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Rio Tinto Water Engagement Initiative
Nechako River Erosion
Final Report, Rev. 2

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- Dale Muir — Principal
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- Andre Zimmermann — Senior Geomorphologist
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1 INTRODUCTION

During Main Table and Technical Working Group meetings of the Nechako Water Engagement Initiative (WEI), concerns were raised regarding potential effects of Rio Tinto operations on riverbank erosion along private property located along the banks of the Nechako River (Issue #56). While this issue is important to some community members and has social significance, the sensitivity to Rio Tinto operations is unknown.

NHC was asked to investigate various geomorphic and hydrologic items and provide guidance on potential impacts and management options. This technical memo was prepared to better understand the relationship between river levels and historical erosion.

Specifically, the primary focuses of this investigation are *lateral erosion* and *channel migration*, which can be defined as follows:

- **Lateral erosion**: A process by which the flow of a river mobilizes sediment along the margins of the channel, causing the lateral boundaries (or banks) of the river shift outwards. Lateral erosion can occur gradually over time, or rapidly during a single high-water event. It may occur on both sides of the river if the overall channel widens, or, more commonly, along the outside (or longest side) of a meander.
- **Channel migration**: A process by which a stream or river channel moves across the floodplain over time. Channel migration can occur progressively, as meanders shift laterally or downstream, or as a rapid change in the channel alignment (termed an *avulsion*). Progressive channel migration typically involves erosion along the outside bank of a meander with compensating deposition along the inside (or shortest side) of the meander, forming a point bar.

It is NHC's understanding that lateral erosion along the Nechako River is causing damage to houses and loss of property in certain areas, including in the community of Miworth near Prince George. Bank erosion is also causing loss of property, as well as damage to fencing and intake structures on agricultural lands upstream of Vanderhoof. It is NHC's understanding that, while there have been some assessments, surveys, and mitigations completed near Miworth, erosion issues upstream of Vanderhoof remain generally unassessed.

2 BACKGROUND

The following subsections provide context regarding the geomorphology (Section 2.1), hydrology (Section 2.2), and sediment regime (Section 2.3) of the Nechako River.

2.1 Geomorphic Context

The Nechako River watershed covers approximately 47,000 km^2 of the Interior Plateau in west-central British Columbia (Figure 2.1). The Nechako River drains the leeward side of the Coast Mountain Range through a series of large lakes located in a physiographic region known as the Nechako Plateau, after which it flows easterly through the Nechako Plains (Holland, 1976) until it joins the Fraser River at Prince George. The Nechako River generally occupies a large meltwater channel valley produced during the Pleistocene glaciation (Rood, 1993). During deglaciation, remnant ice impounded several large lakes in the region, forming thick deposits of glaciolacustrine sediment generally consisting of silt interbedded with fine sand and clay (Plouffe and Levson, 2001). The river has since incised into this deposit, creating high terraces that rise 20 to 30 m above the current floodplain elevation along the outside of meander bends.

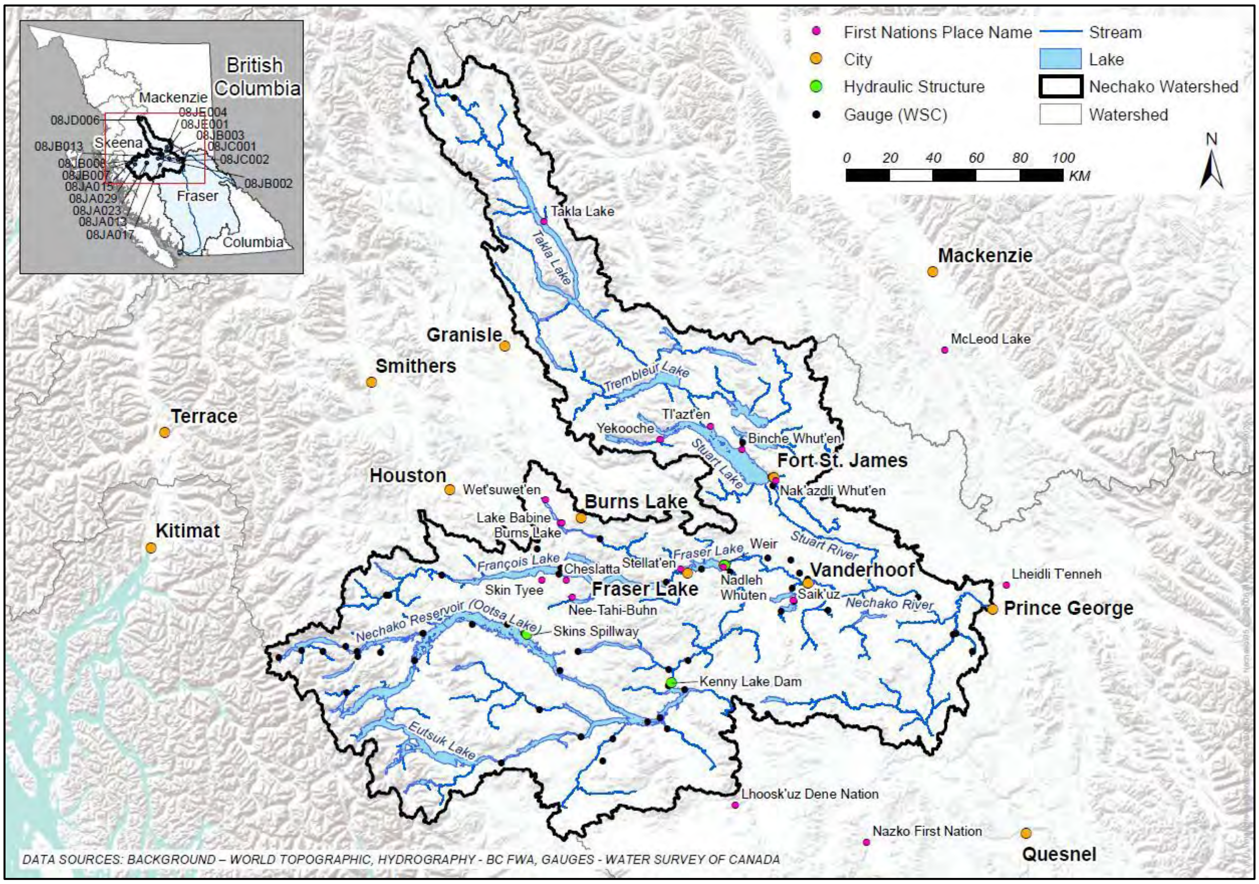


Figure 2.1 Map of the study area. The Nechako watershed outline is shown on the main map, with relevant features identified in the legend. The inset map shows the Nechako watershed location in British Columbia and within the Fraser watershed.

2.2 Flow Regulation

Flow regulation on the Nechako River began in 1952 with the construction of the Kenney Dam and flow diversion tunnel to the Kemano Generating Station near Kitimat, BC. Historically, the natural hydrograph of the Nechako River was driven by spring snowmelt on the leeward side of the Coast Range and the Interior Plateau (NHC, 2003). Peak annual flow typically occurred in June, with the receding limb of the annual hydrograph periodically re-supplied by large frontal rainstorms during the latter portion of summer and into fall. Spring flows exceeding 1,000 m^3/s at Vanderhoof were not uncommon and the estimated mean annual peak daily discharge was 658 m^3/s (NHC, 2003).

The Nechako Reservoir was filled from 1952 to 1956, reducing the mean annual peak daily discharge to 233 m^3/s. Since then, two water management strategies have been implemented; the first from 1957 to 1979 and the second from 1980 to present. The mean annual peak daily discharge during these periods has been 426 m^3/s and 360 m^3/s, respectively, which represents an approximate 45% reduction from historic flows. The timing of peak flow has also been changed from June to August because the current management plan was developed to control the stream temperature of the lower river during the sockeye salmon migration (referred to as the *Summer Temperature Management Program*, or STMP).

The substantial out-of-basin diversion has decreased discharge throughout most of the year, although some variation in peak flows still occurs due to environmental conditions and/or reservoir operations. As shown in Table 2.1, the peak daily flow at Vanderhoof has nearly reached, or exceeded the pre-regulation mean annual peak discharge of 658 m^3/s several times since the onset of flow regulation.

Table 2.1 Years when maximum daily discharge has exceeded 600 m^3/s at Vanderhoof during the post-regulation period (1952-2021).

Year	Maximum daily discharge at Vanderhoof (WSC 08JC001)
1952	629 m^3/s
1958	625 m^3/s
1964	600 m^3/s
1976	744 m^3/s
2007	784 m^3/s
2015	693 m^3/s

2.3 Bank Erosion and Sediment Supply

Reservoir impoundment, flow regulation, and the diversion of flow through the Murray-Cheslatta system via the Skins Lake Spillway undoubtably impacted the sediment regime of the Nechako River. However, the degree to which the sediment regime was altered, as well as the consequent impacts on channel form and function, remain uncertain due to the lack of data or information describing the sediment transport regime prior to impoundment. Given the complexity of natural systems, it is likely that the impacts of flow regulation on the sediment regime and character of the Nechako River have varied both spatially and temporally since the construction of Kenney Dam in 1952. For further discussion on how the sediment regime may have changed in response to flow regulation, refer to NHC (2023b).

2.3.1 Pre-regulation period

Acknowledging that little is known about the pre-impoundment sediment transport regime of the Nechako River, a few key items can be inferred based on the surficial geology and geomorphology of the region, as well as pre-impoundment historical imagery. The limited available information suggests that the amount of *coarse sediment* (i.e., gravels and cobbles) supplied to the Nechako River was likely relatively low prior to the onset of flow regulation due to the following characteristics:

- The lake-headed nature of the system, where coarse sediment produced by the headwater tributaries in the Coast Mountain Range would have been deposited within upstream lakes prior to reaching the main river
- The presence of long (~50 km) depositional reaches controlled by non-alluvial (e.g., bedrock) features, where the river would have historically had a very limited capacity to transport gravel downstream (e.g., upstream of the Nautley River confluence)
- The glacial legacy of the area, where the contemporary river generally flows through an oversized meltwater channel valley that was likely shaped by large, post-glacial floods; thus, the overall width of the existing river corridor is larger than what would have been created by more recent, pre-regulation flows (i.e., flows over the past few hundred years), reducing the amount of sites where the channel is directly eroding the valley walls
- The remnant glaciolacustrine sediment deposits that form discontinuous, high terraces along the channel margins do not contain a large proportion of gravel, as they are predominantly composed of silt and sand (Rood, 1993).

2.3.2 Post-regulation period

Several studies have characterized the geomorphology of the Nechako River, including descriptions of channel type, bed material, and sediment transport (e.g., Envirocon Ltd., 1984b, 1984a; Rood, 1993; Rood, K. M. and Neill, 1987; Sutek Services Ltd., 1988). Of these, Sutek (1988) and Rood (1993) provide quantitative volumetric estimates of sediment inputs from various sources within the watershed during the early post-regulation period (1953-1986). These volumetric estimates provide key benchmarks that can be used to evaluate if and how the rate of sediment input to the river has changed *during the post-regulation period*. The main findings of these studies are summarized below.

Rood (1993) completed identification and ranking of sediment sources in the upper Nechako River. The two main sources of sediment to the river identified by the study were: 1) bank and valley wall erosion and 2) tributary sediment inputs. Rood (1993) estimated that the annual volume of sediment input to the Nechako River by bank erosion and tributaries were roughly equivalent over a 33 year period (1953 to 1986) following the construction of Kenney Dam in 1952. Overall, it was estimated that the annual sediment input rate over the 33 year period was on the order of 8,000 Mg (5,500 m^3) and 6,000 Mg (4,000 m^3) from the valley walls and tributaries, respectively.

It was found that the largest tributaries, including Greer, swanson, Smith and Targe Creeks, supply much of the *coarse* sediment load supplied by tributary systems to the upper Nechako River, although the dominant grain size fraction delivered by these tributaries was sand (NFCP, 2005). As stated in NFCP (2005):

> *"From 1953 to 1986, Swanson Creek added approximately 20,000 m^3 of coarse material to its fan. Targe Creek also added approximately 20,000 m^3 (Reid Crowther and Partners Ltd., 1987) while Smith Creek supplied approximately 3,000 to 4,000 m^3. The load from Greer Creek is assumed to be similar to that of Swanson and Targe Creeks. This means that the total coarse sediment accumulation in the upper river during that time was (approximately) 60,000 m^3, or 2,000 m^3/year."*

While active erosion of the bank and valley walls was observed at approximately 38 sites along the upper Nechako River, Rood (1993) found that only a few sites contribute much of the annual sediment load supplied to the river by bank erosion. These sites are located where the river is laterally eroding into high terraces along the channel margins. Specifically, Rood (1993) states that the most important bank erosion sites that contributed sediment to the upper Nechako River between 1953 to 1986 were:

- On the right bank opposite Targe Creek, where bank erosion contributed approximately 13,000 m^3 over 33 years (1953-1986), or 400 m^3/year
- Along the right bank at the downstream end of Diamond Island, where bank erosion contributed approximately 11,000 m^3 over 33 years (1953-1986), or 300 m^3/year
- Along the left bank of the upper Nechako River where the channel is deeply incised into high glaciolacustrine terraces, where bank erosion contributed approximately 300,000 m^3 over 33 years (1953-1986), or 8,700 m^3/year.

Subsequent to the Rood (1993) study, NHC (in prep.) assessed how the river morphology has changed over the following 31 year period between 1990 and 2021 based on repeated channel surveys. Selected results of the change detection analysis for the 1990-2021 period, along with a cursory assessment of how sediment input rates at these key sites compare to those reported by Rood (1993) for the 1953-1986 period, are provided in Section 4. For the complete set of 1990-2021 change detection results, including all resurveyed transects, refer to the Geomorphic Atlas of the Nechako River (NHC, in prep.).

3 PROCESS OF EROSION

The following subsections provide some discussion around the process of erosion, including how and why it occurs (Section 3.1), how it relates to stream and ecosystem function (Section 3.2), and how it applies to the Nechako River (Section 3.3).

3.1 Conceptual Model of Lateral Migration

A fundamental process of channel migration is the gradual, lateral erosion of channel bends that occurs as the flow of water erodes one bank and deposits sediment along the other (Leopold and Wolman, 1960). Lateral erosion across a floodplain can occur at a range of spatial and temporal scales, where the rate and type of channel migration is influenced by numerous environmental factors, including the stream's ability to entrain and transport sediment and the erosional resistance of the floodplain sediments forming the channel banks (Nanson and Croke, 1992).

Lateral erosion occurs when the flow imparts sufficient stress along the channel boundaries to detach material forming the banks, which then enters the stream and may be transported further downstream. As previously mentioned, lateral erosion is most concentrated along the outside of meander bends as the stream shifts toward the bank that is being undercut, with compensating deposition along the inside of channel bends forming point bars (Figure 3.1). Lateral channel migration is thus dependent on the flow conditions within the channel and the ability of the bank to resist erosion by the flow.

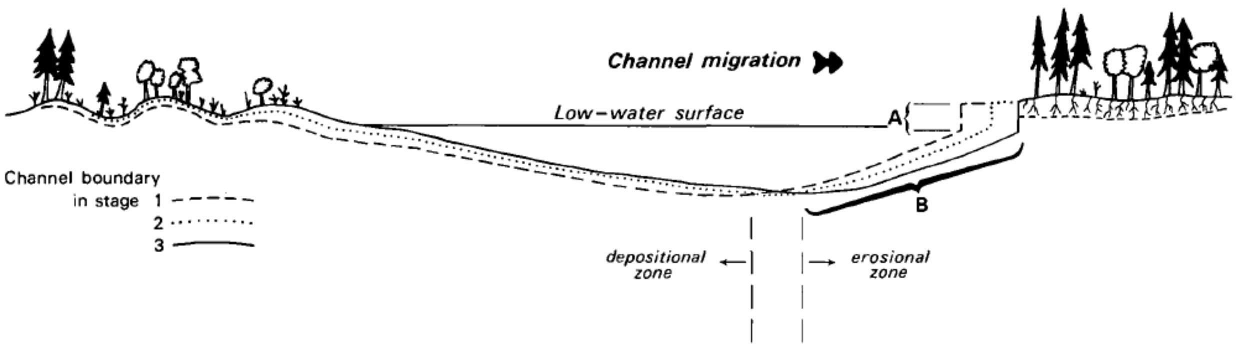


Figure 3.1 Schematic diagram of lateral channel migration by Nanson and Hickin (1986); the extents of boundary shear stress acting on the outer bank and bed are denoted by the letters A and B, respectively.

As previously mentioned, several factors can influence the rate at which channels migrate by directly or indirectly affecting the ability of the stream to erode sediment from the banks. Firstly, the erosive potential generally increases with stream power, which is directly related to discharge; therefore, larger channels, or channels with higher flows, tend to migrate at greater rates (Legg and Olsen, 2014; Nanson and Croke, 1992).

The 6mountt of sediment being conveyed by the stream (referred to as the *sediment load*) also strongly influences the channel's tendency to migrate laterally, as an increase in sediment supply can lead to greater deposition along the inside of meander bends (i.e., accretion of point bars) acting to divert flow towards the opposite (outer) bank (e.g., Knighton, 1998; Legg and Olsen, 2014). Increases in bed material supply can also increase the channel width-to-depth ratio and overall propensity of the channel to bifurcate (Eaton et al., 2010a).

Geological and post-glacial features, such as the bedrock canyons and high glaciolacustrine terraces found along the Nechako River, can also exert a strong influence on channel form and behavior by controlling the valley gradient and width. Geological and post-glacial features that control the channel gradient can create large depositional reaches that are more prone to increased channel migration (e.g., Legg and Olsen, 2014; Montgomery and Buffington, 1998). Geological and post-glacial features can also confine the width of the valley bottom (i.e., the floodplain), and hence the spatial extent within which the contemporary channel can migrate (Fryirs et al., 2016; Garcia Lugo et al., 2015).

Patterns of forest cover and riparian vegetation can also influence the channel form, bank strength, and rate of channel migration (e.g., Millar, 2000; Nanson and Croke, 1992). Intact forests and riparian vegetation have been shown to stabilize channels and reduce channel migration rates as compared to floodplain areas with non-existent or immature forests (Eaton et al., 2010b; Micheli et al., 2004). Woody debris inputs to the stream from riparian zones with intact forests also contribute to a variety of important geomorphological and ecological processes, as further discussed below (Section 3.2).

3.2 Erosion and River Function

Bank erosion is an important process that can help maintain both physical and ecological processes within a river system (e.g., Church, 2006; Florsheim et al., 2008; Montgomery, 1999). Lateral erosion allows the river to adjust its width, and hence capacity to transport sediment, in response to changes in sediment supply, discharge, slope, bank strength, and grain size (e.g., Blench, 1969; Eaton and Church, 2007; Eaton and Millar, 2004).

If the channel is not able to migrate laterally, for example if it is confined by bedrock or bank revetments, changes in the flow and sediment regimes may instead be accommodated by changes in bed texture (i.e., grain size), elevation, and slope. Vertical adjustments in the channel geometry, including raising or lowering of the riverbed (respectfully termed *aggradation* and *degradation*), may have impacts on the geomorphology and ecology of the river, including further destabilization of the riverbanks, increases in flood elevations, and loss of habitat (Florsheim et al., 2008; Nanson and Croke, 1992).

Bank erosion can also provide an important supply of coarse sediment and woody debris to the channel. As the river erodes it's banks, coarse sediment (i.e., gravels) contained within the bank material enter the river, and are then stored and redistributed along the riverbed, creating important substrate habitat for macroinvertebrates and fish (Florsheim et al., 2008). Bank erosion also provide important inputs of woody debris to the river system, which can influence the channel morphology and increase the complexity of instream habitat (e.g., Davidson and Eaton, 2013; Fausch and Northcote, 1992; Hassan et al., 2008).

Lateral erosion strongly influences the rate of sediment exchange between channels and floodplains (termed *floodplain turnover*). Channel migration and floodplain turnover are important processes in maintaining habitat for aquatic species and form the landscape upon which channel-floodplain ecosystems develop (Beechie et al., 2006; Tomlinson et al., 2011). Meandering-type and island-braided (or *wandering*) rivers in particular may experience moderate rates of floodplain turnover, which in turn promotes riparian vegetation succession and can support the highest biological diversity (Beechie et al., 2006).

The valley bottoms of these river systems typically contain the greatest biological diversity and productivity within their watersheds, which is in-part due to their propensity for flooding and erosion (Legg and Olsen, 2014). However, these same valley bottoms are often the sites of residential and agricultural development, creating a challenging and complex environment to balance floodplain management with restoration of fluvial systems.

3.3 Understanding the Issue

Bank erosion is a natural geomorphic process that can benefit stream and riparian ecosystems. Erosion is a dynamic process, where the movement, sorting, and distribution of sediment and organic material create a diversity of habitats. Lateral erosion and the redistribution of sediment also allows the channel to adjust to changes in flow and sediment inputs.

However, excessive channel erosion, often brought upon by anthropogenic factors, can also be detrimental to ecosystem health. Excessive channel erosion can both vertically and laterally disconnect the stream from critical riparian and floodplain habitat that are important in aquatic organism life cycles. Excessive bank erosion can also trigger downstream changes in channel form and function through increases in sediment input, and can threaten public property, agricultural land, and residential developments along river corridors. Channel erosion with a loss of bank strength can result in wider, shallower channels that provide less suitable habitat and are subject to warmer water temperatures in the summer.

The rate of lateral erosion on the Nechako River has likely changed over time due to both natural and anthropogenic factors. Limited information regarding the pre-impoundment sediment transport regime of the Nechako River creates uncertainty regarding what “natural” (i.e., pre-regulation) rates of erosion may have been. Nevertheless, it is qualitatively understood that the rates of erosion prior to regulation would have likely been higher than they are now, but still relatively low compared to other gravel-bed rivers of similar size and substantially reduced from what they were following deglaciation when the contemporary Nechako River corridor was formed (NHC, in prep.).

Regulation, coupled with an increase in residential and agricultural development within the floodplain, has led to the following key questions:

- How much erosion has occurred following regulation?
- How much erosion is “enough erosion” to maintain geomorphological and ecological functions?
- How much erosion (or deposition) is anticipated for different flow releases?

4 EROSION ON THE NECHAKO RIVER

This section of the report presents evidence-based examples of historical erosion on the Nechako River using a technique called *change detection*. Change detection involves comparing two or more spatial datasets (e.g., air photos, survey data, etc.) that were acquired at different times to identify changes in the landscape that have occurred within that timeframe. Several spatial datasets exist for the Nechako River, with which change detection may be completed, including:

- 1990 channel survey from Fort Fraser to Cheslatta Falls
- 2006/2007 channel surveys within the Vanderhoof reach
- 2015 channel and bankline survey within the Vanderhoof reach

- 2017 channel and bankline survey within the Vanderhoof reach
- 2017 orthophoto and LiDAR of the Vanderhoof reach
- 2021 survey from Vanderhoof to Cheslatta Falls
- 2021 orthophoto and LiDAR from Prince George to Cheslatta Falls

This report will present specific results and examples of lateral erosion and channel migration at key sites between Fort Fraser and Cheslatta Falls (Section 4.1), and within the Vanderhoof reach (Section 4.2).

