Movements of wild-captured juvenile, subadult, and adult White Sturgeon among putative population areas in the Upper Fraser Watershed 1995-2019.

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A Technical Report Prepared by

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For consideration by the

Nechako White Sturgeon Recovery Initiative's Technical Working Group

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Acknowledgements

Many individuals, communities and organizations contribute to the management of White Sturgeon in the Fraser River watershed. The authors wish to acknowledge the extensive collective efforts made over the last three decades to manage this species in central British Columbia which has resulted in the dataset used in this report. The Upper Fraser River falls within the Traditional Territories of many aboriginal communities, including people from the Dakelh, Sekani, Tsilhqot'in, St'at'imc and Secwepemc Nations. First Nations have interacted with White Sturgeon both culturally and as a food source for time immemorial. Since the British Columbia Government imposed a no-kill regulation on recreational White Sturgeon harvesting within the Fraser watershed in 1994, almost all First Nations with Territories in the watershed have voluntarily complied with this restriction and continue to avoid incidental harvest in their own food and social fisheries. Many have also worked directly and in collaboration with governments and stakeholders toward the recovery of listed populations and the management of non-listed populations.

Table of Contents

Table of Figures

List of Tables

Introduction

Sturgeon species show wide geographical distributions and can undertake movements of many hundreds of kilometers (km) to feed or reproduce successfully. Long distance movements make sturgeon particularly vulnerable to dams, dykes, flow diversions and other largescale changes to habitats that sever habitat connectivity (Fisheries and Oceans Canada 2014). In Canada, White Sturgeon (*Acipenser transmontanus*) populations are found only in British Columbia and represent the northern most extent of this species distribution (Scott and Crossman 1973; McPhail 2008). White Sturgeon are long-lived, with a generation time of approximately 30-40 years and a potential lifespan of greater than 100 years (McPhail 2008). Three of six distinct White Sturgeon populations in BC are at imminent risk of extirpation, including two in the Upper Fraser Watershed (COSEWIC 2012).

Sampling programs for White Sturgeon (henceforth: sturgeon) have been ongoing within the Upper Fraser watershed since 1995. On first capture, it is standard for all sturgeon to be tagged with passive integrate transponder tags (PIT). Sturgeon in Upper Fraser programs are also radio tagged with uniquely coded transmitters. Application of unique PIT and radio tags allow for an opportunity to record the movements of individuals over a large and complex geographic range and long periods of time through re-captures and radio tracking (Figures 1 and 2). The species longevity allows us to monitor individual sturgeon over decades and therefore record and assess movement patterns. Since 1995, a considerable amount of capture location, life-history and movement data has been amassed in various population studies and radio telemetry surveys of White Sturgeon in the Fraser River watershed and elsewhere (Figure 2). Three reviews of data collected on Upper Fraser White Sturgeon have occurred over the last twenty-five years (RL&L Environmental Services Ltd 2000; Sykes 2008; Courtier 2010b)However, the most spatially comprehensive investigation was completed by RL&L Environmental Services more than 25 years ago. At the conclusion of this 5-year study, RL&L proposed the confluence of the Nechako at Prince George as a putative boundary for three populations (Figure 2). The authors developed this model based on geography, movements and genetic evidence. The analysis indicated that there was uncertainty in species/population boundaries due to a low number of captures and limited power of the genetic analysis for the area downstream of Prince George to the Cottonwood River.

Recent data reviews focused on the Nechako population only (Sykes 2008; Courtier 2010b). Within the Upper Fraser watershed, sturgeon appear to have high fidelity to the population area associated with their capture origin. However, it has been noted that some Upper Fraser White Sturgeon do move distances of hundreds of kilometers between various habitats, potentially for spawning and rearing (Smyth et al. 2016). Smyth et al.

acknowledged that there were unpublished Provincial Government data that showed a number of sturgeon moved between adjacent population areas leading to the idea that there was some level cohabitation for the Middle Fraser and Upper Fraser populations in the area downstream of the Prince George (river kilometer (rkm) 798) to the confluence of the Cottonwood and Fraser Rivers near Quesnel BC (rkm 674). However, the present study is the first effort since RL&L 2000 to review the entire dataset for movements of White Sturgeon between populations areas since. Twenty years of monitoring of White Sturgeon within the Upper Fraser has taken place since and these data have not yet been used to validate the recommended population boundaries.

The primary objective of this work is to explore the movements of radio and PIT tagged White Sturgeon that have crossed population boundaries identified in RL&L Environmental Services (2000) and Smyth et al. (2016) at least once since 1995. A secondary objective of this study is to highlight current data gaps and opportunities for further studies aimed to improve understanding of life-history patterns, better define critical habitats and inter-population mixing of Upper Fraser White Sturgeon. This information would be used be to develop projects that lead to more precision in the definition of locations and the function of important habitats for various life stages for use in population management and also the recovery of listed populations.

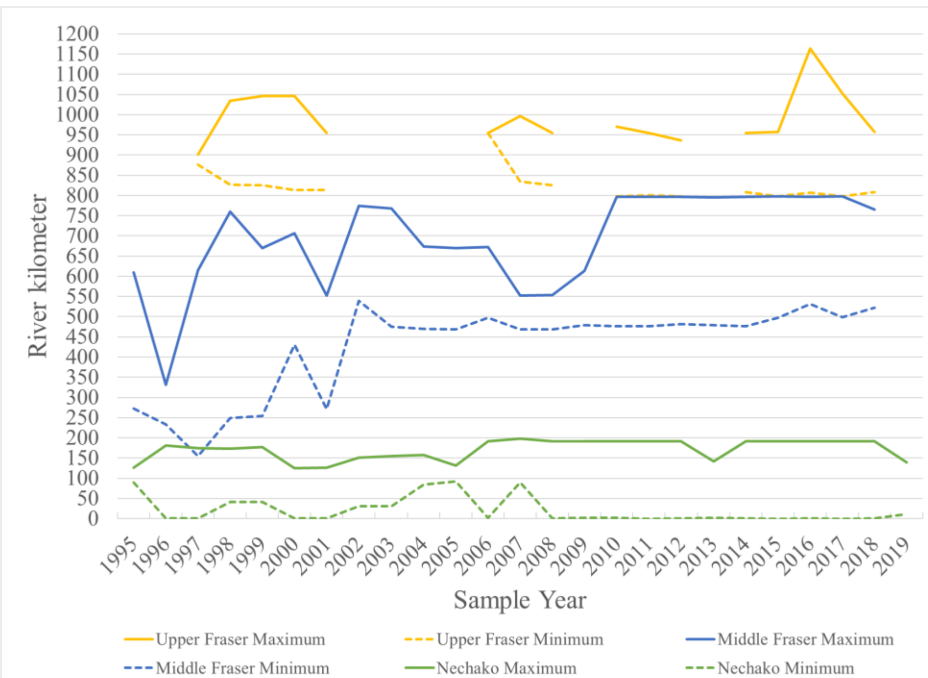


Figure 1. Index of sampling coverage showing maximum and minimum of river kilometers for positive encounters plotted across samples year for the Nechako, Middle Fraser River and Upper Fraser River population areas. For the purpose of this study an encounter refers to a capture, recapture or telemetry location for White Sturgeon. River kilometer zero on

the Nechako River and river kilometer 798 on the Fraser River occur at approximately the same location.

Purpose and Objectives

This report intended to summarize existing information up to June 2019 and to provide recommendations for future analyses or further study.

The objectives of this report are to:

1. Collate the available capture, life-history and radio telemetry data into one dataset: namely the Nechako White Sturgeon Recovery Initiative (NWSRI) sturgeon data base.
2. Tabulate and summarize apparent "out of area" or inter-NSP movements for White Sturgeon caught in each of three populations.
3. Review the associated biological data including basic life-history data for each fish.
4. Present qualitative patterns of movement observed and make recommendations for future studies to better understand the context of these movements.

Materials and Methods

Study Area

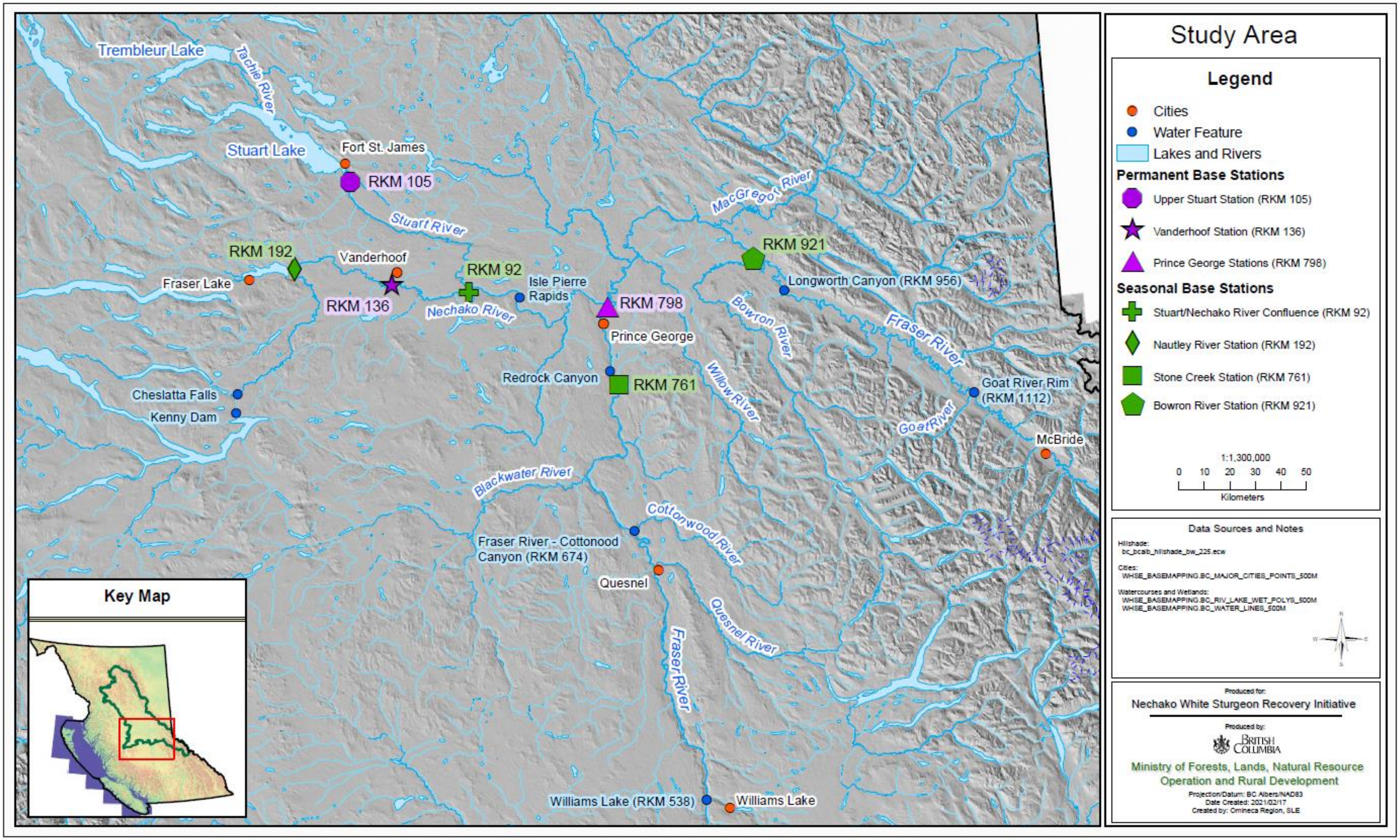
The present study encompasses the Upper Fraser watershed north of Boston Bar, BC upstream of Fraser River rkm 220 and includes the Nechako River and Stuart River watersheds (Figure 1). White Sturgeon within the study area occupy mainstem habitat of large rivers and lakes in the Nechako Watershed. Three genetically distinct populations of White Sturgeon are present the Upper Fraser watershed, including Middle Fraser, Nechako and Upper Fraser populations. No migration barriers limit movement of White Sturgeon and most other fish species within the study area; indeed, six species of anadromous salmonids (*Oncorhynchus sp*.) and Bull Trout (*Salvelinus confluentus*) (McPhail 2008) migrate annually upstream and downstream of the known range of White Sturgeon (McPhail 2008). The range of the Middle-Fraser population includes the mainstem Fraser River upstream of rkm 220 near Boston Bar, BC to Prince George, BC at rkm 798 (RL&L Environmental Services Ltd 2000). The range of the Upper Fraser White Sturgeon includes the Fraser River from the confluence of the Nechako River, upstream to the community of McBride as well as the lower reaches of the Bowron and McGregor Rivers (Lheidli T'enneh 2002). The upstream limit is not clearly defined, and knowledge may largely be constrained by sampling effort in this remote section of the Fraser River. The range of the Nechako sturgeon population includes mainstem and large lake habitat of Nechako watershed; including the Nechako River to at least 20 km upstream of Fort Fraser (~rkm 220), Fraser Lake, the Stuart River past rkm 110 near the outlet of Stuart Lake as well as

Stuart Lake to Takla Lake including Trembleur Lake, Tachie River, Middle River and Takla Lake (Smyth *et al.* 2016).

In August 2006, two Nationally Significant Populations (NSPs) of White Sturgeon in the Fraser River watershed, 'Nechako' and 'Upper Fraser' were placed on Schedule 1 of Canada's *Species at Risk Act* (SARA) (Fisheries and Oceans Canada 2014). The Nechako population was recommended for listing due to ongoing recruitment failure lasting more than four decades and the Upper Fraser due to a limited stock size. In 2012, the Upper Fraser, Nechako and mid-Fraser populations were reassessed by COSEWIC and combined into one "designatable unit" (DU). The DU has been the subject of a more recent Recovery Potential Assessment (Smyth et al. 2016), and a listing decision for the DU is under regulatory consideration.

A precise location for putative stock boundaries has not previously been defined. To better delineate the previous stock boundaries, we used a critical habitat unit at the confluence of the Nechako and Fraser Rivers to define population areas. A 1-2 km portion of the lower Nechako River is seasonally part of a single critical habitat for area White Sturgeon that includes rearing, feeding and possibly reproduction (Fisheries and Oceans Canada 2014). Therefore, to avoid arbitrarily bisecting a habitat unit based on river name, encounters in the Nechako River between rkm 0 in the Nechako up to the radio telemetry base station at rkm 2.5 km were included in the Upper Fraser population area for the data analysis. Encounters upstream of that location were considered Nechako (NPA) encounters. Any encounters upstream of rkm 798 on the Fraser were also designated Upper Fraser (UFPA), and finally, encounters downstream of rkm 798 on the Fraser were considered Middle Fraser (MFPA).

Figure 2. Overview map of study area with relevant landmarks and approximate river kilometers.



Data Collection and Review

Captures

Annual tagging and radio telemetry projects between 1995 and June 2019, focused on White Sturgeon were completed in the Fraser River Watershed. Capture work in the study area has included index-type population surveys (e.g. (RL&L Environmental Services Ltd 2000) brood capture for conservation fish culture (Courtier 2010b), and focused index sampling to monitor wild recruitment and survival of sturgeon released from a conservation fish culture program (Beardsall 2017). Brood capture efforts began in fall 2005 (Golder 2006) and were more intensive starting in 2014 with the construction of a conservation hatchery in Vanderhoof.

Set-lines and angling have been the primary methods used for captures in Upper Fraser studies. Juvenile index efforts from 2006-2009 of the Nechako White Sturgeon Recovery Initiative (NWSRI) also included gillnetting, however, gillnets were found to have limited capture success, were potentially lethal to a protected species and their use was later abandoned (Courtier 2010a). Standardized capture and handling procedures are used and include PIT tagging of all new captures e.g. (Courtier 2010b). PIT tags, once implanted in juvenile and adult sturgeon, are a very reliable mark and appear to have a negligible loss rate once applied.

Capture effort among projects is difficult to compare due to different project objectives and the diverse physiography of capture locations and was therefore not analyzed in this study. Among projects, hook sizes ranged number 2 to 16/0. Within projects, hook size targeted specific life-stages, typically either juveniles or adults. For the present study, juvenile White Sturgeon have been defined as those under 1.0m fork-length, sub-adults 1.01.4-m fork-length. Specific length based benchmarks for staging of White Sturgeon in this study were estimated from data collected from the Upper Fraser DU (Table 8).

Radio Tagging and Telemetry

Radio tags have been applied to monitor habitat use and movements of White Sturgeon at a population and individual level. Radio tags were applied externally to dorsal scutes by RL&L between 1995 and 1999, however tag loss as the result of scute breakage was observed; consequently, all radio tags since 2000 have been surgically implanted ventrally using methods adapted from Golder (Golder 2006). Radio telemetry surveys have been conducted using various mobile approaches as well as fixed station receivers (Figure 2). Mobile surveys were completed using fixed-wing aircraft, helicopters, boats and walking surveys for transport. Since RL&L 2000 virtually all radio tags used have been various models of high frequency coded tags made by Lotek Inc along with a small number of Sigma-8 Inc. tags. Nominal tag life has ranged from approximately one-year to up to eight-years with a pulse interval typically between five and five and one-half seconds. Since 2011, the majority radio tags applied to adults have had a nominal life of 7-8 years. Mobile tracking was completed with Lotek Inc. SRX400, SRX600 and SRX800 receivers of various configurations usually with a 2-4 element Yagi antenna. Fixed station sites have used Lotek Inc and Sigma-8 Inc. receivers with either two or three multi-element directional antennae respectively to monitor movements both up and downstream in mainstem locations and tributary confluences. Three stations are operated continuously (Lower Nechako, Upper Stuart and Vanderhoof. The remaining stations are operated seasonally during open water when sturgeon are typically (Table 1).

Table 1. List of fixed telemetry base-stations employed in the Nechako and Upper Fraser watershed to monitor White Sturgeon movements from 1995-2019.

Station Description	River	rkm	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Nechako Fraser Confluence	Nechako	0.1																										
Nechako Fraser Confluence (Cottonwood)	Nechako/ Fraser	0.2 /798																										
Spruce City Wildlife Association Hatchery	Nechako	2.5																										
Stuart Nechako Confluence	Stuart /Nechako	91.7/0																										
110 Overwintering	Nechako	111																										
116 Overwintering	Nechako	116																										
125 Overwintering	Nechako	125																										
134.5 Staging	Nechako	134.5																										
Vanderhoof Spawning Area	Nechako	136.1																										
Nautley River Confluence	Nechako	191.7																										
Upper Stuart	Stuart	104.9																										
Stone Creek Confluence	Fraser	761																										
Bowron conflunce	Fraser	921																										

Station: Continuous annual operation
Station: Continuous seasonal operation
Station: Historical - no longer in operation

Mobile survey data are collected by crew of two to three people, a driver and at least one data recorder. Two personal monitor the relative volume of the tag ID and the vehicle (normal a boat or aircraft) is re-positioned until a maximum signal is obtained and the tag frequency, code, geographic position (UTM) and other physiographic data are then recorded. The process to obtain and verify a manually tracked tag is iterative and the potential for erroneous tag detections is low and discrimination of tag codes is considered precise. Fixed station receiver located at specific sites (Figure 2) and are typically downloaded monthly using a test tag to "open" and "close" a data-log file. The receiver acts as a data logger that digitally records tag signals as they are discriminated in real time by the receiver's processor. Areas near human development typically have high levels of radio noise which substantially increases the number of false positive codes that are recorded by a station. In some cases, there can be hundreds of thousands of false positive codes recorded per month with error rate dependent on local radio activity and the gain setting of a receiver. False positives codes are relatively simple to identify as they have a discontinuous record versus actual fish which show a continuous and consistent record over a short time-interval. Therefore, a semi-automated quality assurance process was undertaken to remove this noise. First, data log files crossed referenced with known tags were used to filter codes that were never deployed. Next, depending on receiver type and location, a standard set of filtering rules unique to the radio noise for each station were then applied to the data files for each site to filter out singular false positive codes events from serial code events that represented actual tagged White Sturgeon. For each site these rules were manually cross-referenced using test data sets and known test tags to ensure that specific queries did not filter radio codes from tagged sturgeon. To reduce the number of individuals detections recorded in the NWRSI-DB, detections at each base station were aggregated by a minimum of one hour where any breaks in continuity of individual code detections of less than one hour were considered continuous. Consequently, breaks in detection of up to one hour were removed and the fish was considered present for the entire hour.

Table 2. Fork-length range (cm), maturity codes for mature sturgeon, total observations and number of unique individuals observed for White Sturgeon in the Nechako River since 1995.

	Fork-length Range (cm)	Maturity Codes	Total Observations	Unique Individuals
Females	146-268	14-17	n=162	n=83
Males	98-258	4-5	n=271	n=135

Nechako White Sturgeon Database (NWSRI-DB)

Capture and radio telemetry data for the Nechako and Upper Fraser NSP have been recorded and stored in the Nechako White Sturgeon Recovery Initiative Database (NWSRI-DB) since approximately 2009 (Nechako White Sturgeon Recovery Initiative Database). The NWSRI-DB was constructed in Microsoft Access following a hierarchical cascading relationship among four data tables: 1) Water body and collection agency; 2) Capture location and sampling effort; 3) Biological and tag and tagging information; 4) radio telemetry detections and locations. Version one of the NWSRI-DB included historic datasets from surveys completed by RL&L Environmental Services (2000) along with White Sturgeon projects that were completed between 2000-2009. Since 2009, annual project data for the Upper Fraser and Nechako populations have been added to the NWSRI-DB. Since 2019, partial capture and radio telemetry data from the Middle Fraser population monitoring was incorporated, however, complete sampling effort information for adult sturgeon projects was not yet provided by the time this report was written. Capture and biotelemetry data for Upper Fraser DU White Sturgeon has been collected and stored for more than 25 years. Throughout this period, improved standards for sampling, data collection, and quality assurance have been implemented.

