the eroded sediment was deposited in a fan on the former Nechako River bed, and the other half was carried down the river (Photos 1 through 13). The avulsion channel has since been dammed and the Cheslatta River joins the Nechako River at the original confluence site (Cheslatta Falls). The fan surface consists of sorted deposits ranging from sand to boulders. The material transported downriver probably consisted mostly of sand and some pebbly gravel and silt. The material would have traveled in suspension a considerable distance down the river during the flood event that triggered the avulsion. There is little evidence of a large sediment-transport event in the cobbly to bouldery reach immediately downstream of Cheslatta Falls, but the avulsion sediment may have contributed to the infilling of pools and the increased sand coverage on the riverbed further downstream. After deposition from suspension during the initial transport event, the sand and fine gravel may have moved as bedload during subsequent flood events, working its way downstream more slowly. One of the key objectives of this study was to identify the fate of this material and its temporal pattern of downstream movement.

4. Methods for Air Photo Analysis of Lower Nechako River

4.1 Air Photo Selection

We selected aerial photography for our historical analysis of geomorphic trends based on the following criteria:

- Temporal sequence of roughly equal time steps representing the various pre- and post-regulation flow regimes.
- Photo sets with complete coverage of the lower Nechako River study area at one point in time.
- Larger scale preferable to smaller scale photography.
- Good photo quality; photo quality can be poor due to age, low light levels, or haze.
- Lower discharge preferable to higher discharge for visibility of channel bed and bars.
- Some high discharge photography useful for identifying floodplain and secondary channel inundation.

There are a large number of air photo rolls covering the lower Nechako River (Table 3). There are 12 complete, or nearly complete, air photo sets (Table 3a), and another 15 photo sets that show smaller portions of the study area (Table 3b). We selected the 1946 and 1953 air photos to represent the river condition prior to regulation, and the 1973, 1985, and 1996 air photos to represent post-regulation conditions. Discharge was particularly low at the time of the 1953 and 1973 photography, providing excellent views of the channel bed, bars, and secondary channels. We also made use of the high-flow photos taken in 1951 to study floodplain inundation near Vanderhoof. Where channel changes were identified, we examined additional photo sets to fine-tune our assessment of the processes and timing involved.

We used the 1985 photography to construct a 1:7500 scale air photo mosaic of the lower Nechako River (eight sheets, provided in Appendix A). The scale matches an upper Nechako River air photo mosaic that was constructed in the 1980's by the NFCP (1978 aerial photography). We chose the 1985 photography for our mosaic over the 1996 photography because of the larger photo scale. We selected the 1985 photography over the 1988 or 1997 photography because of the lower discharge. Table 4 lists the air photos used in the mosaic and lists the reaches covered by each sheet.

4.2 Reach Classification

Ideally, classification and description of river channels should be based on homogeneous reaches that exhibit a consistent response to uniform hydrology, sediment supply, boundary materials, geomorphic setting, and geologic history (Kellerhals et al. 1976). Practically, the most important factors in classifying reaches in the Nechako River are major tributary confluences, channel pattern, degree of floodplain development, and channel confinement by terraces or hillslopes.

Rood and Neill (1987) divided the upper Nechako River – from Cheslatta Falls to Vanderhoof – into seven study reaches. River kilometrage started at Km 0 at Cheslatta Falls and ran to Km 142 at the Vanderhoof bridge. Our geomorphic analysis of the lower Nechako River is meant to provide a downstream continuation of the upper river geomorphic study. Therefore, we have continued the reach numbering and kilometrage from the upper river study. Unfortunately, this will not coincide with the system used in other sturgeon studies (e.g. RL&L 2000) where distance was referenced upstream from Prince George; however, conversion between studies should not be difficult if sufficient cross-references are provided. Nor does our kilometrage coincide with the upper Nechako River air photo mosaic, in which Km 0 was set at Kenney Dam and the total channel length between Cheslatta Falls and Vanderhoof was reported as 149 km compared to 142 km in Rood and Neill (1987).

We divided the lower Nechako River – 75 km from Vanderhoof to the Isle de Pierre Rapids – into four study reaches, numbered 8 through 11 (Table 5). Our river kilometrage starts at Km 142 in Vanderhoof and runs to Km 217 at the Isle de Pierre Rapids. The four reaches are defined by the Hulatt Rapids and the downstream limit of continuous floodplain (Reach 8/9 break, Km 173.1), by the Stuart River confluence (Reach 9/10 break, Km 186.2), and by the upstream limit of exposed bedrock at the Isle de Pierre Rapids (Reach 10/11 break, Km 214.5).

For each reach, we made approximate measurements of floodplain, island, and bar area, and secondary channel length by type, from the uncontrolled mosaic to provide comparisons between reaches (Table 5).

4.3 Field Reconnaissance

We visited the lower Nechako River in early October 2002. Craig Nistor (**nhc**) and local boat operator, Colin Barnard, boated downriver from Vanderhoof to Km 197 and back, on 02 October. Craig Nistor visited road-accessible sites along the river, including the Isle Pierre area, on 01 and 03 October. During our field reconnaissance, we verified our air photo interpretation and noted smaller-scale features not visible on air photos, particularly:

- Bed and bar sediment texture and distribution.
- Vegetation succession.
- Bank and scarp erosion.
- Secondary channels: sediment at inlets, vegetation encroachment, wetted connectivity.
- Maximum channel depth using a depth sounder.

Discharge in the Nechako River on 02 October was 57.2 m^3/s at Vanderhoof (WSC 08JC001) and 193 m^3/s at Isle Pierre (08JC002). The flow at Vanderhoof was close to the post-1980 mean autumn flow of 58 m^3/s (Table 2), meaning that channel observations upstream of the Stuart River confluence can be considered representative of typical autumn conditions. The flow at Isle Pierre was higher than the post-1980 mean autumn flow (149 m^3/s) due to above-average flow in the Stuart River. By comparison, however, the 02 October flow was much lower than the post-1980 mean spring and summer flows (375 and 449 m^3/s, respectively).

During our field reconnaissance, we made note of recent high-water marks (Summer 2002). Average summer flows in the post-1980 flow regime are similar to autumn flows in the pre-regulation flow regime (Table 2), so we assumed that secondary channel wettedness this past summer would provide a decent representation of pre-regulation autumn flow conditions. We used the observed summer high-water marks and the 02 October water levels to compare pre-regulation and post-1980 autumn flow conditions, particularly for an assessment of the seasonal wettedness of secondary channels.

5. Results of Air Photo Analysis of Lower Nechako River

5.1 Channel Planform

The Nechako River's planform has remained remarkably stable since at least the 1940's, the earliets period with complete air-photo coverage of the lower river. Aerial photography from 1928 in the meandering Reach 8 suggests that lateral erosion rates were low even prior to regulation. Today, most of the alluvial riverbanks and glaciolacustrine terrace scarps are not actively eroding, as indicated by the presence of deciduous vegetation along the base of most of these features (Photos 36 and 37). The reduction in flood magnitudes has likely caused this near cessation of the minor lateral erosion that used to occur.

The only site of significant, contemporary, lateral erosion in the lower Nechako River is at the terrace scarp at Km 152.9, where the river continues to directly attack the scarp as the flow is forced around a tight bend (Photo 29). Not coincidentally, this was the deepest point along the channel that we found on our river reconnaissance (approximately 7 m deep). Secondary currents associated with the sharp bend in flow likely maintain this deep hole. River depths adjacent to the other, stable terrace scarps in the lower Nechako River were generally on the order of 2 to 3 m during our reconnaissance. It is likely that pre-regulation flows used to attack some of these other scarps more directly and maintain deeper holes through scouring secondary currents, and that these holes have since filled in.

5.2 Channel Bars at Tributary Confluences

The most obvious morphologic changes in the lower Nechako River have occurred at tributary confluences, especially the Stuart River confluence (Km 186.2), and to a lesser extent the Cluculz Creek confluence (Km 180.3). Bars have grown at the confluences and at preferential deposition sites shortly downstream, probably in response to reduced water levels in the Nechako River triggering channel degradation in the tributary channels. The degradation would produce re-graded tributary beds marked by fresh bar surfaces, and short-term sediment inputs into the Nechako River. Large bars of cobbly to pebbly gravel have formed in the Stuart River at the mouth (Photos 49 through 51) and in the big horseshoe-shaped bend approximately 2.5 km downstream from the confluence (Km 189, Photos 52 through 58). The bar growth was observed in the 1966 photos and had definitely achieved the present condition by 1973. Similarly, the existing Cluculz Creek fan of cobbly gravel (Photos 46 and 47) could be seen in the 1966 air photos to have increased in area, extending 0.5 km downstream to coalesce with an existing bar. Also, a new bar of pebbles and sand formed at the secondary channel outlet at Km 182, approximately 1.7 km downstream from the confluence (Photo 48). As with the Stuart River confluence, the Cluculz confluence effects became evident in 1966 and were clearly evident in 1973, with little change since then. We suspect that the channel changes in the vicinity of the Stuart and Cluculz confluences occurred earlier than 1966, but could not be identified in the 1958, 1960, or 1963 air photos because flows were too high. We emphasize that these channel changes are very unlikely to be linked to the 1961 Cheslatta River avulsion because the location and sediment texture.

5.3 Channel Bars Elsewhere in the Channel

There are numerous sand and gravel bars along the lower Nechako River, but none have shown the rapid growth seen near the Stuart River and Cluculz Creek confluences. The largest sediment storage site in the lower Nechako River occurs at the downstream end of Reach 8. A large bar stretches for nearly 2 km upstream of the Hulatt Rapids (Km 171 to 173, Photos 38 through 42). The bar has not grown significantly in area since 1953, but it is difficult to say whether the bar surface elevation has increased due to fine sediment deposition. In most of the selected photo sets with low to moderate discharge, the submerged and subaerial portions of the bar can be seen, but since discharge varies between photo sets, we cannot easily determine whether the bar morphology has changed. Minor sand bar growth occurred at Km 152.5 and Km 156.5 in the period 1953 to 1973.

An interesting change in bar morphology occurred on a mid-channel bar at Km 175.7. At low flow in 1953, the bar showed an amorphous pattern characteristic of a dewatered channel bed. In 1966, however, the bar had grown somewhat (i.e. same subaerial area at higher flow) and it showed evidence of active sand transport as one sheet with a well-defined, arcuate leading edge was in the process of overriding a lower layer. In later photos, the bar had adopted a rounded shape characteristic of an inactive, remnant feature. During our 2002 river reconnaissance, we noted that the bar surface was vegetated with grasses and sedges, typical of stable bars that are wetted by summer cooling flows (Photo 44).

Aside from the sites described above, bars in the lower Nechako River have remained remarkably stable in size and location since the 1950's. Bars upstream of Stuart River (except the bars near Cluculz Creek) consist of silt, sand or granules. Silt deposits have occurred in particularly quiet water zones, often where the channel widens at a secondary channel inlet. Silt does not normally form channel bar morphology, so we assume that the silt overlies a coarser sub-stratum composed of formerly mobile bedload material. For example, the bed material at the secondary channel inlet at Km 149.4 consists of pebble gravel blanketed by a few centimetres of silt (Photos 21 through 23). The nearby bar surface in the main river channel consists of clean, recently mobile granules (Photos 24 and 25) representing contemporary bedload, presumably overlying coarser gravels representing past bedload. Cobble and pebble gravel are exposed in bars at a few points along the river, but it is difficult to estimate a depth of overlying finer sediment in areas where the gravel is covered. Downstream of Stuart River, bars consist of cobble gravel and we assume that contemporary bedload more closely resembles past bedload material, dominated by Stuart River inputs.

5.4 Channel Bed

In some places along the sand-bed portion of the river upstream of the Stuart River confluence, the channel appears to have become shallower over time, although this is hard to quantify. The two clearest examples are at Km 157.0 and Km 179.5. At Km 157.0, the channel bed is visible in 1985, although it was not visible at much lower flows in 1953 or 1973. The morphology of the visible channel bed suggests a sheet of sand bedload material. At Km 179.5, the main river channel (the left channel around the island) appears to have become shallower between 1953 and 1985. The channel became shallower between 1953 and 1966, as seen in air photos taken at nearly identical discharge. The channel bed is even more clearly visible in 1985 air photos compared to 1973, despite higher flow at the time of the 1985 air photos, indicating ongoing deposition.

During our field reconnaissance, we observed shallow water (less than 0.5 m) throughout the sand-bedded left channel at Km 179.0 to Km 179.9. In fact, our boat grounded on the sand spit near the downstream tip of the island and we were able to observe its morphology. A recently mobile, rippled sheet of sand lay only a few centimeters below the water surface. A 20-cm high avalanche face (the steep, ravelling slope on the leading edge of an advancing sand sheet) demarcated the downstream front of the sand sheet (Photo 45). Lower sheets of sand were covered with algae indicating less recent mobility, but several older avalanche faces of similar height indicated that a similar process had been operating for some time. These observations support our air-photo interpretation of long-term sand accumulation between Km 179.0 and Km 179.9. Our boat operator informed us that the main (left) channel used to be easily navigable at all flows as recently as 10 to 20 years ago, whereas the former secondary (right) channel is now the deepest. This suggests that the main-channel deposition has been continuing since the 1985 air photos were taken.

5.5 Riparian Vegetation

Vegetation has encroached into the lower Nechako River channel in an interesting pattern. A thin strip of deciduous vegetation a few decades in age can be seen along much of the channel (e.g. Photo 37). Presumably, this represents colonization of the elevation band between the pre-regulation high-water mark and the high-water mark during the first phase of post-regulation flows. At a lower elevation in the channel, strips of sedges and grasses line the river channel margins and cover large expanses of bar tops (e.g. Photos 41 and 42). The grasses and sedges are low enough to be inundated by the summer cooling flows. This pattern matches that identified by Rood and Neill (1987), except that deciduous species have not succeeded the grasses and sedges. Deciduous species are probably not able to overcome the prolonged summer flooding in this elevation band.