4.1 Fort Fraser to Cheslatta Falls

The results presented in this section were obtained by comparing cross-sectional channel transects originally surveyed in 1990 and resurveyed in 2021. This section does not provide an exhaustive review of the findings, as the complete dataset includes nearly 300 resurveyed transects (Figure 4.1). The complete analysis, including all resurveyed transects, is presented in the Geomorphic Atlas of the Nechako River (NHC, in prep.).

The observations below are presented from upstream to downstream, from Cheslatta Falls to the Nautley River confluence at Fort Fraser. The location of each observation is indicated using the survey transect number (e.g., *XS 287*). Figure 4.1 provides an overview map showing the locations of the 1990-2021 survey transects, where specific transects are annotated based on the channel segments described in the following subsections of this report, while reference maps showing the locations of all transects are provided in Appendix A.

Note that all cross-sectional transects presented in this report are drawn facing downstream, where the left bank of the channel is located at a cross-channel distance of 0 m on the left side of the figure.

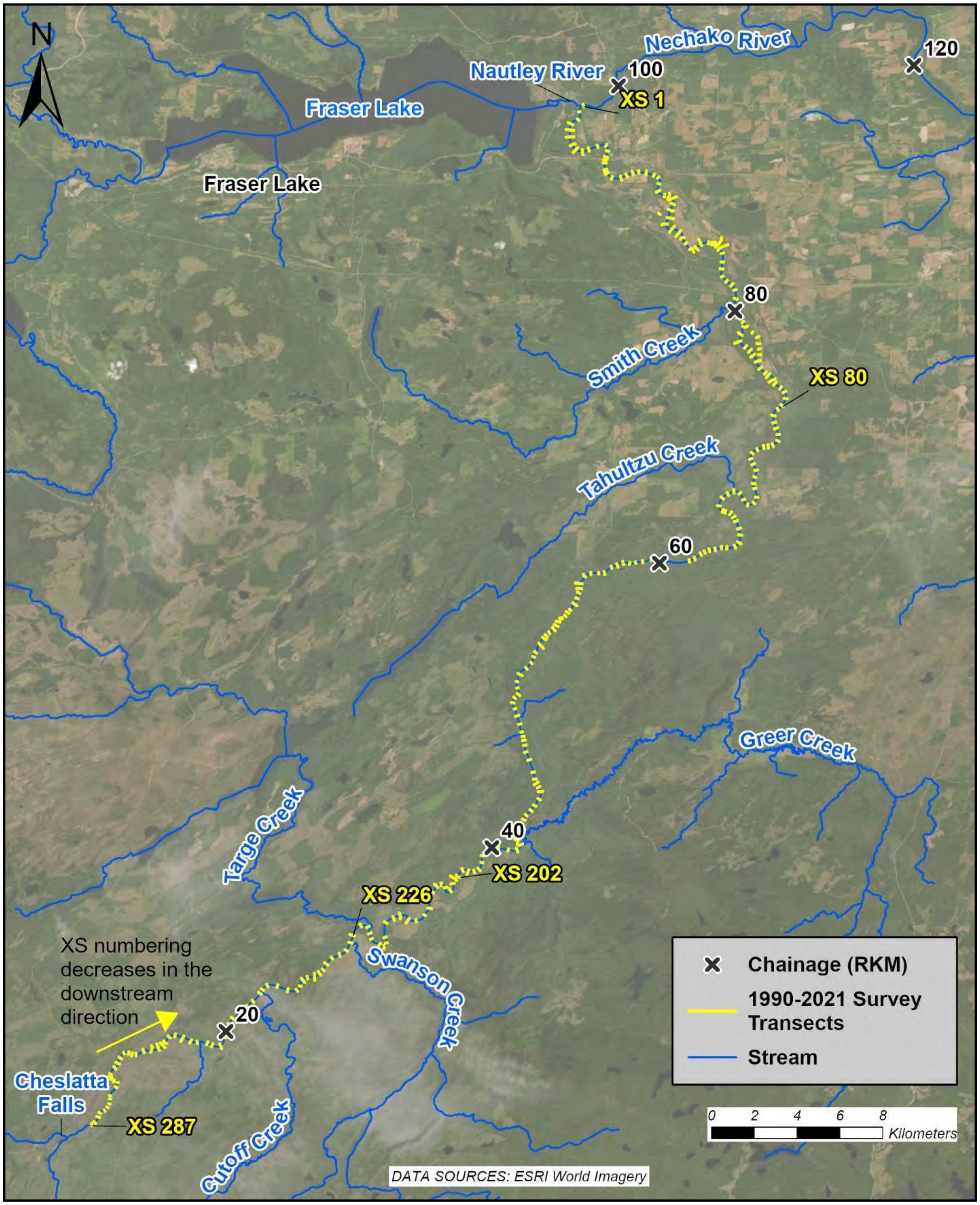


Figure 4.1 Overview map showing the locations of the 1990-2021 survey transects; specific transects are annotated based on the channel segments described in the following subsections.

4.1.1 Cheslatta Falls to Swanson Creek (XS 287 to XS 226)

Within the upstream section of the river, from XS 287 to XS 226, the channel banks have remained relatively stable since 1990, despite some scour and fill of the channel bed. At XS 282, the right portion of the channel filled in due to localized sediment input from the valley wall (Figure 4.2). Similarly, at XS 267, sediment input from a tributary along the left bank has caused localized sediment deposition and fill within the Nechako River (Figure 4.3). Interestingly, XS 261 shows a large amount of channel change, with deposition and infilling of the side-channel along the left bank and compensating scour of the riverbed along the mainstem, right bank channel (Figure 4.4). This large amount of change was highly localized, as the survey transects upstream and downstream of XS 261 show much less change. Swanson Creek, located at XS 227, also caused erosion of the alluvial terrace forming the right bank of the Nechako River (Figure 4.5). While the bankline appears to have remained relatively stable along the property located at XS 253 (possibly very minor erosion), some lateral erosion appears to have occurred along the property located on the right bank at XS 231 (Figure 4.6).

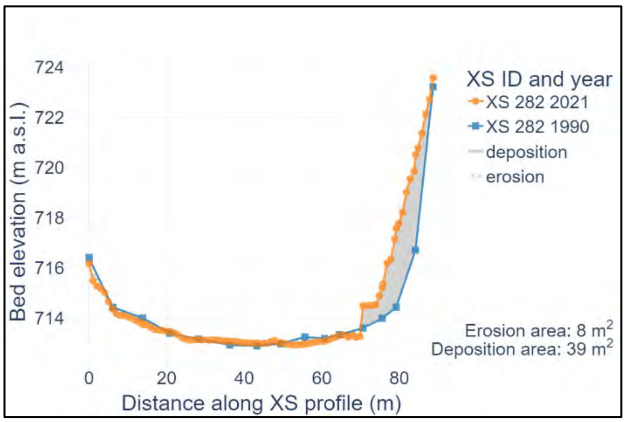


Figure 4.2 Sediment input from the valley wall and associated channel fill along the right bank at XS 282 (1990-2021).

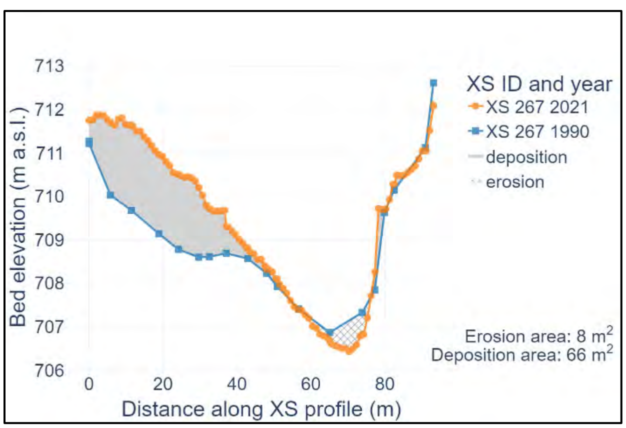


Figure 4.3 Tributary sediment input causing localized deposition and fill along the left bank at XS 267 (1990-2021).

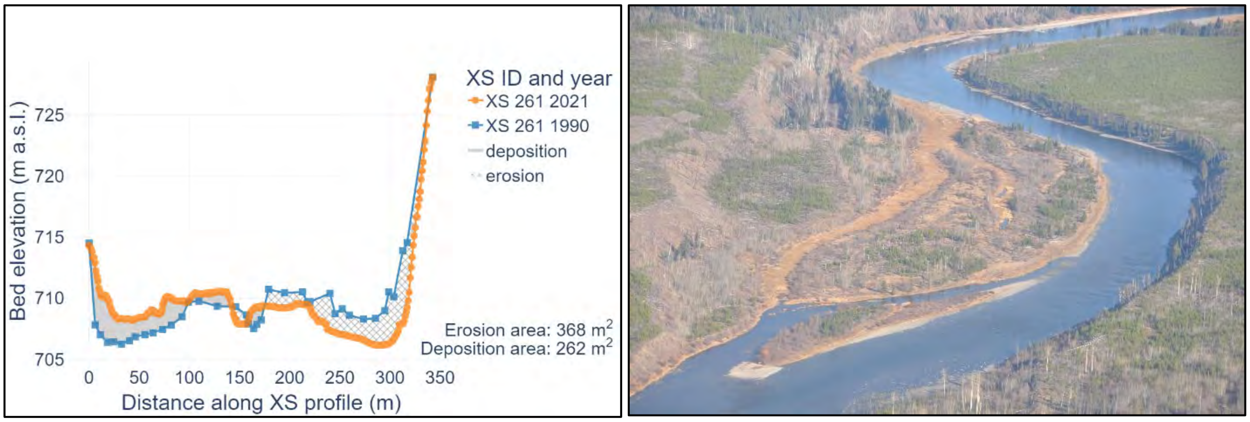


Figure 4.4 Deposition and infilling of the side-channel along the left bank and compensating scour of the riverbed along the mainstem, right bank channel at XS 261 (1990-2021).

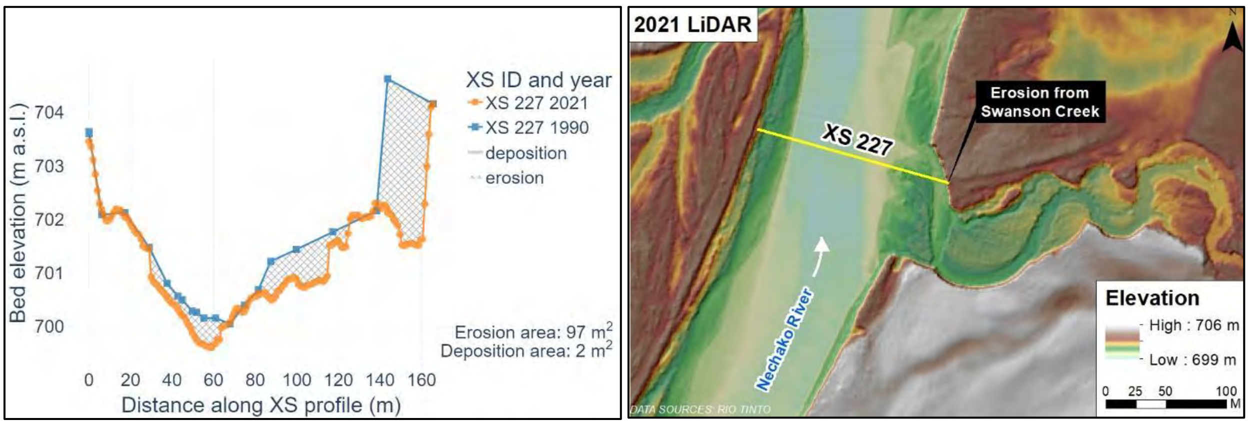


Figure 4.5 Swanson Creek eroding the alluvial terrace forming the right bank of the Nechako River at XS 227 (1990-2021).

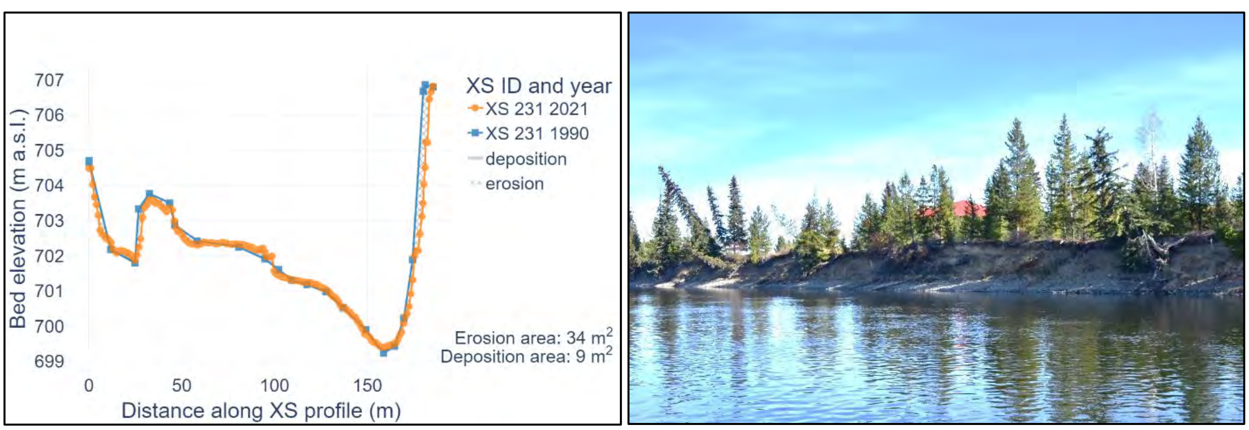


Figure 4.6 Lateral erosion along the property located on the right bank at XS 231 (1990-2021).

4.1.2 Swanson Creek to upstream of Greer Creek (XS 226 to XS 202)

The following section of river extends from XS 226 to XS 202, which includes a series of four high eroding banks (or *cutbanks*) formed where river meanders are eroding into glaciolacustrine terraces. The upstream-most cutbank is located between XS 225 and XS 223, a section of river which also includes the confluence of Targe Creek. This high bank appears to have remained relatively stable since 1990, with limited lateral erosion and potentially minor fill due to ongoing downslope sloughing of materials (Figure 4.7).

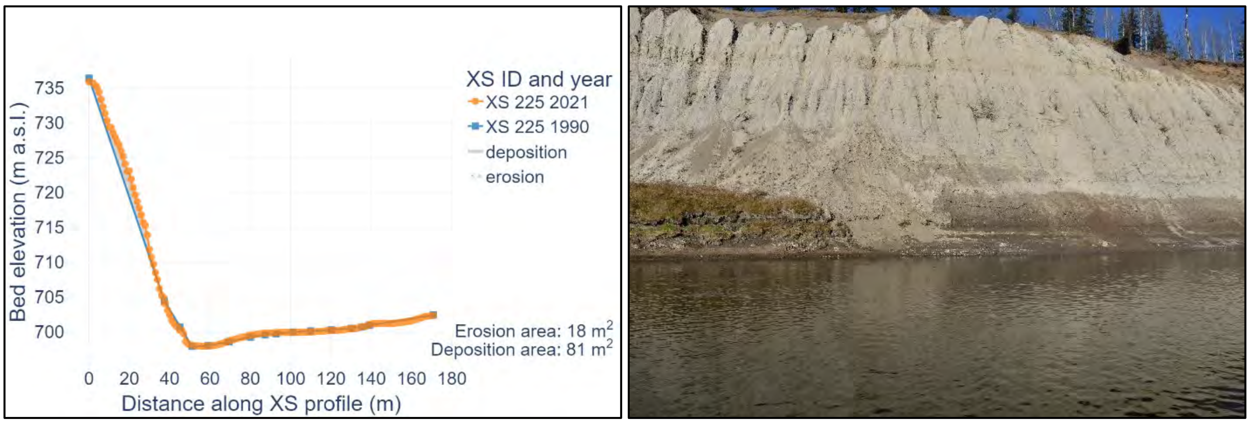


Figure 4.7 High cutbank that has remained relatively stable, with limited lateral erosion and potentially minor fill due to ongoing sloughing of materials at XS 225 (1990-2021).

However, a considerable amount of lateral erosion has occurred at XS 223, located immediately downstream of the confluence with Targe Creek, where sediment input from the creek is depositing in the form of an alluvial fan, redirecting the flow of the Nechako River towards the opposite bank (Figure 4.8). In addition to gravel inputs from Targe Creek, the ongoing bank erosion also appears to be contributing gravels to the channel (Photo 4.1).

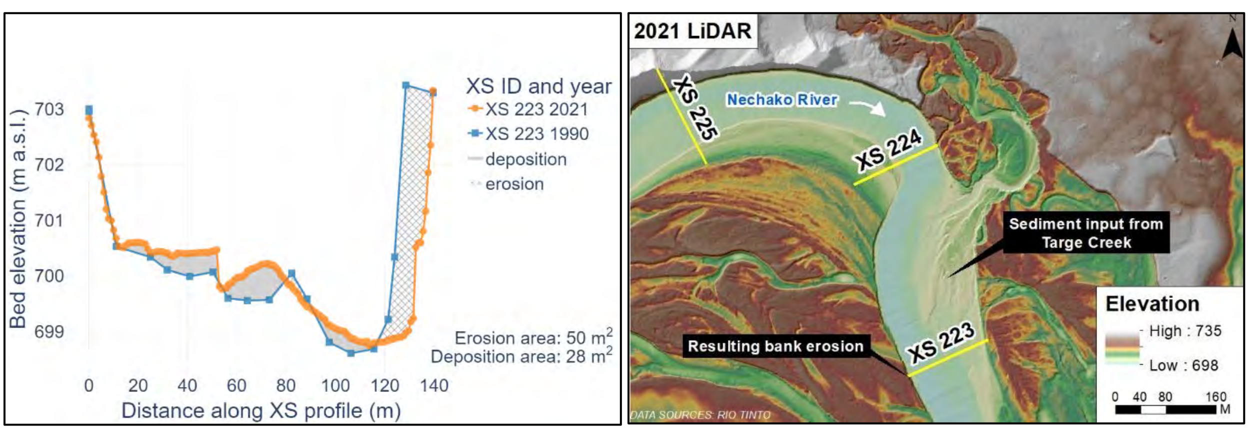


Figure 4.8 Sediment input from Targe Creek pushing the mainstem of the Nechako River into the opposite bank at XS 223 (1990-2021); note that a cross-channel distance of 0 m on the transect plot corresponds to the left bank of the Nechako River.

Photo 4.1 Gravel input to the Nechako River from right bank erosion at XS 223.

The next large cutbank, located between XS 217 and XS 215, appears to have remained relatively stable over time. While a minor amount of erosion may have occurred immediately upstream of the river meander (Figure 4.9), little to no lateral erosion appears to have occurred along the high cutbank itself since 1990 (Figure 4.10).

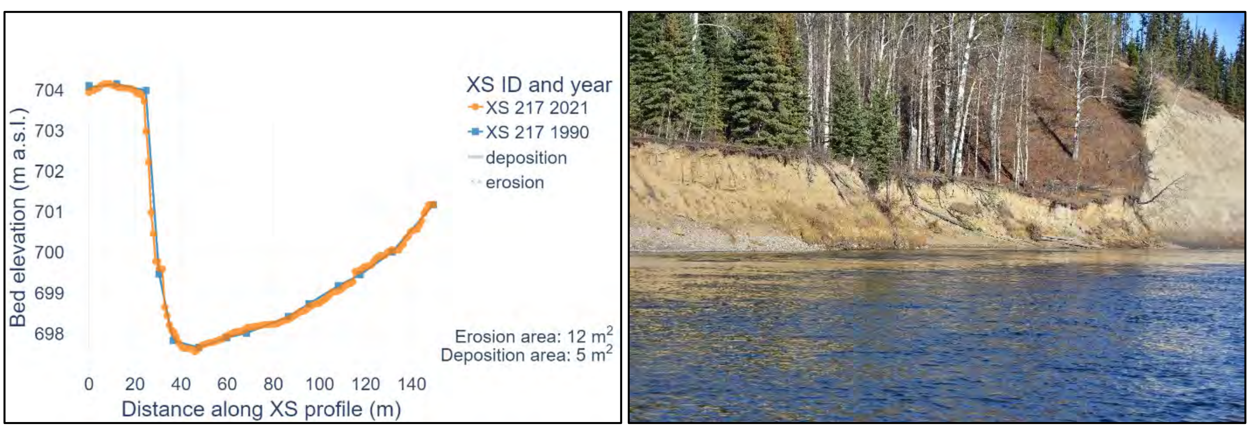


Figure 4.9 Minor erosion immediately upstream of the river meander at XS 217 (1990-2021).

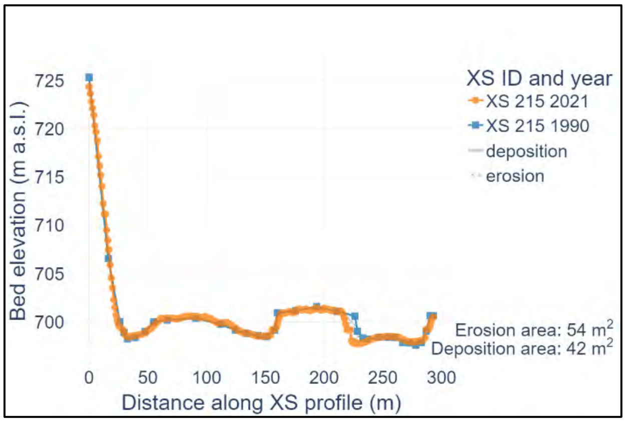


Figure 4.10 Relative stability of the high cutbank at XS 215 showing little to no lateral erosion (1990-2021).

In contrast to the cutbank between XS 217 and XS 215, a considerable amount of lateral erosion has occurred along, and especially downstream of, the third cutbank located between XS 208 and XS 206. While the upstream portion of this meander at XS 208 has remained stable over time, some lateral erosion of the high cutbank has occurred throughout the middle section of the meander at XS 207 (Figure 4.11). Immediately downstream of the high glaciolacustrine terrace, at XS 206, the channel has eroded into lower elevation floodplain deposits as the river has migrated laterally by approximately 30 m (Figure 4.12).

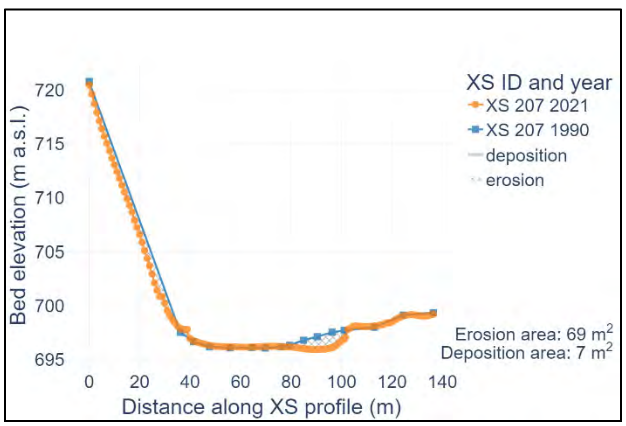


Figure 4.11 Minor erosion of the high cutbank at XS 207 (1990-2021).