To detect and address potential past inconsistencies in codification, formatting or entry, a detailed quality assurance step was undertaken prior to completing final database queries for analyses in the present study. This included cross checking key data fields, locating errors, and missing values. Where possible, missing values and errors were corrected. Key fields from the NWSRI-DB for this analysis included tags (PIT, Floy and radio), geographical information (rkm, UTM, waterbody) and biological information (fork-length, sexual maturity). Sexual maturity was coded using a system adapted from Conte et al. (1988) by RL& L (2000). Data collected before and after 2009 used different approaches to derive rkm. Data collected prior to 2009 rkm were assigned rkm that were derived manually using a map-wheel and paper NTS maps. This rkm system is relatively inaccurate with estimated error plus/minus up to several hundred meters. Data collected after 2008 were assigned standardized rkm using GIS interpolated rkm position and are considered accurate. For the present study, the relative precision of both coordinate sets was not considered substantial enough to affect the analysis, particularly at population boundaries thus both rkm were combined into one data field.

Data Analyses

Database queries were developed within the NWSRI-DB database to tabulate 1) the number of White Sturgeon captured 2) the number of White Sturgeon tagged with PIT tags and 3) number unique sturgeon implanted with radio tags. Using the putative population model developed by RL&L (2000) and modified to incorporate the Nechako Fraser confluence critical habitat area, White Sturgeon captures and radio telemetry observations were assigned to one of three population areas: Upper Fraser population area (UFPA), Middle Fraser population area (MFPA) and Nechako population area (NPA). First, individual White Sturgeon movements across populations zones were determined using an MS Excel pivot table query of the capture and radio telemetry data. White sturgeon that were captured or observed with radio telemetry in two or more populations areas were tabulated. Second, any sturgeon that were recorded progressing past the fixed station at rkm 2.5 on the Nechako were also included in in the summary.
Thousands of individual radio telemetry encounters are recorded at fixed telemetry base stations that have been in continuous operation near the margins of the population range or at key tributary confluences. Fixed based station arrays were not all implemented in the same years with new stations having been added through time as the recovery program developed (Table 1). Sampling intensity at the fixed stations is continuous either on a seasonal basis for remote station or all year where reliable 110V power is available. Mobile telemetry is discontinuous seasonally and interannually and was collected for project specific objectives. Therefore, data at the margins of the range or in key sturgeon habitats (e.g. spawning area) is clumped relative to the dispersed data collected in mobile surveys. To account for this, maximum and minimum rkm encounters for each fish were tabulated rather than mapped to account for the higher sampling intensity at these gates. For individual White Sturgeon that were observed crossing populations zones, various statistics including the total number of captures, visits to spawning reach at Vanderhoof BC (rkm 136), sex, maturity status for each capture, and fork-length were tabulated by zone and by life-stage. Records for individual White Sturgeon that were included in the NWSRI-DB as June of 2019 and has

recapture records were used for this analysis. Telemetry records from June 2019- Dec 2020 for individual sturgeon that were found to have moved across population boundaries before June 2019 were included in this report. To explore the potential effect of sampling intensity on the frequency of observations the frequency of movements was compared with the number of radio tags present in radio tagged White Sturgeon the moved between population areas. Last, to explore the seasonal timing and potential reasons for movements, the number radio tag hits for both sturgeon that moved between areas and those that were not observed were tabulated by two-week intervals and plotted on a common day and month axis for the entire study period.

We recognize that angling guide tag data obtained in the Lillooet area were not used in this report or analyses; At time of this study, the authors have no evidence of movement of fish tagged in Lillooet north to within the area subject of this report.

Results

White Sturgeon PIT Tagging

A total of 2,203 PIT tags were applied to wild origin White Sturgeon in the entire UFDU since 1995 (Figure 3). In the MFPA a total of 1,200 PIT tags were applied, with 705 tags applied between 1995-1999 and 495 applied since 2000. In the NPA, a total of 625 PIT tags were applied, with approximately 27 new PIT tags applied to White Sturgeon each year. The fewest PIT tags were applied (n=378) in the UFPA, where approximately 16 tags were applied annually. Tagging in the UFPA was focused in three time periods:1998-2002, 2007-2008 and 2018-2019 with 126 tags applied in 2018 and 2019.

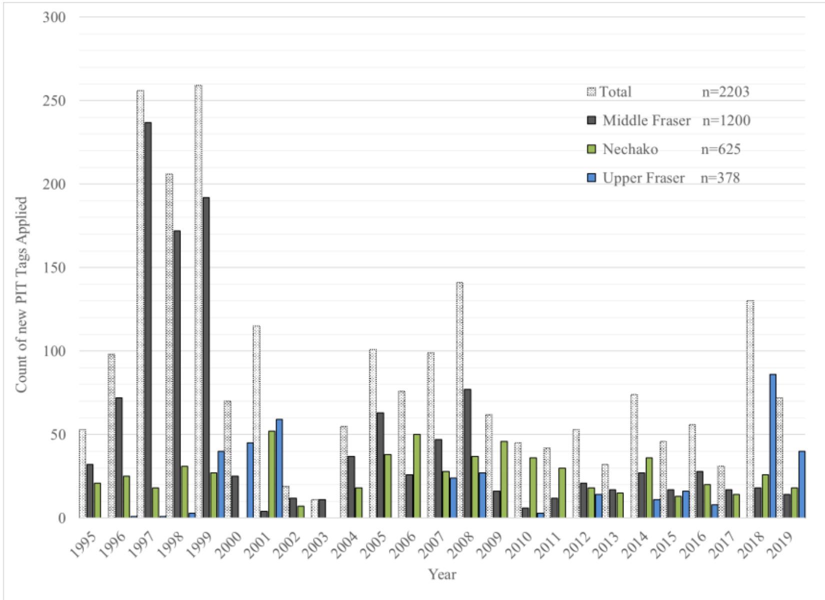


Figure 3. Total number of new PIT tags that were applied each year to wild origin White Sturgeon encountered in the Upper Fraser DU area from 1995 to 2019. Population areas were assigned based on area of capture for each encounter.

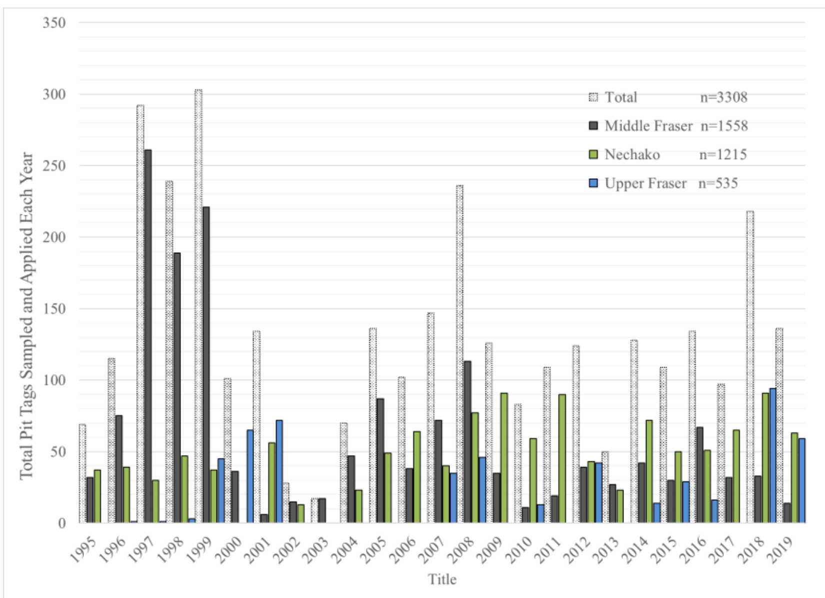


Figure 4. Total number of PIT tags encountered, (applied plus recaptured) each year for wild origin White Sturgeon for the Upper Fraser DU from 1995 to 2019. Population areas were assigned based on area of capture for each encounter.

Captures

There were 3308 total captures and recaptures of PIT tagged White Sturgeon from 1995-2019 (Figure 4,

Table 3). NPA had the highest number and proportion of recaptures (n_r=590; 49%) followed by MFPA (n_r=358, 23%) and UFPA (n_r = 157, 29%) respectively (

Table 3.)

Table 3. Population of mature fish (N_m >160 cm), population of fish (N > 50 cm); Total number of captures (n_c), number of individuals PIT tagged (n_p), number of recaptures (n_r), and mean number of captures per sturgeon showing 1 standard deviation and the range (minimum and maximum) of observed captures per sturgeon that were caught from 1995-2019.

	N_m	N	n_c	n_{PIT}	n_{rc}	mean ± 1 SD	Range
Middle Fraser	749	3700	1558	1204	358	1.3 ± 0.71	1-8
Nechako	243-630	243-630	1215	638	590	1.9 ± 1.67	1-12
Upper Fraser	185	685		385	157	1.4 ± 0.82	1-6
Total	1177-1564	4628-4973	3308	2227	1081	1.5 ± 1.16	1-12

Radio Tagging and Telemetry

A total of 359 radio tags were applied to UFDU White Sturgeon since 1995 (Figure 4). Of these, 342 radio tags were applied to adults and subadult sturgeon and an additional 17 applied to juvenile sturgeon. The NPA has had the most tags applied (n=208) followed by the MFPA (n=126), and the UFPA (n=24). The number of radio tag applied each year has been more variable through time compared with PIT tagging in all three areas. There were 59 radio tags applied in the MFPA between 1996-1999 and 67 from 2007-2019. Radio tags were applied more frequently starting in 2005 for the NPA and the UFPA respectively. Eight radio tags were applied to juveniles in the NPA, eight in the MFPA and one in the UFPA.

Recently applied tags will remain active beyond the data cut-off date (June 2019) for this report, and tags are continuously being add and monitored by several programs. Similarly, telemetry data is being collected continuously and will add data for subsequent analyses. For the most recent status and data, please contact the NWSRI.

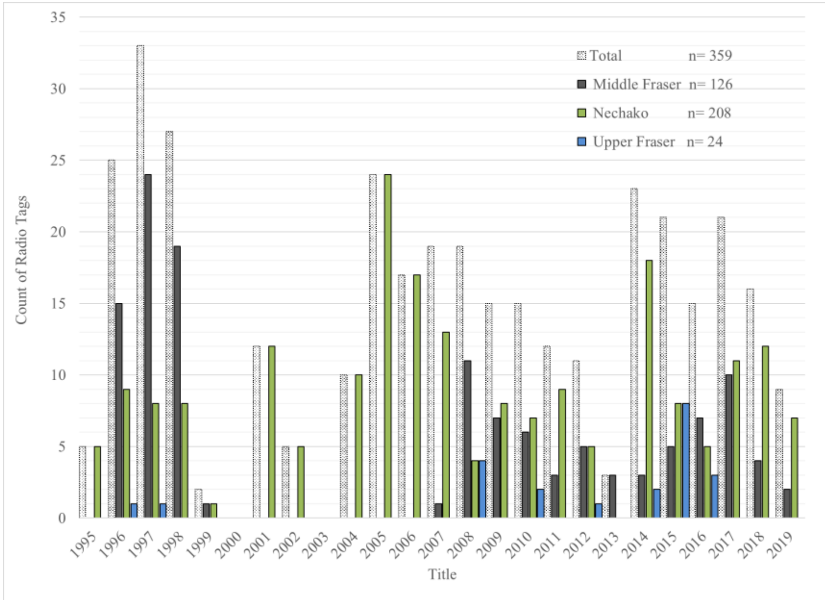


Figure 4. Total number of new radio tags that were applied each year to wild origin White Sturgeon in the Upper Fraser DU area including a breakdown by Zone for each of the three populations from 1995 to 2019. Population areas were assigned based on area of capture for each encounter.

White Sturgeon Movements 1995-2019

Movements of tagged White Sturgeon across all three areas were confirmed (Table 4,

Table 5) and these movements differed by sex and by life-stage (Table 6). The number of movements between areas that were detected increased with the duration of these (Figure 6).

Thirty-nine individual White Sturgeon were found to have crossed the putative population area boundaries near Prince George between 1995 and 2019. Five years of monitoring by RL&L detected three movements, six more movements were detected from 2000-2005, and the remaining 140 movements were detected from 2006-2019 (Table 6). Movements occurred almost exclusively during the spring-fall months and occurred with similar timing and relative magnitude as fish that were present next to the stations but had not been recorded moving between population areas (Figure 5). The highest number of detections of fish that moved were observed at the Vanderhoof station in association with spawning and the Upper Stuart Station had the lowest number of detection of fish that moved.

White Sturgeon tagged in the NPA and UFPA showed the highest number of movements across zones (n=27) followed by NPA-MFPA (n=9) and MFPA- UFPA (n=1). The category with the highest number movements was NPA-UFPA where 5.0 % of adults and 2.7 % of all fish that were tagged fish moved between areas. The lowest proportion of movements was between UFPA and MFPA where 0.13% of the adults and 0.06% of the total number of tagged fish moved.
The number of movements across area boundaries differed between population areas and among sex of individuals (Table 5, Table 6). Fifteen females, sixteen males and eight sturgeon of undetermined sex were observed moving between population zones. More females were observed moving between the Nechako (n=12) and Upper Fraser (n=3) than between the Nechako and Middle Fraser. There were a similar number of males that moved between the Nechako and the two other population areas (Table 5). Two males were also observed moving between all three population areas. Eight juvenile fish of undetermined sex showed movement between two sets of areas, with seven of the eight having moved between the Nechako and Upper Fraser and the remaining two between Nechako and Middle Fraser.

Movements differed among life-stages where adults made multiple movements (mean 4.8 movements) between population areas 4 times more frequently compared with juveniles (mean 1.2 movements), despite similar average periods of observation of about 5 year per fish (Table 6). Time from capture to the first observed movement for juveniles was 8.9 years versus 4.5 years for adults. Adult movements were most often made in association with spawning (Table 6, Table 8). Mode of detection differed among life stages where adult sturgeon movements were most often detected through telemetry after the first capture. Whereas the more limited number of juvenile movements that were observed were detected through captures after juveniles moved from the Upper Fraser near Prince George to the Nechako. The two radio tags placed in previously PIT tagged juvenile individuals were placed as a result of the observation that they moved to the Nechako. Juveniles were captured two times more frequently (mean 4.4 captures per fish) than adults (mean 2.2 captures per fish). The two radio tags placed in previously PIT tagged juvenile individuals were placed as a result of the observation that they moved to the Nechako. Juveniles that made a net movement to the Nechako and appeared resident, whereas adults showed frequent movements between what may be feeding areas or areas of residency with periodic movement to the spawning reach in Vanderhoof, BC (Table 6). Considering the differing modes of detection, caution should be made in the interpretation of potential motivation for movement between juveniles and adults and further study is needed where more juveniles should be radio tagged to increase sample size and frequency of detections.

Table 4. Movement zones for all White Sturgeon in the Upper Fraser DU that were observed in two or more of the three putative population areas. Each column presents the sum of individuals from 1995-2019. n designates the number of fish that moved for each categories; n_T shows the combined number of individuals PIT tagged, n_a shows the total number of adults PIT tagged from, and %Total shows the percentage of sturgeon that moved between category relative to the number of fish PIT tagged in each category as well as for those that were larger than 1-m (% Adults).

Movement Categories	n	n_T	%Total	n_a	% Adults
Nechako ↔ Upper Fraser *	27	1003	2.69	537	5.03
Nechako ↔ Middle Fraser	9	1825	0.49	1161	0.78
Mid Fraser ↔ Upper Fraser	1	1578	0.06	772	0.13
Nechako ↔Middle Fraser ↔ Upper Fraser	2	2203	0.09	1235	0.16
Total	39				

* Four of these individuals also entered the Stuart River

Table 5. Categorized numbers of individual females, males and sturgeon of undetermined sex that moved between population areas.

Movement Categories by Sex		n
Total Females		**15**
	Nechako ↔ Upper Fraser *	12
	Nechako ↔ Middle Fraser	3
Total Males		**16**
	Nechako ↔ Upper Fraser *	8
	Nechako ↔ Middle Fraser	6
	Nechako ↔Middle Fraser ↔ Upper Fraser	2
Total Unknown		**8**
	Nechako ↔ Upper Fraser *	7
	Mid Fraser ↔ Upper Fraser	1
Total All Sturgeon		**39**

* One male, two females and a fish of unknown sex also entered the Stuart River

Table 6. Summary of individual White Sturgeon biological history and movements across populations areas from 1995-2019. **Bold** text with an underline indicates a capture event, standard text indicates a telemetry observation. Light grey cells indicate the period of radio telemetry observations for an active tag. Red boxes indicate that a fish was captured as a mature spawner and or that spawning was assumed based on subsequent movement and residency in the spawning reach at Vanderhoof. Brackets denote mature spawners were detected or observed. Brown boxes indicate inferred spawning based on timing and residency in the spawning reach when other observation of spawning occurred. Last, blue boxes indicate a capture of a juvenile sturgeon < 1-m in length.

PIT TAG	Sex	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	# Cap	# Years Obs	# Move	# Years to first Move	# Years Cap to last Obs
Adult Sturgeon																															
Females-N-UF																															
50201F5930	F						**UF**									**N**		**N**-UF	N-UF-N	N-UF	UF-N	UF	UF-N	(N)-UF	N-UF	N-UF	4	11	15	9	19
7F7D77302F	F		**N**	N-S-N	N	**UF**	**UF**							**UF**	N	**N**	UF	UF-N-UF								**N**-UF	**6**	11	9	3	23
41250F5929	F							**N**								N-UF-N	UF	**UF**		N-UF		(N)-UF	N	UF-N	UF	UF	4	10	11	8	18
424D3D5403	F							**UF**											**N**		UF	N-UF	N-UF			(N)-UF	3	6	8	11	18
4529141153	F											**N**	N-UF		**N**				**UF**				UF-N	N-UF			3	6	6	1	12
422D6C5513	F													**N**								**UF**	UF-N-UF			UF	2	4	3	8	12
6C00073005	F																					**UF**	UF-N	(N)			2	3	1	1	2
4A0C486A5B	F														**N**										**N**-UF-N	N	3	3	3	10	1
4B0A17720D	F																	(N)-S-N				UF	N-S				1	3	5	1	5
6C00072612	F																								(N)-UF		1	1	1	1	0
6C00072616	F																						(N)-UF				1	1	1	1	0
Females-N-MF																															
4124680C7A	F							(N)	N	MF													(N)		MF	MF	2	6	3	2	18
144713737A	F														**MF**	MF-(N)-MF		**MF**				MF					**2**	4	2	1	7
4A0C2F5E35	F														**N**								**MF**				2	2	1	8	8
Males-N-UF																															
22236F2C51	M	**N**	**N**	**N**		N								**UF**		(N)-UF	UF					UF					**6**	8	3	12	20
422E4E027A	M													**N**	N-S-N	N		N-S-N-UF					(N)	S	N		2	7	8	4	11
7F7B031824	M			**N**		N								**UF**			UF		UF				(N)-UF			UF	3	7	3	10	22
6C00072615	M																				(N)-UF	UF	N-UF	UF	(N)-UF	UF	2	6	5	17	5
412479017D	M				**MF**													(N)-UF		N-UF		UF-N		MF			2	5	6	13	6
4A0D1A4862	M															**N**					(N)-UF	N	UF			UF	2	5	3	5	10
501F7A3051	M						**UF**	**N**					**N**											(N)		**N**	**5**	5	1	1	19
424D493156	M														UF-N		UF-N-UF		UF								1	3	3	0	4
6C00072532	M																								(N)-UF		1	1	1	0	0
Males-N-MF																															
401D52192D	M																(N)-UF	(N)-MF	N	(N)-MF		(N)	UF		UF	N-MF	2	8	9	0	9
4B002E1006	M																	(N)	**N**-MF-N	N-MF-N	N-MF-N	N-MF	N-MF				2	6	9	1	7
41250F0A39	M							**N**		MF-N											(N)-UF		UF-N-UF	MF	N		2	6	8	2	17
4B18396613	M																	(N)-UF	N	N-UF	UF-N	N-UF-MF		N-UF			1	6	9	0	6
6C00072540	M																				**N**	N-MF	**MF**			MF	2	4	1	1	5
4A0D3F302F	M														**N**								**MF**		UF		2	3	3	8	2
Unknown Sex																															
423C054334	Unk													**UF**		N	UF	N									1	4	3	2	4
5028364E1D	Unk					**UF**																			N- **UF**-N- S	UF	2	4	6	0	1
422E6C0733	Unk													**UF**		N-UF		UF									1	3	2	2	4
																										Mean Adlt	2.3	5.0	4.8	4.5	9.3
Juvenile Sturgeon																															
501F6E292A	F					**UF**	**UF**	**UF**															N				3	4	1	17	17
50283B6C65	M					**UF**	**UF**	**UF**						**N**	**N**	**N**	**N**	**N**						**N**	**N**	N	10	11	1	8	20
501F701824	Unk					**UF**	**UF**									**N**					N	N		N			6	6	1	10	18
5020160D6E	Unk													**UF**	**UF**		**UF**		**UF**				UF-N	UF-N			5	6	3	9	10
424F201F7F	Unk							**UF**				**N**		N		**N**											3	4	1	4	8
424D7F6C3E	Unk							**UF**									**N**										2	2	1	9	9
6C00073031	Unk																				**UF**					**MF**	**2**	2	1	5	5
																										Mean Juv	4.4	5.5	1.2	8.9	12.4

BOLD Capture event
Period of telemetry records
(N) Confirmed mature or ripe sturgeon in spawning area
Suspected spawning based on timing, location and duration of presence on Vanderhoof base station
Encounters in the Stuart River
Capture as juvenile sturgeon < 1-m