5.6 Secondary Channel Morphology

There are 22 secondary channels in the lower Nechako River, with a total length in 1985 of 11.3 km (Tables 6 and 7). Most of the secondary channels (9.2 km) are located in the less-confined section of river upstream of the Stuart River confluence. Only three secondary channels appear to have been morphologically altered over time.

At Km 172.9, the secondary channel along the large bar upstream of Hulatt Rapids has been colonized by deciduous vegetation, starting between 1966 and 1973 (Photo 43). Given the timing, the vegetation encroachment is probably the result of sediment deposition in the channel or at the channel inlet in the 1960's, rather than lowered water levels in the 1950's.

At Km 182.0, a new gravel bar formed at the channel outlet in response to the post-regulation bed adjustments in Cluculz Creek (Photo 48). The secondary channel is still continuously wetted at high flow, but was dewatered during our 2002 reconnaissance. At Km 189.0, a new sand bar formed near the left bank (Photos 55 and 56), probably in response to post-regulation bed adjustments in the Stuart River. The new bar created a new secondary channel and constricted an existing secondary channel. Both channels were continuously wetted during our field reconnaissance. As discussed in Section 5.2, the post-regulation bed adjustments in Cluculz Creek and Stuart River probably occurred soon after regulation in the 1950's. The changes in secondary channel morphology at Km 182.0 and Km 189.0 are thought to have occurred during this period as well.

5.7 Secondary Channel Wettedness

We classified the secondary channels in three ways: by type, as defined by Rood and Neill (1987), by size (width) relative to the main channel, and by temporal change in seasonal wettedness (Tables 6 and 7). The first classification scheme is useful in quantifying the changing nature of secondary channels in a river with changing morphology and riparian vegetation. However, this was not a significant process in the lower Nechako River. We used the 1985 air photos to classify the secondary channels and the bars and islands that separate them from the main channel. Since 1980 (new flow regime), grasses and sedges, but little in the way of deciduous growth, have colonized all bar surfaces. Slightly higher bars that were undergoing deciduous colonization in the 1985 air photos have continued to reforest.

Secondary channel classification by size indicates that most of the channels are "small", narrower than 30% of the main channel width. Only two channels were classified as "large", wider than 60% of the main channel width. One of these is the channel at Km 182 where the Cluculz Creek sediment formed a large new bar at the channel outlet.

We developed a new classification scheme to address the seasonal wettedness of secondary channels during the various flow regimes, using the assumed changes in water level presented in Table 2 and Figures 4 and 5. Our classification relies on observations of secondary channel wettedness at the following times (continuous wettedness from inlet to outlet):

- 1953 air photos.
- Summer 2002 (high-water evidence during 2002 reconnaissance).
- October 2002 (water level during 2002 reconnaissance).

The 1953 air photos were taken at various times between May and October of that year. Discharges varied but were generally low because of the reservoir filling. Discharges during the 1953 air photos are similar to the average autumn discharge in the post-1980 flow regime, and the discharge during our 02 October 2002 field reconnaissance. Therefore, we compared secondary channel wettedness in the 1953 air photos and during our field reconnaissance and assumed that differences in wettedness must be related to secondary channel sedimentation. At sites where 1953 and 2002 wettedness were similar (i.e. no significant sedimentation), we used the estimated Summer 2002 water level to represent the average pre-regulation autumn water level. Thus, we could identify secondary channels that had become dewatered due to flow regime, separate from issues of sedimentation and vegetation encroachment.

With our wettedness classification, we found that two secondary channels had reduced wettedness due to factors other than water level alone. These are the channels at Km 173 and Km 182 discussed above.

We found that 10 secondary channels had experienced reduced autumn wettedness due to lowered water levels alone (Table 6, wettedness category 3). These were channels which had been wetted in the summer of 2002 but were disconnected from the main channel at the inlet during our field reconnaissance, despite the lack of significant bar growth or vegetation encroachment. Examples are shown in Photos 21 and 22 (Km 149.4), Photos 33 and 34 (Km 162.1), and Photos 64 through 66 (Km 214.7). These channels would likely have been continuously wetted (inlet to outlet) throughout the autumn months prior to regulation and in the first regulated flow regime (1957-1979) when mean autumn flows were not significantly altered. The affected channels are not spatially concentrated.

We found that 10 secondary channels had experienced no reduction autumn wettedness. These were high-elevation channels that were probably not wetted in pre-regulation autumn conditions (Category 4), or low-elevation channels that were wetted during our field reconnaissance (Category 5, example shown in Photos 27 and 28, Km 152.2).

5.8 Floodplains

The lower Nechako River is bounded by nearly continuous floodplain in Reach 8 (Vanderhoof to Hulatt Rapids, Km 142.0 to Km 173.1). Photos 30 and 31 show a typical view of the floodplain about 17 km downstream of Vanderhoof. Using provincial floodplain maps (BC MOE 1984) and air photo interpretation, we estimate the floodplain area in Reach 8 to be approximately 1100 ha (Table 5). Discontinuous pockets of floodplain in Reach 9 (Hulatt Rapids to Stuart River, Km 173.1 to Km 186.2) amount to another 80 ha. There is no significant floodplain downstream of the Stuart River confluence.

The topography of the Nechako River floodplain is dominated by meander scroll morphology, in which ancient channel meanders and point bars are preserved as rolling ridges and troughs with a relief of a few metres. The ridges and troughs show up clearly in deforested areas on aerial photography due to differences in moisture regime and vegetative growth between the well-drained ridges and moister troughs.

The 1951 air photos illustrate the nature of floodplain inundation near Vanderhoof at roughly the mean annual flood in the pre-regulation flow regime. The floodplain was not a smooth flat surface covered by a uniform depth of overbank floodwater. Rather, flooding occurred mainly in the numerous fingerlike depressions related to the meander scroll topography on the floodplain, as well as in the backwatered estuaries of tributary streams. Therefore, even during modest flood events in the pre-regulation and pre-settlement era, the floodplain would have contained numerous channels with depths of a metre or more, bordered by slightly higher, densely vegetated ground, forming a rich, complex aquatic habitat.

The lower Nechako River floodplain has been altered by land clearing for agricultural and urban development, and by lowered water levels and less frequent inundation. Most of the agricultural land clearing occurred prior to regulation in the 1950's. The town of Vanderhoof existed on the floodplain prior to regulation, but urban development on the floodplain around Vanderhoof proceeded through the 1960's and 1970's (e.g. Photos 15 through 20), and to a lesser extent since the 1980's to the present. There are no dikes along the lower Nechako River, but most urban development occurs on locally higher ground, either on the scroll ridges or on fill. The exisiting troughs are usually cut off or infilled in the process (e.g. Photo 20).

The loss of floodplain habitat is related to the reduction in flood flows through the 1960's and 1970's, coupled with floodplain development in that same period. Even if a typical pre-regulation freshet were to occur now, the extent and character of floodplain inundation around Vanderhoof would be markedly different than in the pre-regulation period. In agricultural areas, we expect that some blockage of low areas may have occurred, so that the extent of floodplain inundation would be reduced in a typical pre-regulation flood. More significantly from a habitat prespective, the character of flooded agricultural areas would be much different than the original densely vegetated floodplain.

During pre-regulation flood events, we estimate that backwatered tributary channels crossing the floodplain in Reach 8 would have provided approximately 7.3 km of habitat similar to deep, narrow, low-velocity secondary channels lined by dense vegetation. Most of these streams have retained a riparian forest buffer strip, but the drop in flood levels through the 1960's and 1970's means that the deep backwater conditions during Nechako River flood events have similarly declined. Photos 26, 32, and 35 show the mouths of Knight Creek (Km 150.5), Chilco Creek (Km 160.4), and Sinkut River (Km 162.8), respectively. The lower reaches of these streams would have provided deep, low-velocity habitat during pre-regulation Nechako River freshets.

6. Specific Gauge Analysis

6.1 Methods

We analyzed discharge rating tables from the Water Survey of Canada (WSC) gauges at Vanderhoof and Isle Pierre to identify patterns of channel aggradation or degradation that would indicate periods of sediment transport and deposition in the river. A discharge rating table relates gauge height (water-surface elevation) to discharge, based on periodic discharge measurements. In a stable channel, discharge and gauge height will be consistently related. However, if the channel geometry changes, the relation will also change. For example, if sediment deposition results in bed aggradation along the river channel, then a given discharge will be associated with an elevated water level. A new rating table would be required to relate gauge height to discharge under the altered channel condition. In a specific gauge analysis, we select arbitrary discharge values and extract the associated gauge height from each rating table, then plot these over time. We updated the specific gauge analysis done by Rood and Neill (1987). The specific discharges of 113, 227, and 340 m^3/s used in this report correspond to the flows that they selected prior to WSC's conversion to metric (multiples of 4,000 ft^3/s).

Annual station analysis notes helped us interpret the rating table shifts. For example, the notes occasionally mentioned that sediment had deposited in the gauge control causing a left shift in the rating curve. "Gauge control" refers to the section of river channel downstream of the gauge that controls water level at the gauge. At low flows, the section at and immediately downstream of the gauge may control water level, while at higher flows the water level is controlled by a longer section of river as local bed topography is drowned out and the water surface profile becomes more uniform. Rating curves are typically plotted with discharge on the abscissa (x-axis) and gauge height on the ordinate (y-axis), so a "left shift" refers to increased gauge height at a given discharge.

The station notes often mentioned channel scour caused by ice and ice jamming at the Vanderhoof gauge, located near the Vanderhoof bridge. Channel scour refers to a localized, sometimes temporary, decrease in bed elevation often caused by acceleration of flow around an obstacle, such as a bridge pier or a jam of woody debris or ice. In contrast, channel degradation refers to a longer-term decrease in bed elevation over a longer length of river channel usually caused by a reduction in sediment load, increase in discharge, or a lowering of the downstream base level. In the example of ice scour at the Vanderhoof gauge, the notes remarked that the rating curve would shift to the right around the time of ice break-up in the spring (i.e. decreased water level at a given discharge), followed by a left shift after the first significant flows of late spring (i.e. return to increased water level as the scour is refilled by local bed adjustments).

A specific gauge analysis plot has a stepped appearance that is a procedural artifact. Vertical portions of the plot indicate when a new rating table was adopted, and horizontal portions indicate the duration that a rating table was applied to the recorded water level data to estimate discharge. However, the overall trend is indicative of channel changes, which may have occurred in a smoother fashion than shown, or may have occurred in discrete steps slightly in advance of the steps shown.

6.2 Nechako River at Vanderhoof (WSC Gauge 08JC001)

The specific gauge analysis for the Vanderhoof gauge shows a slight decline in gauge height from the 1950’s to the 1960’s, followed by a more pronounced rise in gauge height from the late 1960’s through to the early 1990’s, then an abrupt drop in gauge height in 1995 (Figure 6a). The absolute range in gauge height for the 340 m^3/s analysis is nearly 0.6 m, from 3.4 m in 1958 to 4.0 m in 1994. The trends are generally consistent over a range of flows from 113 to 340 m^3/s. The pattern illustrated by the specific gauge analysis suggests minor channel degradation immediately following regulation in the 1950’s, followed by the passage of a sediment wave related to the 1961 Cheslatta avulsion causing channel aggradation from the late 1960’s through to the early 1990’s, followed by exhaustion of the upstream sediment load as the wave passed resulting in renewed channel degradation. Lower peak flows following the 1960’s may also have contributed to local aggradation.

The station analysis notes for the Vanderhoof gauge (Table 8) provide some interesting supportive evidence as well as descriptions of potentially complicating factors. The Vanderhoof gauge site is characterized by frequent ice jamming, probably related to collection of ice at the bridge piers, causing localized scour and temporarily lowered gauge readings at a given discharge. The first significant flows of the late spring, even prior to summer cooling releases, cause infilling of the scoured channel. This is more a localized bed adjustment than an indication of sediment transport along the river. This is not an ideal site for a gauge because of the annual cycle of scour and fill; however, these annual cycles in bed elevation should not disguise long-term trends of degradation and aggradation.

The station notes indicate that the 1970's were a period of significant sediment movement over and above the simple annual cycle of scour and infilling. In 1972, a moderately large freshet reportedly caused significant movement of bar material upstream of the gauge (Photo 14) and caused deposition in the gauge control. A larger flood in 1976 caused further deposition in the gauge control. The river then eroded the deposited sediment over the next three years. The gauge analysis indicates continued deposition in the gauge control through the 1980's, but the station notes do not provide clear corroboration as they do for the 1970's, apart from a remark that silt was deposited in the control in 1986.

6.3 Nechako River at Isle Pierre (WSC Gauge 08JC002)

The Isle Pierre gauge site is characterized by a stable rating curve (Table 8, Figure 6b). The only adjustments that were required were due to modifications and removal of ferry ramps. Based on the stable stage-discharge relation at this site, we infer that no significant channel adjustments have occurred at the gauge or at the downstream control.

The Nechako River is mainly cobble-bedded downstream of the Stuart River confluence, including at Isle Pierre. The finer sediments (silt, sand, granules) that are found on the channel bed and bars near Vanderhoof are found only in protected pockets near Isle Pierre (Photos 61 and 62). Therefore, even if a wave of this finer sediment had reached Isle Pierre, it would not have affected channel morphology because the river would have carried it rapidly downstream. In general, the geomorphic effects of regulation and the Cheslatta avulsion are likely to be much less significant downstream of the Stuart River confluence than upstream, because the Stuart River flows have maintained a flow regime in Nechako River closer to the pre-regulation regime.

7. Chronological Summary

The following is a chronological summary of post-regulation geomorphic changes in the lower Nechako River. In previous sections, we discussed the methods and results of our air-photo and specific-discharge interpretation, on which the following generalized summary is based. Key dates in the chronological sequence are related to four flow-regime periods, the Cheslatta avulsion, and the flood events following the avulsion.

The flow-regime periods are:

- Prior to 1952: pre-regulation.
- 1952-1956: reservoir filling.
- 1957-1979: first post-regulation flow regime.
- 1980 onward: second post-regulation flow regime for chinook management.