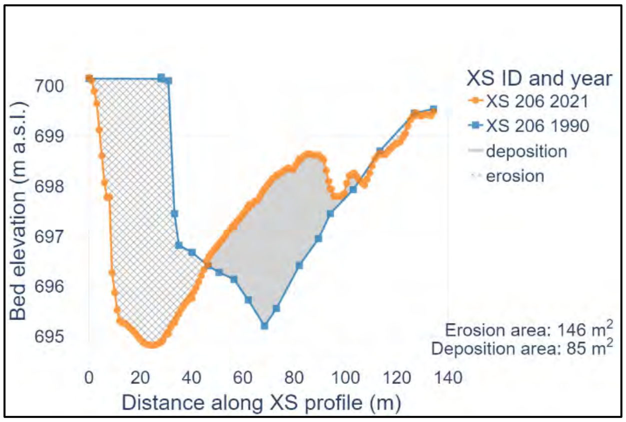


Figure 4.12 Approximately 30 m of lateral channel migration into the floodplain observed at XS 206 located immediately downstream of a high glaciolacustrine terrace (1990-2021).

The downstream-most and final high cutbank within this section of the river is located between XS 204 and XS 202. This high cutbank has also undergone erosion since 1990, as XS 203, located near the middle of the meander, shows that the left (outside) bank of the meander has migrated laterally by approximately 10 m (Figure 4.13).

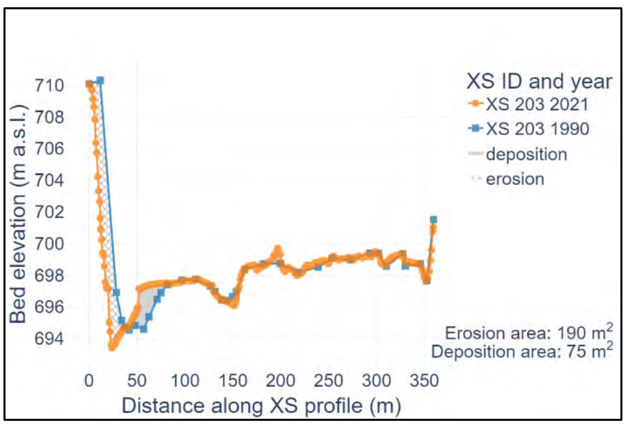


Figure 4.13 Lateral migration and erosion of the high, glaciolacustrine terrace at XS 203 (1990-2021).

As mentioned in Section 2.3.2, Rood (1993) estimated bank erosion and sediment input rates for key sediment sources along the Nechako River. Of the three key bank erosion sites identified in the study, two are located within this section of the river:

- Opposite Targe Creek, between RKM 29-30 on the right bank, where bank erosion contributed approximately 13,000 m^3 over 33 years (1953-1986), or 400 m^3/year
- Along the left bank between RKM 28-38, where the river is deeply incised and eroding into high glaciolacustrine terraces, where bank erosion contributed approximately 300,000 m^3 over 33 years (1953-1986), or 8,700 m^3/year.

Consistent with Rood (1993), the change detection analysis between 1990 and 2021 (NHC, 2023a) showed a large amount of erosion along the right bank of the Nechako River opposite from Targe Creek at XS 223, where sediment input from the creek is depositing in the form of an alluvial fan, pushing the mainstem of the Nechako River into the opposite bank. Cursory estimates based upon the single available cross-section (XS 223) at this location suggest that bank erosion contributed approximately 14,000 to 19,000 m^3 of sediment over the 31-year period (1990-2021), or 450 to 600 m^3/year. These estimates are very similar to those presented by Rood (1993) for the 1953-1986 period (13,000 m^3, or 400 m^3/year).

The change detection results between 1990 and 2021 also indicate that the high glaciolacustrine terraces within this reach have continued to erode over the past 31 years, albeit to varying degrees. Several of the high cutbanks reported to have been eroding prior to 1986 (Rood, 1993) appear to have remained relatively stable since 1990, possibly indicating stabilization of the high eroding cutbanks. In contrast, considerable erosion occurred along the high glaciolacustrine cutbank at XS 203, where approximately 51,000 to 76,000 m^3 of sediment appears to have been eroded between 1990 and 2021. The change detection analysis also showed notable erosion of approximately 29,000 to 50,000 m^3 of material along the lower elevation floodplain at XS 206, located immediately downstream of the high glaciolacustrine terrace.

In total, the results of the change detection analysis between 1990 and 2021 suggest that approximately 120,000 m^3 to 190,000 m^3 of sediment was eroded from the banks within this segment of the river (RKM 28-38, corresponding to XS 226 to XS 202) over the past 31 years. This estimate only considers erosion along the outer bank of the channel, as opposed to erosion across the entire channel width, and was estimated by multiplying the area (m^2) of bank erosion at each transect by the estimated downstream distance of erosion, estimated visually using aerial imagery. The resulting estimate is lower than the amount of erosion estimated by Rood (1993) to have occurred between 1953 and 1986 (500,000 m^3 ± 200,000 m^3, likely around 300,000 m^3). In terms of annual rates, Rood (1993) estimated that the average annual erosion rate between 1953 and 1986 was approximately 8,700 m^3/year, while the change detection results suggest that the average annual erosion rate between 1990 and 2021 was approximately 4,000 to 6,000 m^3/year. When accounting only for the high glaciolacustrine terraces that were reported to have been the major sediment contributors between 1953 and 1986 (Rood, 1993), the estimated total and annual erosion rates between 1990 and 2021 further decrease to between 72,000 and 104,000 m^3, and 2,300 and 3,400 m^3/year, respectively.

It is important to acknowledge that there is high uncertainty in these estimates given limitations in available data and methodologies, including uncertainty associated with air photo mapping and the sparse distribution of survey transects. Acknowledging this uncertainty, the preliminary results suggest that the rates of bank erosion and sediment input along this section of the river (XS 226 to XS 202) have decreased over time (i.e., 1953-1986 compared to 1990-2021). The locations of key erosion sites also appear to have shifted over time, where greater erosion may be occurring in recent years at specific high glaciolacustrine terraces and along certain segments of lower elevation floodplain. Bank erosion sites are expected to continue to shift over time, and new sites will likely develop, as the river continues to adjust its morphology in response to changes in the flow and sediment regimes (Rood, 1993).

As noted by Rood (1993), “there is an obvious connection between maximum discharges in the Nechako River and the intensity of bank and valley wall erosion along the Nechako River.” Following this logic, it is likely that much of the erosion observed between 1990 and 2021 occurred as a result of infrequent high flows, including those in 2007 and 2015 (Table 2.1; Table 5.1), as the 30-year period preceding 2007 saw relatively low peak flows. Further study would be required to confirm the relation between flow and erosion during this period and may help reduce the overall uncertainty in the bank erosion estimates presented above. Upstream of Greer Creek to upstream of Diamond Island (XS 202 to XS 80)

The following section of river extends from XS 202 to XS 80, which corresponds to a relatively straight, confined section of the river. While there has been some localized bank erosion, as well as scour and fill within the channel, the overall geometry of the channel and positions of the banklines have remained relatively stable since 1990. This section of the river includes the confluence of Greer Creek, located immediately upstream of XS 190, which appears to have remained remarkably stable over time despite a considerable amount of tributary sediment input from Greer Creek (Figure 4.14).

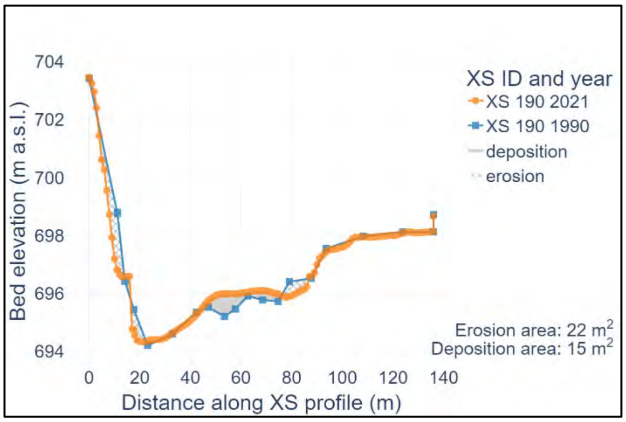


Figure 4.14 Relative channel stability at XS 190 located immediately downstream of Greer Creek (1990-2021), despite sediment inputs from Greer Creek (confluence shown on the right).

This section of the river contains numerous post-glacial landforms and sediment deposits, including kettles, ice-contact deposits, glacial meltwater features, and perched (relict) glacio-fluvial terraces (Figure 4.15). The landscape shows evidence that the river was much more dynamic following deglaciation approximately 8,000 to 10,000 years ago (Clague, 1981; Clague and Ward, 2011), as the river migrated laterally across the valley bottom while it reworked and down-cut through valley fill sediments. In more recent history (i.e., past few hundred to thousands of years) and prior to regulation, the rate of lateral migration and geomorphological activity have greatly decreased, as the banks have become increasingly stabilized over time (Figure 4.16).

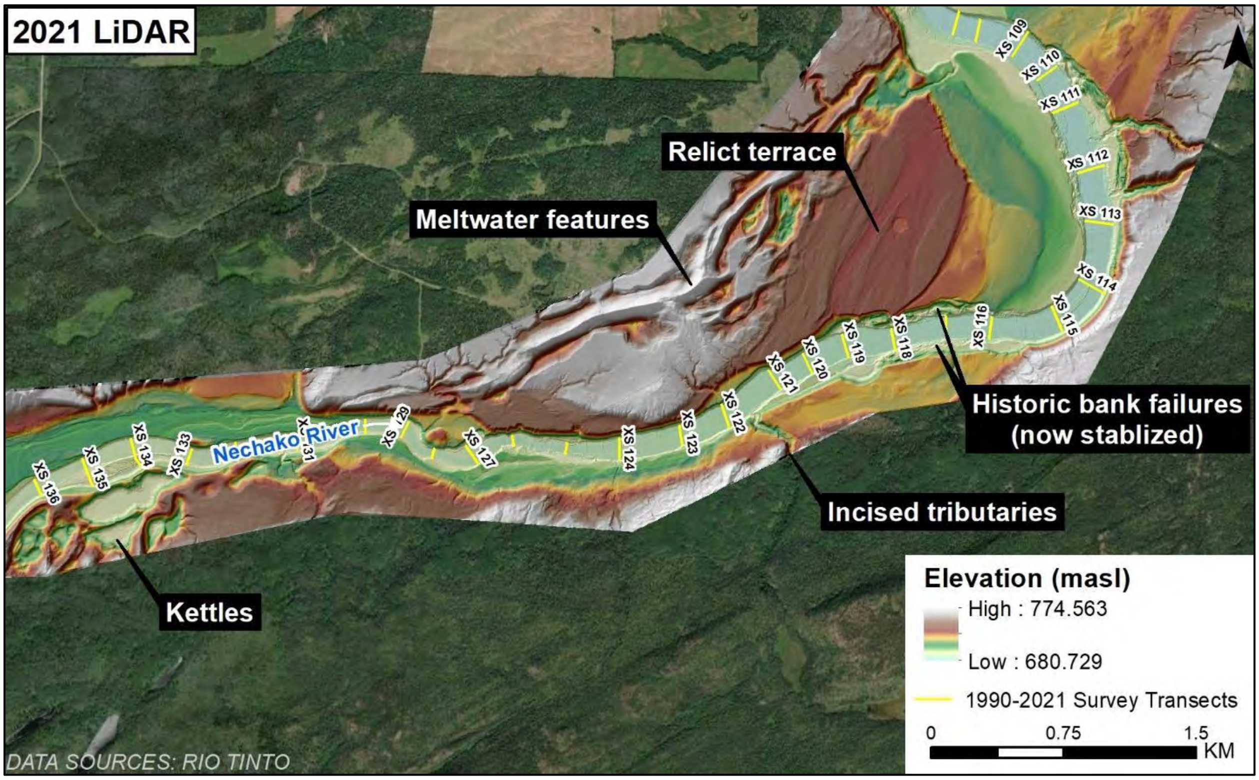


Figure 4.15 Post-glacial landforms within the Nechako River valley showing evidence that the river was more dynamic following deglaciation and has since stabilized.

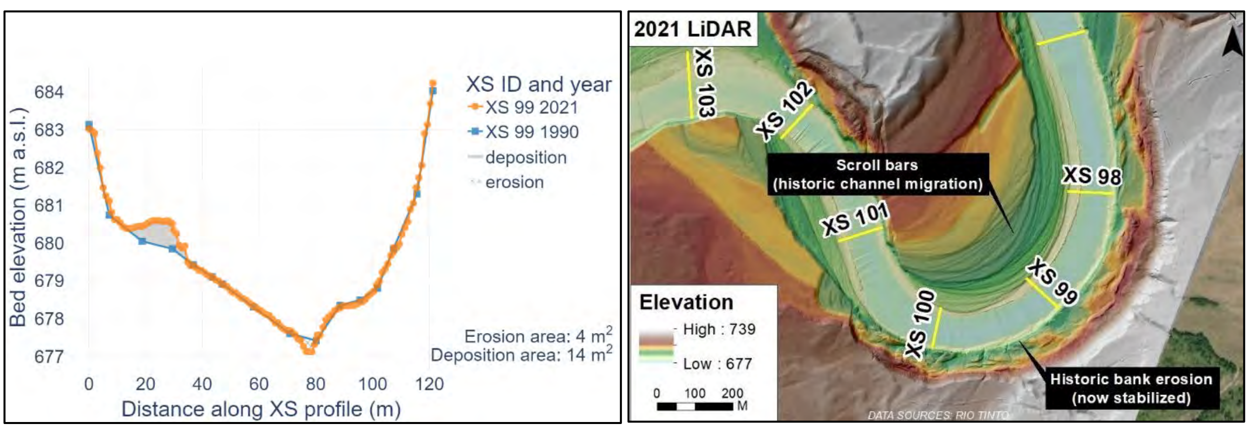


Figure 4.16 Landscape features showing evidence of lateral migration and geomorphological activity following deglaciation, while the banks have remained very stable in recent history at XS 99 (1990-2021).

4.1.3 Upstream of Diamond Island to Nautley River (XS 80 to XS 1)

The final section of river extends from XS 80, located upstream of Diamond Island, to XS 1, located immediately downstream of the Nautley River confluence. Within this section, the river transitions from a wandering, multi-threaded gravel bed reach to a single-thread, meandering sand bed reach. In general, this section of the river has experienced more lateral erosion since 1990 than upstream sections.

Lateral erosion within this section of the river appears to begin around XS 75 (Figure 4.17). This reach includes numerous properties along the riverbanks, including around Diamond Island from XS 60 to XS 58. Within this area, the historical comparison shows that the dominant channel (or *thalweg*) has shifted laterally as the gravels within the channel are reworked by the flow, with erosion of the floodplain contributing additional gravels to the channel (Figure 4.18). The historical comparison shows that some erosion of the right bank has occurred adjacent to properties located around XS 59 (Figure 4.19).

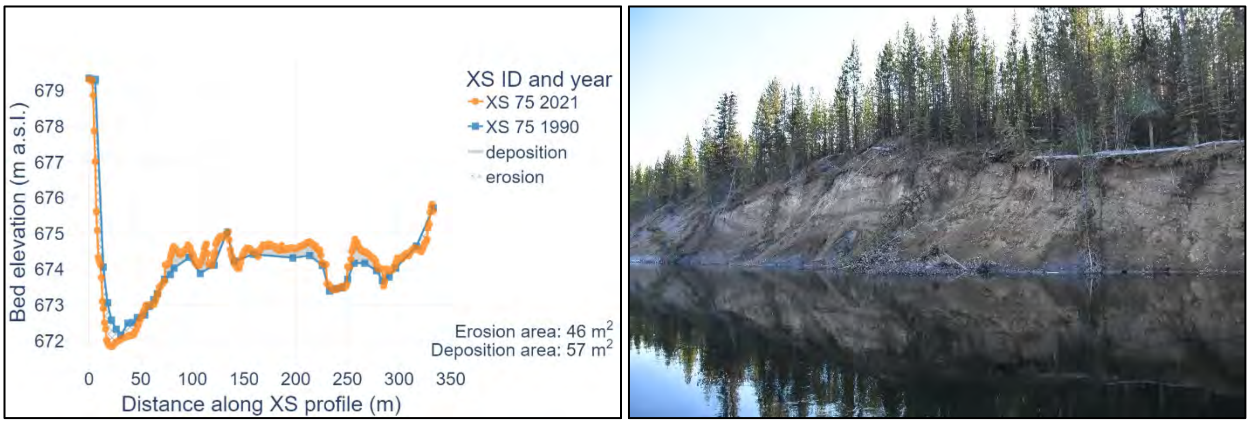


Figure 4.17 Lateral bank erosion at XS 75 (1990-2021).

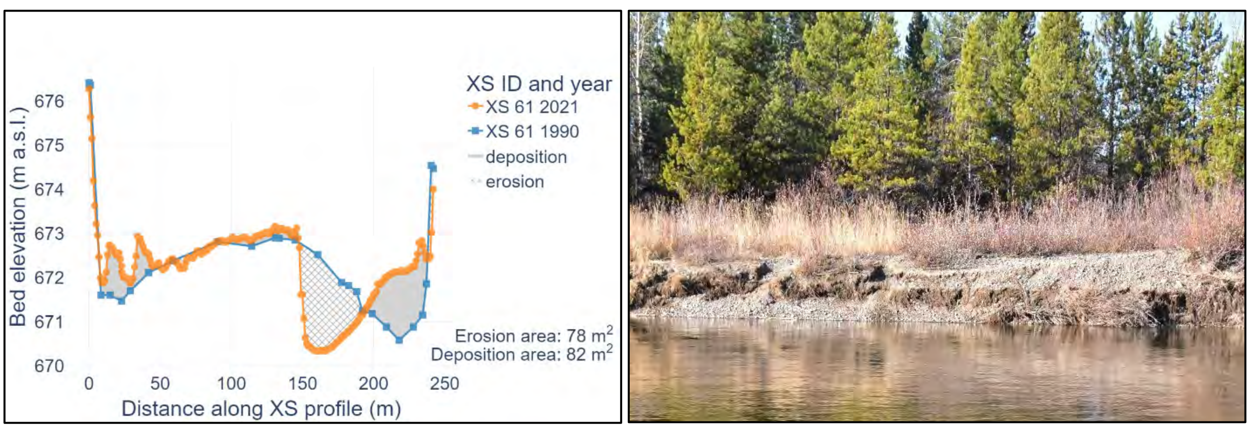


Figure 4.18 Lateral shift in the position of the dominant channel (or *thalweg*) at XS 61 (1990-2021), where erosion of the floodplain is contributing additional gravels to the channel.

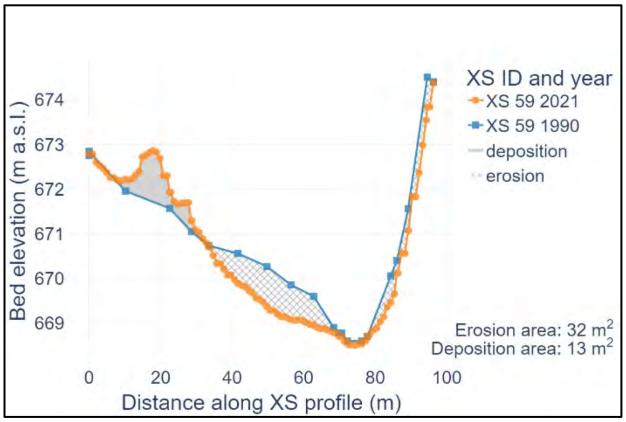
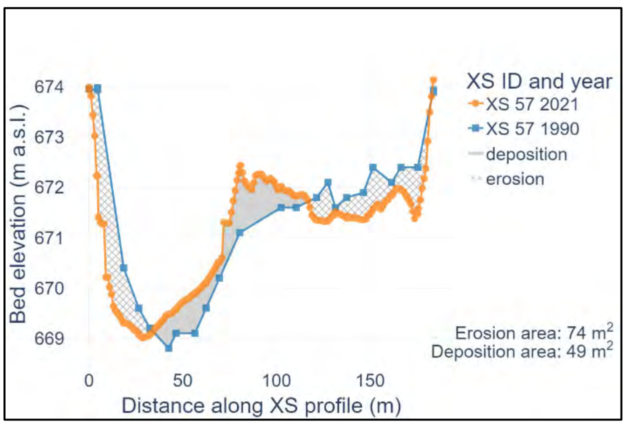


Figure 4.19 Erosion of the right bank adjacent to properties at XS 59 (1990-2021).

Downstream of the residential developments, between XS 59 and XS 42, the banks of the river appear to have remained relatively stable over time, except for lateral channel migration and associated erosion of the left bank at XS 57, XS 48 (minor erosion), and XS 45 (Figure 4.20).



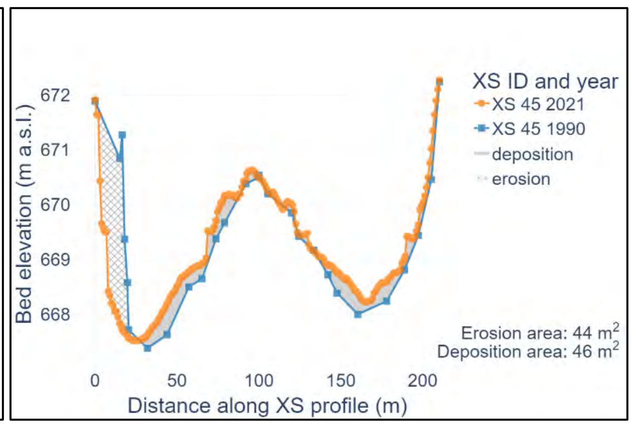


Figure 4.20 Lateral channel migration and associated erosion of the left bank at XS 57 (left panel) and XS 45 (right panel) (1990-2021).

Erosion has also occurred at XS 43, where the thalweg has shifted towards the right and eroded into a vegetated mid-channel bar (Figure 4.21), and to a lesser extent along the agricultural fields at XS 38 (Figure 4.22). A considerable amount of lateral erosion has also occurred at XS 31, located approximately 300 m downstream of a residential building on the right bank (Figure 4.23). Riprap bank protection has been placed locally upstream of XS 32 to mitigate further erosion adjacent to a residential building.