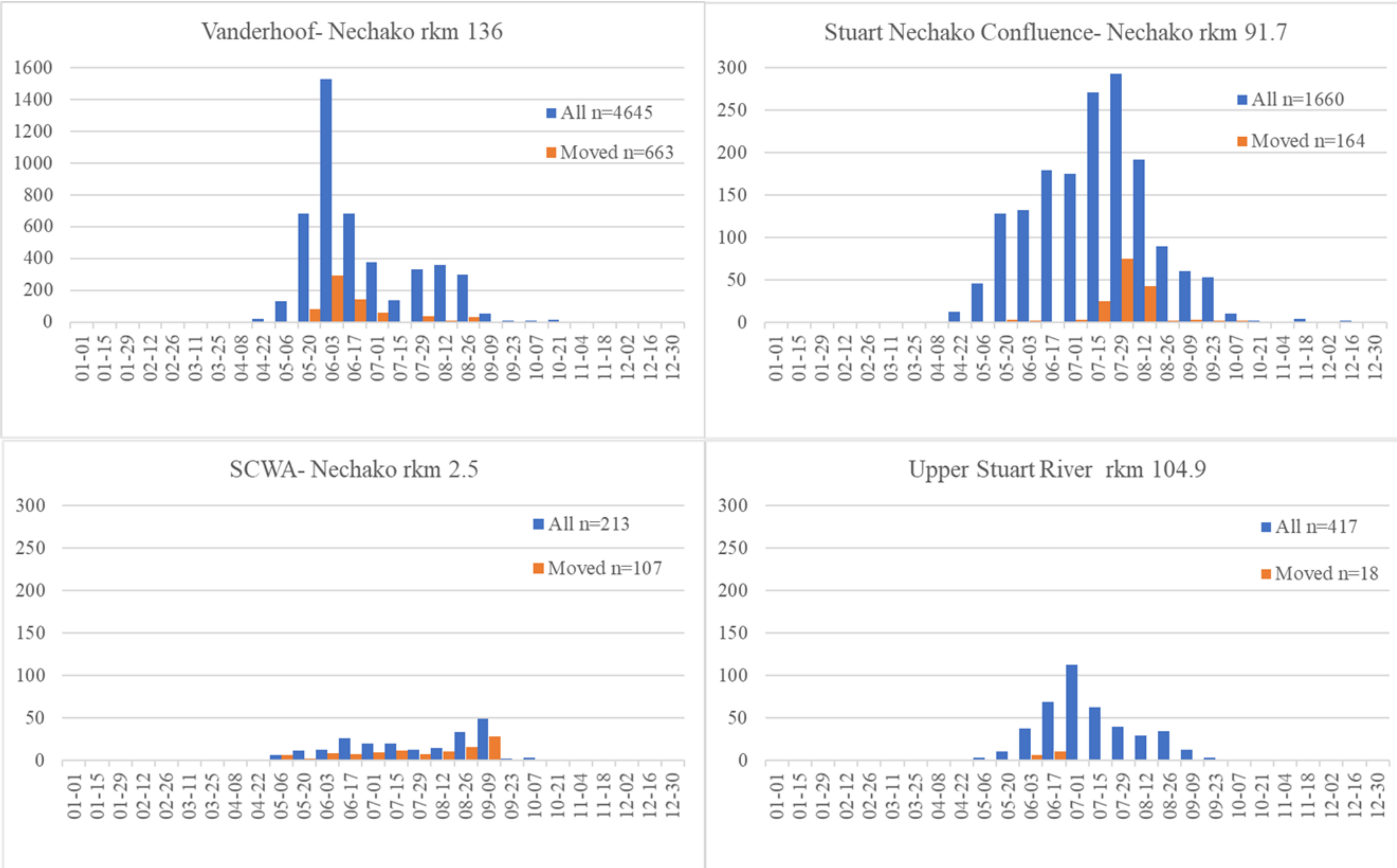


Figure 5. Counts of radio telemetry observations of white sturgeon at four fixed station locations in the Nechako watershed. Blue bars show all sturgeon telemetry observations (All) and orange bars show observations for sturgeon that crossed putative population boundaries (Moved).

Figure 6. Summary of movements between population areas and active radio tags from 1995-2019. Active radio tags is a count of active radio tags each year in fish that moved between population areas at some point during the course of this study.

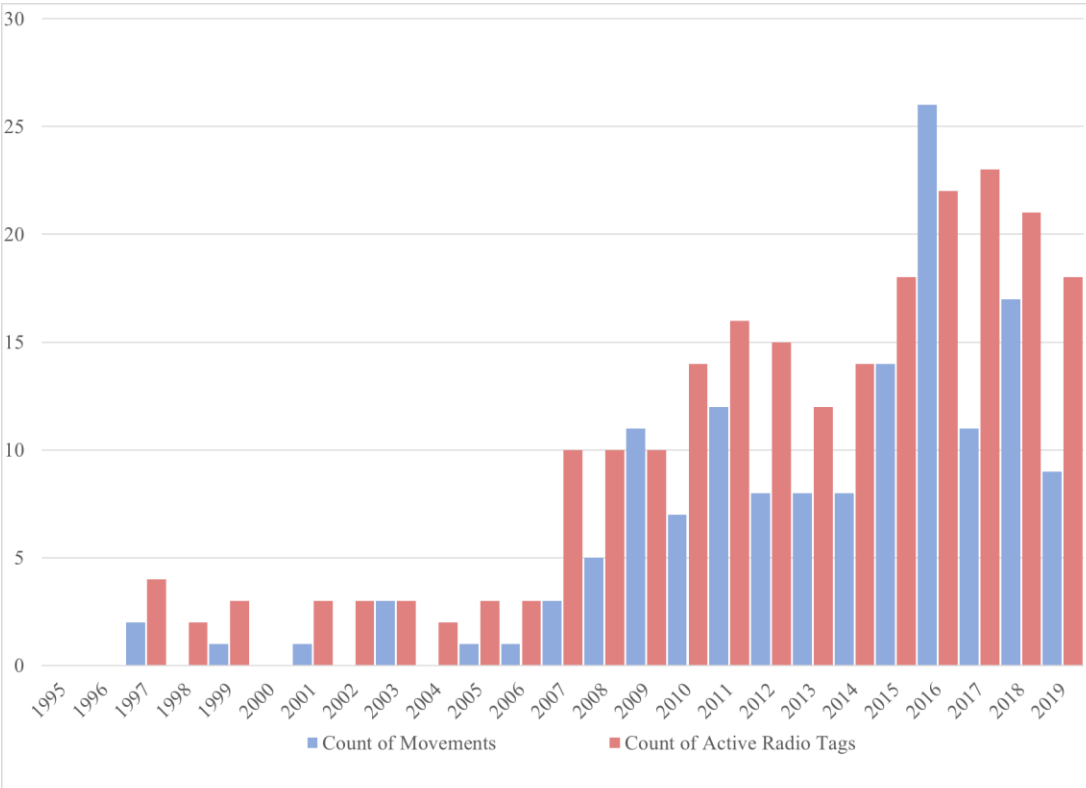


Table 7. Individual PIT tag number, sex and minimum and maximum river kilometer (rkm) encounters for White Sturgeon that moved between moved between population zones. Maximum and minimum rkm are listed for the Fraser. Nechako and Stuart rivers. The Upper Fraser population boundary is located at rkm 798 on the Fraser River and rkm 2.5 on the Nechako River at Prince George, BC.

Pit Tag	Sex	Fraser River		Nechako River		Stuart River	
		min rkm	max rkm	min rkm	max rkm	min rkm	max rkm
144713737A	F	533.0	550.0	136.1	136.1		
4A0C2F5E35	F	617.9	678.7	91.9	136.4		
4124680C7A	F	655.6	774.3	47.4	134.1		
50201F5930	F	795.0	797.9	0.4	136.1		
4529141153	F	796.7	956.8	0.5	136.1		
422D6C5513	F	796.7	812.9	0.6	136.1		
6C00073005	F	796.7	957.2	0.6	136.1		
7F7D77302F	F	796.8	952.5	0.1	123.5	50.2	50.2
41250F5929	F	796.8	886.2	0.6	136.1		
424D3D5403	F	801.6	896.8	0.5	136.1		
501F6E292A	F	834.0	835.0	134.4	134.4		
412479017D	M	550.0	703.5	2.5	136.8		
6C00072540	M	554.6	797.4	91.7	122.3		
4A0D3F302F	M	677.1	949.7	125.1	125.1		
4B18396613	M	678.0	689.0	0.6	136.9		
4B002E1006	M	738.0	771.4	2.5	136.1		
41250F0A39	M	764.9	767.5	0.4	138.3		
401D52192D	M	769.3	797.4	0.4	191.7		
424D493156	M	791.7	916.7	0.7	91.7		
4A0D1A4862	M	796.6	933.3	0.6	129.5		
22236F2C51	M	796.8	955.1	0.6	126.0		
6C00072615	M	803.4	827.4	0.6	137.1		
50283B6C65	M	825.8	834.0	110.2	136.1		
7F7B031824	M	835.3	956.7	91.7	177.4		
422E4E027A	M	848.1	933.2	2.5	138.9	58.9	104.9
501F7A3051	M	-	-	0.5	137.5		
6C00073031	Unk	550.0	808.1				
5020160D6E	Unk	795.8	935.5	0.4	136.1		
422E6C0733	Unk	796.8	896.6	0.2	91.7		
424F201F7F	Unk	813.3	813.3	91.7	122.5		
501F701824	Unk	826.8	835.3	111.9	136.1		
423C054334	Unk	834.2	834.2	2.5	128.3		
5028364E1D	Unk	835.3	835.3	2.5	139.5	104.9	104.9
424D7F6C3E	Unk	954.7	954.7	132.6	132.6		

All captures and radio telemetry observations, maturity status and fork-length are plotted by rkm and encounter date and are summarized for each individual fish in Appendix A.

The mean number of captures for White Sturgeon that crossed zones was 2.94 (1.88 (range 1-10) and the mean number of visits per fish to the Vanderhoof spawning reach during the spawning period in May and June was 1.97 1.88 (range 1-7 visits) (Table 8). Twenty-six of the 35 White Sturgeon that moved between zones were present in the Vanderhoof spawning reach at spawning time between 1 and 7 times. Out of 42 captures in the NPA where assessments of maturity were made, 26 were of males and females in an advanced state of maturity within one year of spawning.

Detailed movement analyses of all 35 individuals identified to have crossed a zone are presented in Appendix I of this report. Below is one example to demonstrate the utility of the analyses.

Figure 7. An example of movement history of one of 35 individuals (PIT 6C00072540). Detailed movements of all 35 individuals are presented in Appendix I of this report.

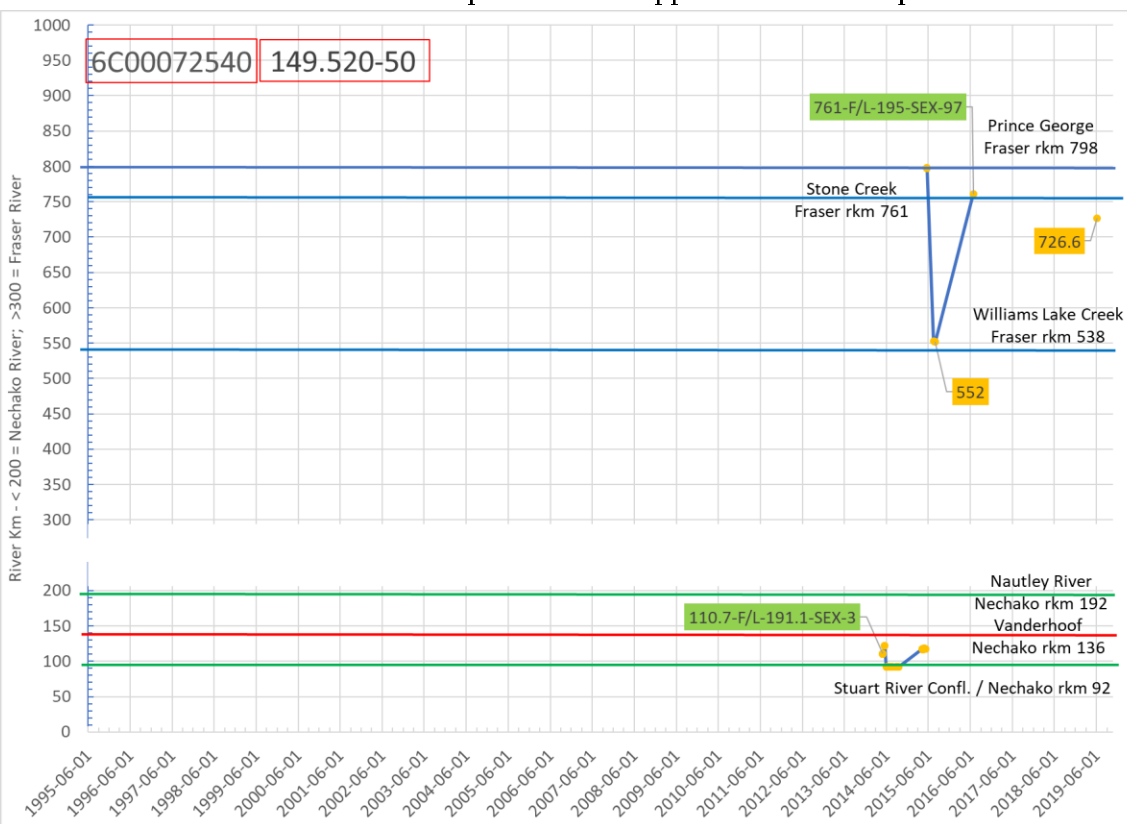


Table 8. Summary of capture and movement history for 39 individual Upper Fraser White Sturgeon that moved between population zones. Number of captures, number of visits to the spawning reach in the Nechako River (~rkm 136), sex, maturity, encounters by stage and general landmarks for the extent of movements are listed. Maturity code for each individual is listed by population zone. Encounters are listed for each life stage. Sex -maturity codes for sturgeon that were captured in a late stage of maturation within one year of spawning are bolded for presentation. Cells in blue indicate juvenile sturgeon < 1-m).

PIT Tag	# of Captures	# Visits to Nechako Spawn Reach	Sex	Maturity Code: Nechako	Maturity Code: Upper Fraser	Maturity Code: Mid Fraser	Populations Areas by Stage: Juvenile < 1-m	Sub-Adult Unknown	Sub-Adult Female (1-1.4 m)	Adult F >1.4-m M >1.0-m	All Stage	Locations of Residency		Residency rkm
144713737A *	2	1	F			14	-	-	-	N MF	N MF	WL	Williams Lake	552
4124680C7A	2	1	F	14 15			-	-	-	N MF	N MF	CW	Cottonwood Canyon	650
41250F5929	4	3	F	15 15			-	-	-	N UF	N UF	UF	McGregor	886
422D6C5513	2	2	F	17	13		-	-	-	N UF	N UF	UF	Bowron	921
424D3D5403	3	1	F	13 15			-	-	-	N UF	N UF	UF	McGregor	900
4529141153	3	4	F	12 12	11		-	-	-	N UF	N UF	UF	McGregor-Longworth	900-952
4A0C2F5E35	2	0	F	15			-	-	-	N MF	N MF	CW	Cottonwood Canyon	679
501F6E292A	3	1	F	12			UF	-	N	-	N UF	SW	Vanderhoof, Willow River	832-834
50201F5930	4	2	F	11 13 15			-	-	-	N UF	N UF	PG	Prince George	798
6C00073005	2	2	F	15			-	-	-	N UF	N UF	UF	Longworth	957
7F7D77302F	6	0	F	13	3		-	S N UF	UF	N UF	S N UF	SW UF	Willow and Longworth	835 & 952
4A0C486A5B	3	2	F	12, 13, 14						N UF	NUF	PG	Prince George	798
4B0A17720D	1	3	F	15						S N UF	S N UF	PG	Prince George	798
22236F2C51	6	3	M	2 3	3		-	-	-	N UF	N UF	UF	Longworth	952
401D52192D	2	6	M	5 5			-	-	-	N MF	N MF	SC	Stone Creek	761
412479017D	2	3	M	5		2	-	-	-	N MF	N MF	CW WL	Cottonwood & Williams Lake Creek	680; 550
41250F0A39	2	4	M	4 5			-	-	-	N MF	N MF	SC	Stone Creek	680
422E4E027A	2	5	M	2 5			-	-	-	S N UF	S N UF	N, S, UF	Nechako; Stuart; Bowron	110; 104; 933
424D493156	1	0	M		2		-	-	-	N UF MF	N UF MF	UF	Bowron	921
4A0D1A4862	2	1	M	4 5			-	-	-	N UF	N UF	UF	McGregor	900
4A0D3F302F	2	0	M	2			-	-	-	N UF MF	N UF MF	CW UF	Cottonwood Canyon & Longworth	673 ;952
4B002E1006	2	3	M	4			-	-	-	N MF	N MF	SC	Stone Creek	761
4B18396613	1	4	M	5			-	-	-	N MF	N MF	BW	Blackwater River	684
501F7A3051	5	7	M	3 2 5 3			-	-	-	N UF	N UF	PG	Prince George	30
50283B6C65	10	0	M	4 4			UF	-	-	N UF	N UF	SW; N	Salmon-Willow then Nechako	5-834; 110-1
6C00072540	2	0	M	3 3			-	-	-	N MF	N MF	WL RR	Williams Lake; Redrock	552-761
6C00072615	2	3	M	5 5			-	-	-	N UF	N UF	SW	Salmon River	832-836
7F7B031824	3	2	M	2 4	2		-	-	-	N UF	N UF	UF	McGregor-Longworth	887-956
422E6C0733	1	1	Unk				-	-	-	N UF	N UF	UF	Mcgregor	900
423C054334	1	1	Unk				-	-	-	N UF	N UF	SW	Salmon River	832
424D7F6C3E	2	1	Unk				UF	N	-		N UF	UF	Longworth	956
424F201F7F	3	0	Unk				UF	N	-		N UF	PG	Shelly	826-835
501F701824	6	5	Unk				N UF	N UF	-		N UF		Salmon Willow	813
5020160D6E	5	0	Unk				UF	-	N UF		N UF	SW UF	Willow and Longworth	835-887
5028364E1D	2	1	Unk				-	-	-	S N UF	S N UF	SW	Willow	835
6C00073031	2	0	Unk				UF MF	-	-		UF MF	PG WL	Prince George, Williams Lake Creek	798; 538
6C00072532	1	1	M	5							N UF	PG	Prince George	798
6C00072612	1	1	F	15							N MF	BW	Blackwater River	703
6C00072616	1	1	F	15							N MF	SC	Stone Creek	761
Count of obs:	103	75		47	6	2	7	4	3	31	39			

* Fish 1447127373A was presumed at capture to be in a late state of maturity, possibly spawning the following year; maturity code of 14 is presumed.

* Maturity stages 4,5 (mature males) and 14,15 and 17 (mature females) are considered to be within 1 year of spawning.

Discussion:

Key objectives of this technical report were to collate the available capture, life-history, and radio telemetry data into one dataset, current to June 2019. This was completed and an updated NWSRI DB is now available to the Nechako White Sturgeon Recovery Initiative and others upon request.

This report further tabulates and summarizes apparent "out of area" (or inter-NSP) movements for White Sturgeon encountered in each of three NSP groups. We reviewed the associated biological data including basic life-history data for each fish and presented qualitative patterns of movement observed. Since 1995 and per June 2019, 35 of 359 tagged individuals made inter-NSP movements in all possible directions (u/s or d/s) and in several cases did so repeatedly, particularly those fish with longer histories. Lastly, our report makes recommendations for future quantitative studies to better understand the context of these documented movements.

Data summarized in this report synthesizes ~25 years of collective sturgeon monitoring in the Upper Fraser watershed by several programs and utilizing a variety of methods over time. For context, the initial RL&L study (RL&L Environmental Services Ltd 2000), foundational to may components of the current programs, summarized ~5 years of data (1995-2000); Thus, the present report is the currently best available and up-to-date data set on movements of individual sturgeon among putative populations or groups. In addition to representing a 5-fold longer data set than RL&L (2000), the number of deployed tags and detections have increased dramatically, adding to the scientific value of the current data set. However, movement data should be viewed as a minimum estimate as most fish PIT tagged were only recaptured once (among 3308 total detections) and relatively few radio tags have been applied or were active at the same time; Moreover, the movements from and to, and residency in the UF and middle Fraser could be even higher than we were able to document here.

The results of this study revealed that what were considered to be boundaries among these distinct groups reflects much more of a continuum and shared habitat zones, utilized by individuals during several life stages during their lifespan. The movements documented in this report further suggest that the putative ranges and extent of each groups are poorly understood, while these may also be impossible to define unless monitoring data are analyzed in conjunction with other methodologies (for example, additional genetics, fin ray microchemistry, or alike). In turn, the results clearly indicate that more habitat than previously documented is shared among various life stages (juveniles/subadults to spawners) of some sturgeon from all three populations. The extent to which individuals documented to have moved among NSPs depend on the availability of these habitats to complete their life cycle remains unclear and warrants further study.

Implied through the movement of individuals, physical, hydrological, or other undocumented barriers do not appear to exist within the study area. However, certain movements only seen by adults suggests that juveniles and subadults may be less likely to utilize all habitats available to adult individuals. However, there appears to exist a pattern of juvenile and sub-adult movements from the Upper Fraser River to the Nechako River, suggesting good connectivity in habitat use between these populations.

The movements documented here will also inform and allow contrasts in the interpretation of past, present, and future genetic assessments of White Sturgeon in the Upper Fraser River (COSEWIC 2012). This, as samples for genetic assignments are often obtained from individuals and assigned to their location of catch. Field assignment of individuals to NSP's can be problematic considering that some individuals move large distances and across putative population boundaries. Similarly, interpreting mark-recapture data should consider the movements discussed herein.

Results of this summary further confirm that radio tagging using tags with long-term battery-life combined with an extensive and continuous monitoring program have yielded an increasing understanding of movements and habitat associations over time. It is critical to continue and to, where possible, expand the monitoring program to identify further movement patterns, and eventually resolve remaining questions related to range, habitat use overlap, competition throughout the life cycle of individuals from the three NSPs.

This report is in sections providing qualitative assessments and interpretation; While we now have summarized information on movements across NSP boundaries, information such as habitat occupancy remains unknown. The interval between captures and between radio identifications is irregular and spaced apart over years; increased sampling frequency and sampling at a higher spatial density coupled with detailed radio tagging analyses could be performed to highlight occupancy of individuals and help identify habitat use by life stage (age or maturity), as well as possible help identify additional spawning sites, so these exist.