The key dates relating to the Cheslatta avulsion are:

- 1961: Cheslatta avulsion.
- 1964, 1967, 1972, 1976: post-avulsion flood events.
- 1966: first good air photos following the Cheslatta avulsion

7.1 Prior to 1952

Prior to regulation, the lower Nechako River (75 km from Vanderhoof to the Isle de Pierre Rapids) was a largely stable, gravel-bed river. The annual hydrograph was dominated by the spring freshet. The river contained 21 secondary channels totalling 11.1 km in length. Most of the secondary channels were small (less than 30% of the adjacent main-channel width). About 40% of the channels were separated from the main channel by permanent islands with mature vegetation, while the remainder were separated by unvegetated bars.

In the first 30 km downstream of Vanderhoof, the river meandered through a broad floodplain. The river impinged against glaciolacustrine terrace scarps at the outside of most meander bends, where secondary currents probably maintained deep holes in the river bed. During the annual spring freshet, Nechako floodwaters inundated floodplain troughs and the lower reaches of tributary streams, providing quiet, off-channel aquatic habitat with plenty of vegetative cover. In rare floods, the entire floodplain would have been inundated. The floodplain was largely vegetated, although there had been some agricultural clearing and localized urban development at Vanderhoof.

Downstream of the Stuart River confluence, the Nechako River was more confined and lacked floodplain, meanders, or deep holes at sites of terrace scarp impingement (except perhaps at a single large bend 2.5 km downstream of the confluence).

7.2 1952-1956

Nechako River flows were very low during the reservoir-filling period. We expect that low water levels in the Nechako River during spring freshets in its tributaries – chiefly Stuart River and Cluculz Creek – triggered bed incision in the tributary channels. This led to the expansion of bars immediately downstream from the tributary mouths.

There would have been no floodplain inundation during this period. The deep holes at meander bends probably remained unchanged despite the reduction in scouring flows because there would have been little sediment transport to fill them in.

7.3 1957-1966

After the reservoir had been filled, Nechako River flows increased again. Flows were similar to pre-regulation conditions in the autumn and winter months, but spring freshet flows were severely reduced. The only freshets to come close to the pre-regulation mean annual flood occurred in 1958, 1960 and 1964. Some minor urban and agricultural floodplain development occurred during this period, reducing the extent of floodplain inundation during these freshets.

The Cheslatta avulsion occurred in 1961 during moderately high flows. A large quantity of sediment – mainly sand, but including fine gravel and silt – probably travelled downriver in suspension during this initial event, filling in pools and contributing to sand deposits on the channel bed during receeding flows. The next significant flood event occurred in 1964, when a portion of this material probably continued downriver as bedload.

In 1966, the WSC gauge at Vanderhoof had yet to experience any specific-discharge increases in water level that would indicate channel aggradation. However, in the 1966 air photos, we were able to identify the following sites downstream of Vanderhoof where there was evidence, albeit subtle, of sand deposition possibly related to the 1964 freshet:

- Km 152.5 and Km 156.5: minor sand bar growth (1966 uncertain, seen in 1973 photos).
- Km 172.9: sediment deposition prior to 1966 suggested by deciduous vegetation encroachment in secondary channel (seen in later air photos).
- Km 175.7: active bedload sand transport suggested by bar morphology.
- Km 179.5: onset of sand-sheet bedload deposition in main channel.

We speculate that Cheslatta-derived sand travelled as bedload in the 1964 freshet, passing Vanderhoof without affecting channel morphology, and depositing at preferential sites between Vanderhoof and the Stuart River confluence, mainly in the Hulatt / Finmoore area. The growth of bars downstream of the mouths of Cluculz Creek and Stuart River – first seen in the 1966 air photos – are thought to have developed earlier, mainly during the reservoir-filling period, as described above. Sand bedload in the 1964 freshet may have contributed to the new bar 2.5 km downstream from the Stuart River confluence, but otherwise any sand that passed the confluence would have been transported direstly downriver with little effect on channel morphology. Some sand may have infiltrated the cobble substrate downstream of the confluence, but we had no means of checking this.

Sand transport and deposition in the 1964 freshet could have resulted in the covering of gravel substrate in the Hulatt / Finmoore area (Reach 9), possibly reducing sturgeon spawning success. The 1964 sand transport and deposition may also have resulted in the infilling of deep pools at the outside of sharp river bends in the meandering section bewteen Vanderhoof and Hulatt Rapids (Reach 8), possibly reducing sturgeon overwintering success.

7.4 1967-1979

During the second part of the 1957-1979 flow-regime period, the only freshets to come close to the pre-regulation mean annual flood occurred in 1967, 1972 and 1976 (the largest post-regulation flood). Ongoing urban and agricultural floodplain development occurred during this period, reducing the extent of floodplain inundation during these freshets.

Rating curve shifts at the WSC gauge at Vanderhoof indicate that channel aggradation started around 1968 and continued until the early 1990's. The 1972 WSC gauge notes indicate significant movement of the normally stable bar material upstream of the gauge. Sediment deposition in the gauge control was noted in 1976. Together, the WSC gauge notes and rating curves suggest that a wave of bedload started to pass through the site. Episodes of bedload transport and net deposition were associated with the 1967, 1972 and 1976 flood events.

In the air photos, we identified the following sites where the ongoing deposition of sand bedload was evident:

- Km 157.0: shallower channel, possible sand-sheet bedload deposition (1973-1985).
- Km 179.5: ongong sand-sheet bedload deposition in main channel.

Sand and granule transport and deposition in the 1967, 1972, and 1976 freshets could have resulted in the ongoing infilling of pools and the covering of gravel substrate throughout the section of river between Vanderhoof and the Stuart River confluence, with negative consequences for sturgeon overwintering and spawning success, respectively.

7.5 1980-2001

In 1980, the salmon-management flow regime was initiated. Since then, annual maximum flows have occurred in the summer, although these summer flows are still reduced from previous flow regimes. The spring freshet was essentially eliminated, and autumn and winter flows were severely reduced. The spring, autumn, and winter flow reductions actually occurred in 1978. As a result of the flow reductions, springtime floodplain inundation and the backwatering of lower tributary reaches was eliminated. Furthermore, autumn wettedness (inlet to outlet) was lost in 10 secondary channels as a result of lowered water levels.

Rating curve shifts at the WSC gauge at Vanderhoof indicate that channel aggradation continued until the early 1990's, followed by degradation from 1995 onward. The specific-gauge analysis likely indicates that a bedload wave passed the gauge site between 1968 and 1995. The bedload material probably consisted of coarse sand and granules – material that is slightly coarser than the material that passed through in the 1964 freshet without depositing at Vanderhoof.

At a key site 38 km downstream of Vanderhoof (Km 179.5), sand deposition was observed in the first low-discharge air photos (1966) following the Cheslatta avulsion, and appeared to be ongoing in 2002. If the Cheslatta sediment-wave theory is correct, we expect that sand deposition at this site will cease within the next decade or so, and that some of the sand will be removed as the channel downcuts in response to diminished sediment supply.

Throughout the affected reaches from Vanderhoof to the Stuart River confluence, the river may downcut through accumulated sand deposits as the sediment wave passes. However, it is unlikely that coarser gravel substrates will be restored due to the reduced flow conditions. Similarly, infilled pools will not reform to their pre-regulation depths because the reduced flows no longer produce the same scour velocities that they once did.

8. References

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Table 1. Mean Annual Discharge by Flow-Regime Period -- Nechako and Stuart Rivers

WSC Gauge		Mean Annual Discharge (m^3/s)			Ratio to Pre-Regulation		
		1930 - 1951	1957 - 1979	1980 - 2001	1930 - 1951	1957 - 1979	1980 - 2001
Nechako River at Vanderhoof	08JC001	242	184	98	1.00	0.76	0.41
Stuart River near Fort St. James	08JE001	110	142	124	1.00	1.29	1.12
Nechako River at Isle Pierre	08JC002	363	338	229	1.00	0.93	0.63

Notes:

1. Discharges at Vanderhoof prior to 1949 have been estimated from Fort Fraser gauge, WSC 08JA001 (Rood and Neill, 1987 -- Fig. 4.5).
2. Discharges at Isle Pierre prior to 1955 have been estimated by adding Vanderhoof and Stuart flows, then adjusting for inflows from minor tributaries (approx 3% of total flow at Isle Pierre).

Table 2a. Mean Seasonal Water Levels Assuming 1952 Gauge Cross-Section
Nechako River at Vanderhoof (WSC 08JC001)

Season	Mean Discharge (m^3/s)			Mean Water Level (m)			Mean Change in Water Level (m)		
	1930 - 1951	1957 - 1979	1980 - 2001	1930 - 1951	1957 - 1979	1980 - 2001	1930 - 1951	1957 - 1979	1980 - 2001
Jan - Apr	99	110	57	2.04	2.14	1.59	0.00	0.10	-0.45
May - Jun	485	295	153	4.28	3.30	2.47	0.00	-0.98	-1.81
Jul - Aug	403	247	204	3.86	3.03	2.78	0.00	-0.83	-1.08
Sep - Dec	181	168	58	2.65	2.57	1.61	0.00	-0.08	-1.04

Notes:

1. Discharges at Vanderhoof prior to 1949 have been estimated from Fort Fraser gauge, WSC 08JA001 (Rood and Neill, 1987 -- Fig. 4.5).

Table 2b. Mean Seasonal Water Levels Assuming 1952 Gauge Cross-Section
Nechako River at Isle Pierre (WSC 08JC002)

Season	Mean Discharge (m^3/s)			Mean Water Level (m)			Mean Change in Water Level (m)		
	1930 - 1951	1957 - 1979	1980 - 2001	1930 - 1951	1957 - 1979	1980 - 2001	1930 - 1951	1957 - 1979	1980 - 2001
Jan - Apr	162	185	123	1.69	1.83	1.42	0.00	0.14	-0.27
May - Jun	679	541	375	4.01	3.57	2.92	0.00	-0.44	-1.09
Jul - Aug	627	532	449	3.85	3.54	3.23	0.00	-0.31	-0.62
Sep - Dec	269	288	149	2.36	2.47	1.59	0.00	0.11	-0.77

Notes:

1. Discharges at Isle Pierre prior to 1950 have been estimated by combining estimated Vanderhoof flows (08JC001) and recorded Stuart River flows (08JE001), plus an adjustment for tributary inflows.

Table 3a. Air photo rolls with complete or nearly complete coverage

Year	Date	Discharge (m^3/s) [1]	Roll No.	Scale	Coverage	Comment
1946	27 Aug	187 (Ft Fraser)	BC 299 / 300	1:32,000	Complete.	Moderate discharge, good visibility of submerged bars.
1950	28-29 Apr	144	BC 1000 / 1037	1:7,000	Complete.	Ice in channel and snow on ground.
	02 May	164	BC 1038			
1953	18 May	66	BC 1703	1:33,000	Complete.	Low discharge, good channel visibility.
	08 Jul	95	BC 1716 / 1717			
	04-07 Oct	34	BC 1600 / 1652 / 1653			
1958	17 Aug	303	BC 2525 / 2526 / 2527	1:20,000	Complete.	High turbidity or reflectance, poor channel visibility.
1960	28-29 Sep	278	BC 2919 / 2928 / 2931 / 2932	1:20,000	Missing big bend d/s of Stuart River confluence.	Moderate discharge, adequate channel visibility.
1973	15 Sep	57	BC 7559 / 7560	1:15,840	Missing Isle Pierre.	Low discharge, good channel visibility.
1978	01 Jun	150	BC 78053	1:20,000	Missing Isle Pierre.	Moderate discharge, adequate channel visibility.
1980	12 Aug	153	BC 80107	1:20,000	Missing Isle Pierre.	
1985	09 Jul	175	BC 85041 / 85042	1:20,000	Complete.	Moderate discharge, clear water, good channel visibility.
	16 Jul	277	BC 85054			
1988	23 Jul	203	BC 88042	1:20,000	Complete.	
	07 Aug	204	BC 88050 / 88057			
1996	07 Jul	280	BCB 96004 / 96007	1:40,000	Complete.	Moderate discharge, moderate channel visibility u/s Stuart, poor visibility d/s Stuart.
1997	10 Aug	422	BCC 97123	1:15,000	Missing Isle Pierre.	High discharge, dark & hazy photos, poor channel

Notes:

1. Daily discharge at WSC Gauge 08JC001 (Nechako River at Vanderhoof), except photos prior to 1949 where the unadjusted discharge at WSC Gauge 08JA001 (Nechako River at Fort Fraser) is provided.
2. Shading indicates key photo sets used for historical analysis of geomorphic changes.

Table 3b. Air photo rolls with partial coverage

Year	Date	Discharge (m^3/s)[1]	Roll No.	Scale	Coverage	Comment
1928	22 Sep	---	A 737	1:12,000	Sheets 1-2: d/s Vanderhoof.	Moderate discharge, good visibility of submerged bars.
1947	18 Jul	314 (Ft Fraser)	A 11799	1:39,000	Sheets 3-8: missing d/s Vanderhoof.	
1951	20 Jun	614	BC 1283	1:10,000	Sheet 1: d/s Vanderhoof.	High discharge, overbank flood extent clearly visible.
1963	17 May	413	BC 5069 / 5070	1:16,000	Sheets 5-8: Stuart River to Isle Pierre.	
1966a	05 May	182	BC 5177 / 5180	1:31,680	Sheets 1-5: Vanderhoof to big bend d/s Stuart River confluence.	Moderate discharge, poor channel visibility.
	06 Jul	283	BC 5194			
	16 Jul	197	BC 5195			
1966b	23 Aug	96	BC 5209 / 5212	1:33,000	Sheets 1-5: Vanderhoof to big bend d/s Stuart River confluence.	Low discharge, good visibility of submerged bars.
1969	11 Jun	202	BC 5335	1:31,680	Sheets 5-8: Stuart River to Isle Pierre.	
1971	12 Aug	228	BC 5435	1:31,000	Sheets 3-5, except gap at Hulatt rapids and u/s bar.	Moderate discharge, good visibility of submerged bars.
	30 Aug	227	BC 5440			
1977	24 Jul	245	BC 77052	1:20,000	Sheets 4-7: Stuart River confluence to Isle Pierre.	
	14 Aug	185	BC 77089			
1990	26 Jul	292	BCB 90058	1:15,000	Sheets 2-6: missing d/s Vanderhoof and u/s Isle	
1991	31 Jul	196	BCB 91058	1:15,000	Sheet 1: d/s Vanderhoof.	
1994	22 Jun	137	BCB 94019	1:15,000	Sheets 5-7: Stuart River confluence to Isle Pierre.	
	23 Jun	135	BCB 94020			
	20 Jul	273	BCB 94032			
1995	21 Jul	299	BCB 95027	1:15,000	Sheets 2-6: missing d/s Vanderhoof and u/s Isle	
1999	02 Aug	246	BCB 99022	1:15,000	Sheets 4-6: u/s and d/s Stuart River confluence.	
	15 Sep	73	BCB 99042			
2000	18 Sep	58	BCB 00029	1:15,000	Sheets 6-7: u/s Isle Pierre.	