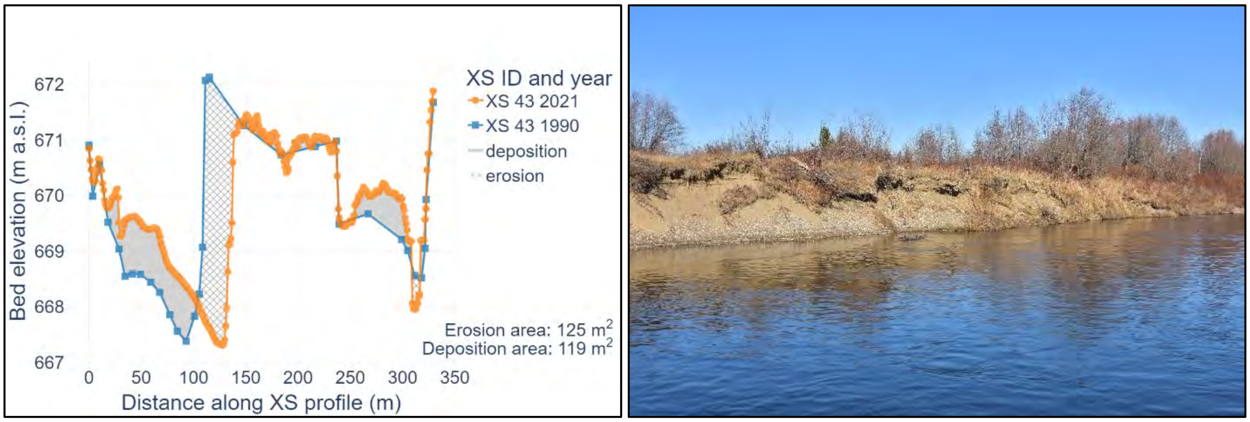


Figure 4.21 Erosion at XS 43, where the thalweg has shifted towards the right and eroded into a vegetated mid-channel bar (1990-2021).

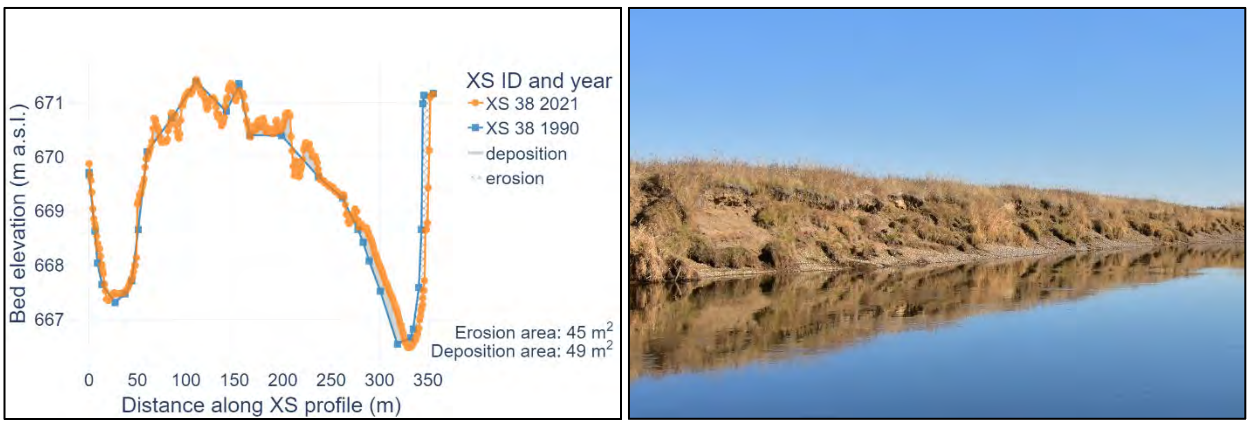


Figure 4.22 Progressive lateral erosion into an agricultural field along the right bank at XS 38 (1990-2021).

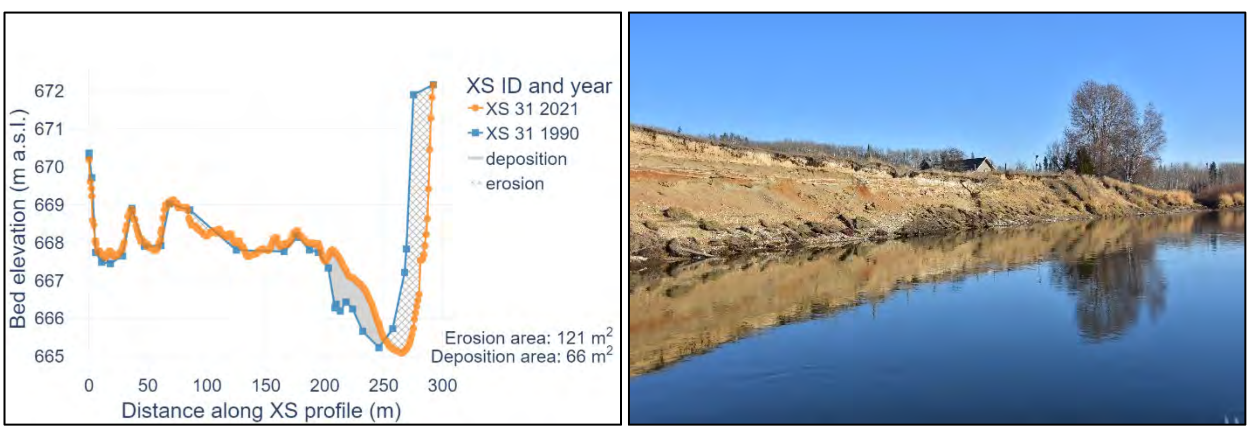


Figure 4.23 Considerable amount of lateral erosion at XS 31 (1990-2021), located approximately 300 m downstream of a residential building on the right bank.

In contrast, the bankline adjacent to the residential properties between XS 25 and XS 21 appears to have remained stable since 1990, although the channel appears to be migrating towards the opposite (left) bank in certain locations (Figure 4.24). And finally, at the downstream-most sites near the Nautley River confluence, the historic comparison shows that while the thalweg of the channel has shifted through the sand-bed reach, the positions of the banks have remained generally stable over time (Figure 4.25). Generally, the riverbed in the sand bed reach is expected to be more mobile and thus greater riverbed dynamics are anticipated.

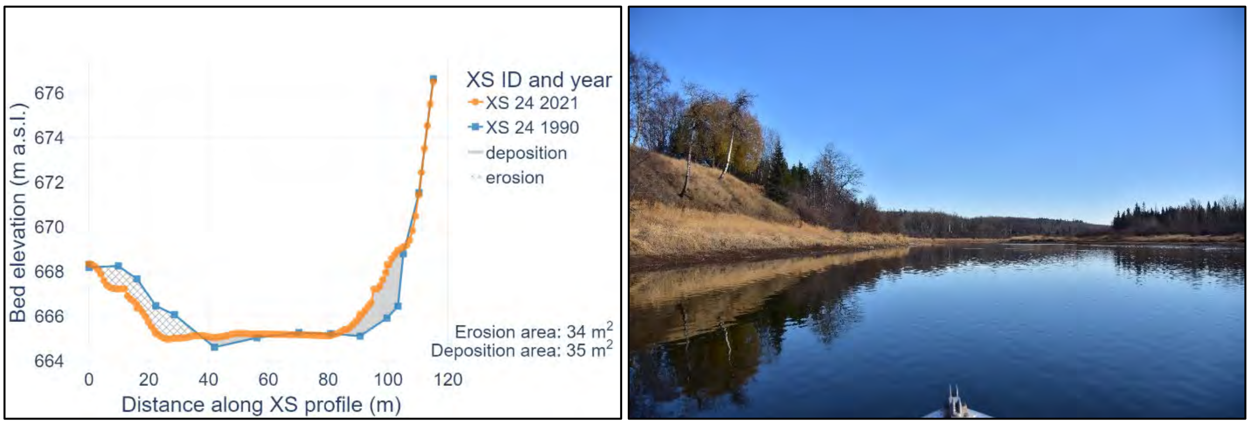


Figure 4.24 Stable right bank adjacent to residential properties at XS 42 with some channel migration towards the opposite (left) bank (1990-2021).

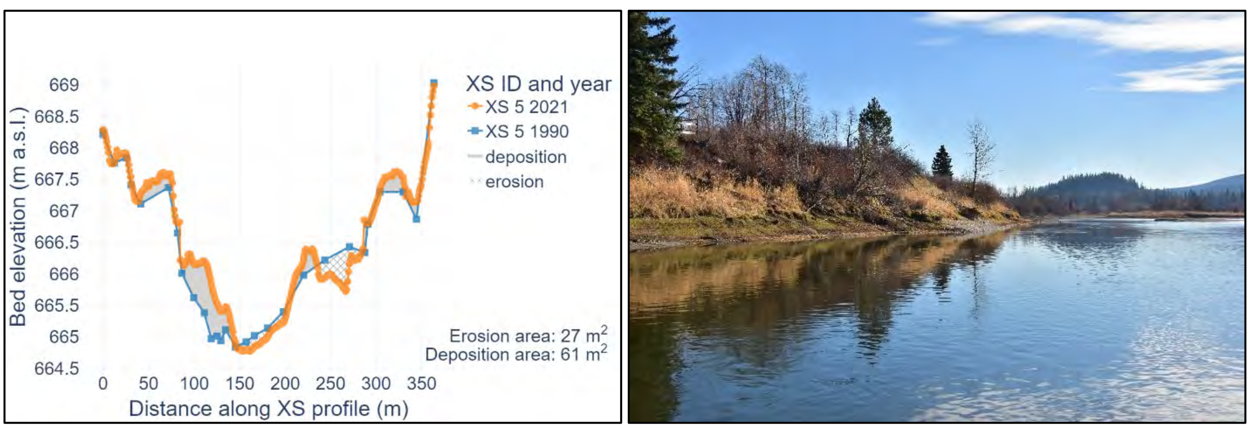


Figure 4.25 Lateral shifting of the thalweg through the sand-bed reach at XS 5 with generally stable banks (1990-2021).

4.2 Vanderhoof Reach

The Vanderhoof reach extends from approximately 3 km upstream of the town of Vanderhoof to 4 km downstream of Vanderhoof. The gradient of the river decreases over the length of this reach, resulting a marked shift in channel morphology from a multi-threaded, cobble and gravel-bed channel to a single-thread, meandering sand-bed channel. This reach is of particular interest as it includes the town of

Vanderhoof, which is subject to high water flooding, as well as the only known spawning area of the endangered Nechako White Sturgeon.

The Geomorphic Atlas of the Nechako River (NHC, in prep.) provides a complete description of the reach and a detailed presentation of the change analysis. Herein, a simplified assessment of lateral migration through the Vanderhoof reach was done by comparing orthophotos collected in 2017 and 2021. The two areas which were assessed are known sites of bank erosion: 1) along the right bank at Riverside Park located at River Kilometer (RKM) 152.5 and 2) the agricultural field along the left bank approximately 2.5 km downstream of the Burrard Ave. Bridge near RKM 156 (Photo 4.2).

The comparison at both locations shows that some erosion did occur along the bank, but that the extent of erosion was generally limited and highly localized (Figure 4.26; Figure 4.27). The extent of lateral erosion at both locations is estimated to be around 1-2 m of localized erosion over 4 years, although the accuracy of this estimate is limited by the resolution of the aerial imagery. Additional surveys and/or higher resolution aerial imagery could be collected in the future to refine the assessment, as further discussed in Section 6.2.

Photo 4.2 Bank erosion along the agricultural field located approximately 2.5 km downstream of the Burrard Ave. Bridge near RKM 156 (Photo taken on 2017-Aug-07).

Figure 4.26 Comparison of 2017 and 2021 bankline positions at Riverside Park located at RKM 152.5.

Figure 4.27 Comparison of 2017 and 2021 bankline positions along the agricultural field located near RKM 156.

5 DISCUSSION

The following subsections provide a summary of the main findings (Section 5.1), highlight key points related to erosional processes on the Nechako River (Section 5.2), and comment on remaining analysis gaps (Section 5.3).

5.1 Summary of Findings

The results from the historical change detection from 1990 to 2021 (Section 4.1) show that the rates of lateral erosion and channel migration vary depending on location along the river system. The total amounts of erosion and deposition across each surveyed transect are shown in Figure 5.1; *note that this includes all erosion and deposition across the length of the entire cross-channel transect, not solely bank erosion*. Figure 5.1 shows that there are no obvious sections of the river which have experienced consistent erosion or deposition; rather, certain portions of the river appear to have experienced different degrees of geomorphic change, characterized by both erosion and deposition across individual transects, as summarized in the subsections below.

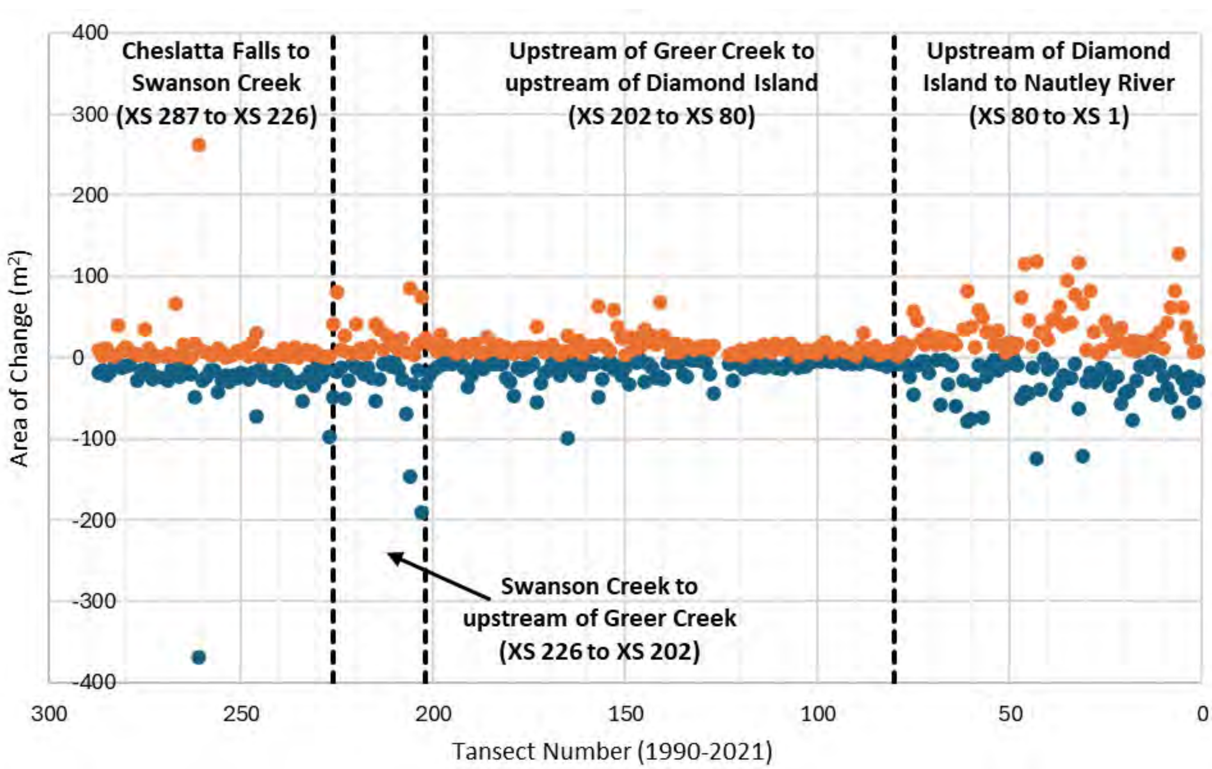


Figure 5.1 Total amount of erosion and deposition calculated across the entire length of each surveyed transect in 1990 and 2021.

5.1.1 Cheslatta Falls to Swanson Creek (XS 287 to XS 226)

The channel banks have remained relatively stable since 1990, despite some scour and fill of the channel bed. There are a few localized sediment sources within this section of the river, including at tributary confluences and where mass-wasting processes are occurring along the valley walls. These point sources of sediment have caused localized sediment deposition within the channel. XS 261 also shows a large amount of channel change, with deposition and infilling of the side-channel along the left bank and compensating scour of the riverbed along the mainstem; however, the change was highly localized at this transect location. A moderate amount of erosion (e.g., 3-5 m) also occurred adjacent to a property located along the right bank (XS 231). Overall, the banks have remained relatively stable throughout this section of the river, with a minor to moderate amount of erosion occurring locally.

5.1.2 Swanson Creek to upstream of Greer Creek (XS 226 to XS 202)

This section of the river includes a series of four high cutbanks along glaciolacustrine terraces. The two upstream cutbanks appear to have remained relatively stable since 1990, with limited lateral erosion and potentially minor fill due to ongoing downslope sloughing of material. In contrast, a considerable amount of lateral erosion has occurred along and especially downstream of the third cutbank, where the channel has migrated laterally and eroded into lower elevation floodplain by approximately 30 m. The downstream-most cutbank has also eroded laterally by approximately 10 m.

In addition to the two cutbanks mentioned above, a considerable amount of erosion has occurred immediately downstream of the confluence with Targe Creek, where sediment input from the creek is depositing in the form of an alluvial fan, pushing the mainstem of the Nechako River into the opposite bank.

In total, the results of the change detection analysis between 1990 and 2021 suggest that approximately 120,000 m^3 to 190,000 m^3 of sediment was eroded from the banks within this segment of the river (RKM 28-38) over the past 31 years. This estimate is lower than the amount of erosion estimated by Rood (1993) to have occurred between 1953 and 1986 (500,000 m^3 ±200,000 m^3, likely around 300,000 m^3). Acknowledging the high uncertainty in these estimates, the preliminary results suggest that the rates of bank erosion and sediment input along this section of the river (XS 226 to XS 202) have decreased over time (i.e., 1953-1986 compared to 1990-2021), possibly indicating stabilization of the high eroding cutbanks. The locations of key erosion sites also appear to have shifted over time, where greater erosion may be occurring in recent years at specific high glaciolacustrine terraces and along certain segments of lower elevation floodplain. While it is likely that much of the erosion observed between 1990 and 2021 occurred as a result of infrequent high flows, including those in 2007 and 2015 (Table 2.1; Table 5.1), further study would be required to confirm the relation between flow and erosion during this period and may help reduce the overall uncertainty in the bank erosion estimates presented above.

5.1.3 Upstream of Greer Creek to upstream of Diamond Island (XS 202 to XS 80)

This is a relatively straight, confined section of the river that was much more dynamic following deglaciation; however, in more recent history (i.e., past few hundred to thousands of years), the rate of lateral migration and geomorphological activity have greatly decreased, and the banks have become increasingly stable over time. While there has been some localized bank erosion and scour and fill within the channel, the overall channel geometry and bankline positions have remained relatively stable since 1990.

5.1.4 Upstream of Diamond Island to Nautley River (XS 80 to XS 1)

This is an unconfined section of the river where it transitions from a wandering, multi-threaded gravel bed reach to a single-thread, meandering sand bed reach. In general, this section of the river has experienced more lateral erosion and geomorphic change since 1990 than upstream sections. These changes include lateral shifting of the thalweg within the channel, as well as lateral channel migration and associated bank erosion. This reach includes numerous residential developments and agricultural fields along the riverbanks, which have been exposed to varying degrees of erosion, ranging from relatively stable bank conditions (e.g., XS 24), to slow, progressive bank erosion (e.g., XS 59), to considerable lateral erosion (e.g., XS 31).

5.1.5 Vanderhoof Reach

Lateral erosion between 2017 and 2021 was assessed at two known erosional sites within the Vanderhoof reach: 1) along Riverside Park (RKM 152.5) and 2) along the agricultural field approximately 2.5 km downstream of the Burrard Ave. Bridge (RKM 156). While some erosion did occur at both locations, the extent of erosion was generally limited and highly localized, estimated to be around 1-2 m of erosion over 4 years.

5.2 Key Considerations

Erosion along the Nechako River is controlled by numerous factors, including the surficial geology, glacial legacy of the area, historical and contemporary sediment sources, landscape disturbances (e.g., pine beetle or wildfire), anthropogenic factors (e.g., development, bank hardening), and the flow and sediment regimes. In general, the rate and extent of lateral erosion along this river system appear to be relatively low at most locations. The degree of geomorphological activity is likely limited due to the following factors:

- The absence of large-scale channel disturbances, such as large pre-regulation floods (e.g., > 1,000 m^3/s) and ice jams
- The overall reduction in magnitude, duration and frequency of peak flows relative to the pre-regulation period, which generally promotes vegetation encroachment and channel bank stabilization
- The relatively limited supply of sediment to the channel from tributaries and bank erosion
- The influence of non-alluvial features that control the channel profile, including bedrock sills and large cobbles that cannot be mobilized by the flow
- The glacial legacy of the area, where the channel has incised into valley fill and glaciolacustrine sediments

- The overall stabilization of the river following deglaciation, and to a lesser extent following the onset of flow regulation.

Meanwhile, the Nechako River is most geomorphologically active in areas where:

- The river channel is less confined by valley walls or incised into glaciolacustrine and valley fill sediments
- There is a decrease in the channel gradient, often in response to a downstream, non-alluvial feature that exerts control on the channel profile (e.g., bedrock constriction or sill)
- The bed, banks and floodplain are composed of erodible alluvial sediment (i.e., sands and gravels)
- There are tributaries or eroding banks that provide a local sediment supply to the river.

Based on the characteristics described above, and in agreement with the evidence-based historical change detection from 1990-2021 (Section 4.1), the two main sections of the Nechako River upstream of the Nautley River confluence that are most prone to lateral erosion and channel migration are:

- Swanson Creek to upstream of Greer Creek (XS 226 to XS 202), and
- Upstream of Diamond Island to the Nautley River confluence (XS 80 to XS 1).

The Vanderhoof reach also generally fits these criteria; however, erosion rates may be limited due to additional factors, such as more cohesive floodplain sediments, a greater reduction in the downstream channel gradient, bank stabilization works, etc.

Lateral erosion and channel migration within these sections of the river are natural processes that occur as the river deposits, stores, and reworks sediment within the channel and floodplain. While maintaining some degree of lateral erosion is important in supporting fluvial and ecological functions (Section 3), there is a trade-off between maintaining (or restoring) these natural processes that have ecosystem benefits and protecting agricultural land and residential developments along the river corridor. This is especially the case downstream of Diamond Island, where there is greater development on the floodplain.

Alluvial reaches, such as those mentioned above, are expected to be most responsive to changes in the flow and sediment regimes. While several relatively high peak flows (for the post-regulation period) have occurred since 1990 (Table 5.1), the amount of lateral erosion detected along the Nechako River from 1990 to 2021 was generally low to moderate, except at a few locations. A cursory assessment of bank erosion rates between Swanson Creek and upstream of Greer Creek (XS 226 to XS 202) suggests that approximately 120,000 m^3 to 190,000 m^3 of sediment was eroded from the banks within this segment of the river over the past 31 years (1990 to 2021). This estimate is lower than the amount of erosion estimated by Rood (1993) to have occurred between 1953 and 1986 (500,000 m^3 ±200,000 m^3, likely around 300,000 m^3). Acknowledging the high uncertainty in these estimates, the preliminary results suggest that the rates of bank erosion along high glaciolacustrine terraces within this section of the river (XS 226 to XS 202) have decreased over time (i.e., 1953-1986 compared to 1990-2021), possibly indicating stabilization of the high eroding cutbanks.