While this report summarized movements across putative boundaries, contrasting these against other movement patterns is yet to be completed. This will require an analysis of all movement data of all fish since inception of the various programs. Data for such analyses are updated each year and available in the NWSRI DB (typically by January following a field season). There will be some limitations to performing such analyses, as a tagging bias (most adults are tagged through brood capture programs) may camouflage movement patterns of non-spawners; To reduce this bias in the future, additional captures and tagging of adults should occur systematically and in more habitats, not only in brood capture programs that target pre-spawning individuals in known staging habitats. However, the brood capture program should continue to maintain knowledge of trends over time.

While the coverage of radio telemetry has recently been expanded, several areas have been understudied or are void of data. The Stuart/Takla watershed upstream of the outflow of the Stuart River is not being monitored. This subsegment of the Nechako watershed is ~400km of lakes and rivers, including Stuart Lake, Trembleur Lake, and Takla Lake, as well as Tachie, Middle, and Driftwood rivers. While confirmed to be sturgeon habitat, no formal monitoring is ongoing in this extensive potion of the watershed. Given the findings of this report, movements in and out of these reaches should be quantified.

Key Recommendations

While this technical report was not intended to provide a fully quantitative assessment of movements, we arrived at insights that lead us to recommending the following future analyses, methods, or additional field studies to shed more light on the three NSPs:

Future analyses of movements and occupancy:

1. Using the NWSRI DB, perform a quantitative 'global movement' analysis of all inter- and intra-NSP movements of wild White Sturgeon in a format that can be annually updated and with outputs that are intuitive (e.g., *R* script or mark down with static or animated maps).
    a. Identify movement patterns within each NSP using a standardized approach
    b. Identify habitat occupancy (location spent between detections)

2. Further standardize sampling and reporting methodology
    a. Standardize and harmonize all data collections to improve data quality
    b. Utilize the NWSRI DB entry processes consistently to enable timely analyses

3. Deploy additional radio telemetry base-stations with remote access capability to increase efficiency in data acquisition, maintenance, and updates;
    a. add a minimum of three stations at the Tachie, Middle, and Driftwood rivers to address the monitoring data gaps in the Stuart Takla watershed.
    b. add a minimum of four stations in the Upper Fraser River upstream of Prince George (potential locations at the McGregor River, Fraser River (near Hubble Homestead), and the Morkill River).
    c. add a minimum of one station in the Mid-Fraser River between Cottonwood River confluence and the Town of Quesnel.

4. Maintain and increase the number of active radio tags in all sturgeon
    a. Develop a systematic approach to expand the tagging of adult fish to include a wider geographic extent, more seasons (than brood capture), and life stages;

5. Where and when appropriate, add acoustic telemetry arrays to address specific questions.
    a. Develop a set of specific objectives or questions that can be addressed using acoustic telemetry arrays.
        i. An example would be exploring lake habitat use or occupancy (Fraser, Stuart, Trembleur, and Takla lakes)
    b. Double tag those individuals that can aid in addressing the questions at hand.
6. Increase number of radio tags deployed in wild juveniles approaching 1-m that are captured in each of the NSP's to better characterize seasonal and interannual patterns residency and movements as fish approach before and as they approach maturity.

References Cited

Conte, F S, S I Doroshov, P B Lutes, and E M Strange. 1988. "Hatchery Manual for the White Sturgeon, Acipenser Transmontanus Richardson, with Application to Other North American Acipenseridae. Cooperative Extension, University of California, Division of Agriculture and Natural Resources."

COSEWIC. 2012. "COSEWIC Assessment and Status Report on the White Sturgeon Acipenser Transmontanus in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa." www.sararegistry.gc.ca/status/status_e.cfm.

Courtier, Jessica. 2010a. "2009 Assessment of Juvenile Nechako White Sturgeon."

———. 2010b. "Nechako White Sturgeon Broodstock Capture Program: 2006 – 2009 Report."

Fisheries and Oceans Canada. 2014. "Recovery Strategy for White Sturgeon (Acipenser Transmontanus) in Canada [Final]. In Species at Risk Act Recovery Strategy Series." Ottawa. 2014. https://www.registrelep-sararegistry.gc.ca/virtual_sara/files/plans/rs_esturgeon_blc_wh_sturgeon_0314a_e.pdf.

Golder. 2006. "REPORT ON NECHAKO RIVER WHITE STURGEON TAGGING PROJECT-2005 DATA REPORT."

Lheidli T'enneh. 2002. "2001/20002 Assessment of Upper Fraser River White Sturgeon. Report Produced by Lheidli T'enneh First Nation for Upper Fraser River Nechako Fisheries Council and Fisheries Renewal BC UFNFC File: 0201-119."

McPhail, J. D. 2008. *The Freshwater Fishes of British Columbia*. *University of Alberta Press*. https://www.uap.ualberta.ca/titles/136-9780888644671-freshwater-fishes-of-british-columbia.

RL&L Environmental Services Ltd. 2000. "Fraser River White Sturgeon Monitoring Program - Comprehensive Report (1995 to 1999). Final Report Prepared for BC Fisheries. RL&L Report No. 815F." http://www.rll.ca.

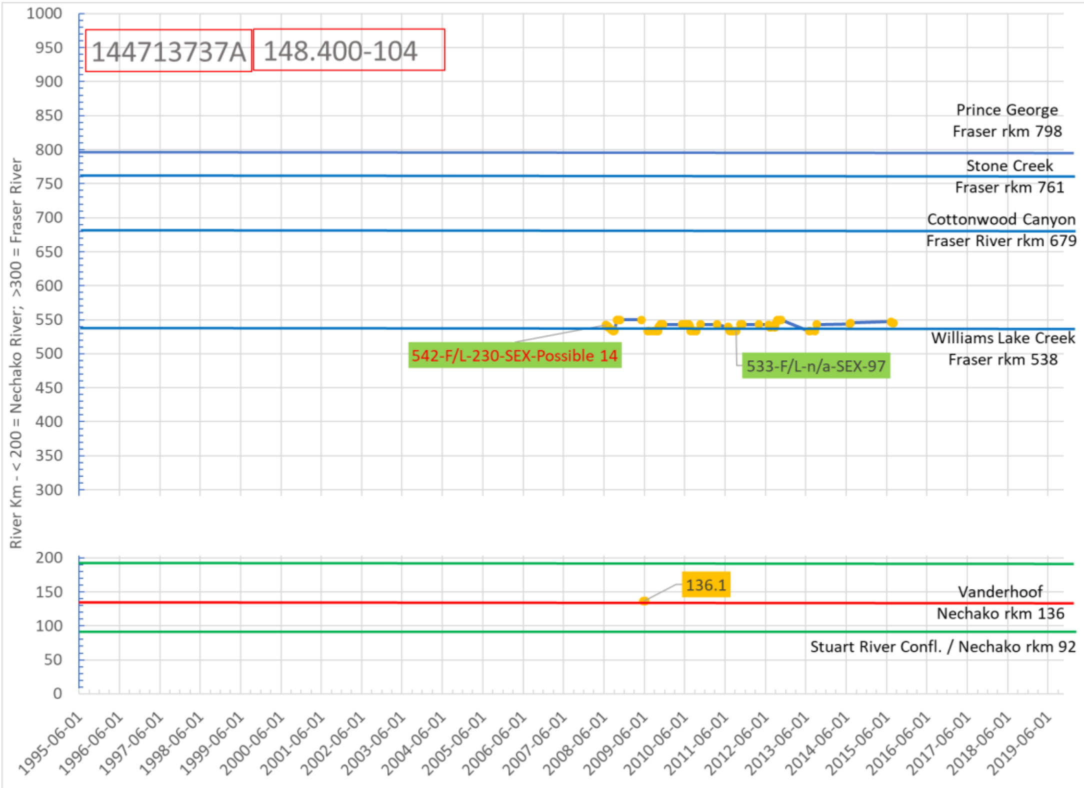
Scott, W. B. (William Beverley), and Edwin John Crossman. 1973. *Freshwater Fishes of Canada*. Bulletin (Fisheries Research Board of Canada). Fisheries Research Board of Canada. https://ci.nii.ac.jp/ncid/BA01327258.bib.

Smyth, E, J Abell, B Toth, and T Hatfield. 2016. "Recovery Potential Assessment for White Sturgeon (Acipenser Transmontanus) Upper Fraser Designatable Unit," no. September: 61.

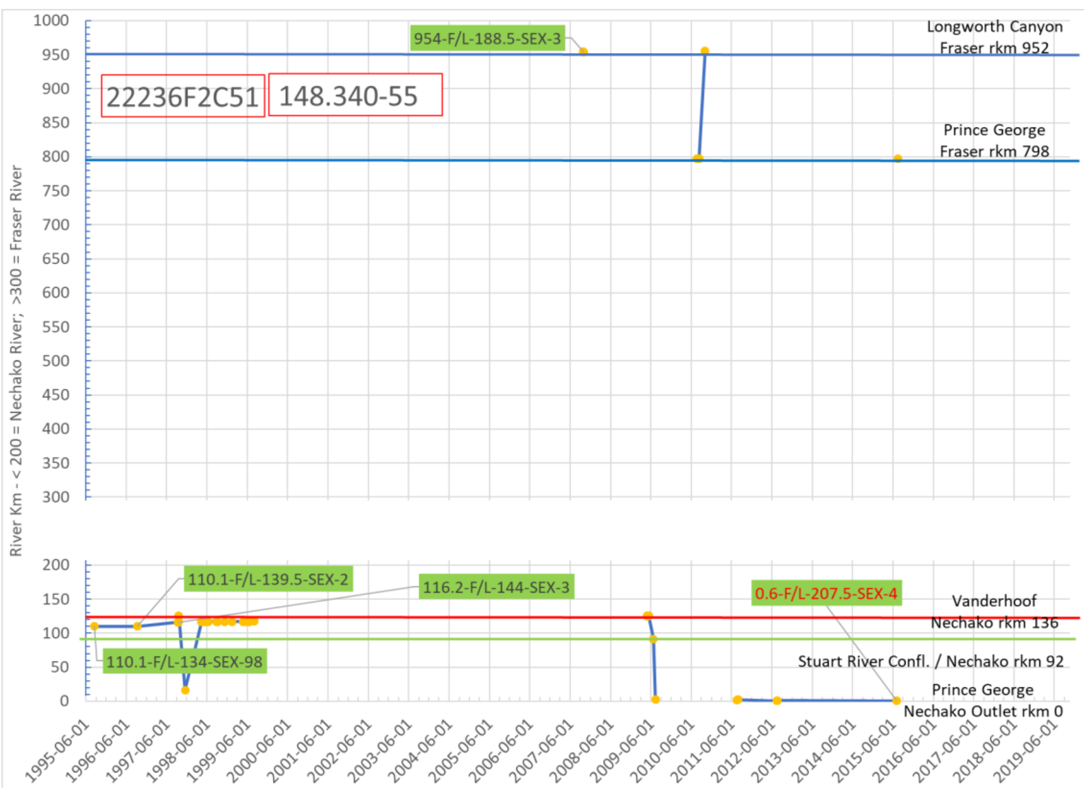
Sykes, Greg. 2008. "Nechako White Sturgeon Database Summary 2007." www.triton-env.com.

Appendix A:

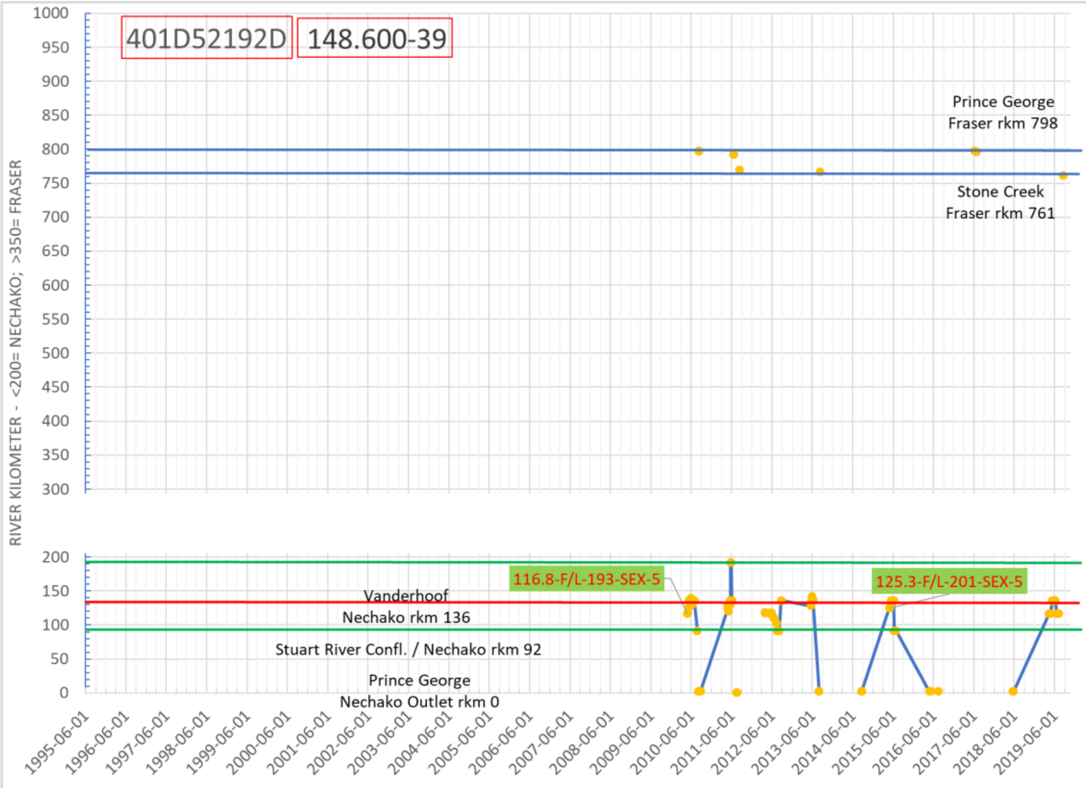
Capture and movement history for 35 individual fish that crossed the putative NSP boundary at Prince George.



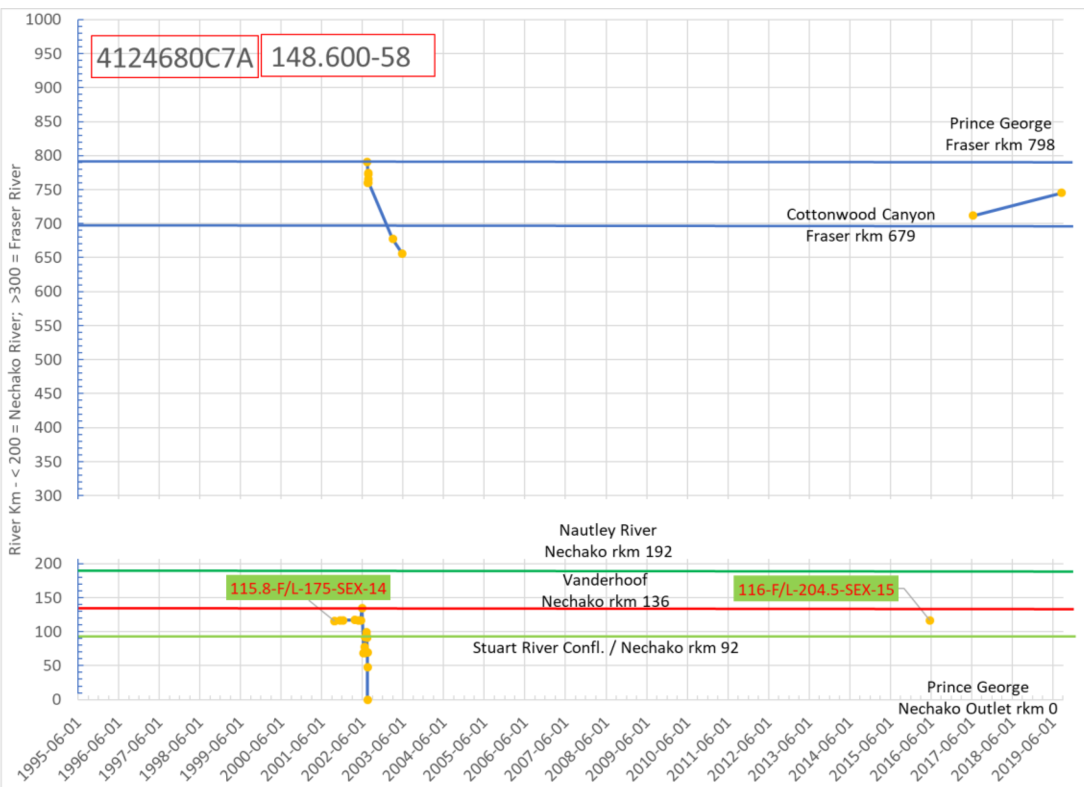
Appendix A Figure 1: PIT 14471373A



Appendix A Figure 2. PIT 22236FC51



Appendix A Figure 3: PIT 401D52192D.



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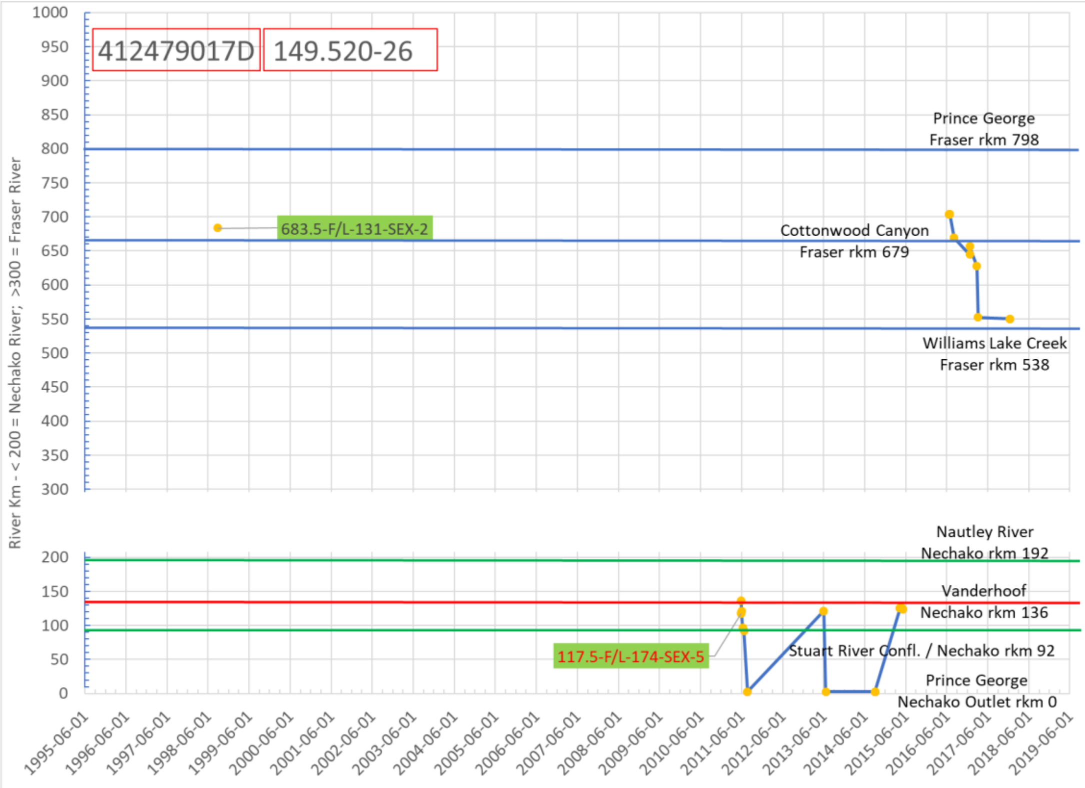