Notes:

1. Daily discharge at WSC Gauge 08JC001 (Nechako River at Vanderhoof), except photos prior to 1949 where the unadjusted discharge at WSC Gauge 08JA001

(Nechako River at Fort Fraser) is provided.

2. Shading indicates key photo sets used for historical analysis of geomorphic changes.

Table 4. Lower Nechako Air Photo Mosaics

Sheet	River Km	Reach	Key Feature	Air Photo No.'s
1	142.0 – 155.7	8	Vanderhoof	BC 85041: #118-121.
2	154.8 – 164.3	8	Sinkut River	BC 85041: #122-123, 254-255.
3	163.1 – 173.9	8 / 9	Hulatt Rapids	BC 85041: #254, BC 85042: #53-56.
4	173.2 – 184.0	9	Cluculz Creek / Finmoore	BC 85042: #57-59, BC 85041: #246-248.
5	183.6 – 196.5	9 / 10	Stuart River / Horseshoe bend	BC 85041: #240-244.
6	196.1 – 206.0	10	Hutchison	BC 85041: #239, BC 85042: #68-71.
7	205.0 – 212.8	10	Big bend (east to south)	BC 85041: #233-235, BC 85042: #74.
8	211.6 – 217.2	10 / 11	Isle Pierre	BC 85042: #74, BC 85054: #24.

Table 5. Description of Lower Nechako Study Reaches

Reach 8

- Start location: Km 142.0 (Vanderhoof bridge).
- End location: Km 173.1 (Hulatt Rapids, d/s limit of continuous floodplain).
- Length: 31.1 km.
- Air photo mosaic sheets: No. 1 – 3.
- Channel type: meandering, partly entrenched by glaciolacustrine terraces.
- Sediment texture: pebbly gravel to sand bed; fine sand to silt bars.
- Floodplain: continuous on one side of channel or the other, some floodplain conversion to low terraces due to reduced flood magnitude and landfilling for development.
  Floodplain A ~ 1100 ha, ~ 85% developed urban & agriculture.
  Most agricultural clearing 1940's or earlier, urban encroachment thru 1960's and 70's.
  CNR runs along southern floodplain margin, only cuts off A ~ 40 ha at Km 22 – 23.
- Islands: occasional, n = 5, A ~ 58 ha (incl. marginal bars).
- Bars: frequent, n = 11, A ~ 53 ha (excl. island margin bars).
- Secondary channels: frequent, n = 11, L ~ 6.2 km.
- Backwatered tributary channels: n = 6, L ~ 7.3 km.
- Small gravel fan at mouth of Sinkut River.

Reach 9

- Start location: Km 173.1 (Hulatt Rapids, d/s limit of continuous floodplain).
- End location: Km 186.2 (Stuart River confluence).
- Length: 13.1 km.
- Air photo mosaic sheets: No. 3 – 5.
- Channel type: wandering, mostly entrenched within low glaciolacustrine terraces.
- Sediment texture: sand bed, sand and silt bars, except for 2 km d/s of Cluculz Creek: cobble and pebble gravel bars.
- Floodplain: infrequent, approx 80 ha, undeveloped.
- Islands: occasional, n = 3, A ~ 29 ha (incl. marginal bars).
- Bars: frequent, n = 10, A ~ 17 ha (excl. island margin bars).
- Secondary channels: frequent, n = 6, L ~ 3.0 km.
- Backwatered tributary channels: negligible, n=1, L ~ 0.1 km.
- Moderate gravel fan at mouth of Cluculz Creek, and several bars downstream of mouth for 2 km, distinct sedimentology from upstream, biggest tributary influence apart from Stuart River.

cont'd…

Table 5. Description of Lower Nechako Study Reaches (cont'd…)

Reach 10

- Start location: Km 186.2 (Stuart River confluence).
- End location: Km 214.5 (u/s limit of bedrock section).
- Length: 28.3 km.
- Air photo mosaic sheets: No. 5 – 8.
- Channel type: straight to sinuous, entrenched within glaciolacustrine terraces.
- Sediment texture: Cobble and pebble gravel bed and bars, sand bars in sheltered sites.
- Floodplain: none.
- Islands: n = 1, A ~ 3 ha (incl. marginal bars).
- Bars: occasional, n = 6, A ~ 9 ha.
- Secondary channels: infrequent, n = 2, L ~ 0.6 km.
- Backwatered tributary channels: none (trib's incised).
- Several tiny tributary fans.

Reach 11

- Start location: Km 214.5 (u/s limit of bedrock section).
- End location: Km 217.2 (d/s end of Isle de Pierre Rapids).
- Length: 2.7 km.
- Air photo mosaic sheets: No. 8.
- Channel type: irregular, entrenched within bedrock, bedrock exposed in channel (bedrock rapids and islands).
- Sediment texture: boulder and cobble bed, cobble and pebble bars.
- Floodplain: none.
- Islands: frequent, n = 3, A ~ 16 ha (bedrock not floodplain).
- Bars: negligible.
- Secondary channels: frequent, n = 3, L ~ 1.5 km.
- Backwatered tributary channels: n/a.
- Tributary fans: n/a.

Table 6. Lower Nechako River Secondary Channel Classification

Mosaic Sheet	Reach	River Km		Length (m)	Type	Width Ratio	Size Class	Change in Wettedness
		Inlet	Outlet					
1	8	149.4	150.5	1300	1	0.21	S	3
1	8	152.2	152.6	450	2	0.31	M	5
2	8	155.0	155.5	500	2	0.11	S	4
2	8	156.4	156.6	275	3	0.20	S	3
2	8	160.0	160.2	250	3	0.20	S	3
2	8	162.1	162.8	450	3	0.75	L	3
2	8	163.4	163.5	175	3	0.43	M	5
3	8	165.1	166.0	1000	3	0.10	S	3
3	8	168.8	169.1	675	3	0.17	S	3
3	8	171.8	172.8	800	2	0.11	S	4
3	8	172.8	173.0	300	1	0.25	S	1
4	9	173.7	173.9	300	2	0.11	S	3
4	9	174.0	174.1	175	3	0.10	S	3
4	9	174.4	174.9	575	3	0.10	S	3
4	9	175.4	175.8	450	3	0.50	M	5
4	9	179.0	179.9	1100	1	0.40	M	5
4	9	181.6	182.0	400	1	0.80	L	2
5	10	188.7	189.0	400	2	0.26	S	5
5	10	189.0	189.1	225	3	0.25	S	5
8	11	214.7	215.1	450	1	0.20	S	3
8	11	216.3	217.2	825	1	0.58	M	5
8	11	217.0	217.2	250	1	0.24	S	5

General:
1. All measurements taken from 1985 air photo mosaic.

Secondary channel types (after Rood and Neill 1987):
1. Separated from main channel by a permanent island with mature vegetation.
2. Separated from main channel by a high bar with deciduous vegetation colonization (emergent island / floodplain).
3. Separated from main channel by a gravel bar with no visible vegetation.

Secondary channel sizes:
Small: Sec. / main channel width ratio < 0.3
Medium: Sec. / main channel width ratio = 0.3 to 0.6
Large: Sec. / main channel width ratio > 0.6

Change in secondary channel autumn wettedness:
Note: referring to continuous wettedness with surface inflow from river mainstem into secondary channel.
Note: categories are hierarchical and not exclusive, degree of channel change decreases 1 to 5.
Note: assume pre-regulation autumn water levels were 1.0 m higher than on 02 October 2002, upstream of Stuart River.
Note: assume pre-regulation autumn water levels were 0.8 m higher than on 02 October 2002, downstream of Stuart River.
1. Abandoned: vegetated with deciduous since 1952.
2. Reduced wettedness due to sediment: wetted at low flow in 1952 and at summer flow in 2002, but not at autumn flow in 2002.
3. Reduced wettedness due to water level: not wetted at autumn flow in 2002, but wetted at pre-regulation autumn flow.
4. Not wetted in autumn 2002, nor at pre-regulation autumn flow.
5. Wetted in autumn 2002.

Table 7. Lower Nechako Secondary Channels -- Number and Length by Category

Reach	Number	Length (m)
8	11	6,175
9	6	3,000
10	2	625
11	3	1,525
Total	22	11,325

Type	Number	Length (m)
1	7	4,625
2	5	2,450
3	10	4,250
Total	22	11,325

Size	Number	Length (m)
S	0	7,475
M	0	3,000
L	0	850
Total	0	11,325

Change in Autumn Wettedness	Number	Length (m)
1	1	300
2	1	400
3	10	5,450
4	2	1,300
5	8	3,875
Total	22	11,325

Notes:

1. All measurements taken from 1985 air photo mosaic.
2. See Table 6 and report text for classification schemes.

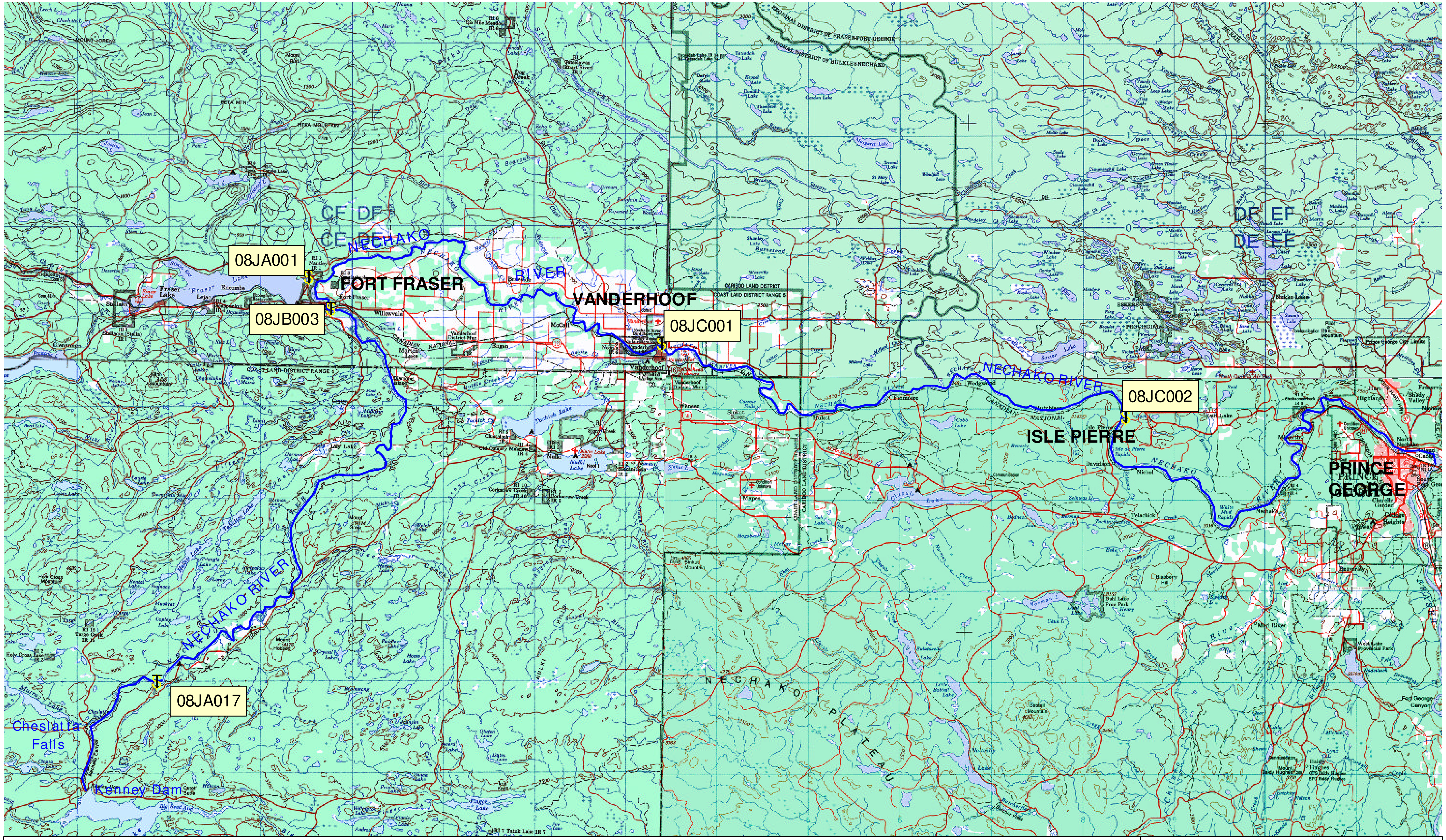
Table 8. Summary of Station Analysis Notes

WSC Gauge 08JC001, Nechako River at Vanderhoof

- 1972: First high flow since 1964 has washed silt from the normally stable islands upstream of the bridge downstream to the gauge control. Rating curve shift to the left.
- 1974: Wintertime spillway release caused ice jam at bridge; bridge damaged. Ice jam caused high water level, but these gauge heights would not be used for rating curve; rating curve not affected.
- 1975, 1983, 1985: control scoured by ice.
- 1976: High flows caused sediment deposition in control resulting in a left shift in the rating curve.
- 1977-79: Gradual scour resulting in right shift of the rating curve at medium discharge.
- 1986: silt deposition during initial freshet.
- 1989: gravel bar upstream of bridge shifted.
- 1990-91: New bridge constructed, cofferdams affected rating curve. Gauge heights at time of discharge measurement were adjusted; rating curve not affected.
- 1994: Typical annual pattern identified (described in detail since 1989, but miscellaneous notes indicate likely occurrence since at least mid-1970's). During ice breakup in the spring, ice scours the channel resulting in a right shift of the rating curve. First high flows in May or June cause infilling of the scoured channel resulting in a left shift of the rating curve.