Based on the change detection results between 1990 and 2021 and the discharge record (Table 2.1; Table 5.1), flows within the 500 to 700 m^3/s range are not expected to cause major changes to the banklines, nor create a highly active channel. Rather, the channel is expected to adjust relatively slowly to flows in this range, and minor adjustments in flow are not expected to produce drastically different outcomes. That said, the relatively recent high flows in the 500-700 m^3/s range (Table 5.1) likely caused much of the erosion observed between 1990 and 2021, as the 30-year period preceding 2007 saw relatively low peak flows, highlighting the importance of maintaining peak flows of this magnitude or greater to promote channel processes. Major increases in channel activity would likely require larger disturbances, such as large pre-regulation floods (e.g., > 1,000 m^3/s) and ice jams.

These results also suggest that the stream power of the river did not greatly exceed the threshold to erode the banks during flows that have been experienced since 1990. Thus, the river may be considered to be *at or near* the threshold for bank erosion during the high flows that have occurred (Table 5.1). Acknowledging that there is limited information regarding pre-regulation erosion rates, it is qualitatively understood that the rates of erosion prior to regulation would have likely been higher than they are now given the higher overall magnitude, duration, and frequency of peak flows. Further contemporary reductions in the flow regime may reduce the stream power below the threshold for erosion, resulting in near-complete stabilization of the banklines. As described in Section 3, this may have negative impacts on both physical and ecological processes within the river system.

Table 5.1 Summary of relatively high (post-regulation) peak daily flows at Vanderhoof since 1990.

Year	Maximum daily discharge at Vanderhoof (WSC 08JC001)
1997	532 m^3/s
2007	784 m^3/s
2011	487 m^3/s
2015	693 m^3/s
2018	526 m^3/s
2022	500 m^3/s

5.3 Limitations of Analysis

The analysis, interpretation and results presented herein are based on available data and are commensurate with the current project scope. Remaining limitations in the analysis include:

- Lack of pre-1990 survey data upstream of the Nautley River confluence, limiting the ability to quantify historical (pre-1990) erosion rates
- Further analysis required to refine historical bank erosion estimates upstream of the Nautley River confluence (Rood, 1993), including additional air photo analysis and mapping
- The downstream spacing of the 1990 and 2021 survey transects (approx. 300 m), which is generally too coarse to assess bank erosion and volumetric sediment input at specific sites

- Lack of historical survey data between the Nautley River confluence and Vanderhoof, limiting the ability to quantify historical erosion rates
- Further analysis required to refine erosion assessment at Vanderhoof, including:
  - Historic 2007/2009 and 2015/2017 NHC surveys
  - Historic 2007 BC Ministry of Environment (BC MoE) surveys
- Better resolution aerial imagery to improve accuracy of bankline mapping.

In the absence of historic survey data, historical air photos could be georeferenced and used to digitize the bankline positions along the Nechako River over the period of record. Comparing the bankline positions over time may provide information about historical bank erosion rates, and may refine existing historical estimates (Rood, 1993). However, this technique would not yield any information about vertical changes in bed elevation. This approach may also be of limited use if the amount of lateral erosion is small enough to be within the degree of accuracy for digitization and mapping, which is likely the case along most of the length of the Nechako River given the relatively low erosion rates in most areas (although limited erosion may be an interesting result in and of itself).

Moving forward, existing datasets may be leveraged by implementing repeated monitoring techniques to assess if/how bank erosion rates are changing along the Nechako River, as further discussed in Section 6.2.

6 PERFORMANCE METRICS

During Main Table and Technical Working Group meetings of the Nechako Water Engagement Initiative (WEI), concerns were raised regarding potential effects of Rio Tinto operations on riverbank erosion along private property located along the banks of the Nechako River (Issue #56). While this issue is important to some community members and has social significance, the sensitivity to Rio Tinto operations is unknown. This technical memo was prepared to better understand the relationship between river levels and historical erosion.

The following subsections discuss potential objectives related to Performance Metrics (PMs) for erosion along the Nechako River (Section 6.1) and provide recommendations for moving forward (Section 6.2).

6.1 Objectives

As mentioned in Section 3.3, key questions which should inform the development and implementation of PMs related to erosion include:

- How much erosion has occurred following regulation?
- How much erosion is “enough erosion” to maintain geomorphological and ecological functions?
- How much erosion (or deposition) is anticipated for different flow releases?

These questions highlight that the objective is likely to have *some* erosion, while mitigating or managing damage and loss of property and land.

To evaluate whether there is "enough erosion" to maintain geomorphological and ecological functions, the following items should be considered:

- What degree of habitat complexity is targeted, and where along the river system should it be?
  - E.g., Multiple channels, flood-forest interaction, variable bed elevations, off-channel ponds and oxbow lakes, etc.
- How is erosion linked to specific ecological functions?
  - E.g., Habitat utilization of undercut banks, ecological function of side-channels (both existing under conditions and the desired state), etc.
  - E.g., Quantity of gravel required to support Chinook spawning, or conversely, maximum allowable quantity of fine sediment to prevent adverse effects during incubation.
- What is the relative importance of gravel contributions from bank erosion to the overall sediment load?
- What are the hydrograph characteristics (i.e., timing, duration, and magnitude of flows) that support the desired level of erosion?
- How does the desired level of erosion change along the river?
  - E.g., Where should the focus be on supporting critical habitat and fluvial processes versus mitigating future erosion?

As previously mentioned in Section 5, the amount of bank erosion that occurred from 1990 to 2021 was generally low to moderate, except at a few locations, despite the occurrence of several flows in the 500-700 m^3/s range (Table 5.1). Thus, minor increases in flows within this range would not be expected to produce major changes in the rate of bank erosion or lateral migration, nor create a highly active channel. That said, the relatively recent high flows in the 500-700 m^3/s range (Table 5.1) likely caused much of the erosion observed between 1990 and 2021, as the 30-year period preceding 2007 saw relatively low peak flows, highlighting the importance of maintaining peak flows of this magnitude or greater to promote channel processes. If a dynamic river environment and the resulting habitat types are sought, flow changes that introduce large-scale channel disturbances (e.g., floods > 1,000 m^3/s and ice jams) would likely be required, which would certainly impact existing development on the floodplain.

It is likely beneficial to maintain rates of erosion that are, as a minimum, similar to those that have occurred since 1990 to renew and sustain aquatic habitats to some degree. However, the target amount of erosion should be defined based on the geomorphological and ecological evaluation criteria outlined above. Given that the present-day Nechako River system generally has limited stream power with which to erode its banks, relatively minor reductions in flows may reduce the stream power below the threshold for erosion, effectively ceasing these ecologically and geomorphologically important processes.

Targeted physical interventions may also be considered to achieve greater habitat complexity at key sites. Such physical interventions may include promoting river-wetland connectivity where appropriate (e.g., Wohl et al., 2021) or promoting increased geomorphological activity at the mesoscale by, for example, diverting more flow through secondary channels using woody debris structures (e.g., Abbe et al., 2018). Any large-scale physical interventions would need to be designed, sited, and monitored based on specific objectives and outcomes, with physical and biological effects monitored in a structured long-term plan.

6.2 Recommendations

Once clear objectives have been formulated, it is recommended that site-specific PMs be developed to evaluate the performance of each objective. For example, these may include:

- Bankline monitoring along an eroding segment of river
- Monitoring bankline erosion in relation to habitat values (e.g., extents, complexity and quality) in important ecological areas
- Quantifying and monitoring sediment inputs from bank erosion at key sites
- Monitoring fish habitat utilization in relation to features found in locations of erosional processes (e.g., undercut banks)
- Continued monitoring of channel migration rates and extents, and side-channel evolution.

Potential techniques that may be implemented as part of future monitoring programs, listed from large-scale to small-scale approaches, include:

- Collecting repeated airborne surveys (LiDAR and orthophotography) to monitor large sections of the river (e.g., every 5 or 10 years)
- Collecting repeated aerial imagery using a Remotely Piloted Aircraft System (RPAS) to monitor small to moderate sections of the river (i.e., reach-scale monitoring)
  - For this approach, it is recommended to use fixed control points and photogrammetric techniques to produce DEMs, allowing for volumetric change detection, as opposed to strictly horizontal (2D) change detection using aerial imagery
- Conducting repeated topographic surveys (e.g., RTK GPS or portable 3D LiDAR scanner) to monitor small sections of the river and specific banklines of interest.

The monitoring techniques listed above do not explicitly provide data on the channel bathymetry, which is useful in understanding and predicting future channel changes. Bathymetric data may be acquired using airborne techniques (bathymetric LiDAR) or traditional surveying techniques (e.g., boat and sounder). Bathymetric information may also be extracted from aerial imagery (e.g., RPAS imagery or orthophotography) using spectral analysis, although this technique would require traditional bathymetric surveying for calibration and is limited by depth and turbidity.

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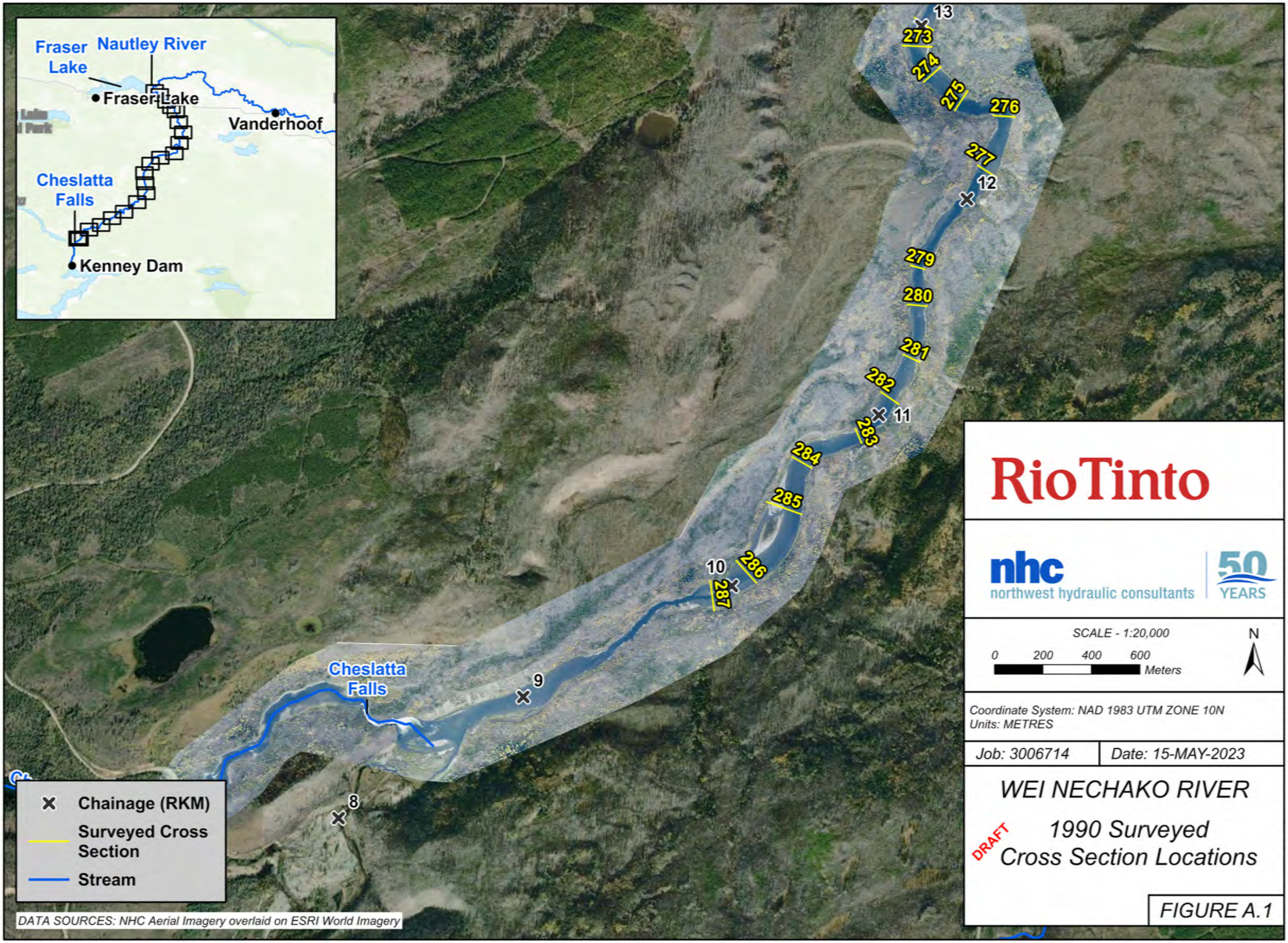
APPENDIX A

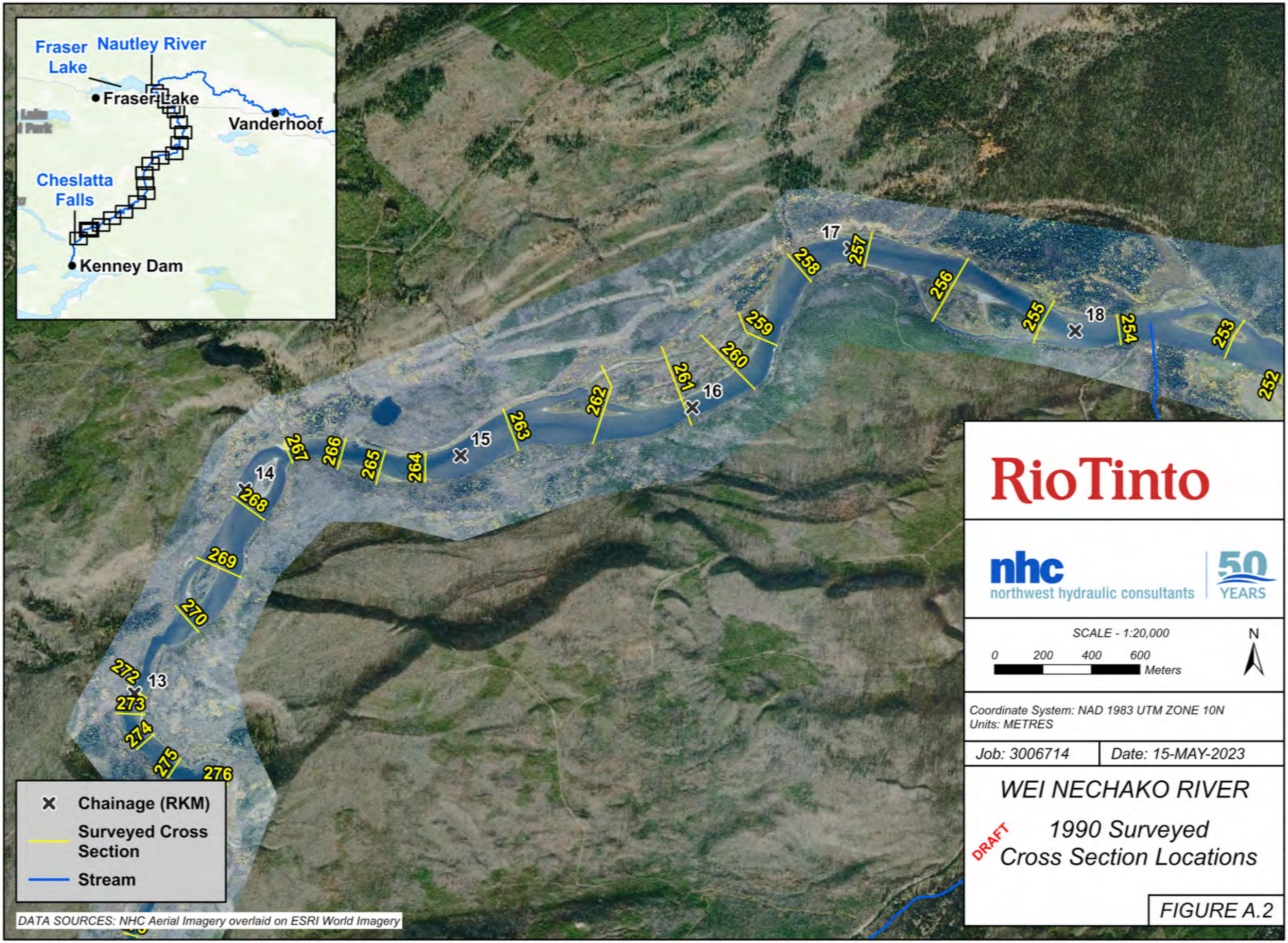
SURVEY TRANSECT LOCATIONS (1990-2021)



WEI NECHAKO RIVER

1990 Surveyed Cross Section Locations

FIGURE A.1



WEI NECHAKO RIVER

1990 Surveyed Cross Section Locations

FIGURE A.2

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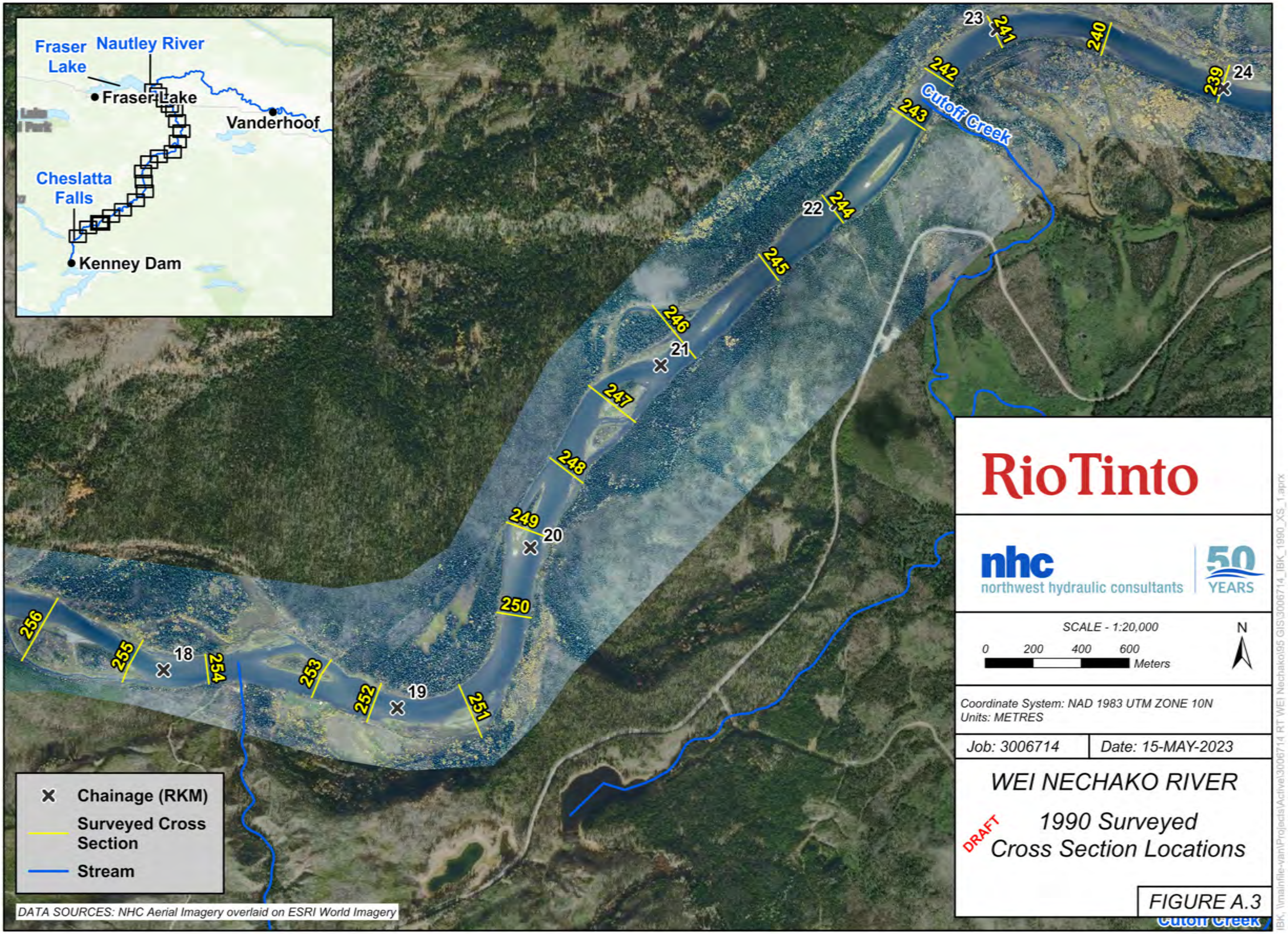
Fraser Lake
Nautley River
Fraser Lake
Vanderhoof
Cheslatta Falls
Kenney Dam
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Cutoff Creek
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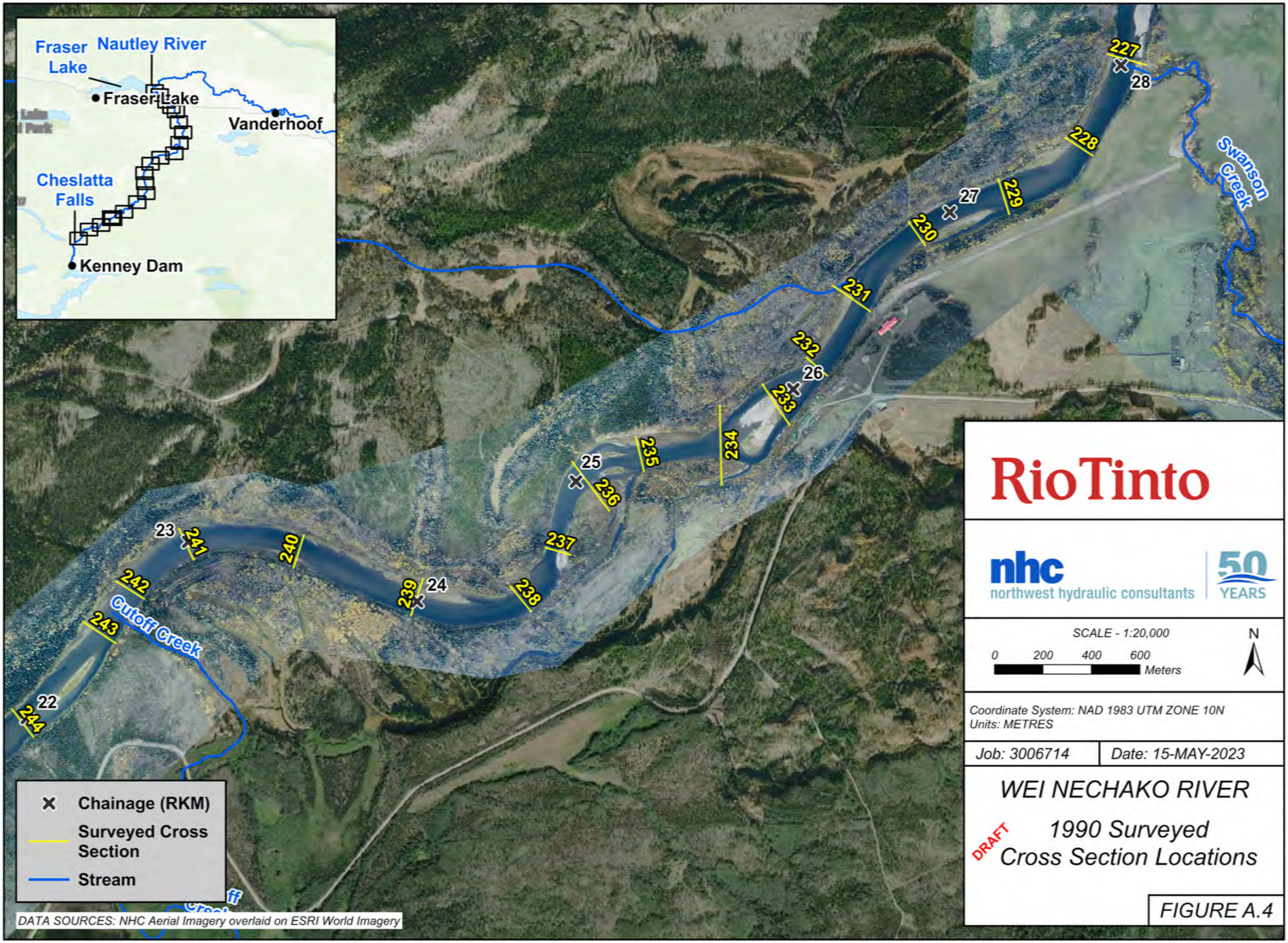
Chainage (RKM)
Surveyed Cross Section
Stream
DATA SOURCES: NHC Aerial Imagery overlaid on ESRI World Imagery
Cutoff Creek
RioTinto
nhc
northwest hydraulic consultants
50 YEARS
SCALE - 1:20,000
0 200 400 600
Meters
N
Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES
Job: 3006714
Date: 15-MAY-2023
WEI NECHAKO RIVER
DRAFT
1990 Surveyed Cross Section Locations
FIGURE A.3
IBK, \\mainfile-van\Projects\Active\3006714 RT WEI Nechako\95 GIS\3006714_IBK_1990_XS_1.aprx



Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES

Job: 3006714 | Date: 15-MAY-2023

WEI NECHAKO RIVER

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1990 Surveyed Cross Section Locations

FIGURE A.4

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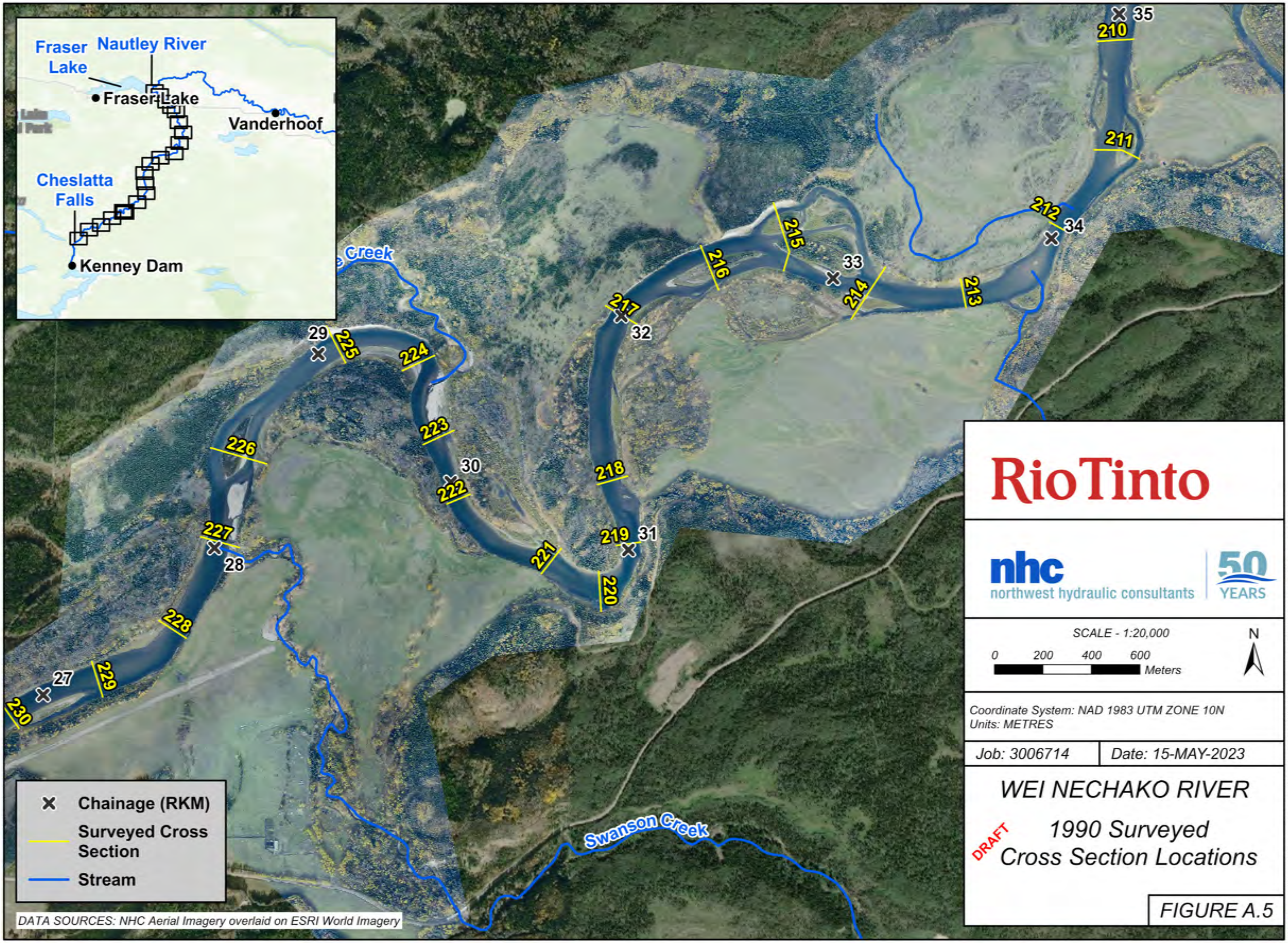

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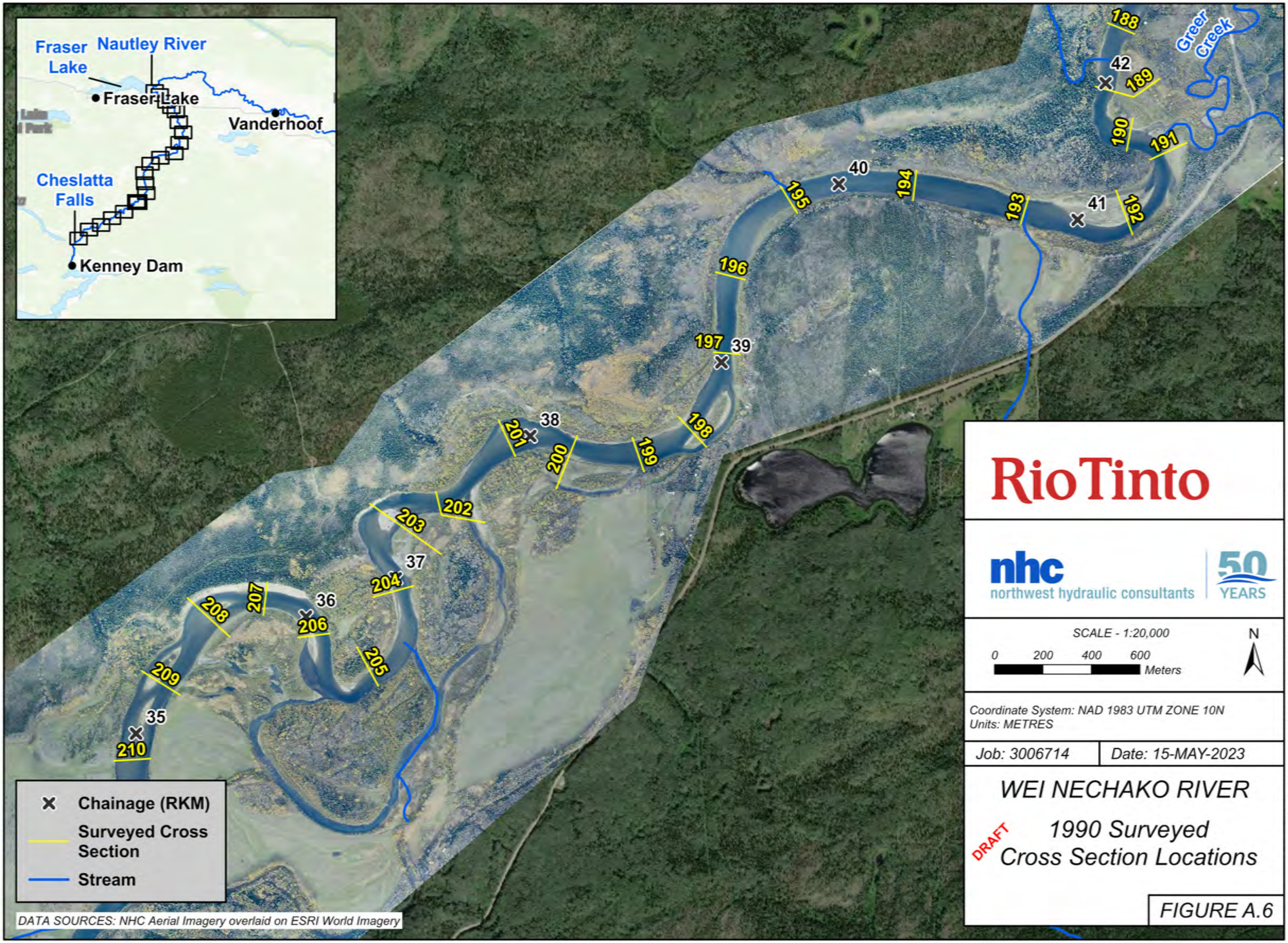
Fraser Lake
Nautley River
Fraser Lake
Vanderhoof
Cheslatta Falls
Kenney Dam
Greer Creek
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Chainage (RKM)
Surveyed Cross Section
Stream
DATA SOURCES: NHC Aerial Imagery overlaid on ESRI World Imagery
RioTinto
nhc northwest hydraulic consultants
50 YEARS
SCALE - 1:20,000
0 200 400 600 Meters
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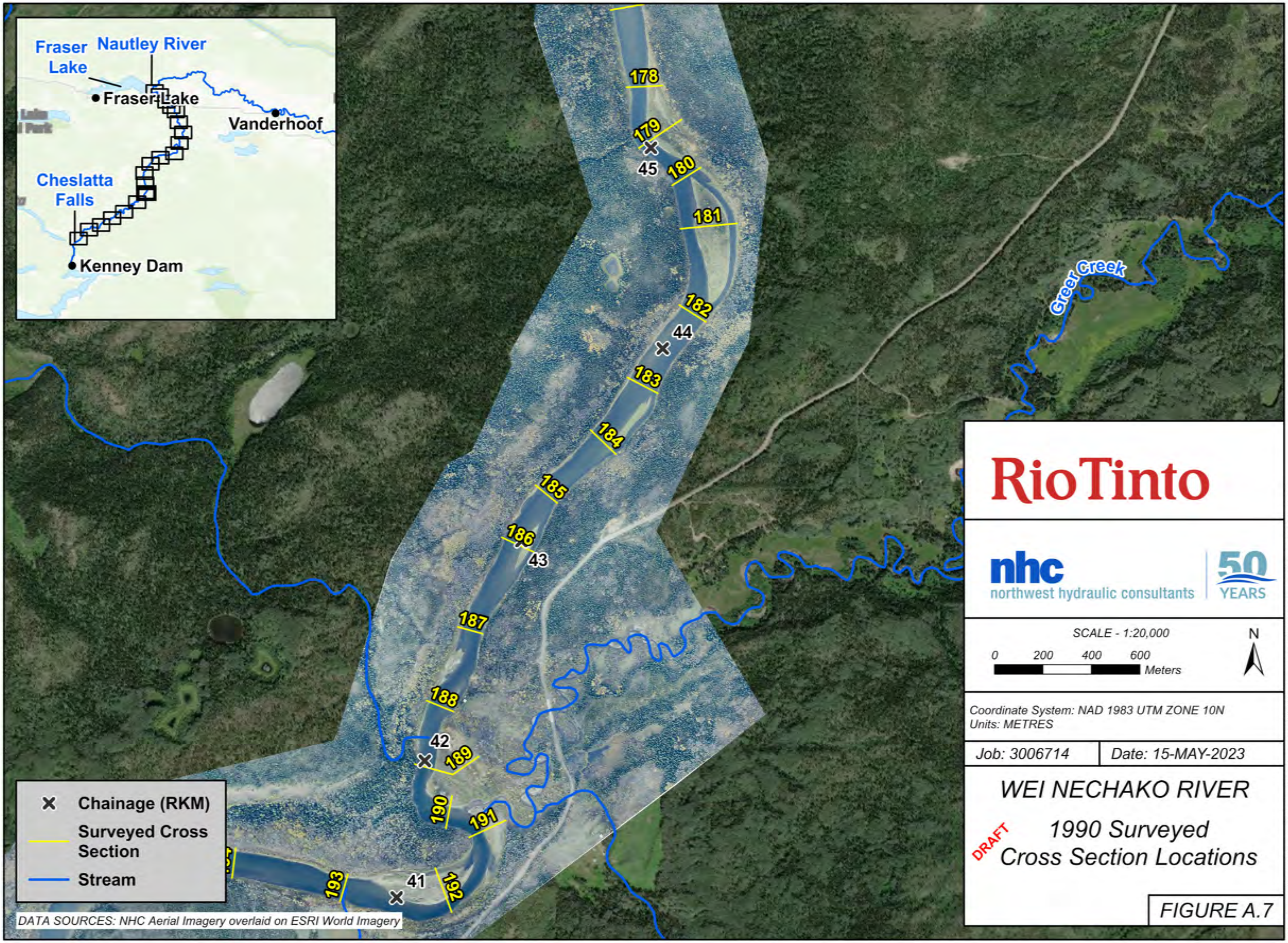
Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES
Job: 3006714
Date: 15-MAY-2023
WEI NECHAKO RIVER
DRAFT
1990 Surveyed Cross Section Locations
FIGURE A.6


Fraser Lake
Nautley River
Fraser Lake
Vanderhoof
Cheslatta Falls
Kenney Dam
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Greer Creek
Chainage (RKM)
Surveyed Cross Section
Stream
DATA SOURCES: NHC Aerial Imagery overlaid on ESRI World Imagery
RioTinto
nhc northwest hydraulic consultants
50 YEARS
SCALE - 1:20,000
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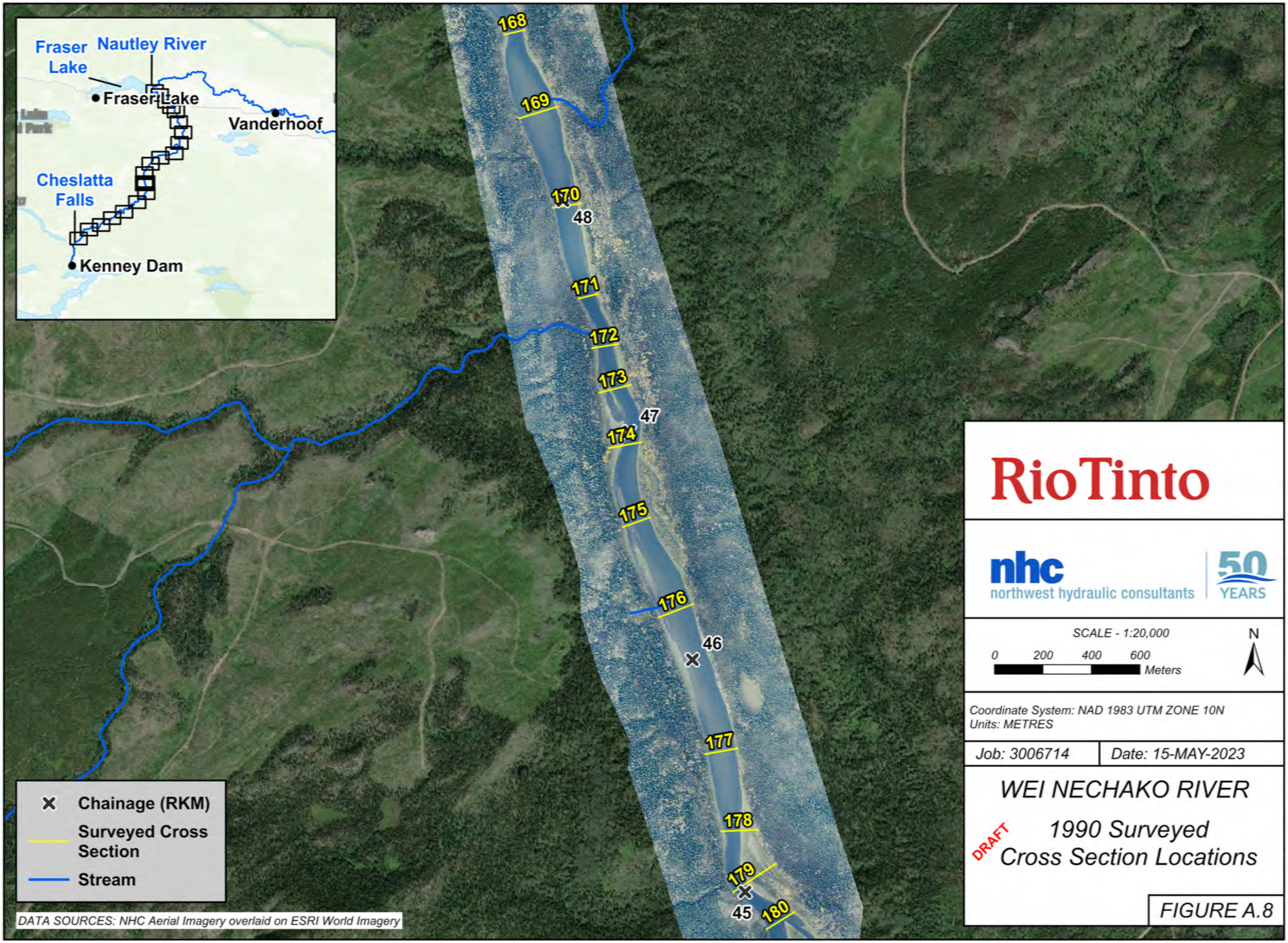
Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES
Job: 3006714
Date: 15-MAY-2023
WEI NECHAKO RIVER
DRAFT
1990 Surveyed Cross Section Locations
FIGURE A.7



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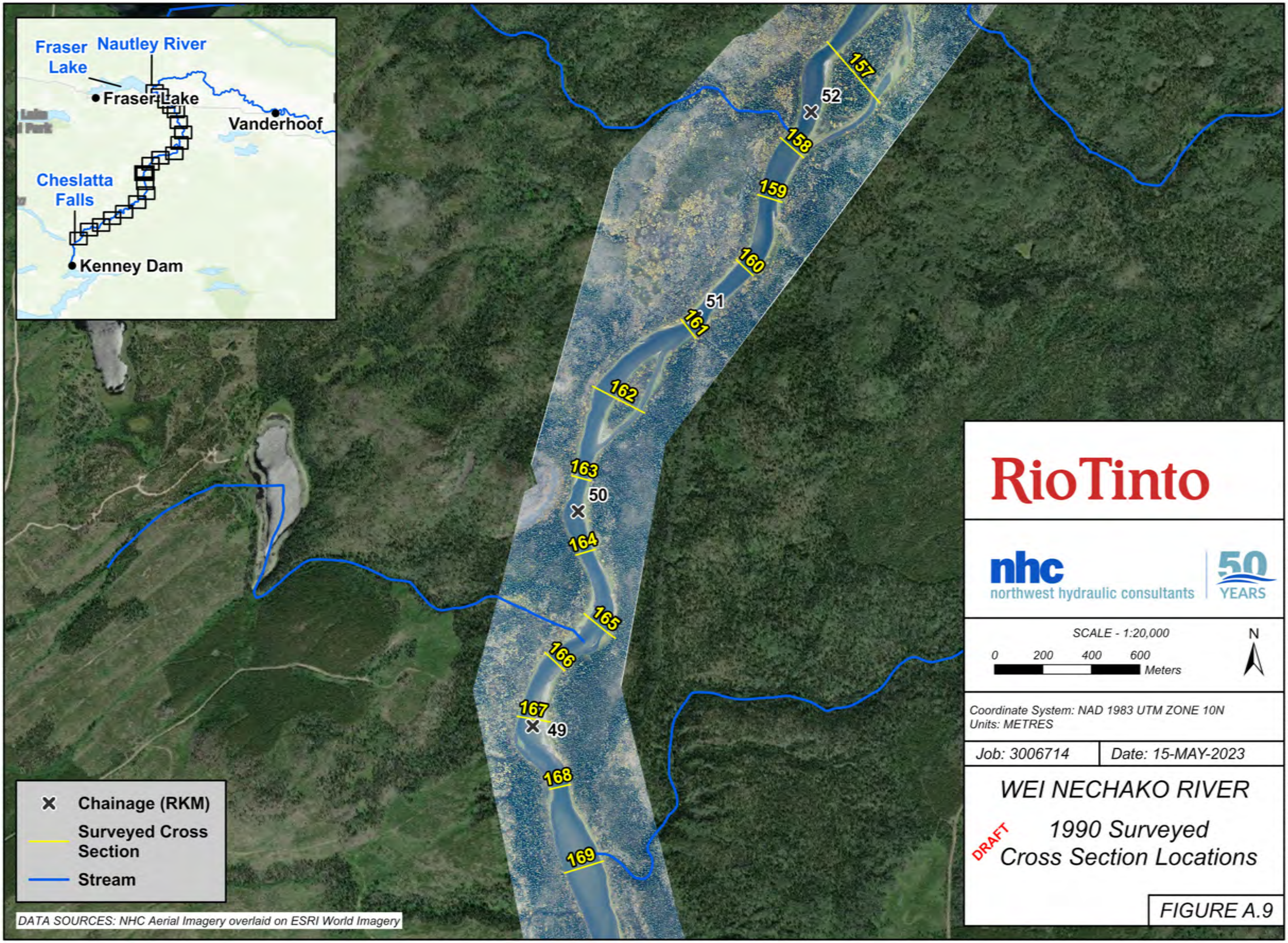