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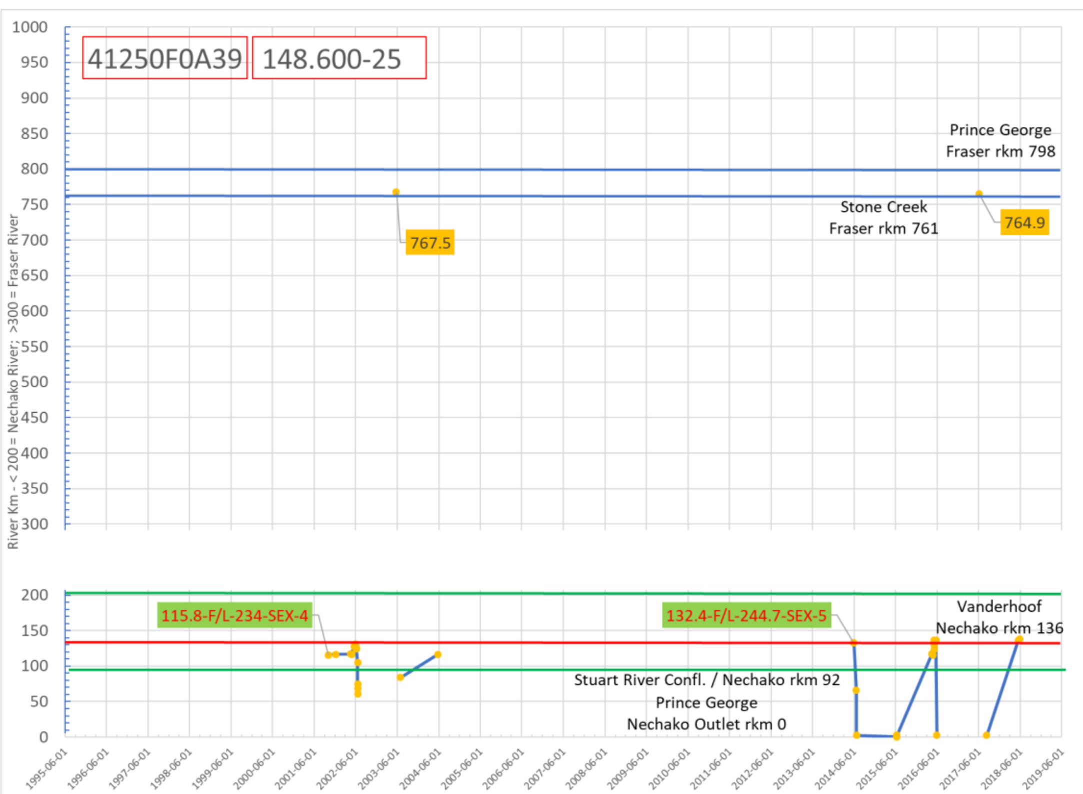
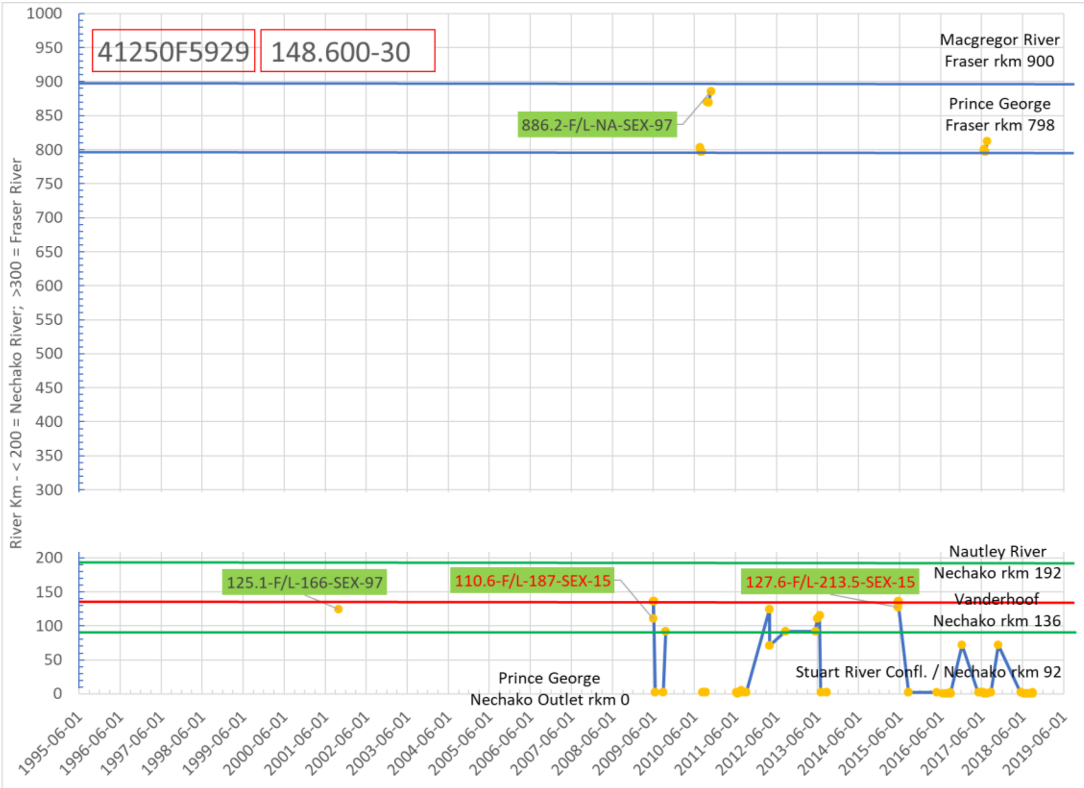


Appendix A Figure 6. PIT 41250F0A39.



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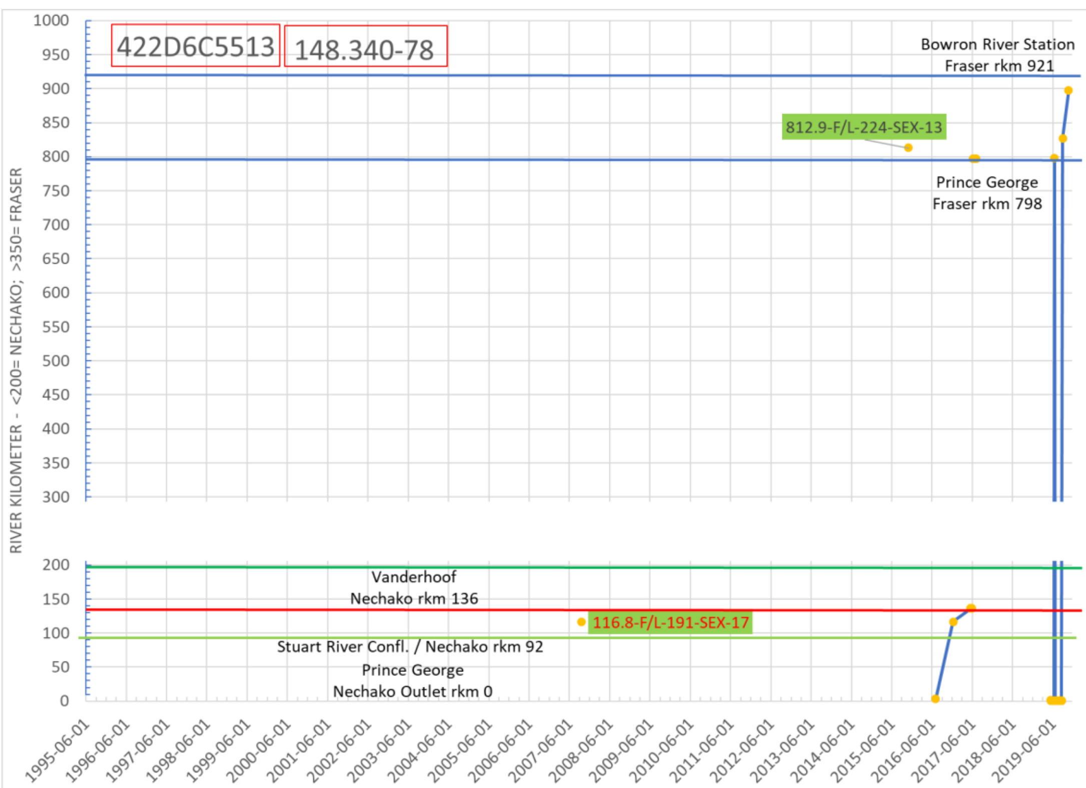
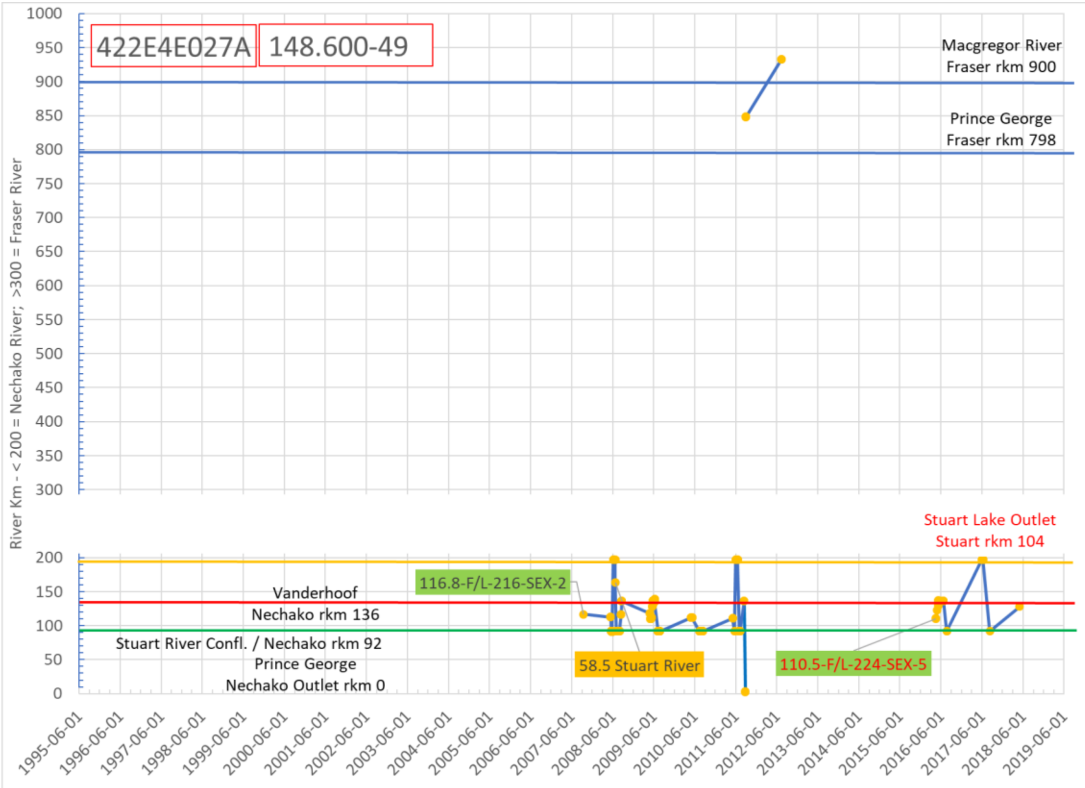
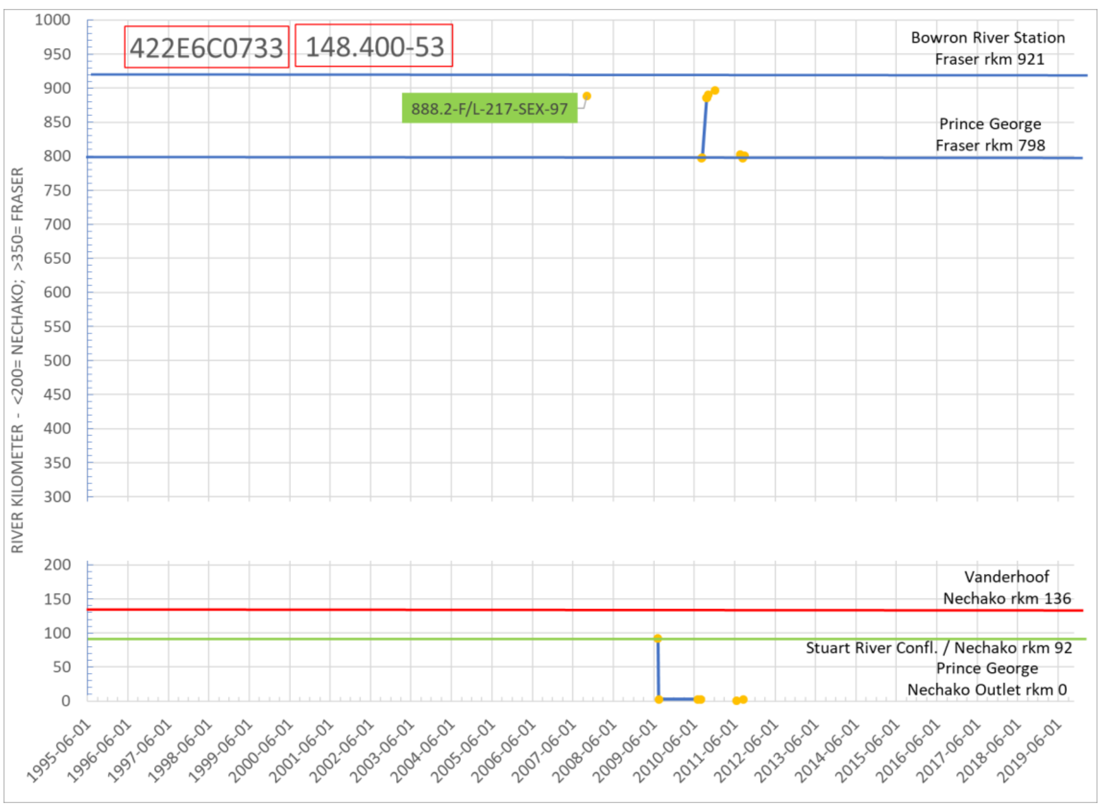


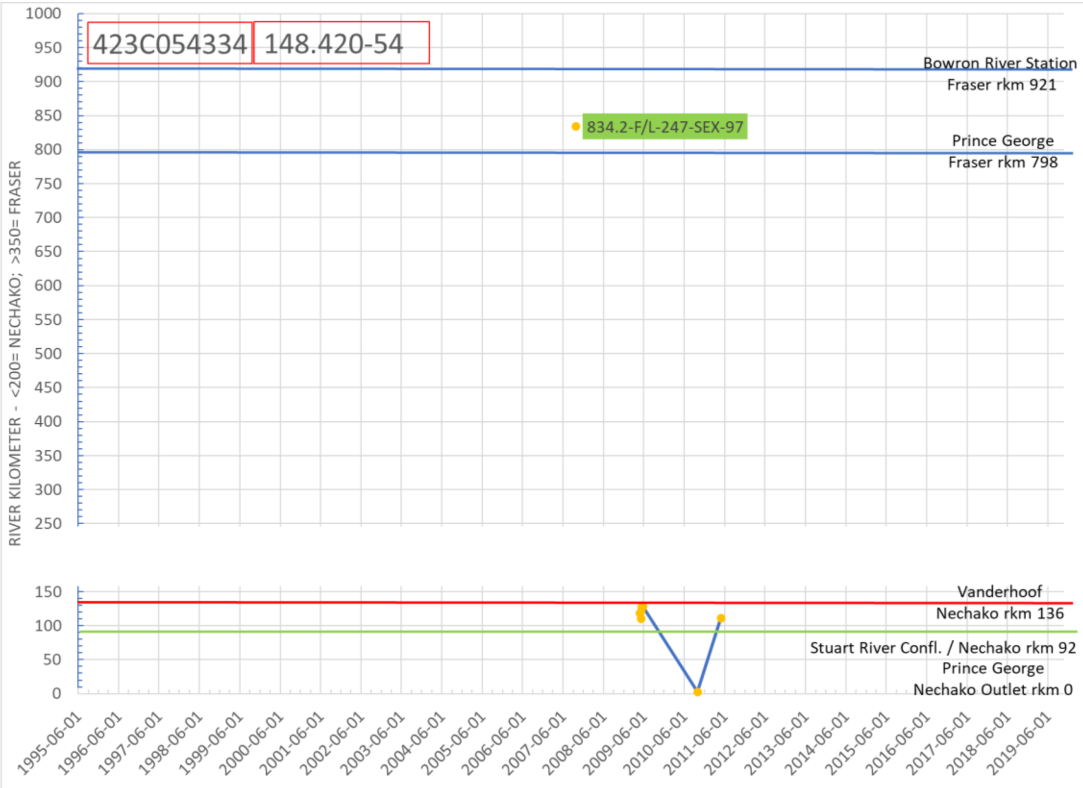
Appendix A Figure 8. PIT 422D3C5513.



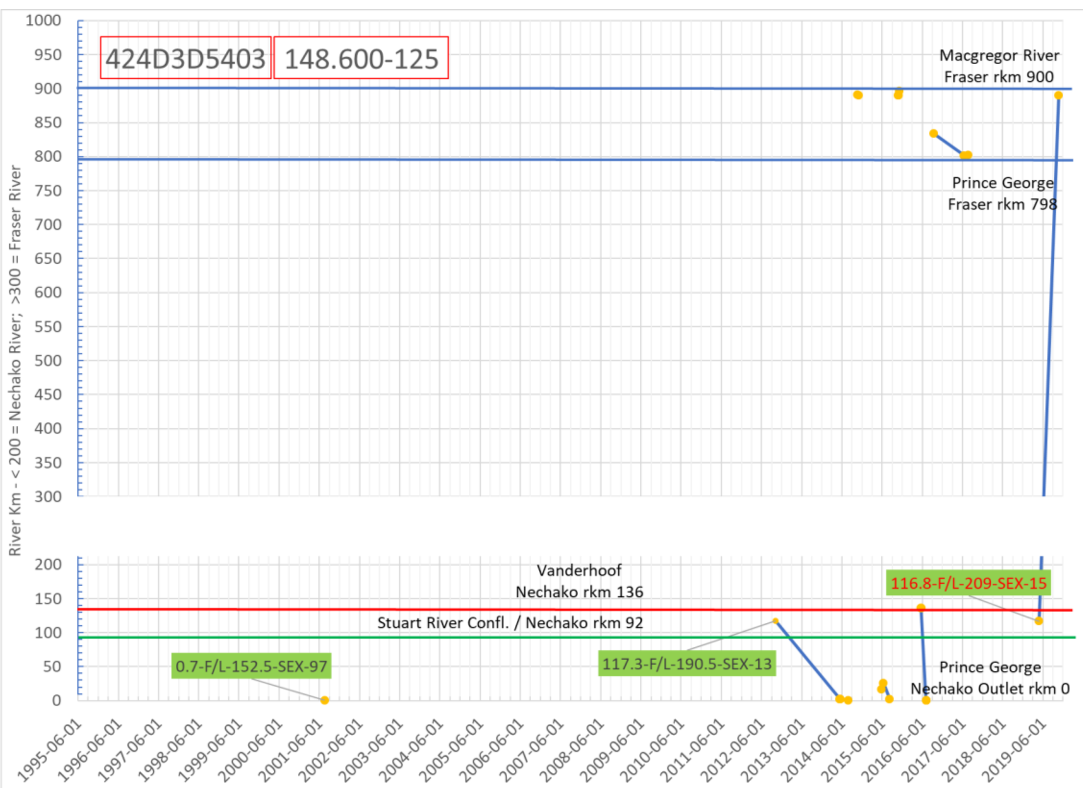
Appendix A Figure 9. PIT 422E4E027A.



Appendix A Figure 10. PIT 422E6C07333.



Appendix A Figure 11. PIT 423C054334.



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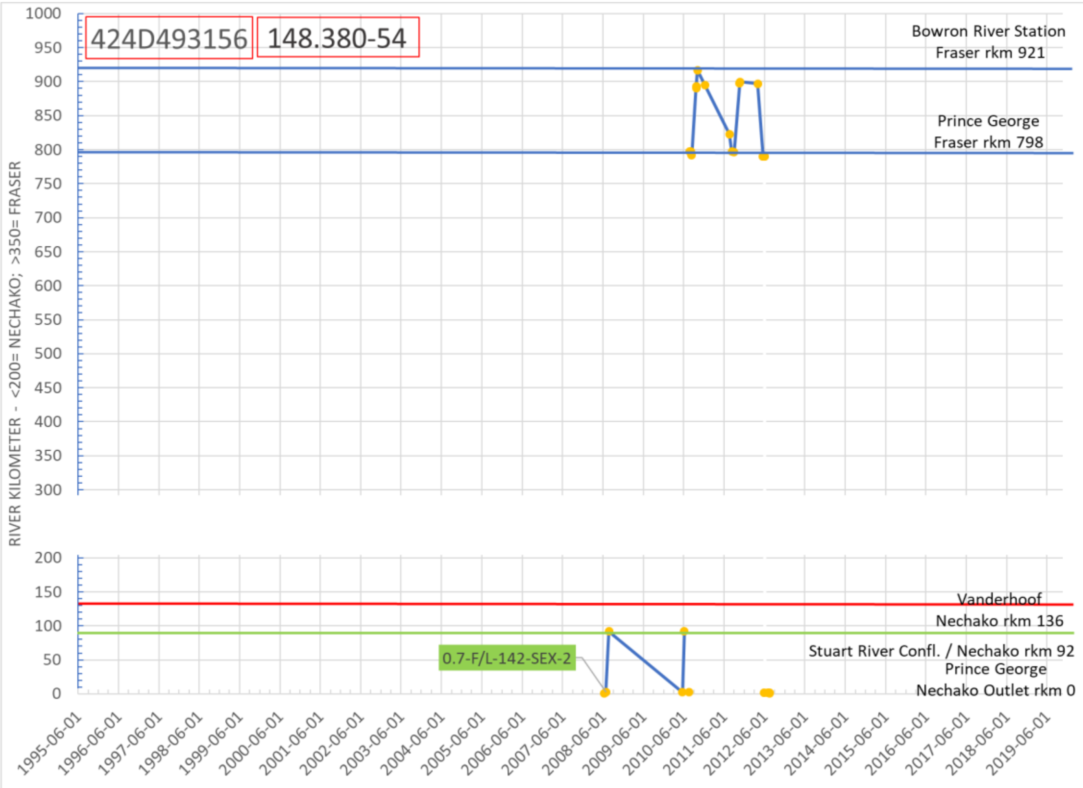