WSC Gauge 08JC002, Nechako River at Isle Pierre

- 1969: The control is exceptionally stable at this station.
- 1972: Dept. of Highways altered the ferry slip in 1969. The altered geometry only affects discharge above a critical gauge height, which was not exceeded until 1972.
- 1978: Discontinuous extension of ferry ramps cause backwater at site, left shift in rating curve. Rating curve is average of discharge measurements in various conditions.
- 1984: ferry service ceased, ramps removed, right shift in rating curve due to ramp removal.



Legend

Ŧ Water Survey of Canada Stream Gauge

10 0 10 20 Kilometers

Scale 1 : 400 000

N

Nechako River Geomorphic Assessment

Nechako River
Location Map

northwest hydraulic consultants

Figure 1

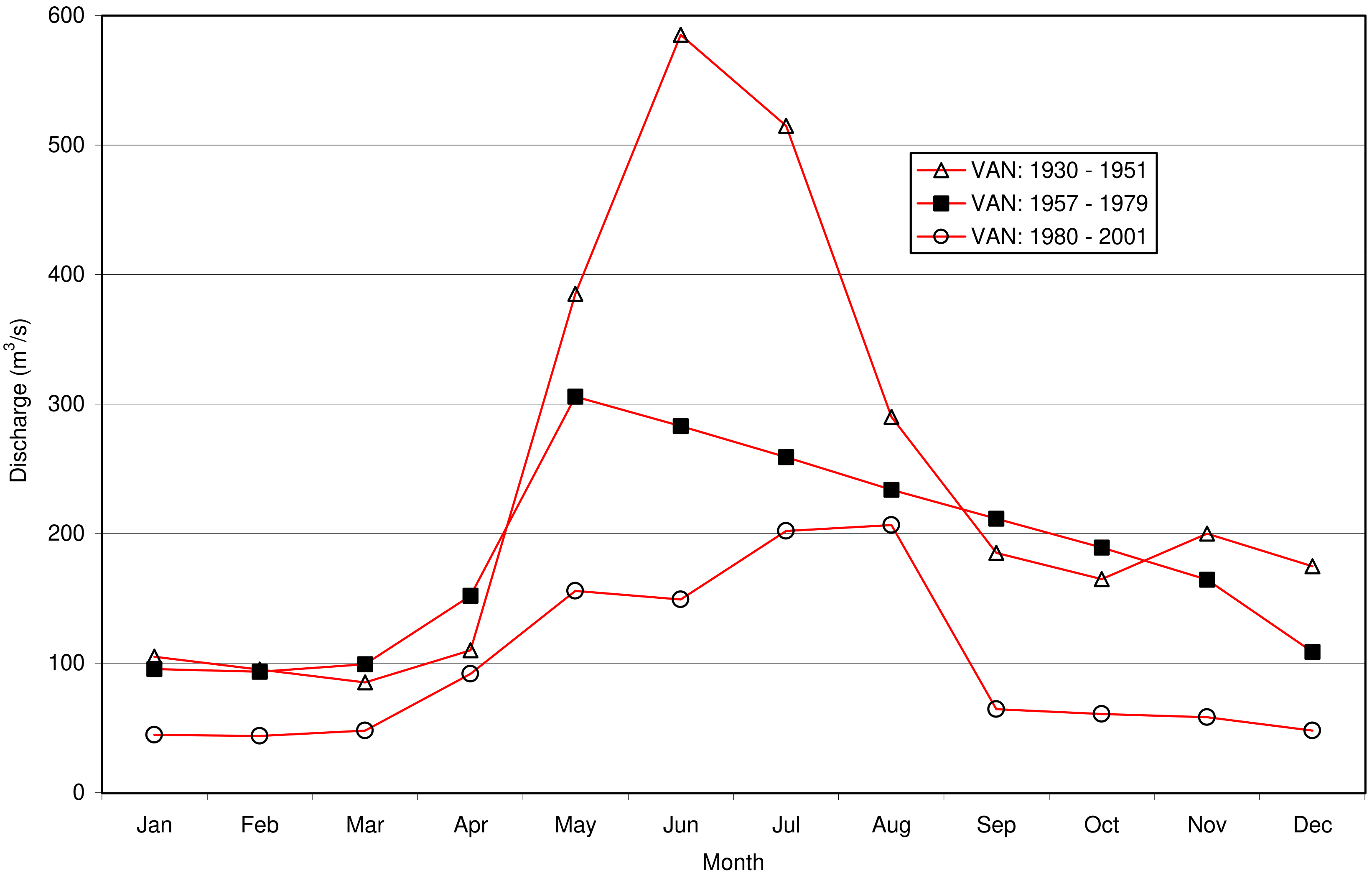


Figure 2a. Mean Monthly Discharge
Nechako River at Vanderhoof (WSC Gauge 08JC001)

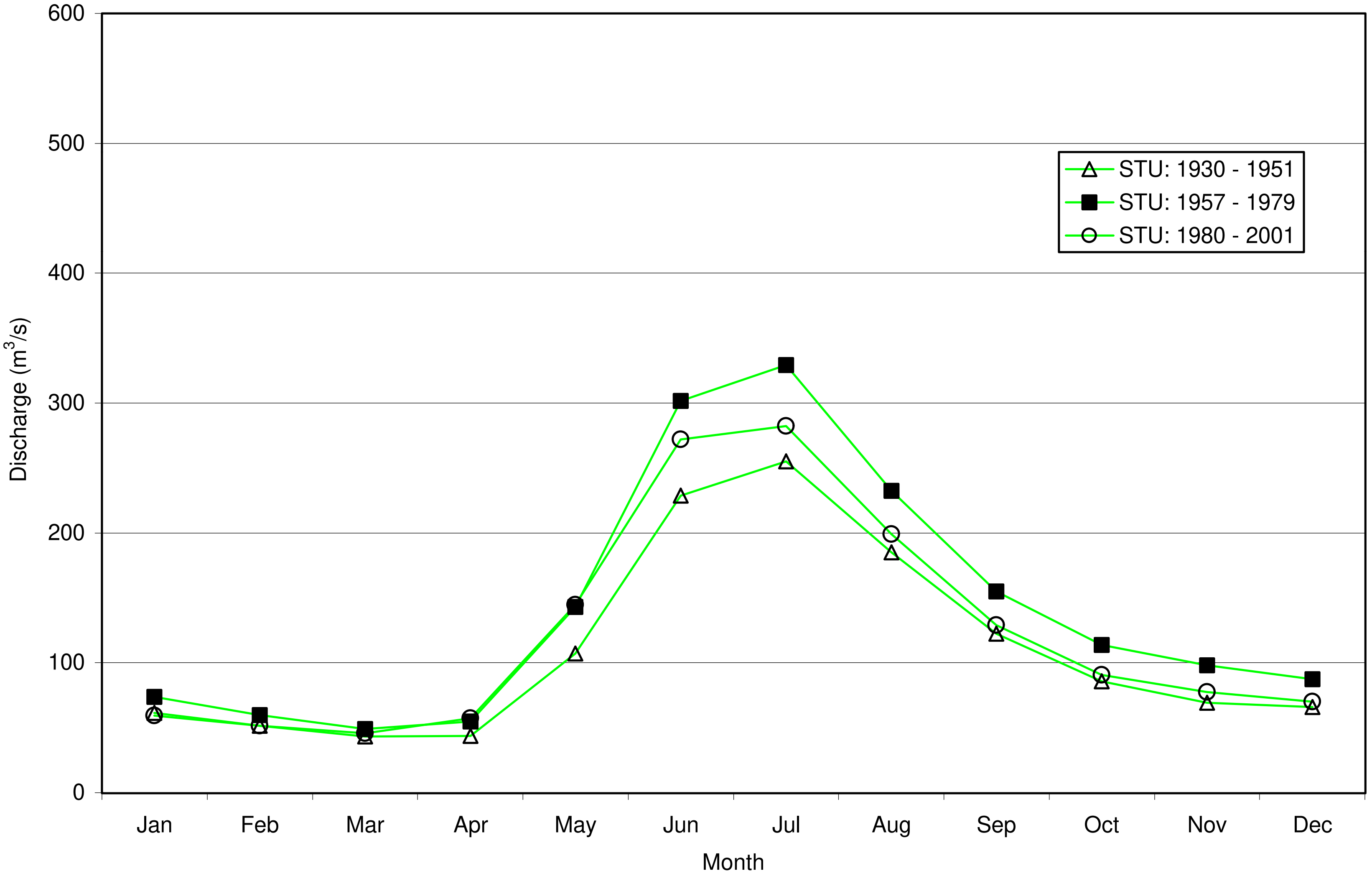
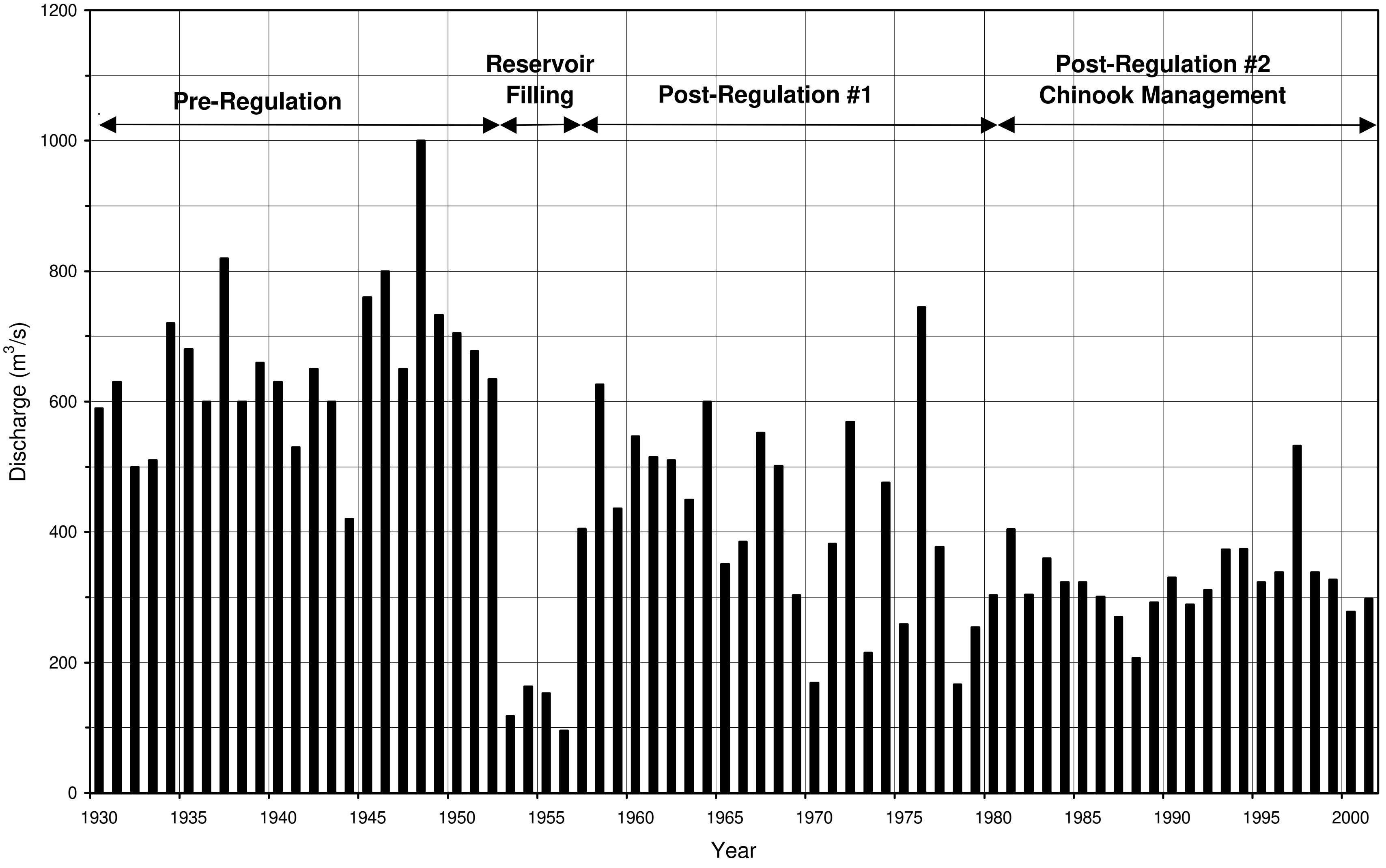
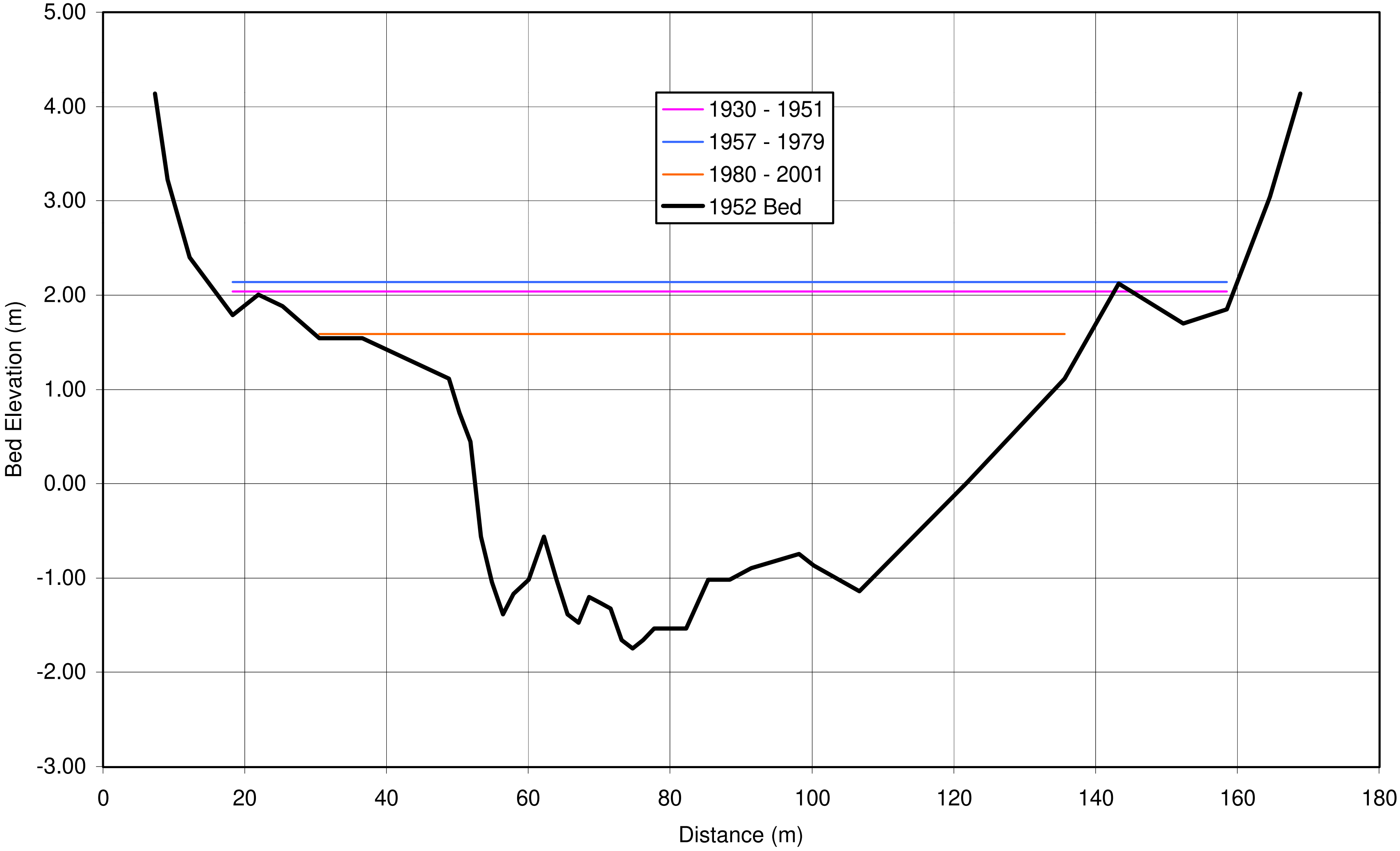