WEI NECHAKO RIVER

1990 Surveyed Cross Section Locations

FIGURE A.9

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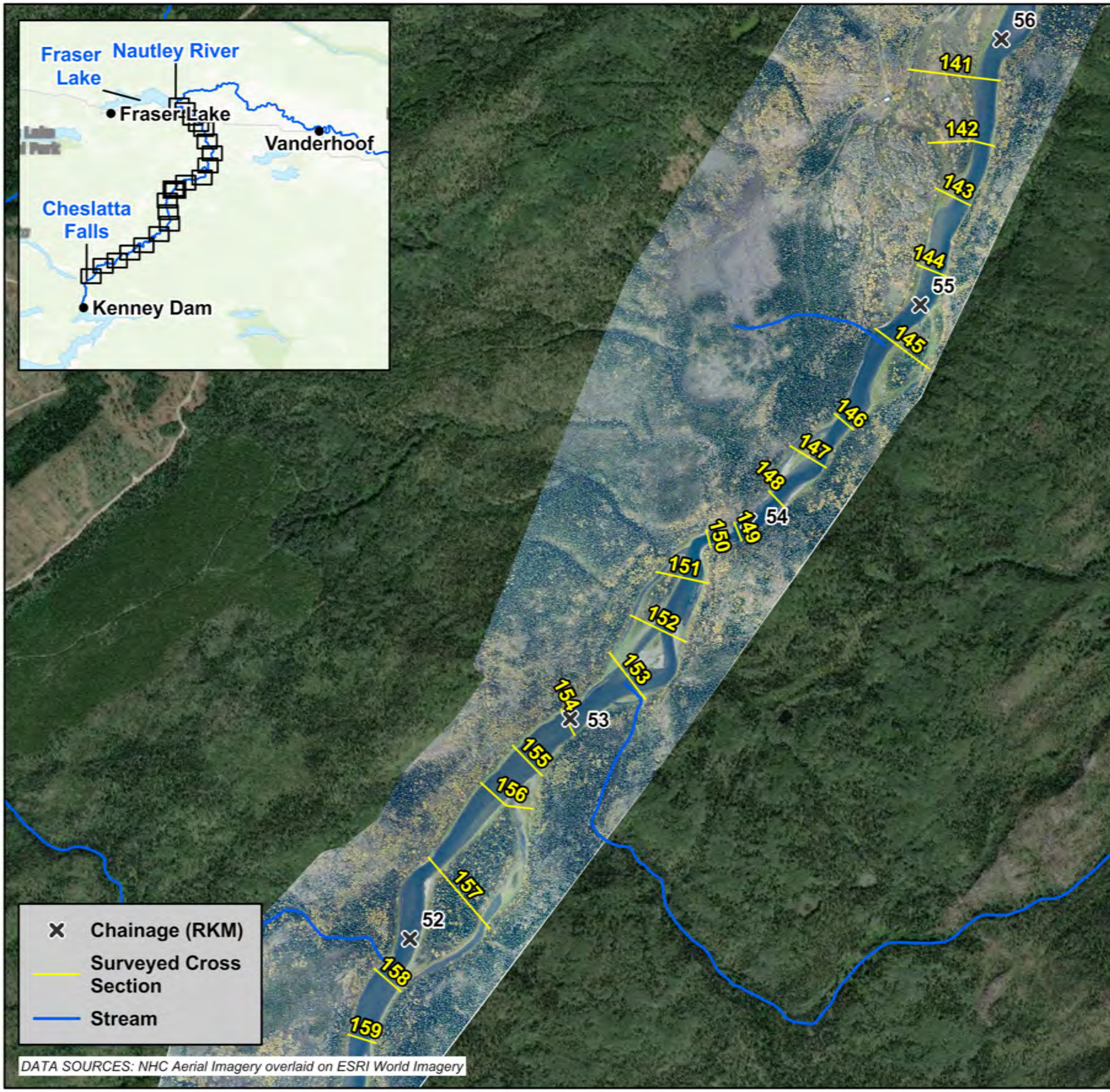


Rio Tinto

nhc northwest hydraulic consultants 50 YEARS

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES

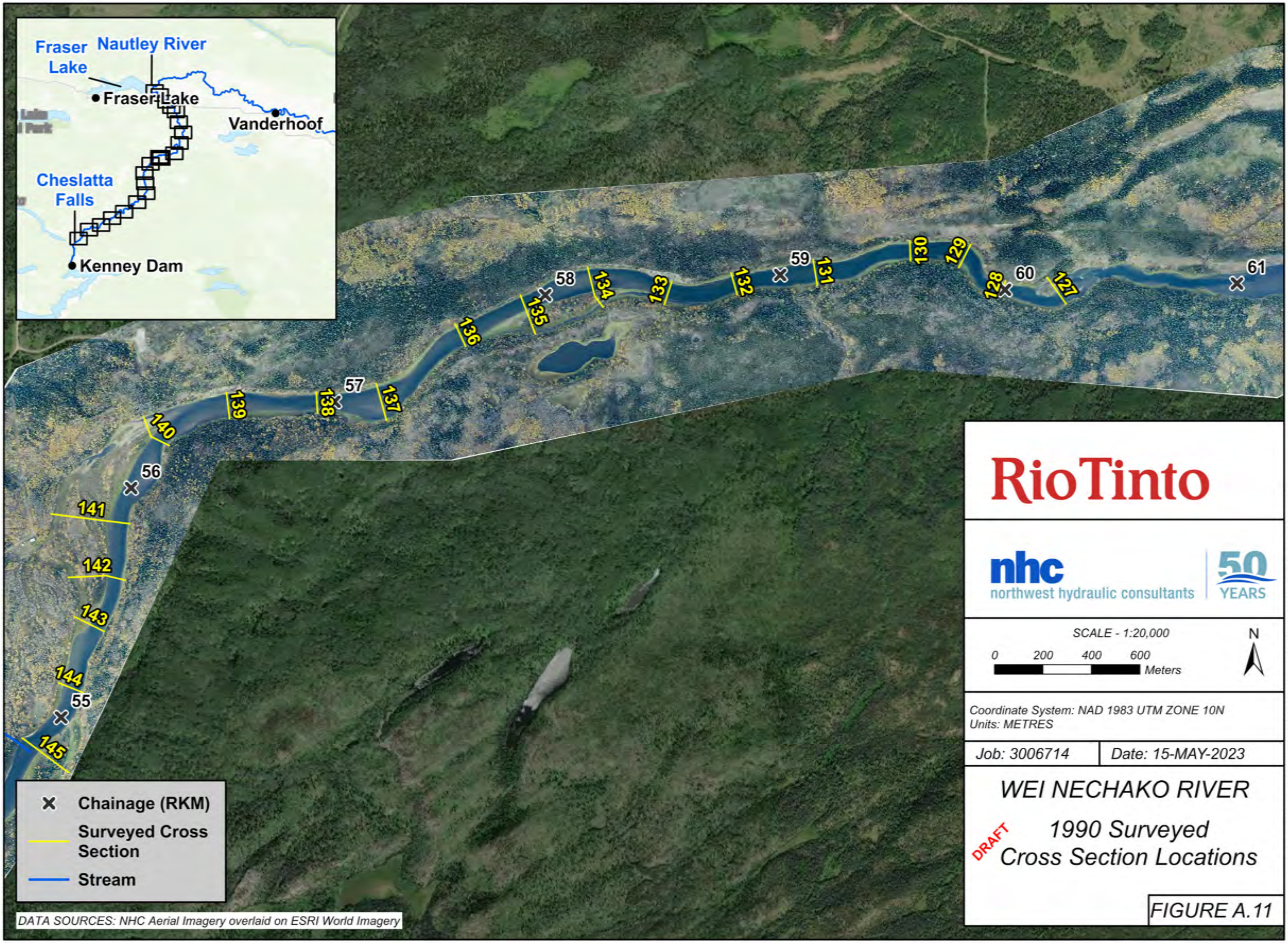
Job: 3006714 | Date: 15-MAY-2023

WEI NECHAKO RIVER

DRAFT

1990 Surveyed Cross Section Locations

FIGURE A.10



Fraser Lake
Nautley River
Fraser Lake
Vanderhoof
Cheslatta Falls
Kenney Dam
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Chainage (RKM)
Surveyed Cross Section
Stream
DATA SOURCES: NHC Aerial Imagery overlaid on ESRI World Imagery
RioTinto
nhc northwest hydraulic consultants
50 YEARS
SCALE - 1:20,000
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Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES
Job: 3006714
Date: 15-MAY-2023
WEI NECHAKO RIVER
DRAFT
1990 Surveyed Cross Section Locations
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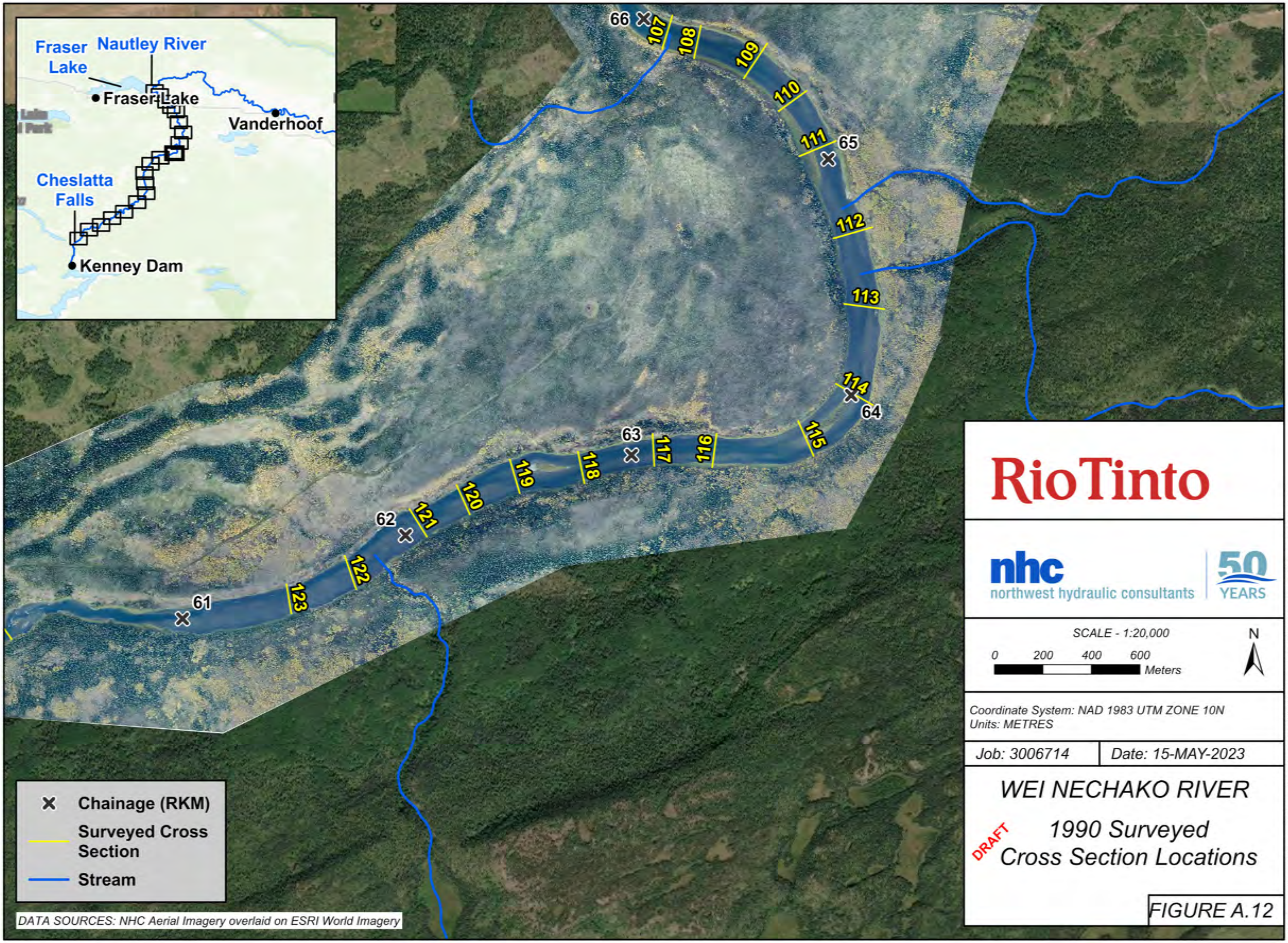
Fraser Lake
Nautley River
Fraser Lake
Vanderhoof
Cheslatta Falls
Kenney Dam
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Chainage (RKM)
Surveyed Cross Section
Stream
DATA SOURCES: NHC Aerial Imagery overlaid on ESRI World Imagery
RioTinto
nhc
northwest hydraulic consultants
50 YEARS
SCALE - 1:20,000
0 200 400 600 Meters
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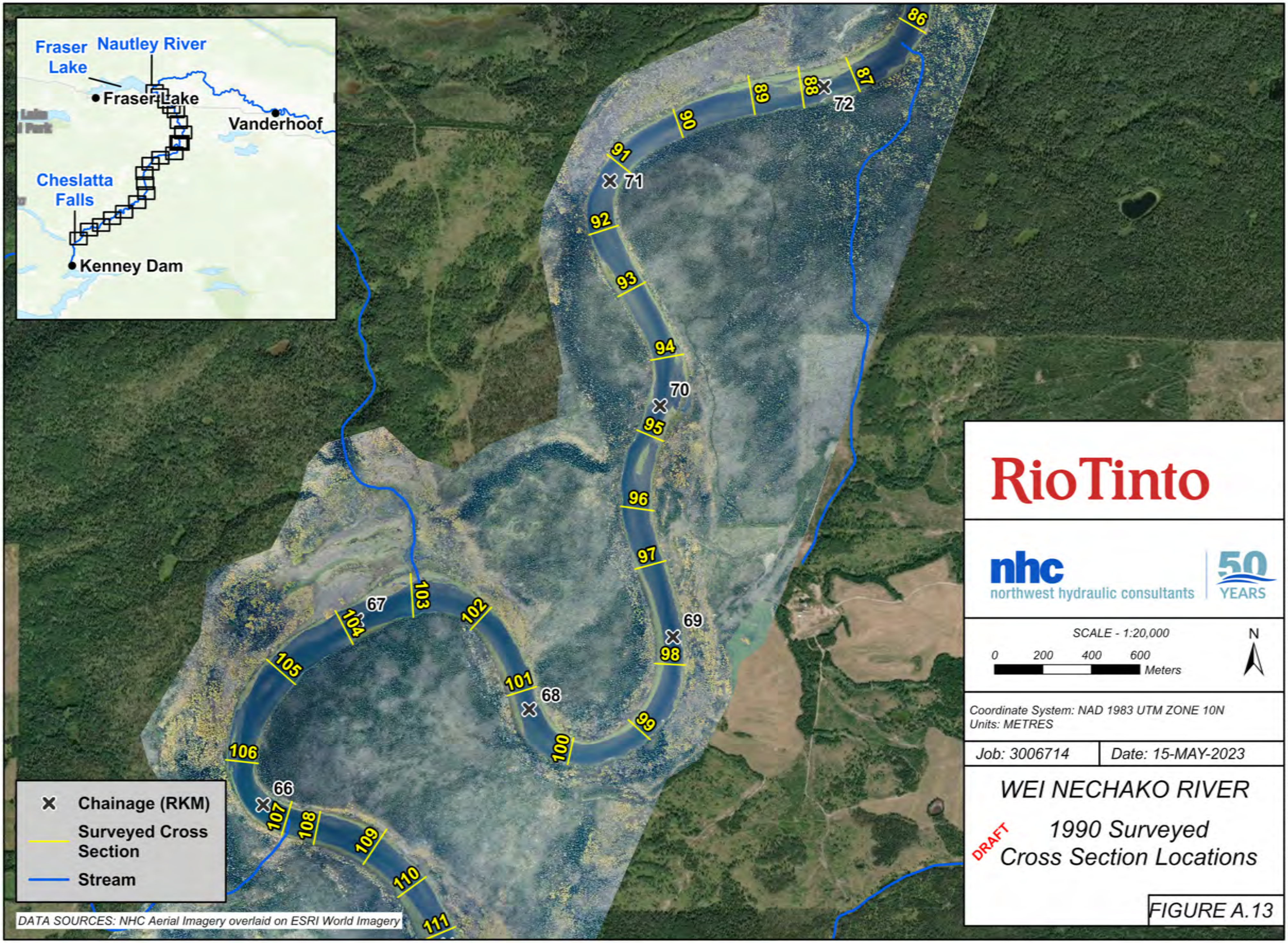
Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES
Job: 3006714
Date: 15-MAY-2023
WEI NECHAKO RIVER
DRAFT
1990 Surveyed Cross Section Locations
FIGURE A.12


Fraser Lake
Nautley River
Fraser Lake
Vanderhoof
Cheslatta Falls
Kenney Dam
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Chainage (RKM)
Surveyed Cross Section
Stream
DATA SOURCES: NHC Aerial Imagery overlaid on ESRI World Imagery
RioTinto
nhc northwest hydraulic consultants
50 YEARS
SCALE - 1:20,000
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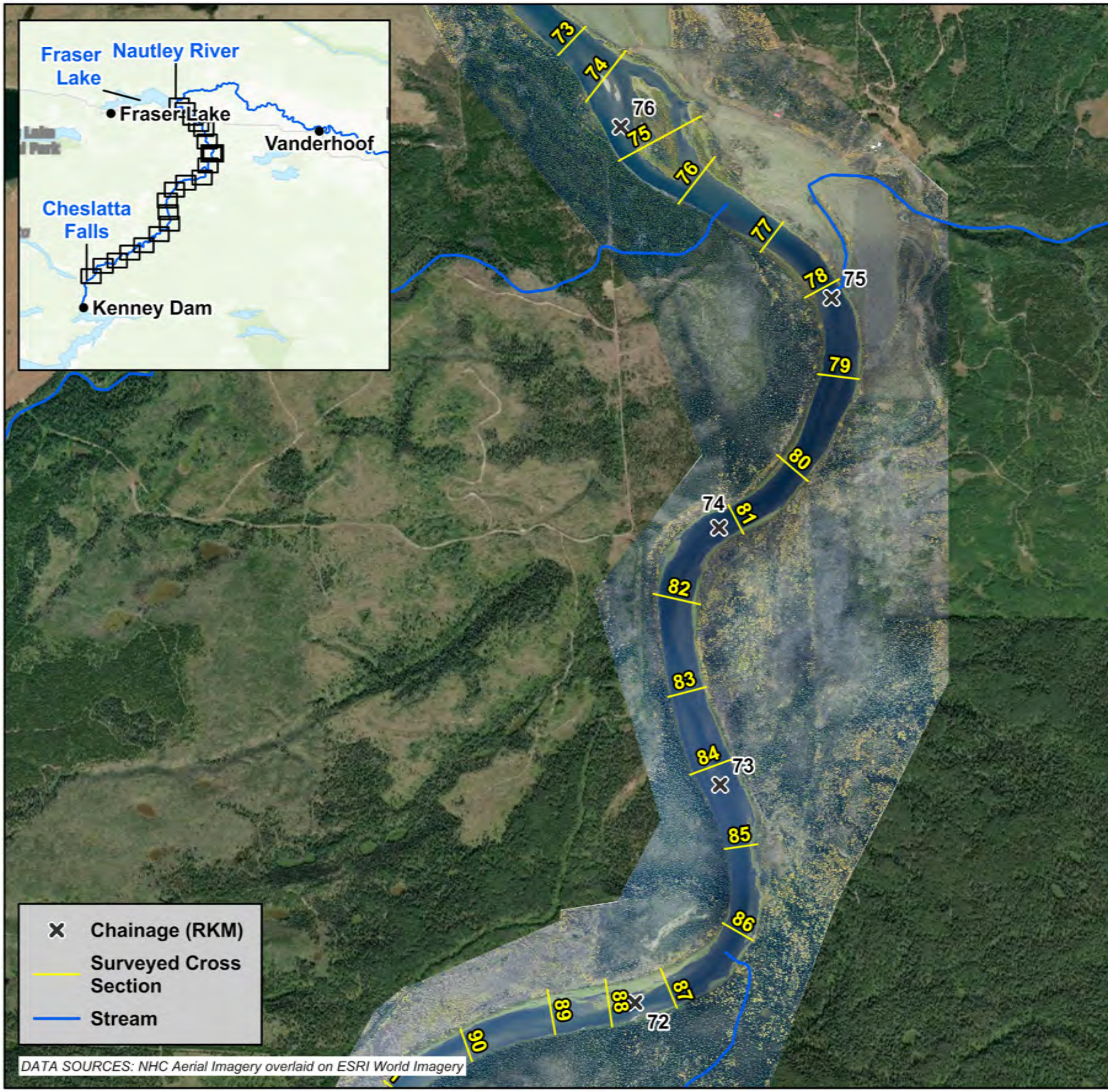
Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES
Job: 3006714
Date: 15-MAY-2023
WEI NECHAKO RIVER
DRAFT
1990 Surveyed Cross Section Locations
FIGURE A.13



Rio Tinto

nhc northwest hydraulic consultants | 50 YEARS

SCALE - 1:20,000

0 200 400 600 Meters

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Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES