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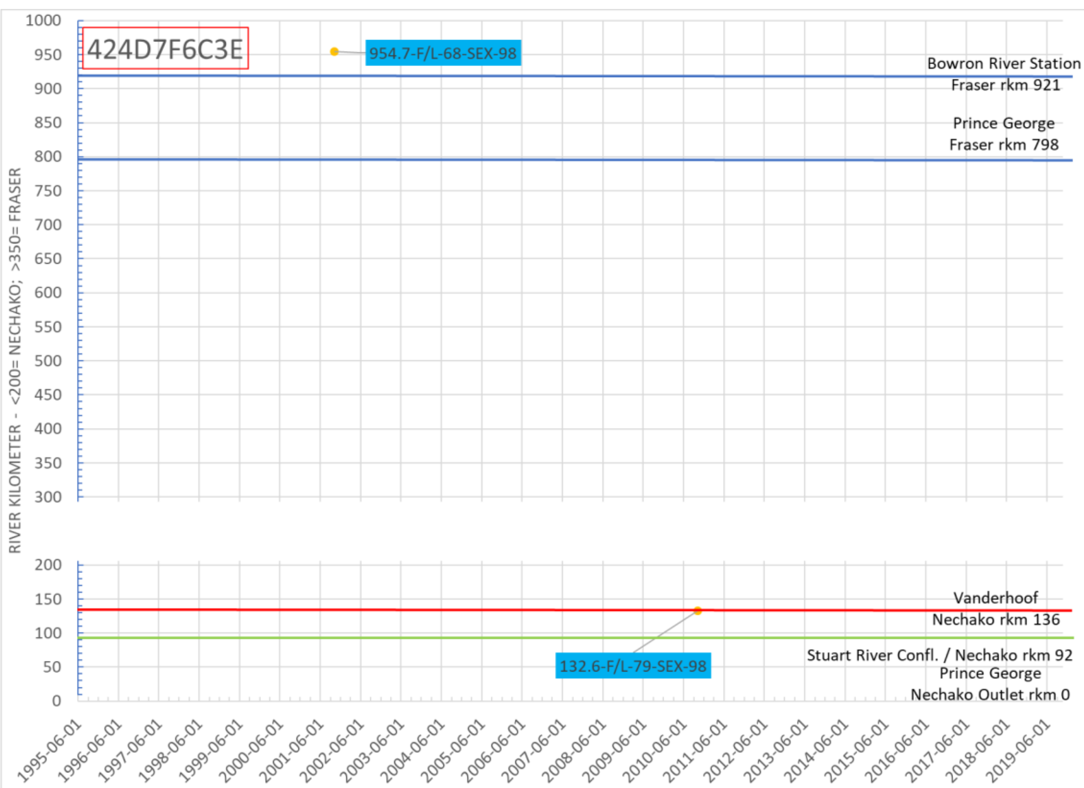
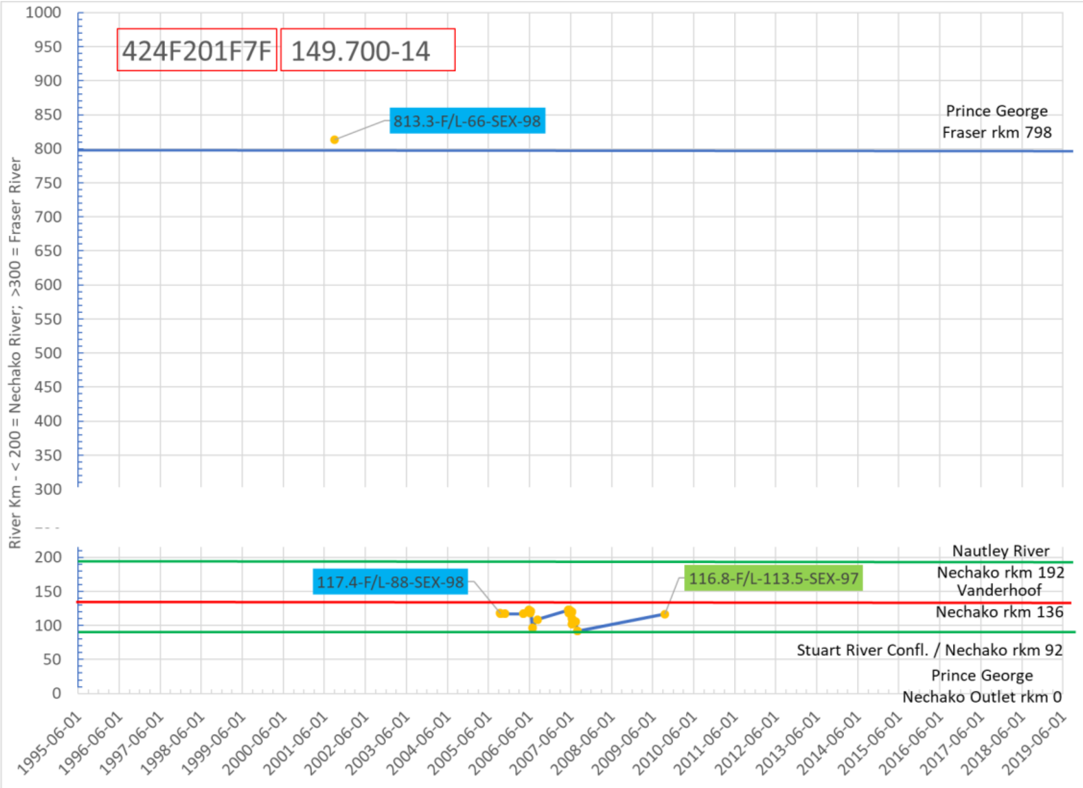
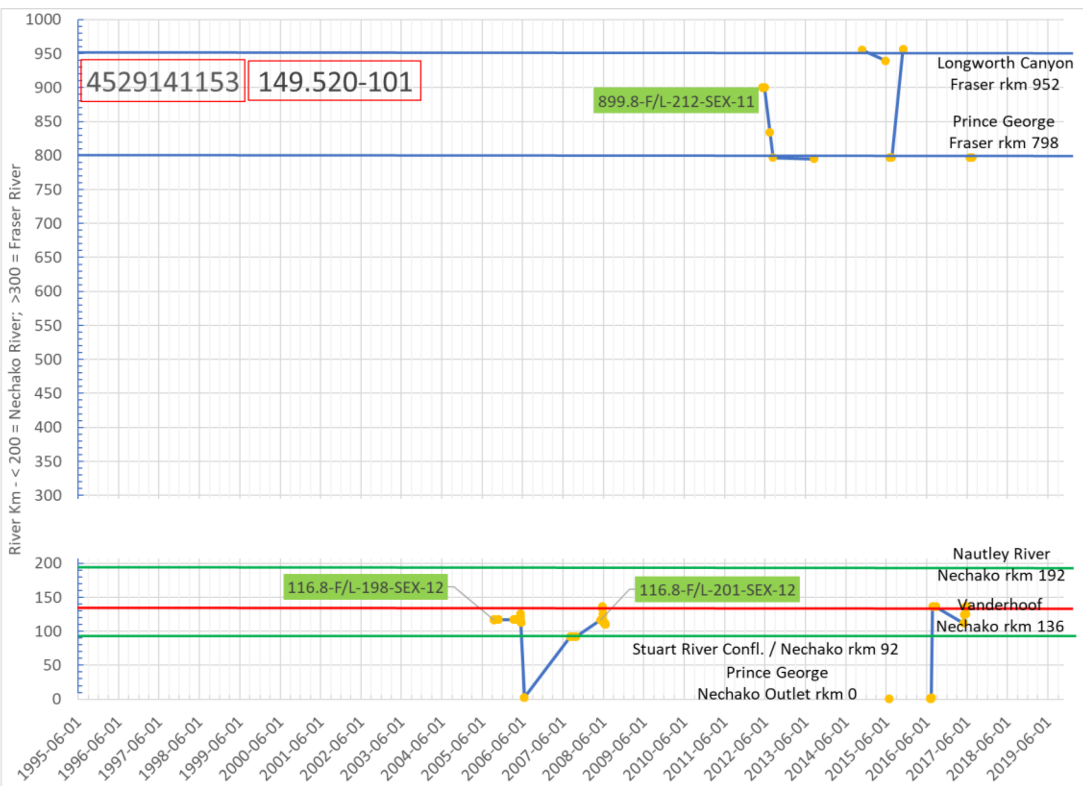


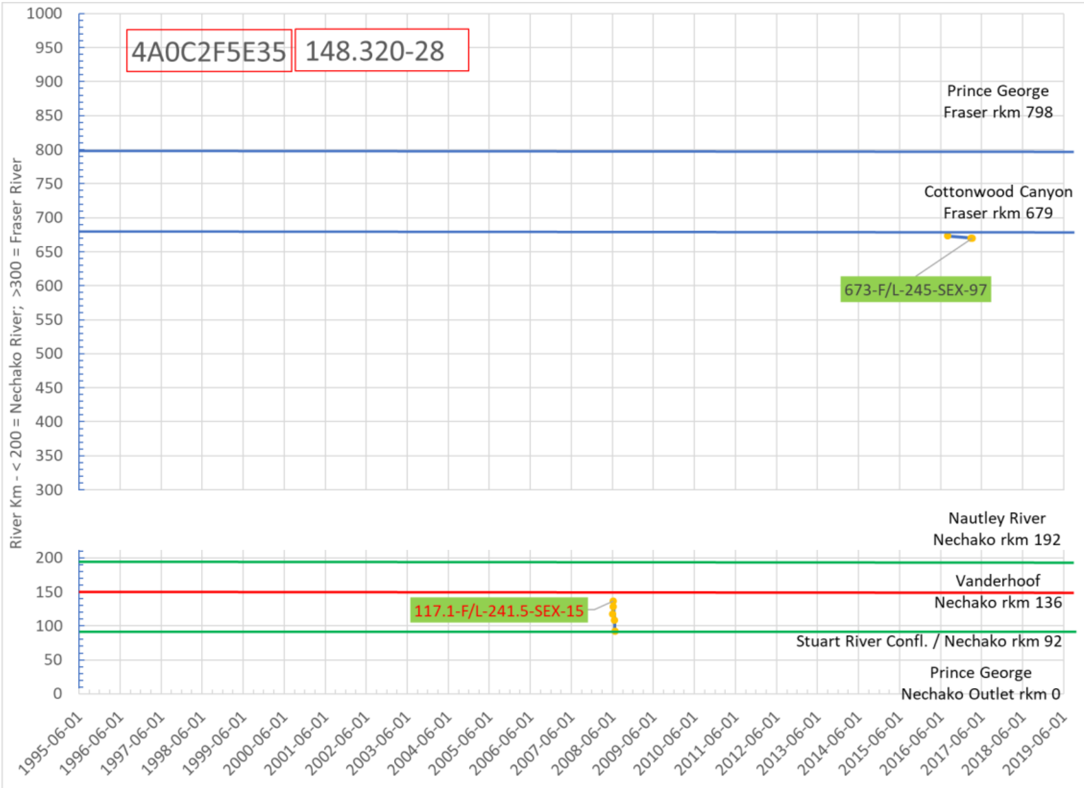
Appendix A Figure 14. PIT 424D7F63E.



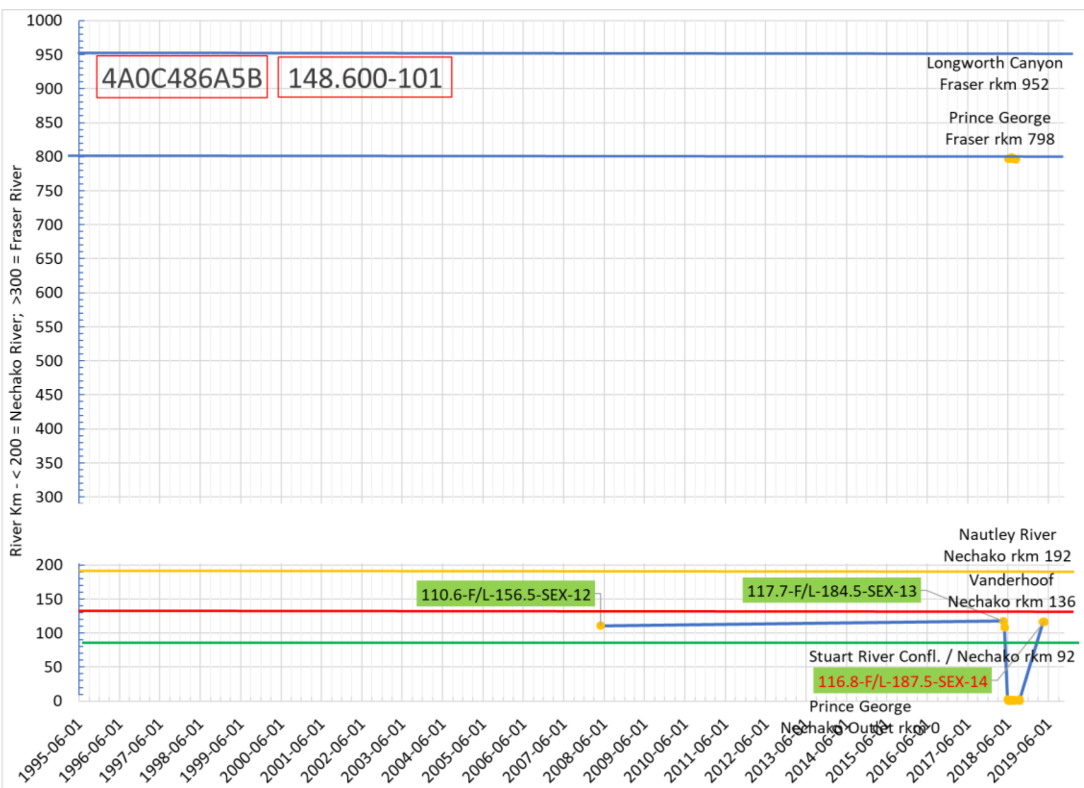
Appendix A Figure 15. PIT 424F201F7F.



Appendix A Figure 16. PIT 4529141153.



Appendix A Figure 17.PIT 4A0C2F5E35.



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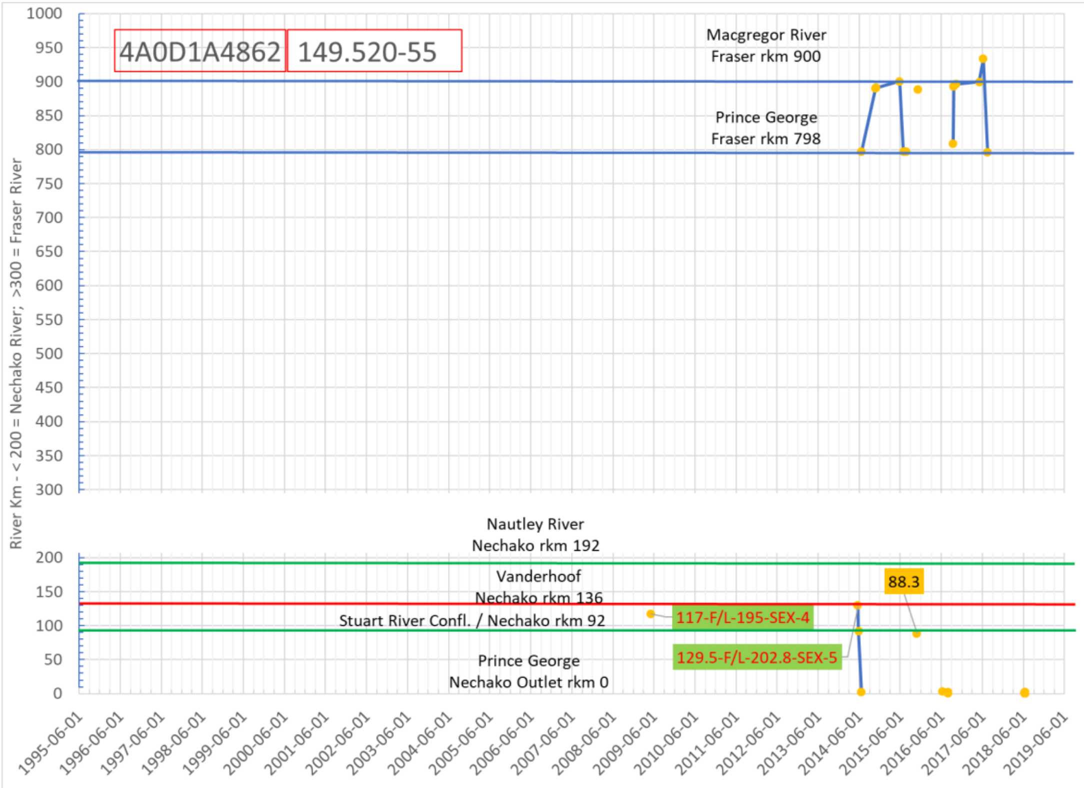

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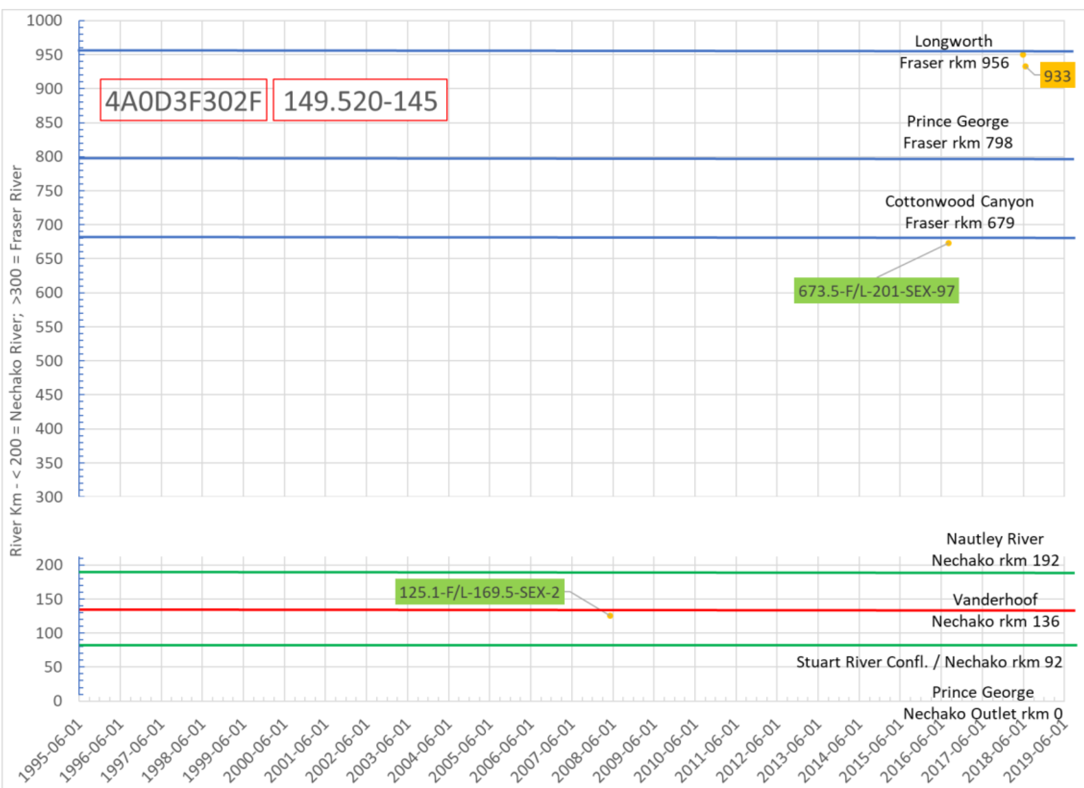
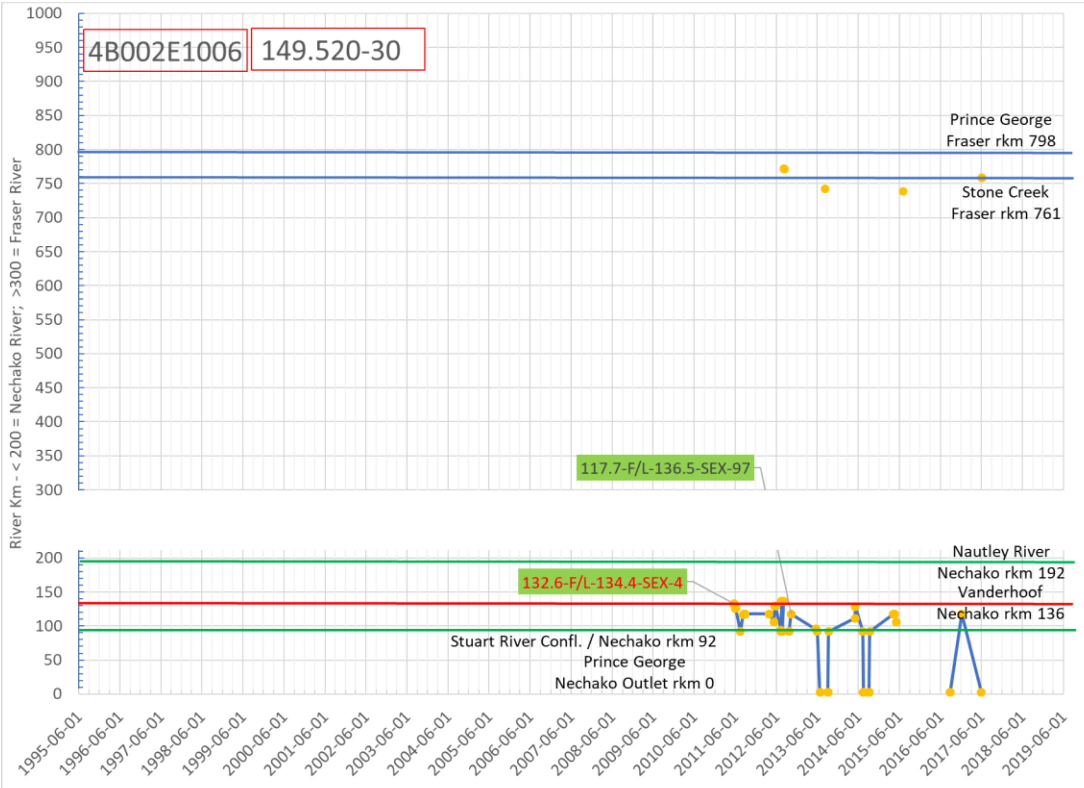
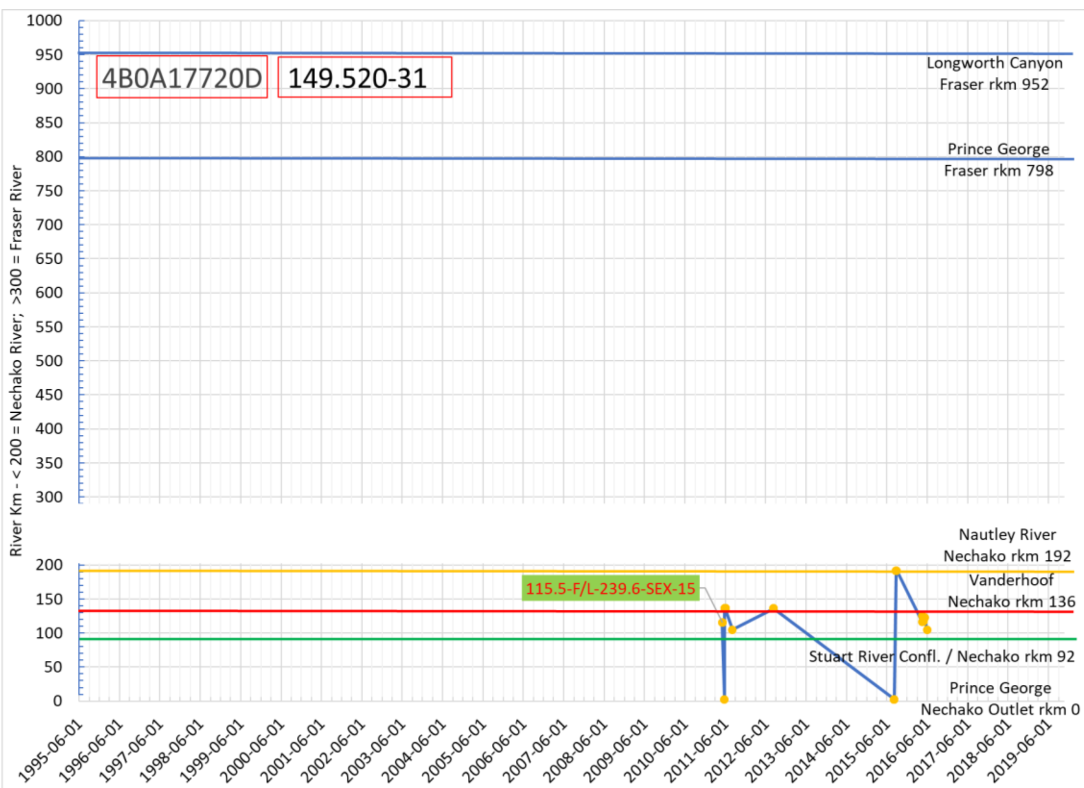