Figure 2b. Mean Monthly Discharge
Stuart River near Fort St. James (WSC 08JE001)

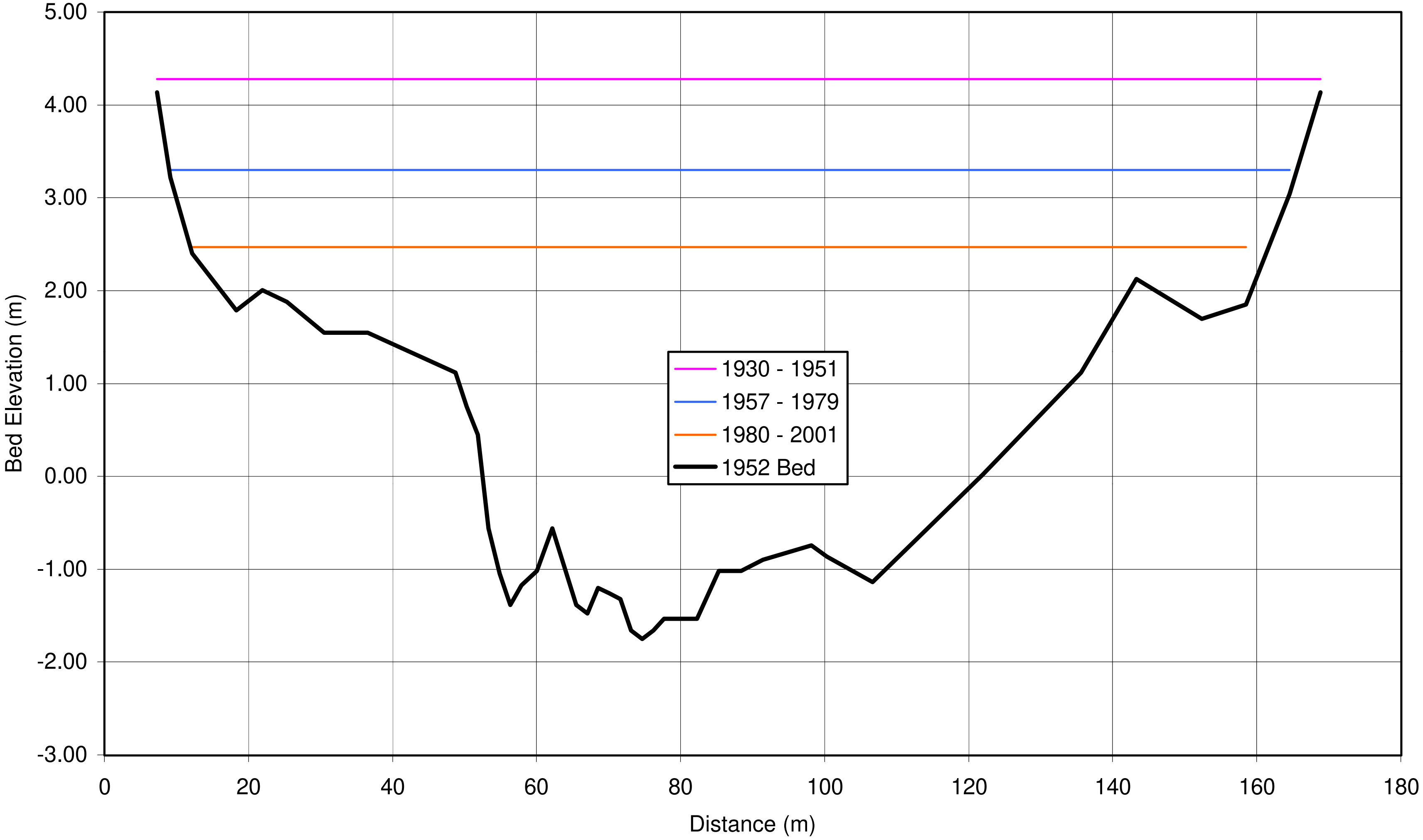
Figure 3. Annual Maximum Daily Discharge
Nechako River at Vanderhoof (WSC Gauge 08JC001)

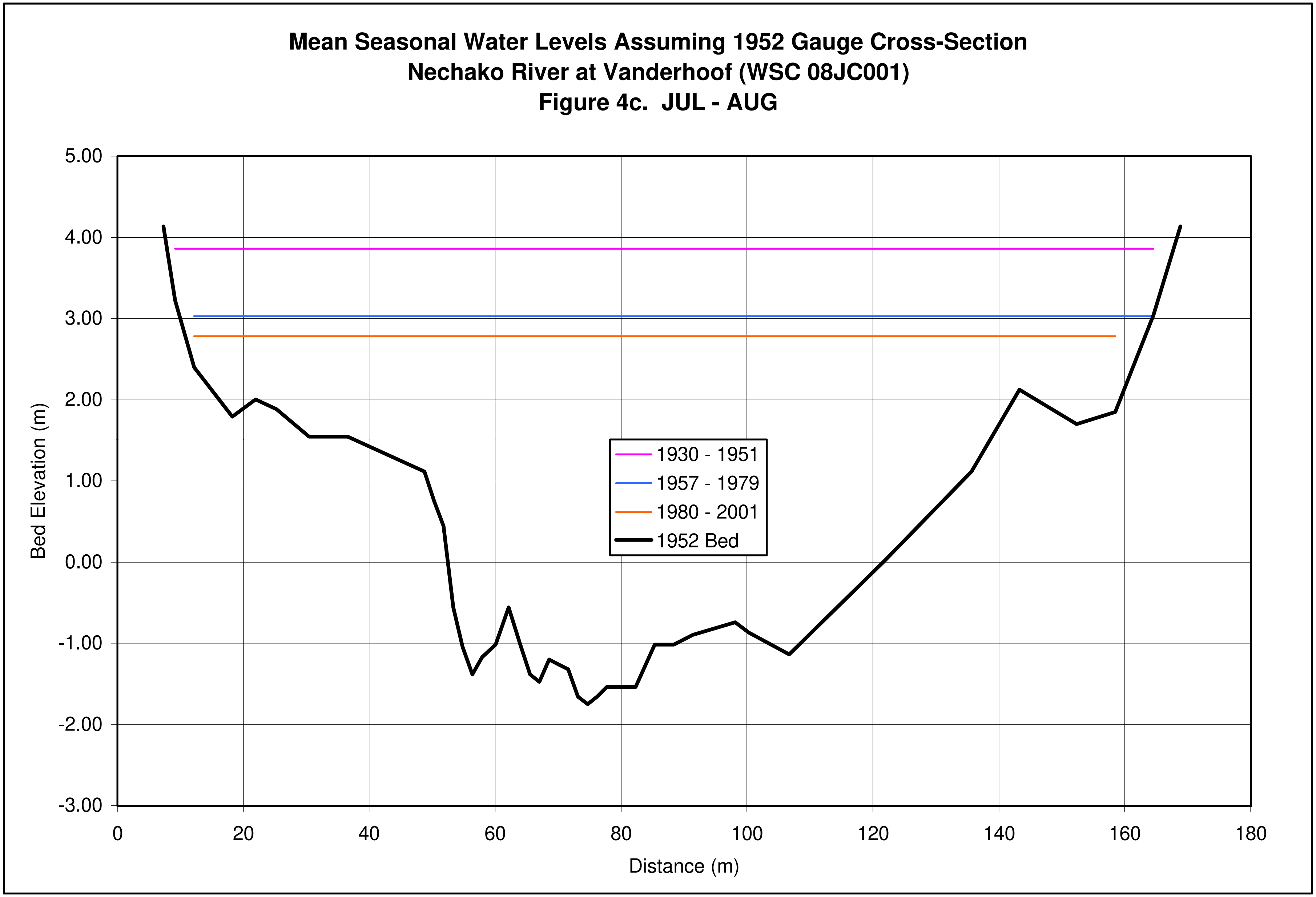


Mean Seasonal Water Levels Assuming 1952 Gauge Cross-Section
Nechako River at Vanderhoof (WSC 08JC001)
Figure 4a. JAN - APR



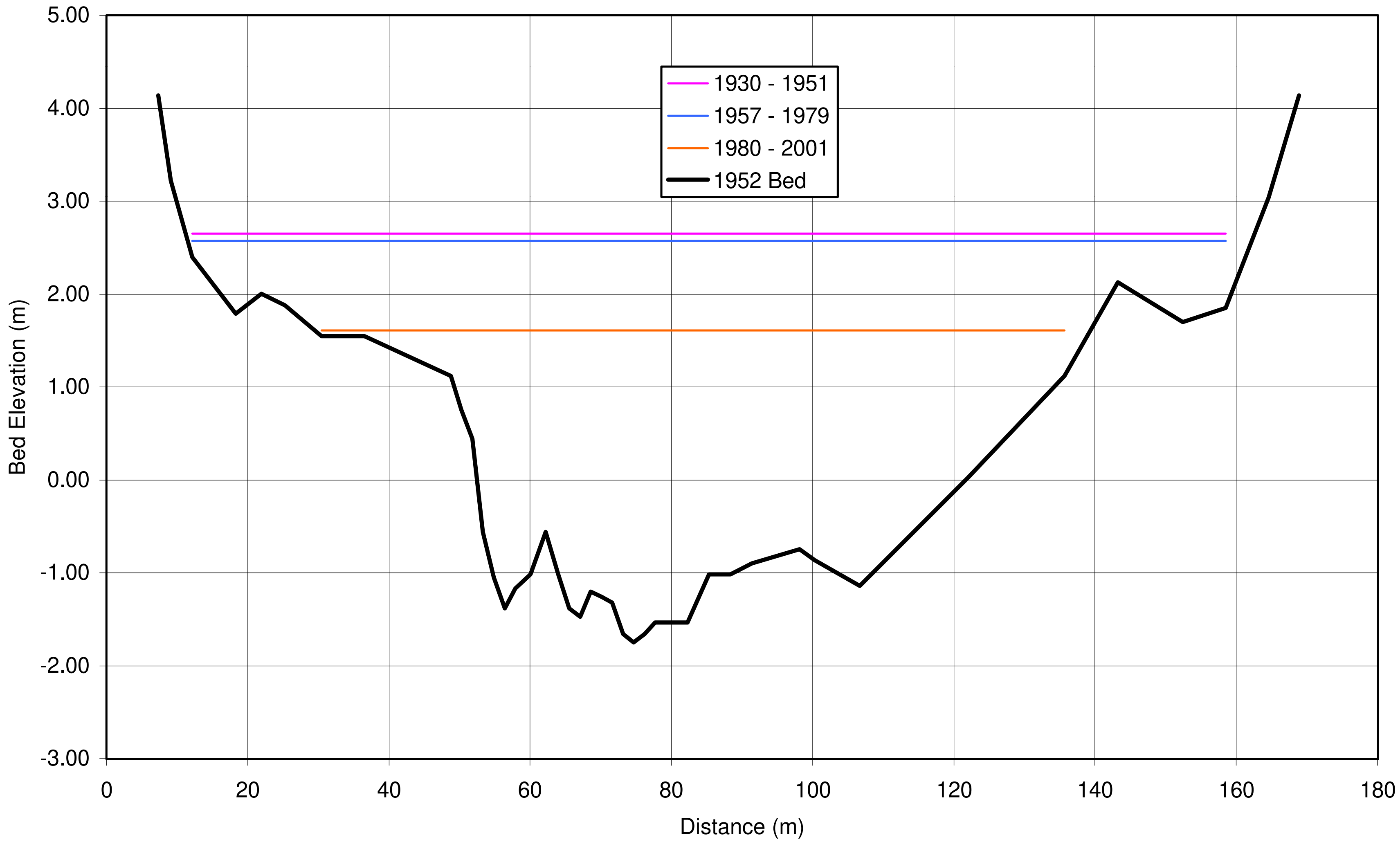
Mean Seasonal Water Levels Assuming 1952 Gauge Cross-Section
Nechako River at Vanderhoof (WSC 08JC001)
Figure 4b. MAY - JUN