Job: 3006714	Date: 15-MAY-2023

WEI NECHAKO RIVER

DRAFT

1990 Surveyed Cross Section Locations

FIGURE A.14

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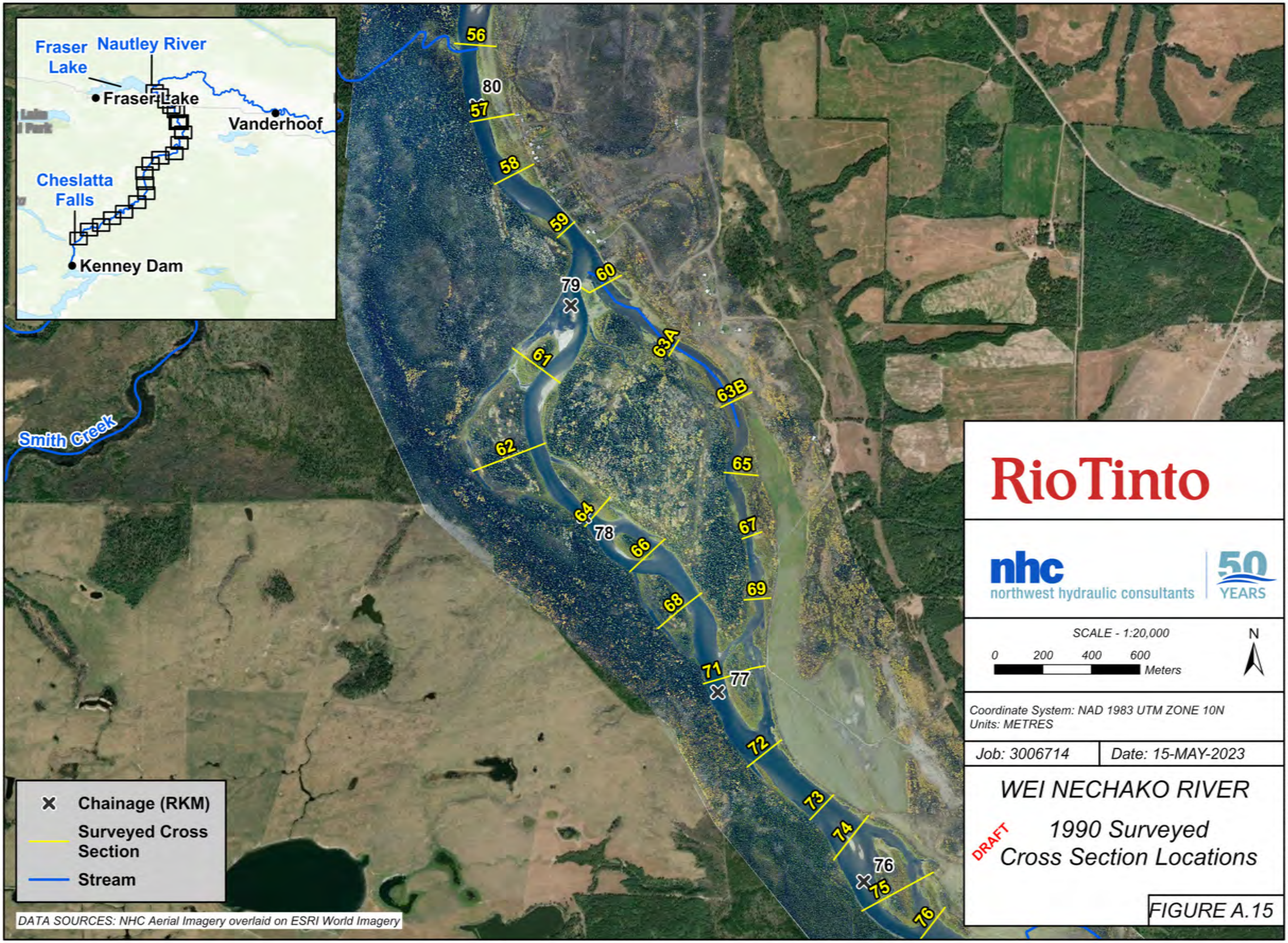
Fraser Lake
Nautley River
Fraser Lake
Vanderhoof
Cheslatta Falls
Kenney Dam
Smith Creek
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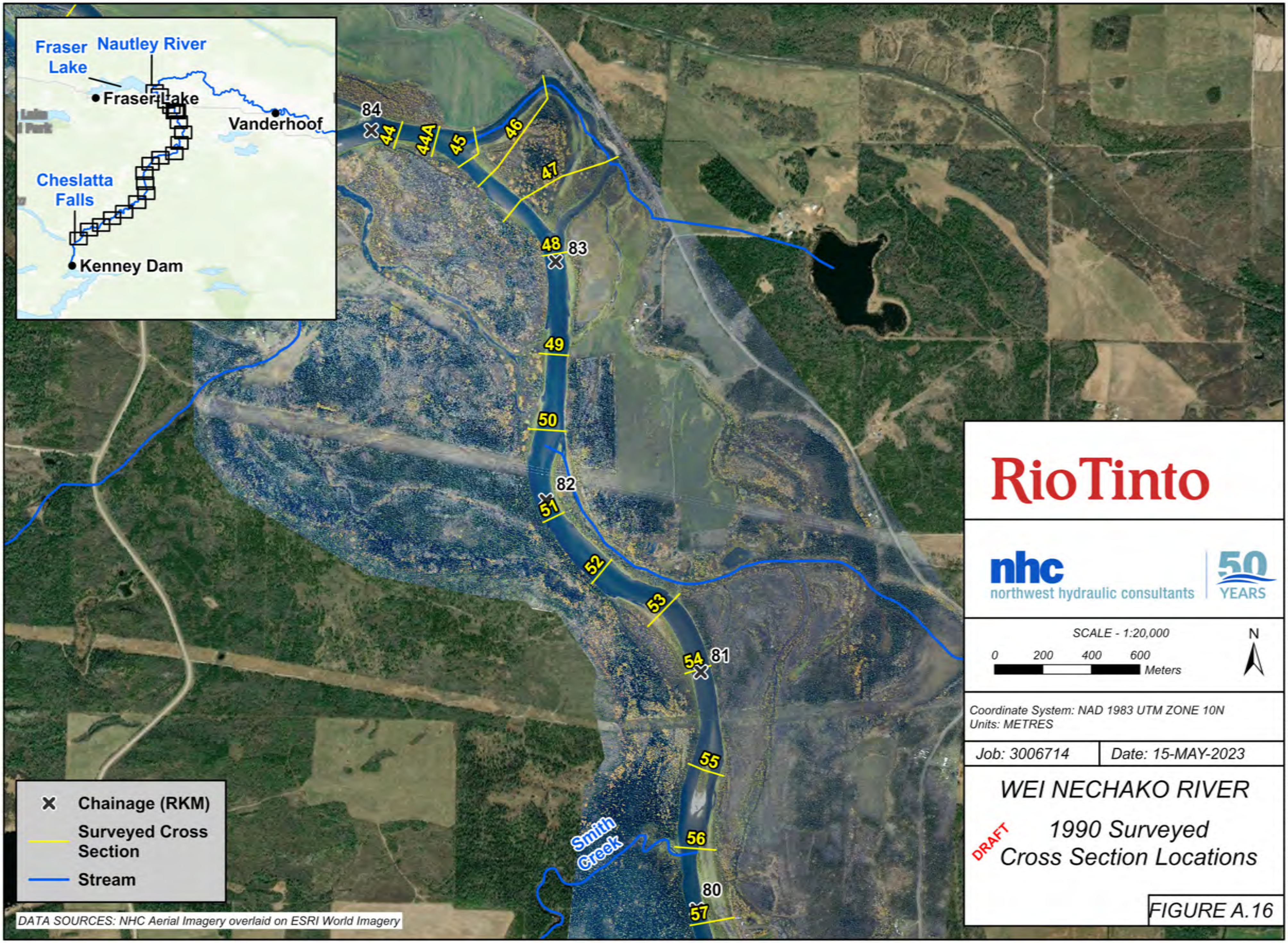
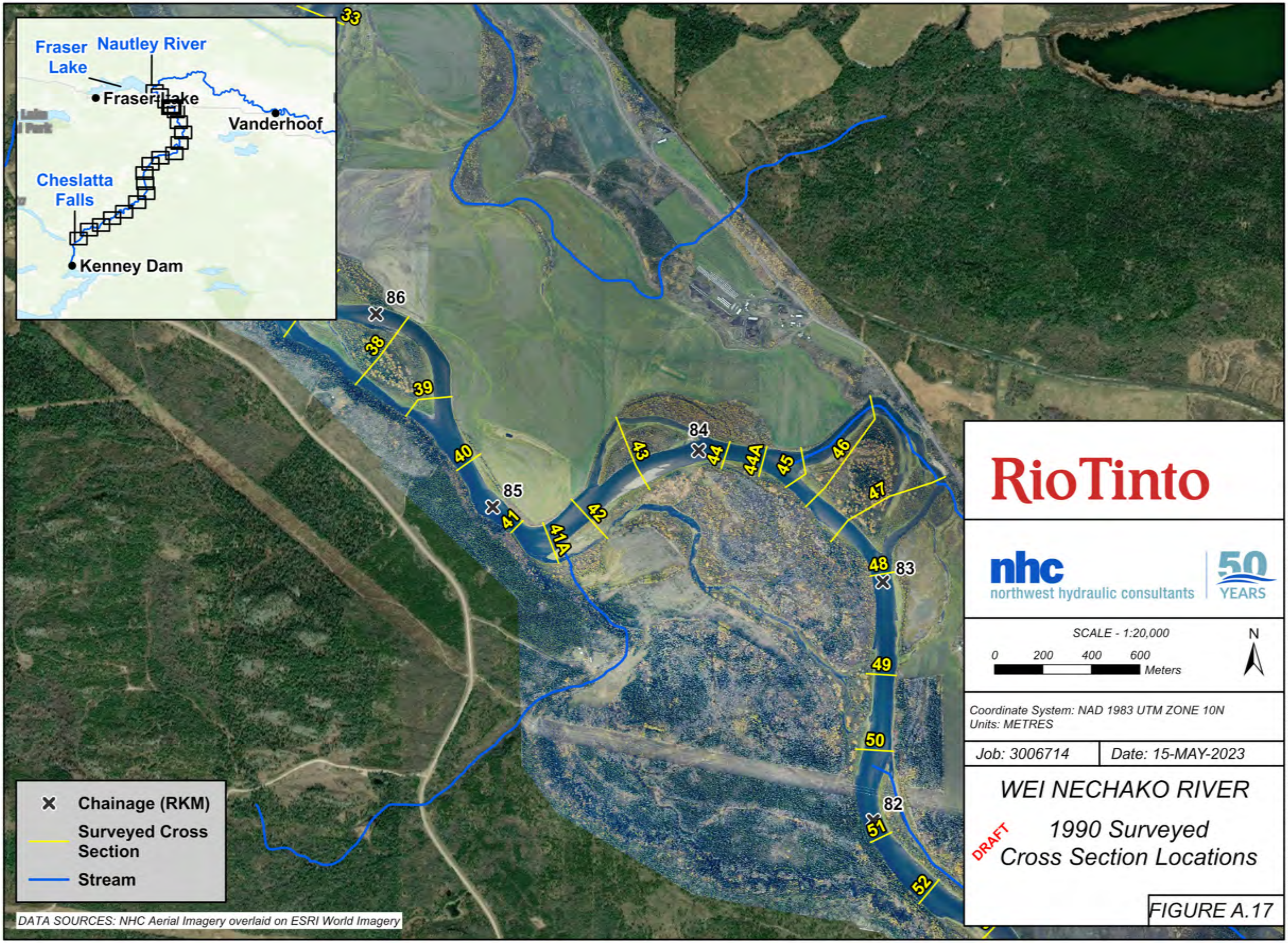
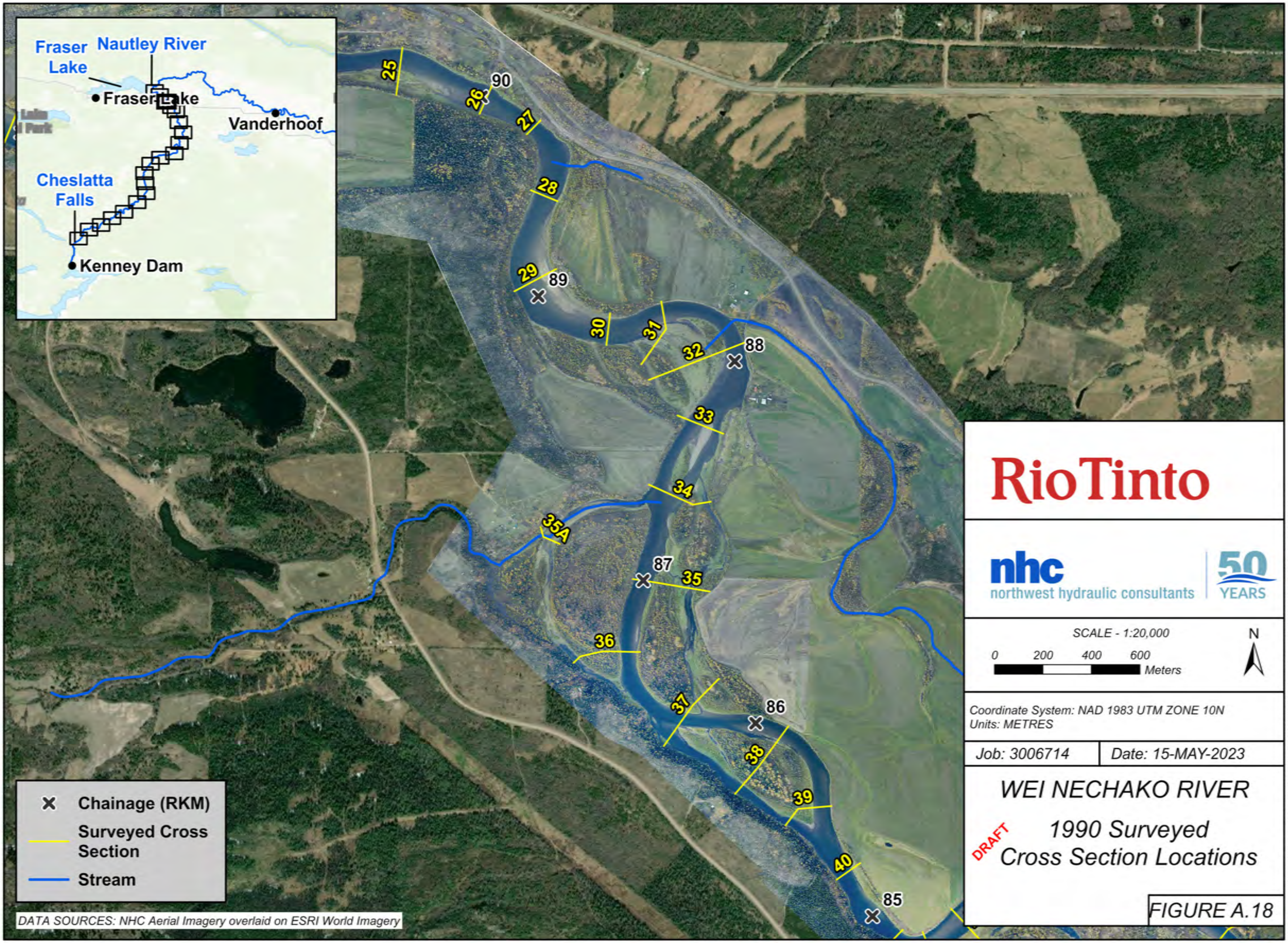
Chainage (RKM)
Surveyed Cross Section
Stream
DATA SOURCES: NHC Aerial Imagery overlaid on ESRI World Imagery
RioTinto
nhc northwest hydraulic consultants
50 YEARS
SCALE - 1:20,000
0 200 400 600 Meters
N
Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES
Job: 3006714
Date: 15-MAY-2023
WEI NECHAKO RIVER
DRAFT
1990 Surveyed Cross Section Locations
FIGURE A.15
IBK, \\mainfile-van\Projects\Active\3006714 RT WEI Nechako\95 GIS\3006714_IBK_1990_XS_1.aprx



IBK; \\mainfile-van\Projects\Active\3006714 RT WEI Nechako\95 GIS\3006714_IBK_1990_XS_1.aprx



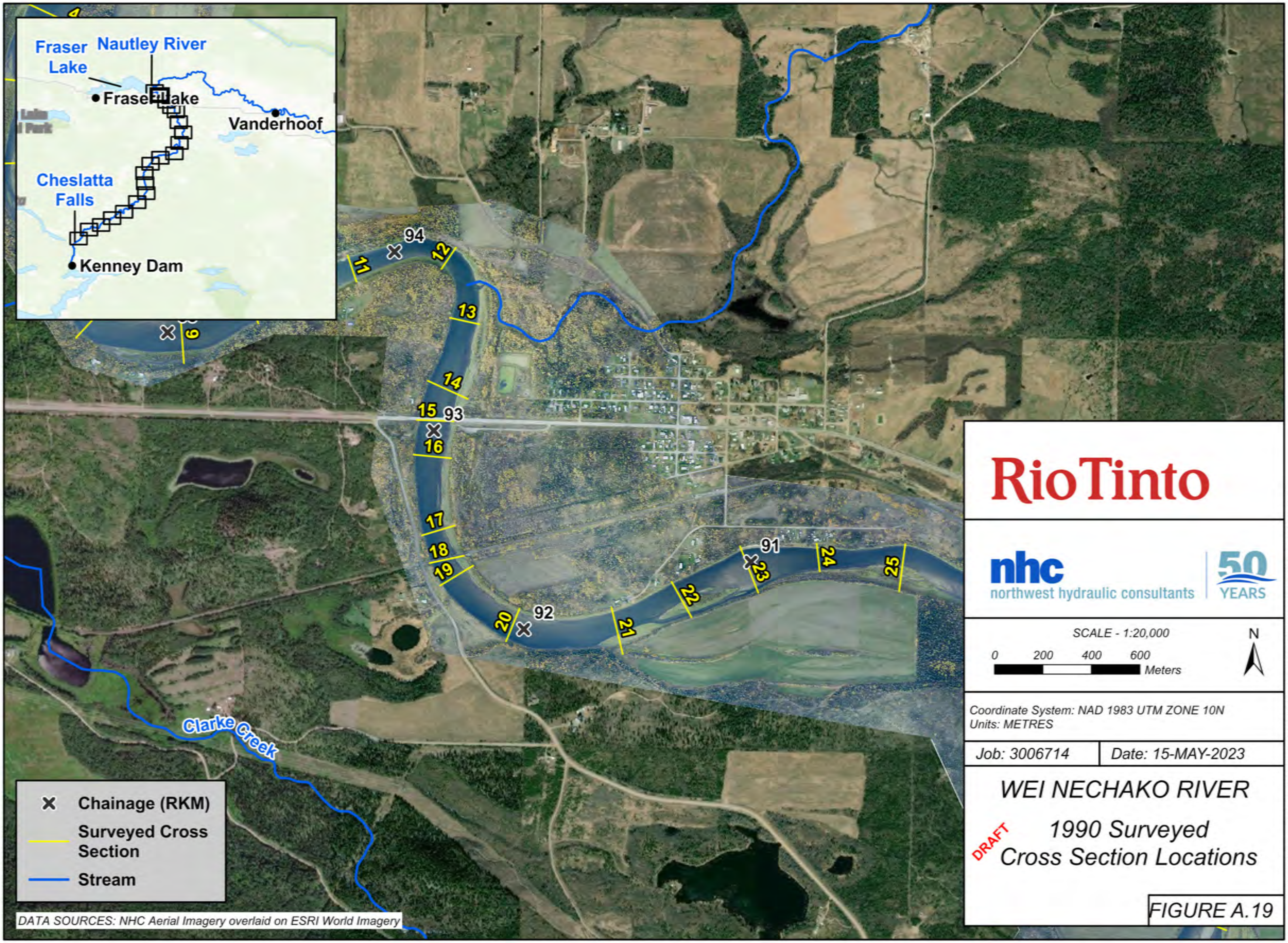
IBK, \\mainfile-van\Projects\Active\3006714 RT WEI Nechako\95 GIS\3006714_IBK_1990_XS_1.aprx



WEI NECHAKO RIVER

1990 Surveyed Cross Section Locations

FIGURE A.18



RioTinto

nhc northwest hydraulic consultants 50 YEARS

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES

Job: 3006714 | Date: 15-MAY-2023

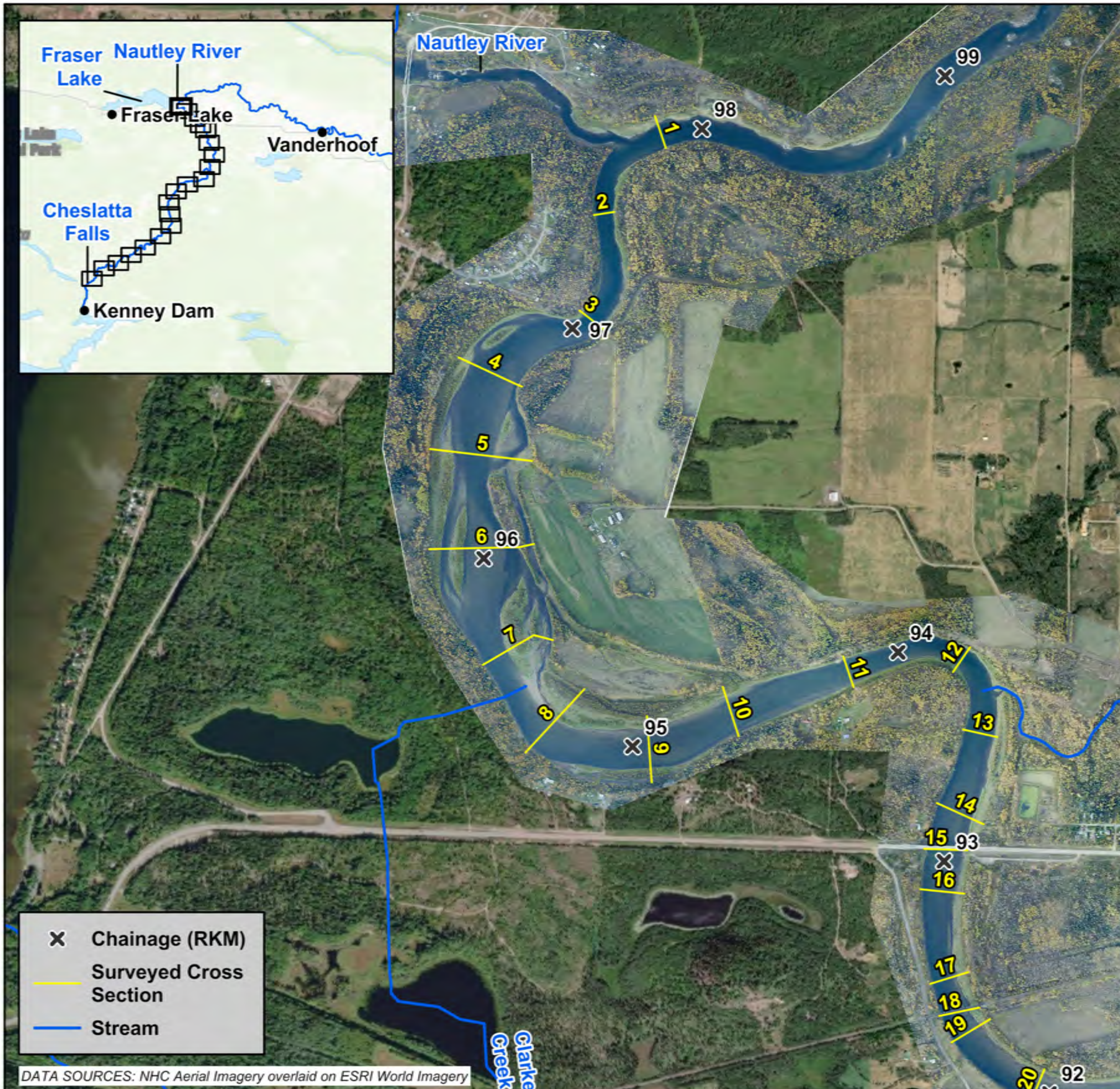
WEI NECHAKO RIVER

DRAFT

1990 Surveyed Cross Section Locations

FIGURE A.19

IBK, \\mainfile-van\Projects\Active\3006714 RT WEI Nechako\95 GIS\3006714_IBK_1990_XS_1.aprx



RioTinto

nhc northwest hydraulic consultants 50 YEARS

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES

Job: 3006714 | Date: 15-MAY-2023

WEI NECHAKO RIVER

DRAFT

1990 Surveyed Cross Section Locations

FIGURE A.20

IBK, \\mainfile-van\Projects\Active\3006714 RT WEI Nechako\95 GIS\3006714_IBK_1990_XS_1.aprx