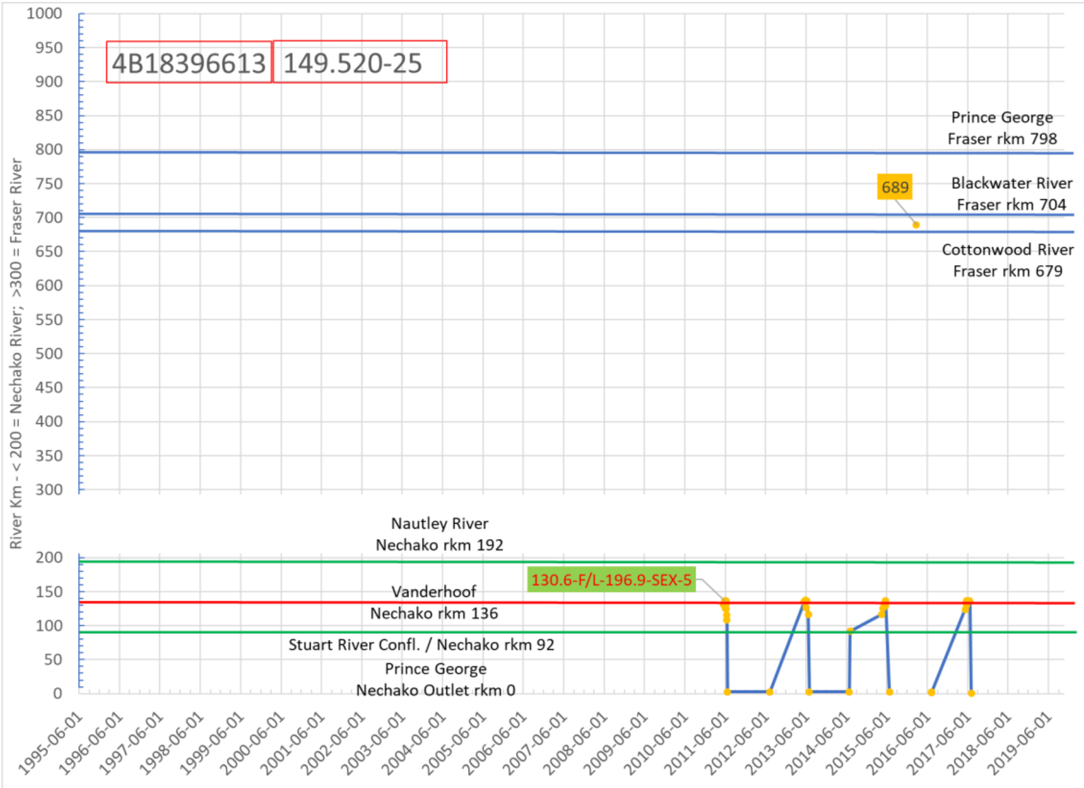
Appendix A Figure 20. PIT 4A0D3F302F.



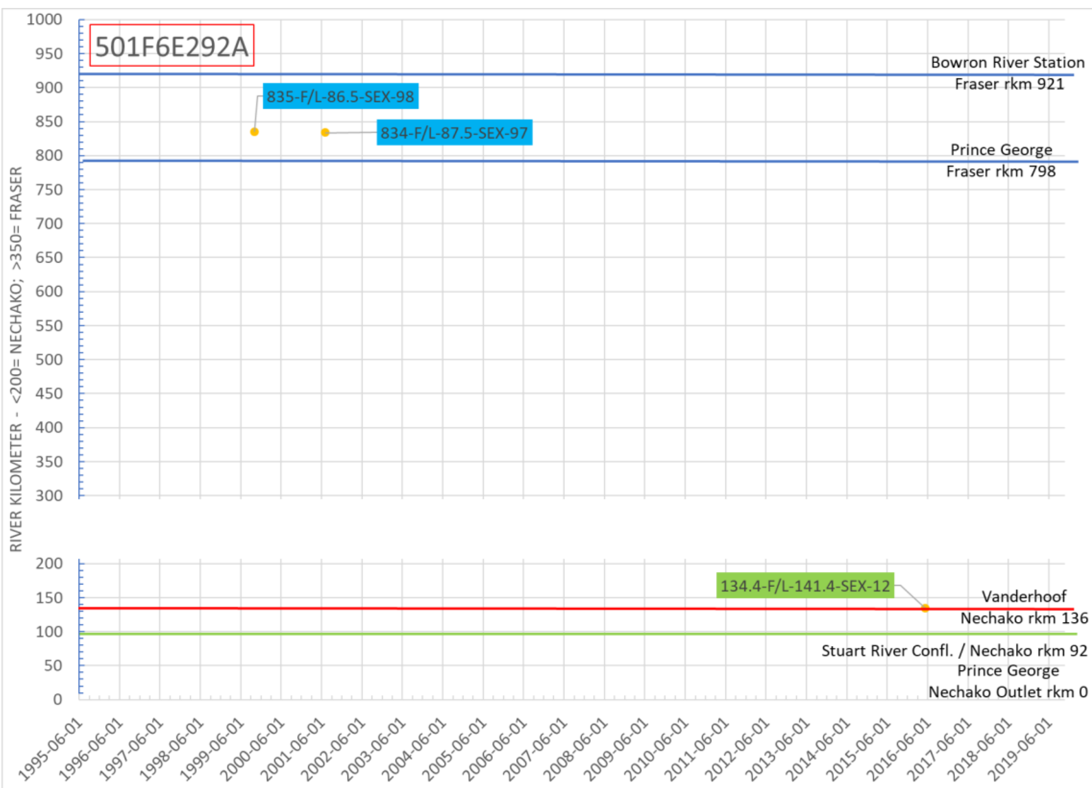
Appendix A Figure 21. PIT 4B002E1006.



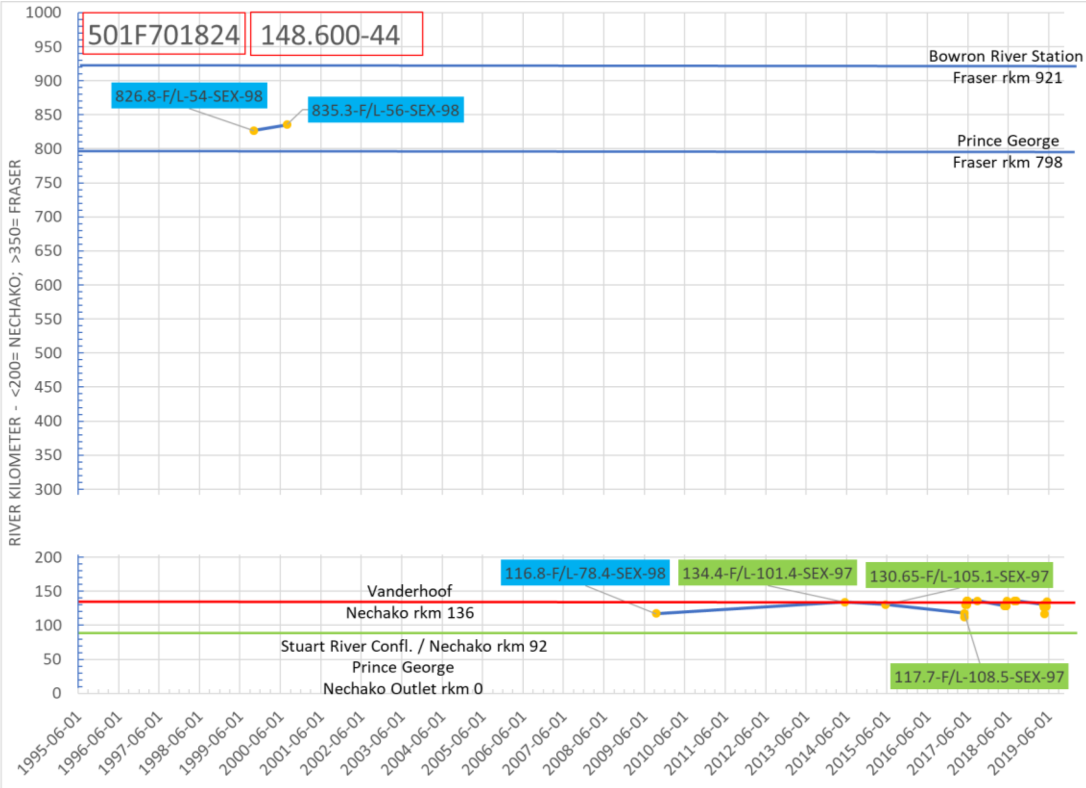
Appendix A Figure 22. PIT 4B0A17720D.



Appendix A Figure 23. PIT 4B18396613.



Appendix A Figure 24. PIT 501F6E292A.



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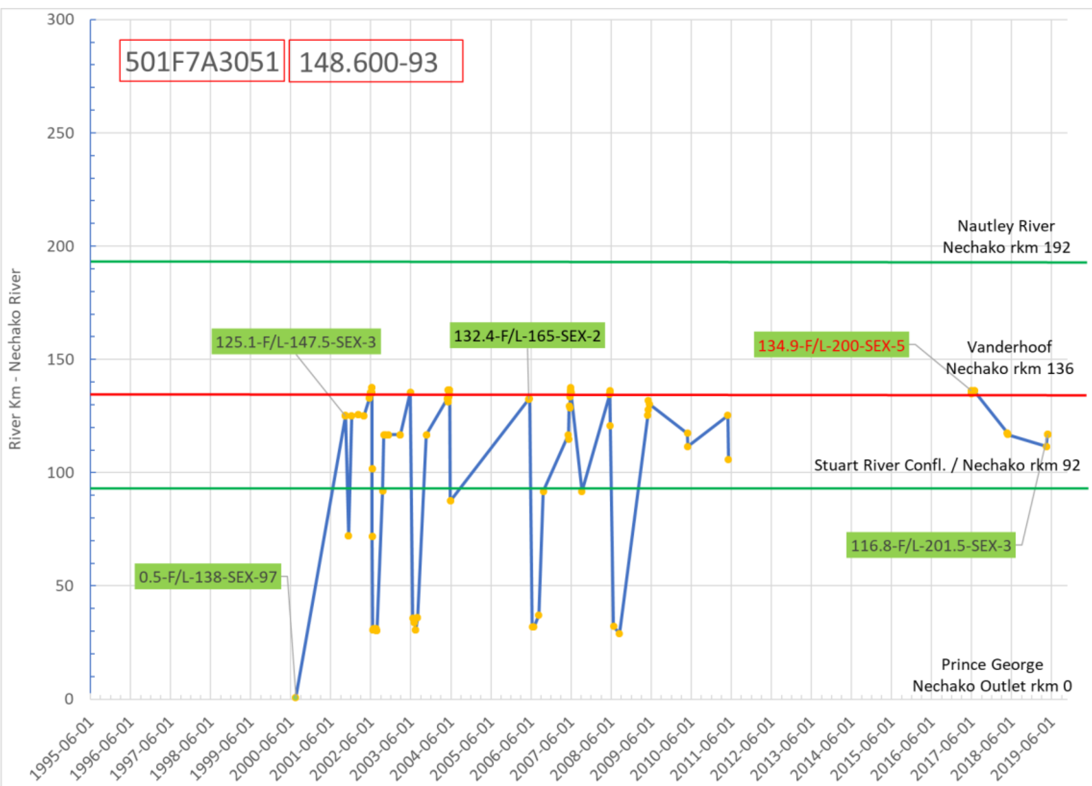
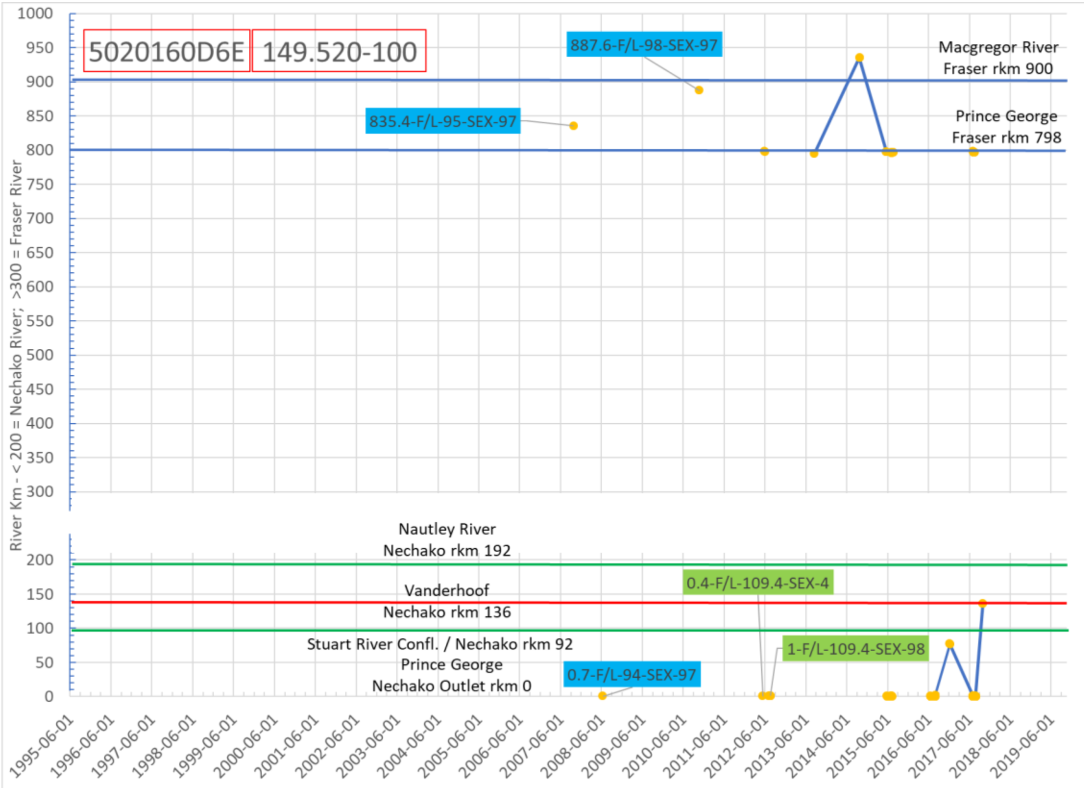
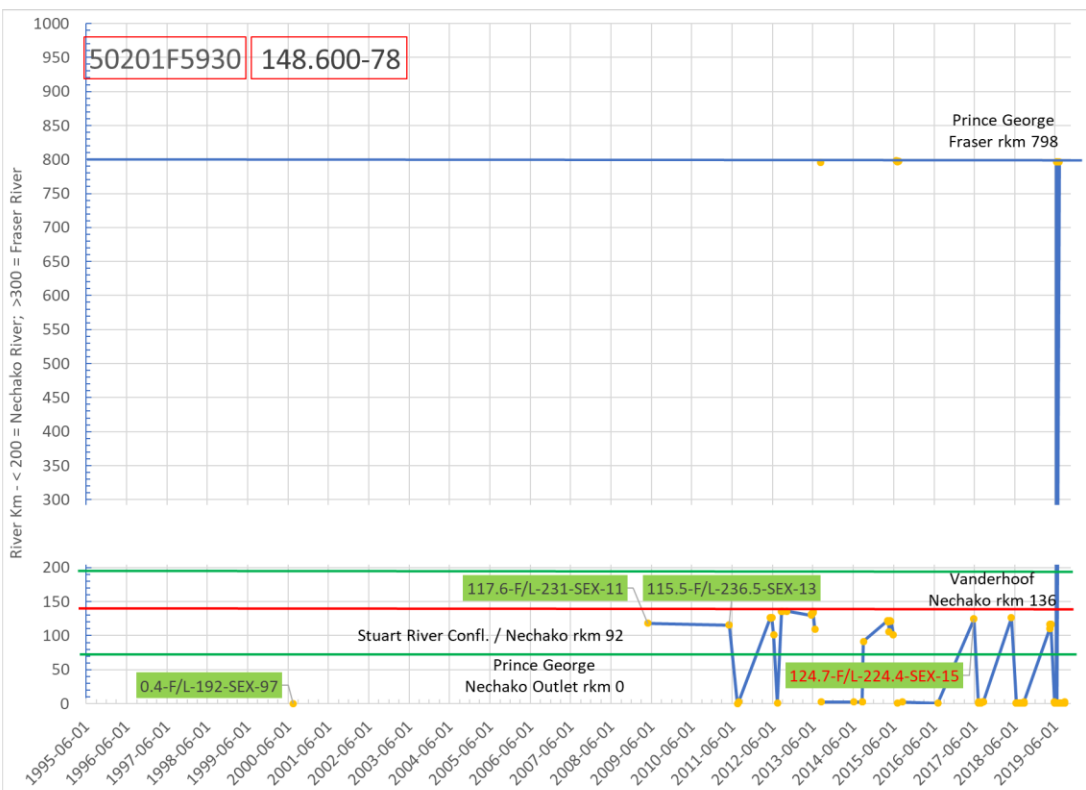


Appendix A Figure 26. PIT 501F7A3051.



Appendix A Figure 27. PIT 5020160D6E.