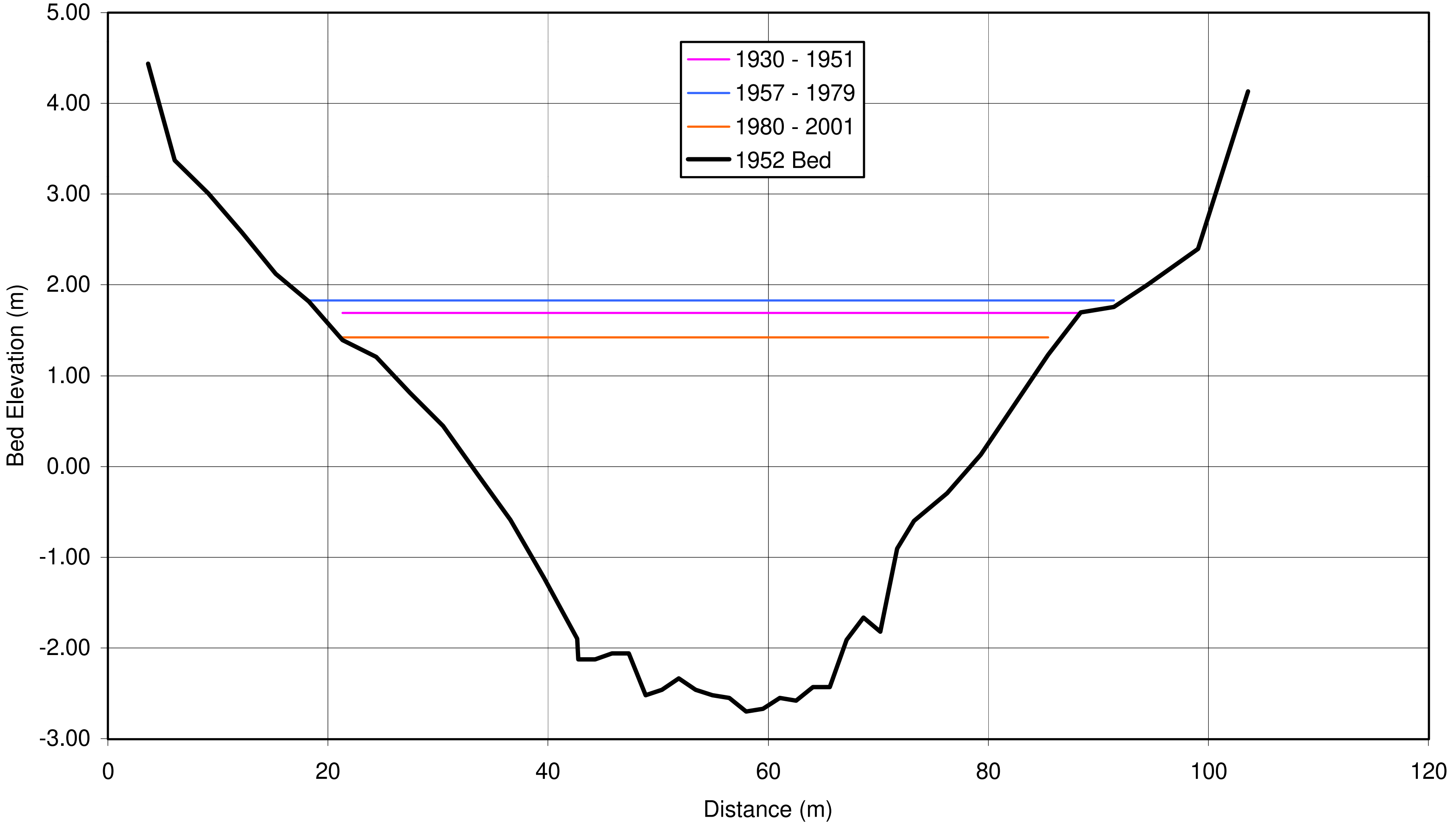


Mean Seasonal Water Levels Assuming 1952 Gauge Cross-Section
Nechako River at Vanderhoof (WSC 08JC001)
Figure 4c. JUL - AUG

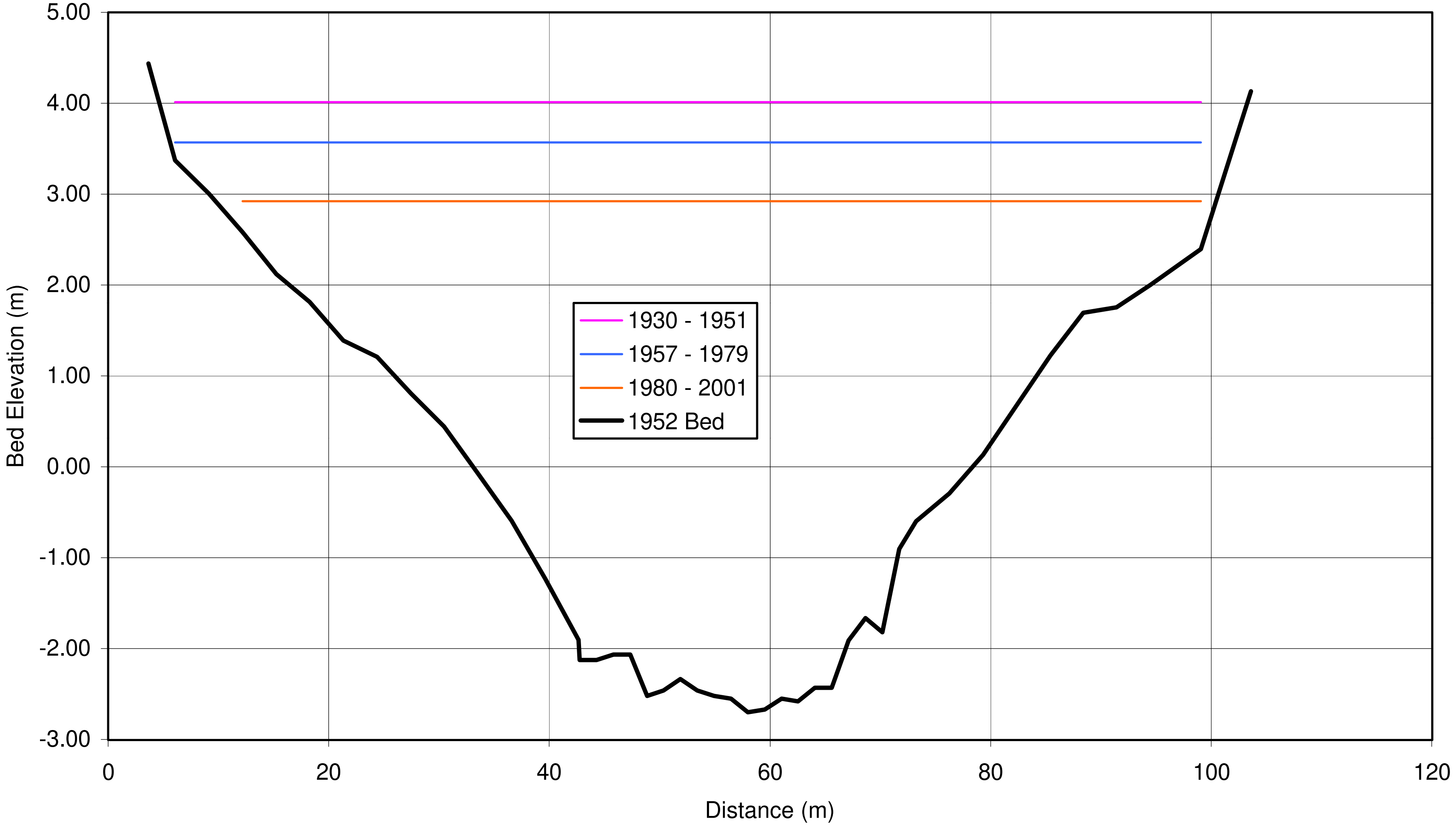
Mean Seasonal Water Levels Assuming 1952 Gauge Cross-Section
Nechako River at Vanderhoof (WSC 08JC001)
Figure 4d. SEP - DEC

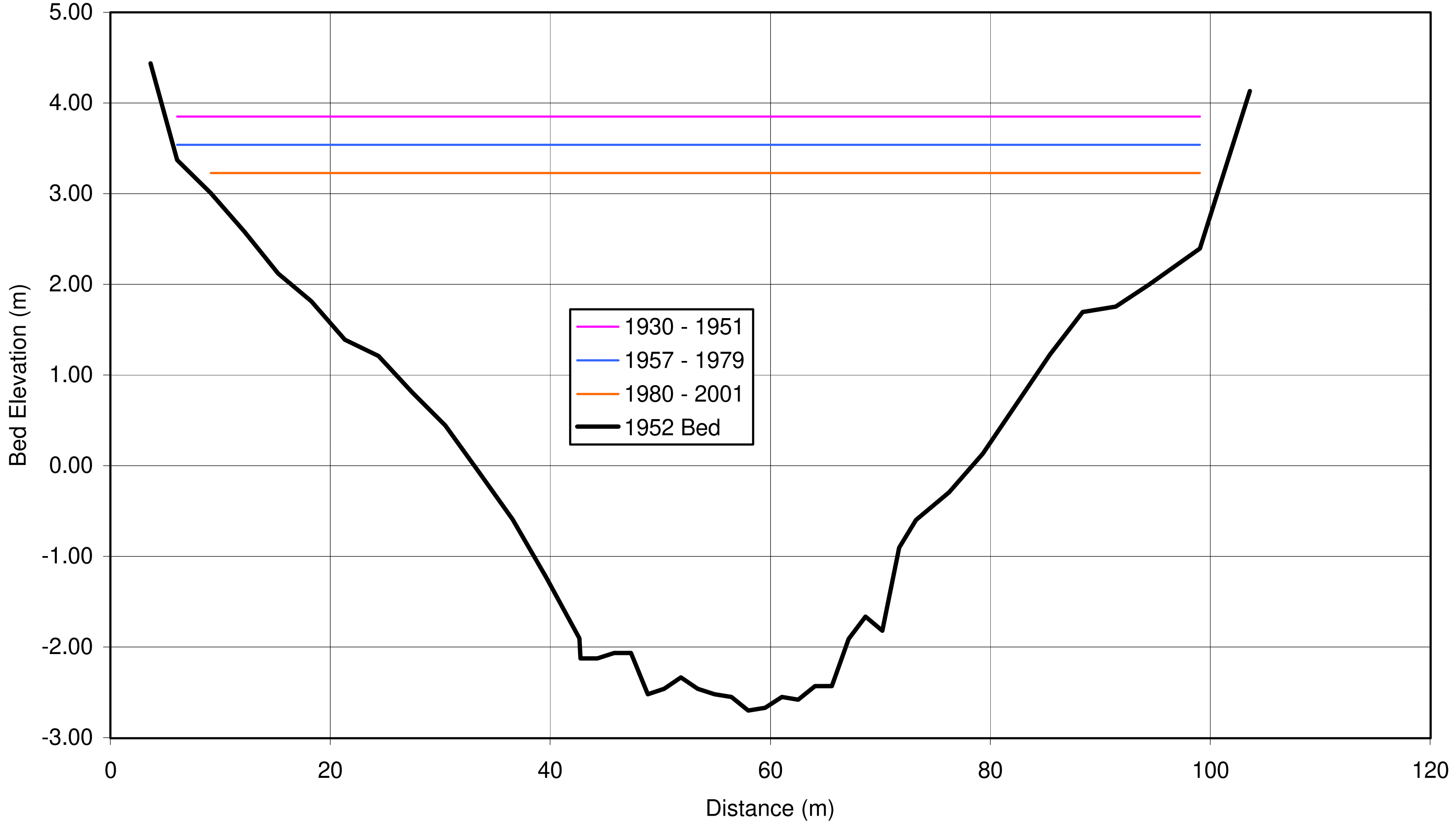


Mean Seasonal Water Levels Assuming 1952 Gauge Cross-Section
Nechako River at Isle Pierre (WSC 08JC002)
Figure 5a. JAN - APR



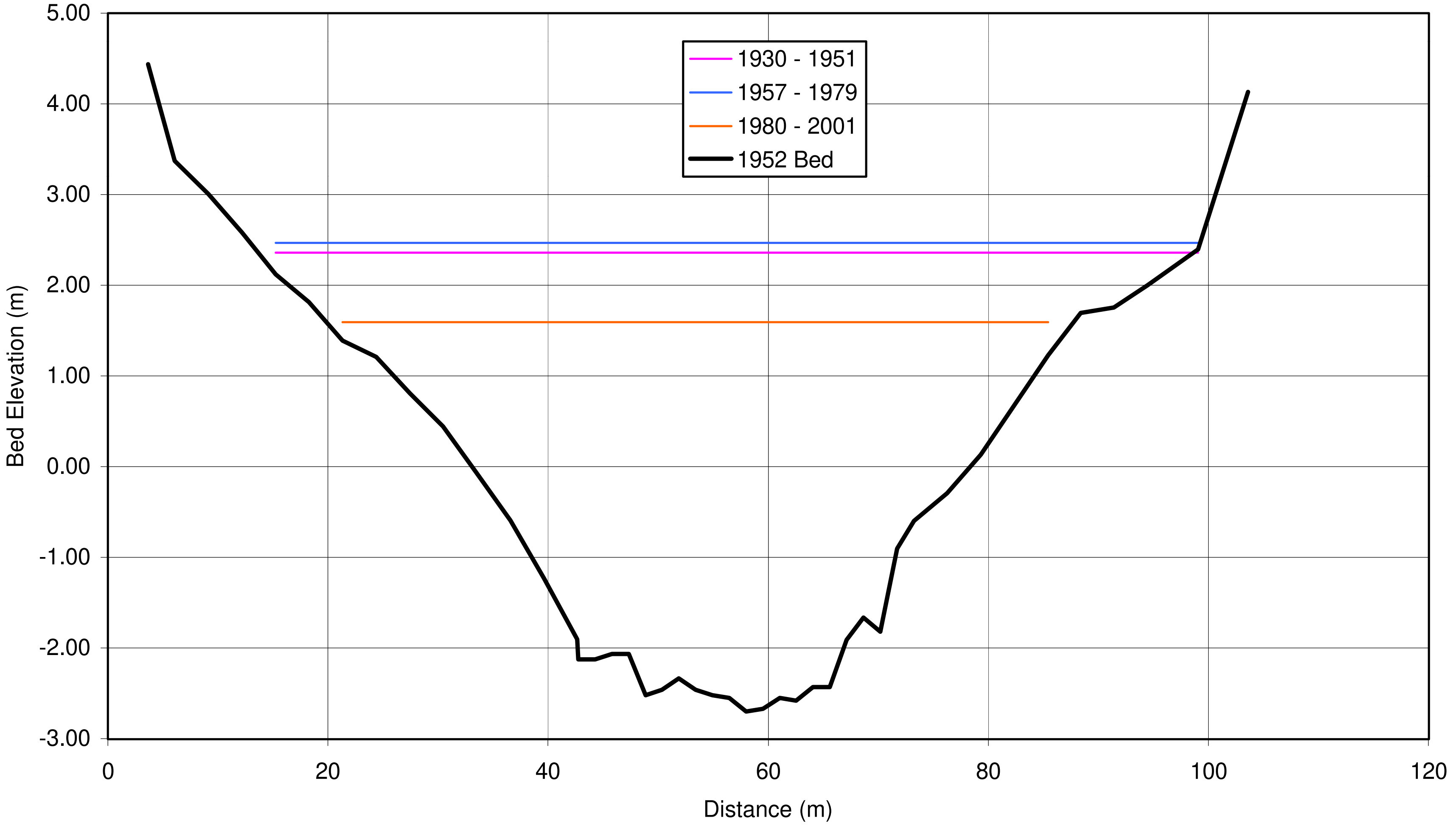
Mean Seasonal Water Levels Assuming 1952 Gauge Cross-Section
Nechako River at Isle Pierre (WSC 08JC002)
Figure 5b. MAY - JUN





Mean Seasonal Water Levels Assuming 1952 Gauge Cross-Section
Nechako River at Isle Pierre (WSC 08JC002)
Figure 5c. JUL - AUG

Mean Seasonal Water Levels Assuming 1952 Gauge Cross-Section
Nechako River at Isle Pierre (WSC 08JC002)
Figure 5d. SEP - DEC



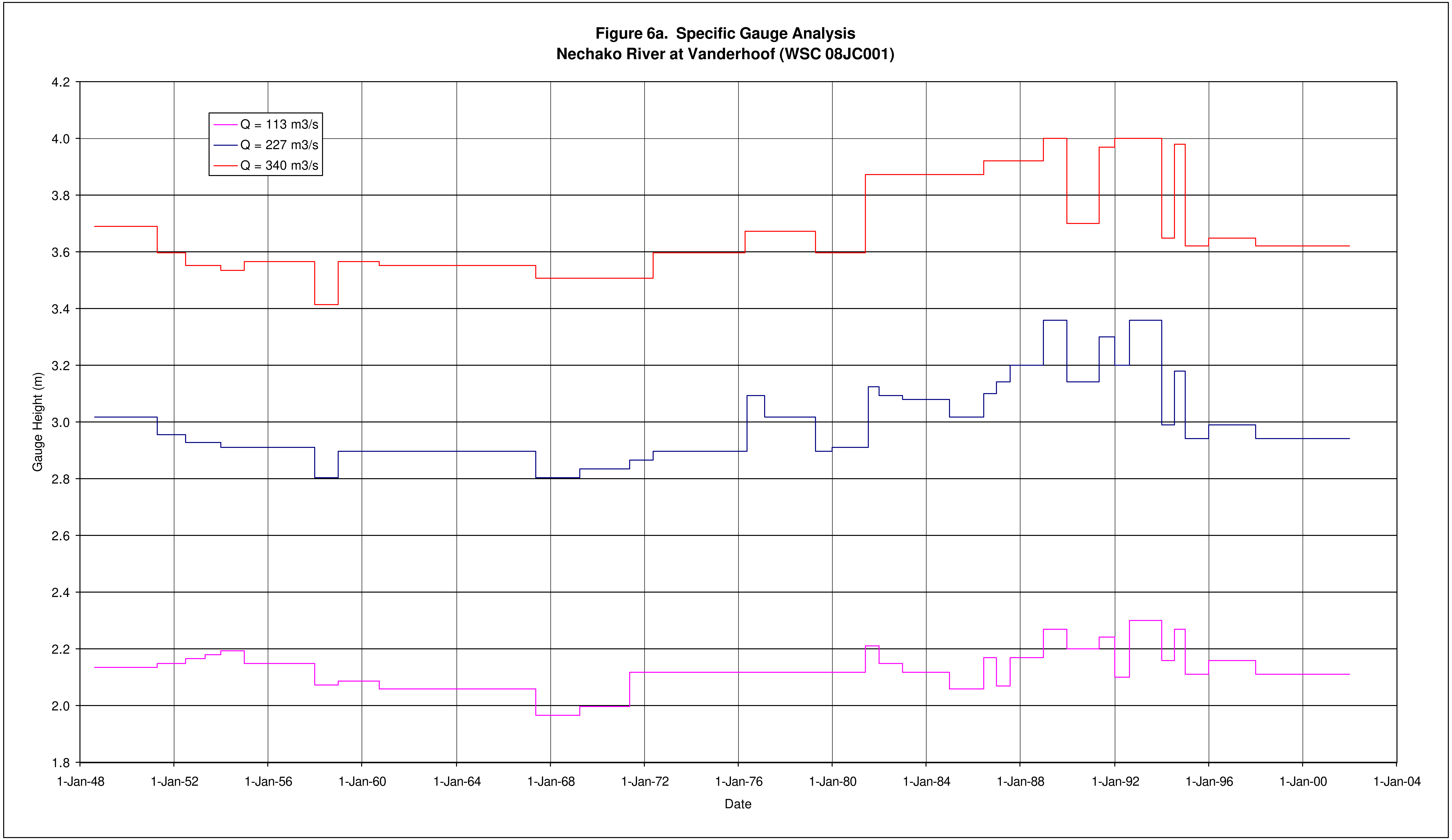
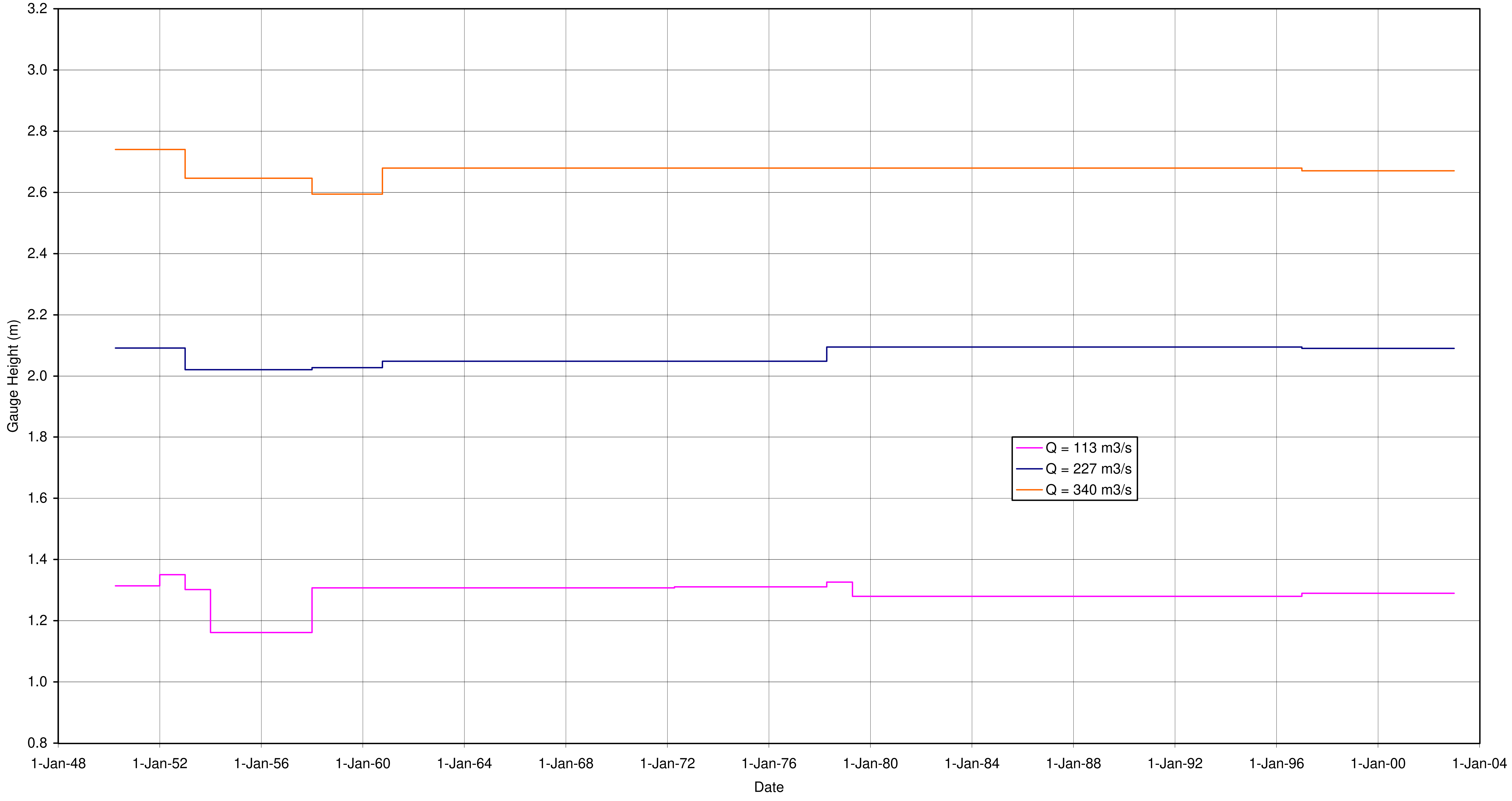
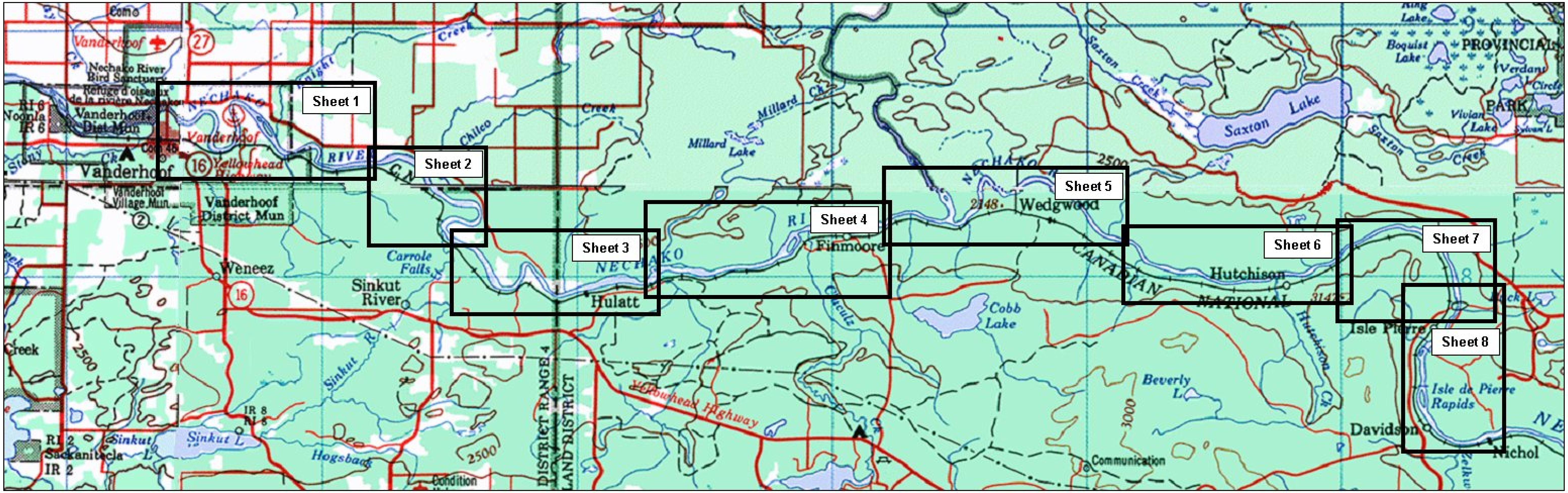


Figure 6a. Specific Gauge Analysis
Nechako River at Vanderhoof (WSC 08JC001)

Figure 6b. Specific Gauge Analysis
Nechako River at Isle Pierre (WSC 08JC002)





Nechako River White Sturgeon Recovery Program

Air Photo Mosaic Index Map

N.T.S. Sheets 93 F, 93 G,
93 J & 93 K

Scale – 1:150,000

N

0 2 4 6 8 km

nhc project no. 3-3683

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