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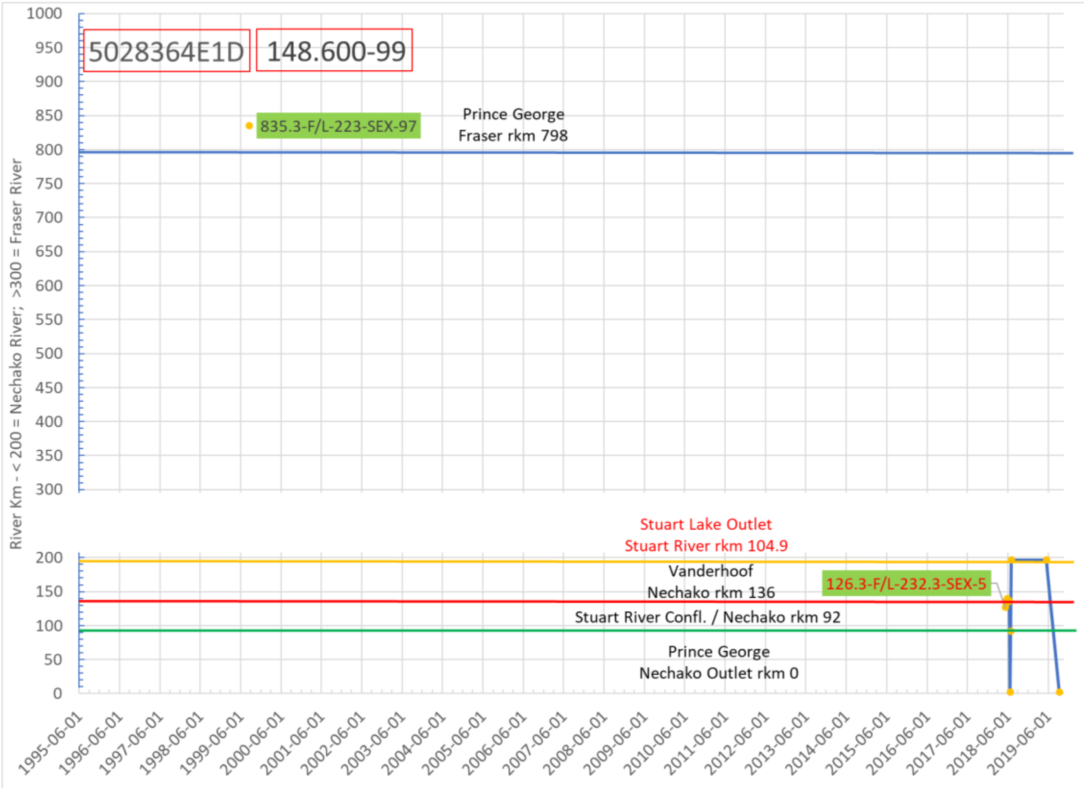
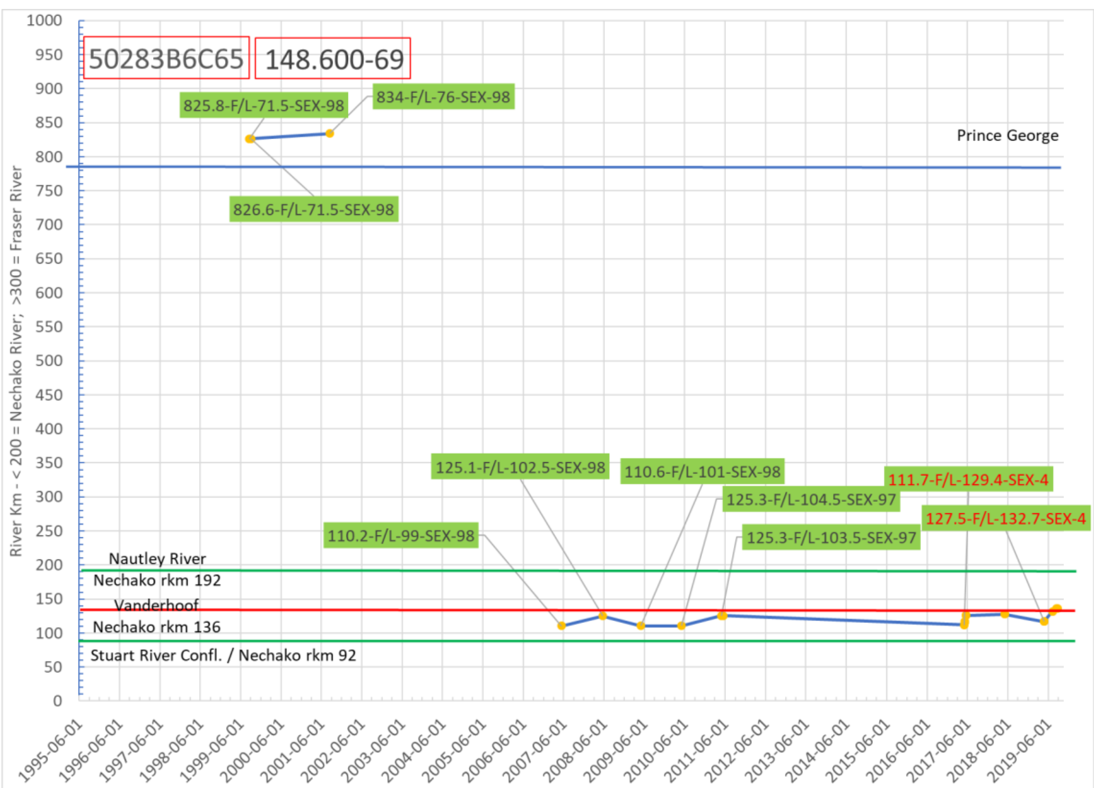
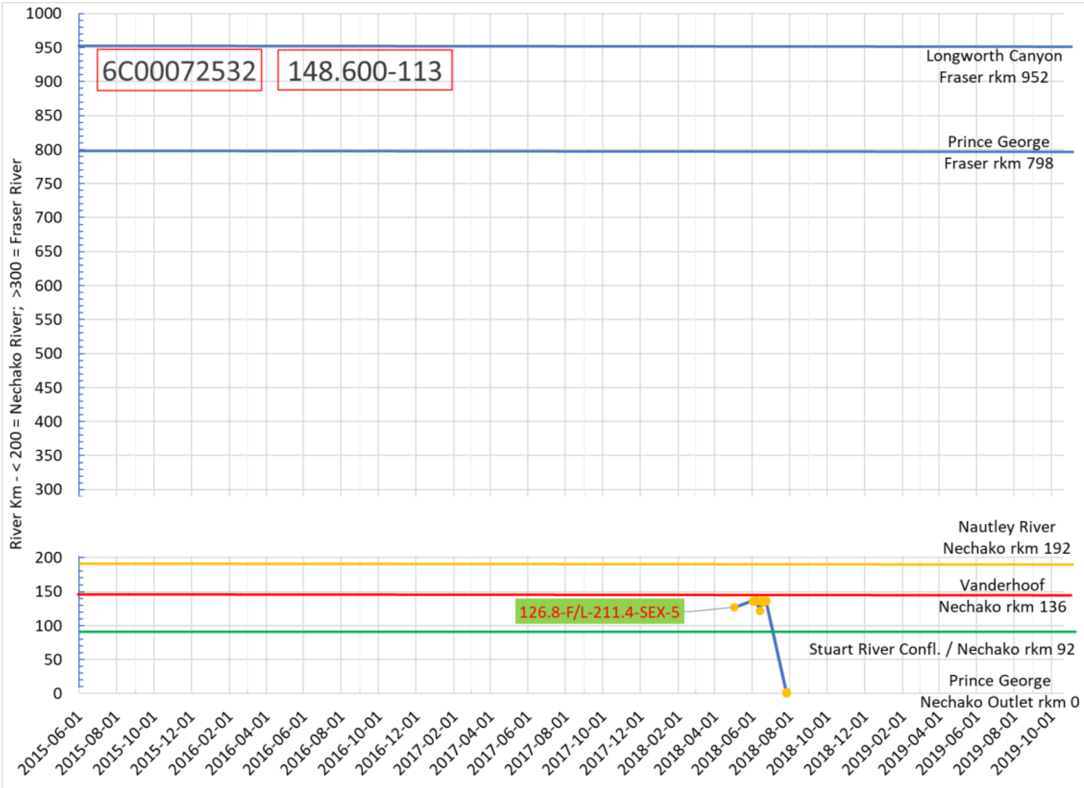


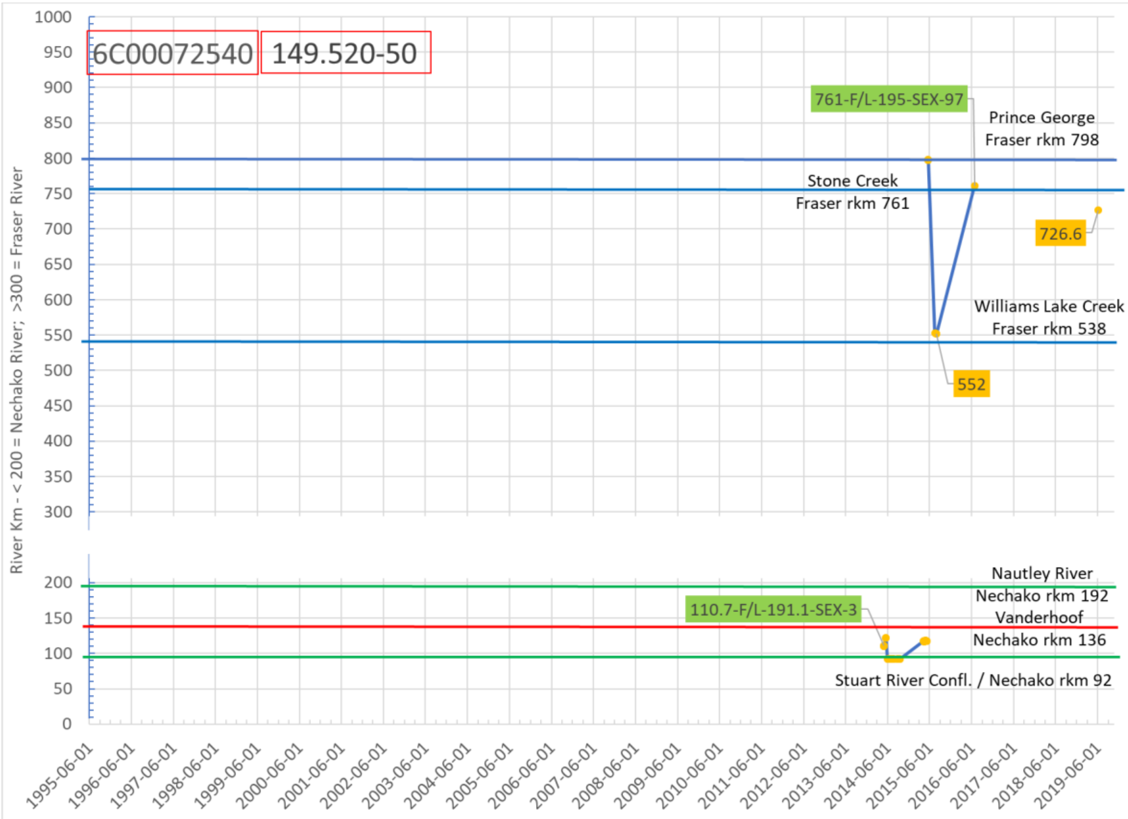
Appendix A Figure 29. PIT 5028364E1D.



Appendix A Figure 30. PIT 50283B6C65.



Appendix A Figure 31. PIT 6C00072532.



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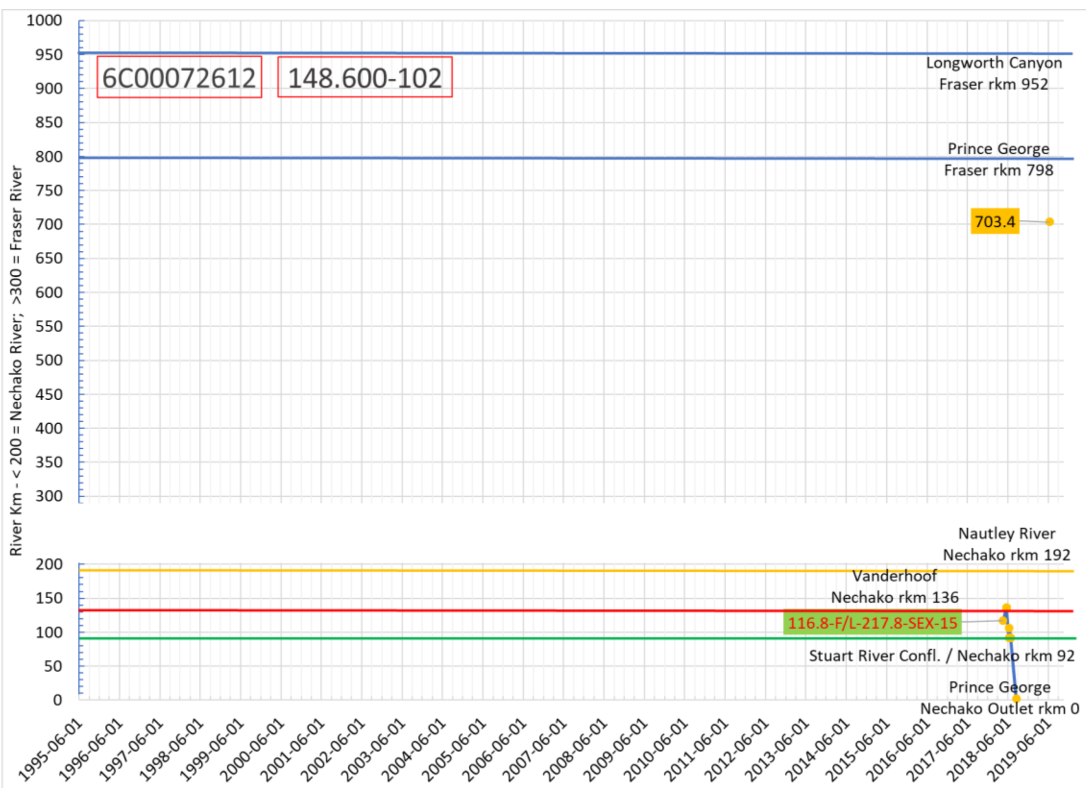

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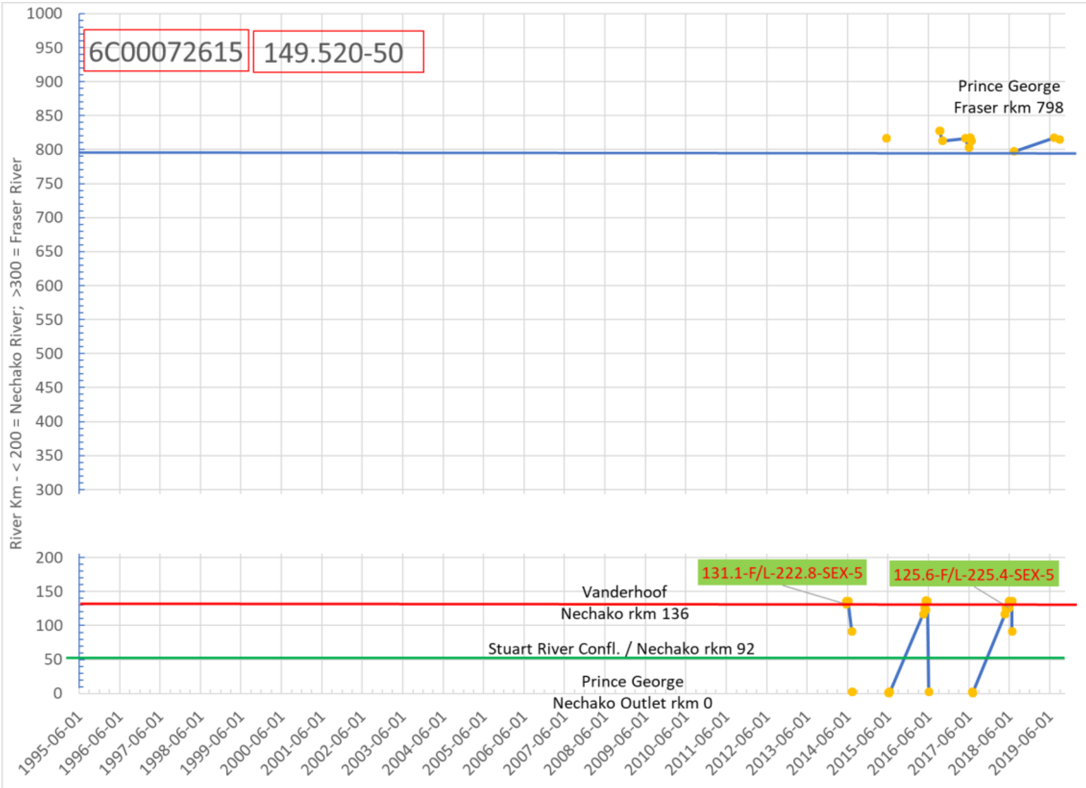

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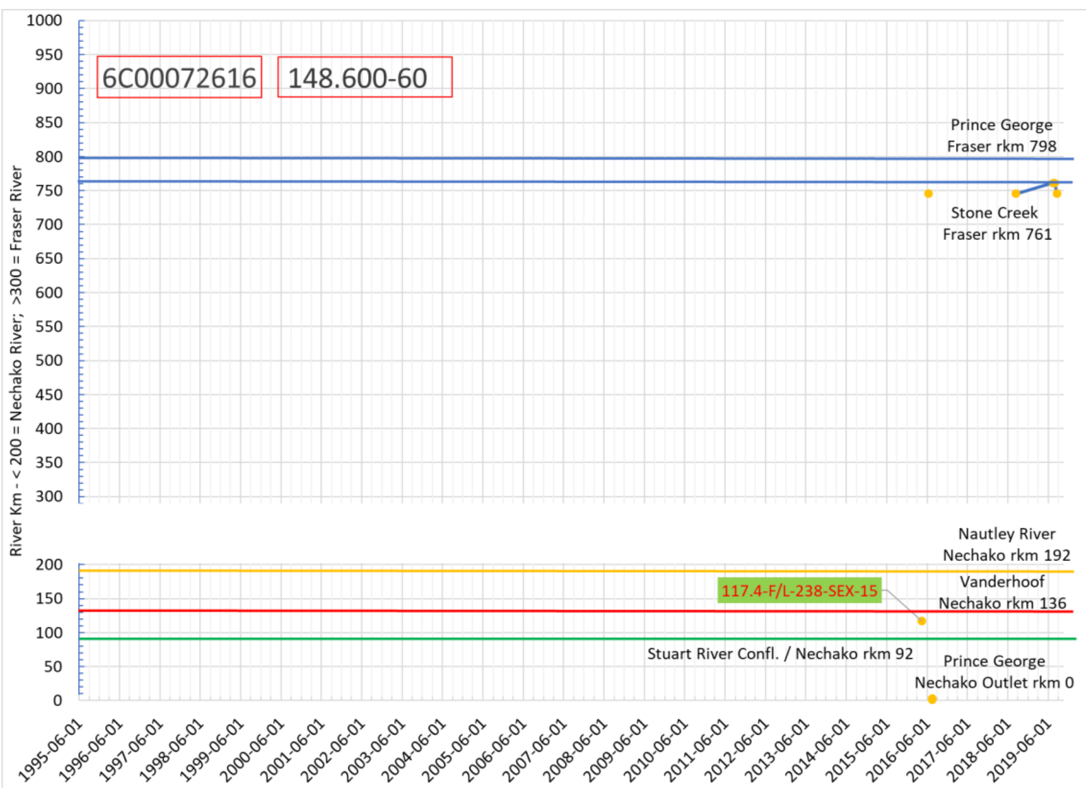

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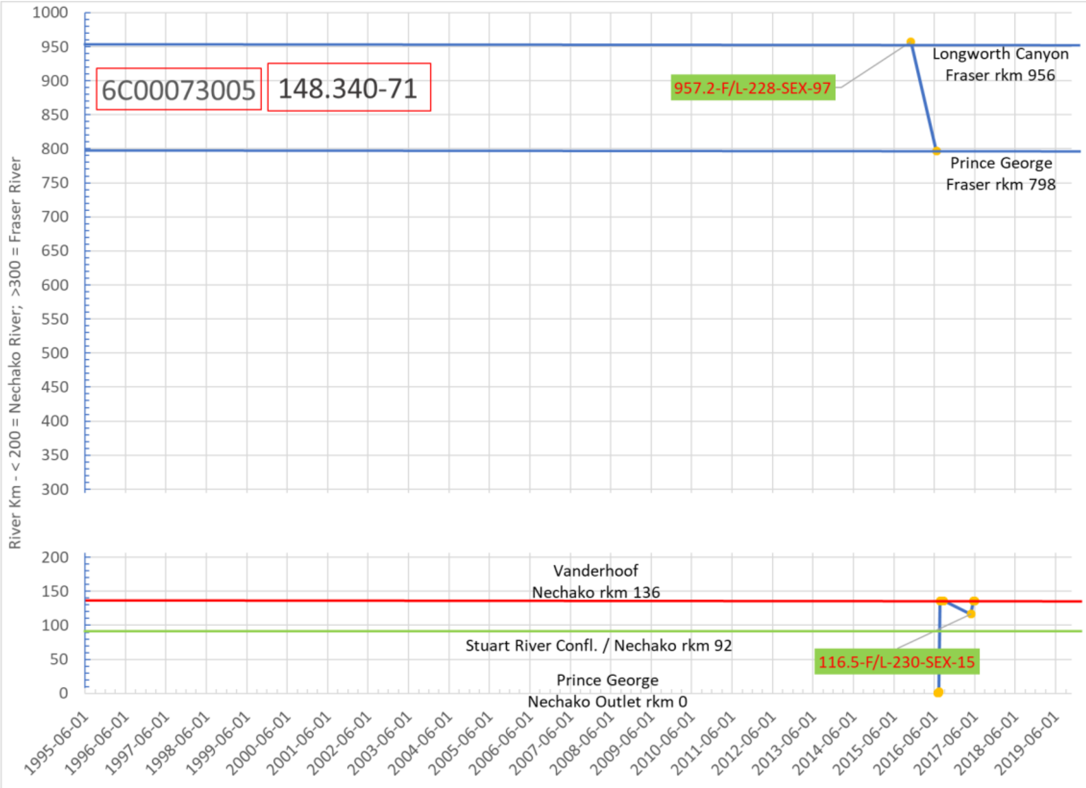

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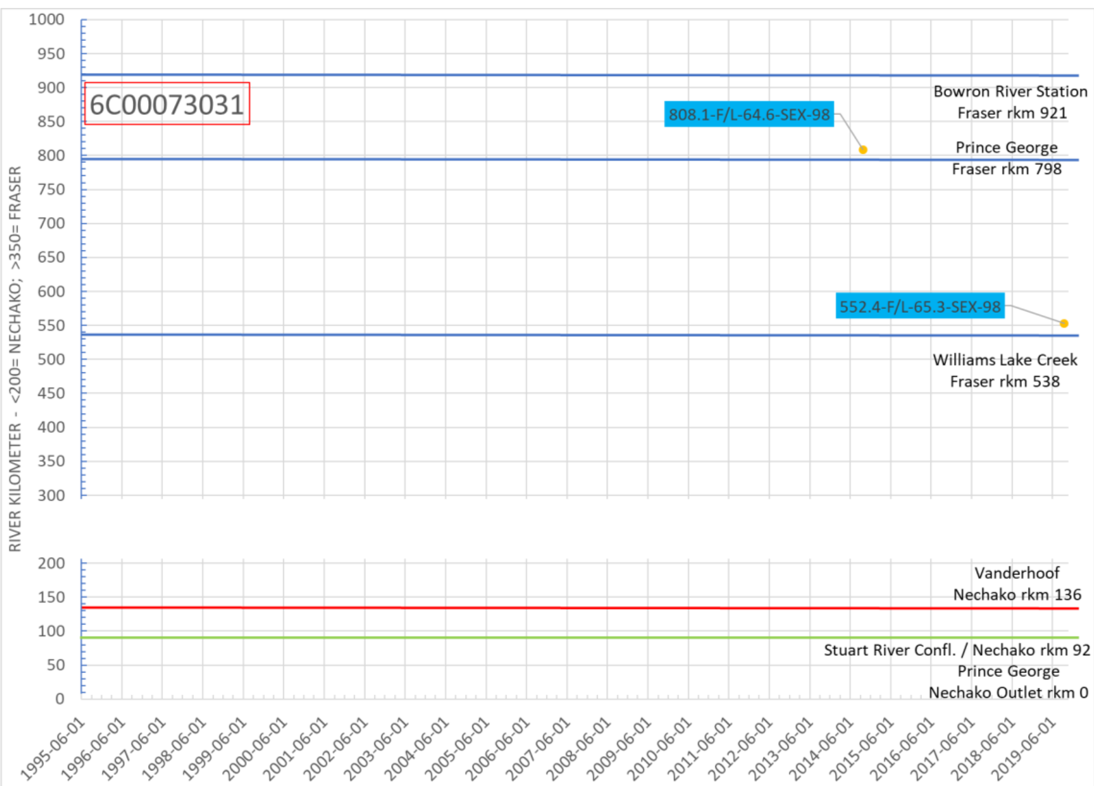

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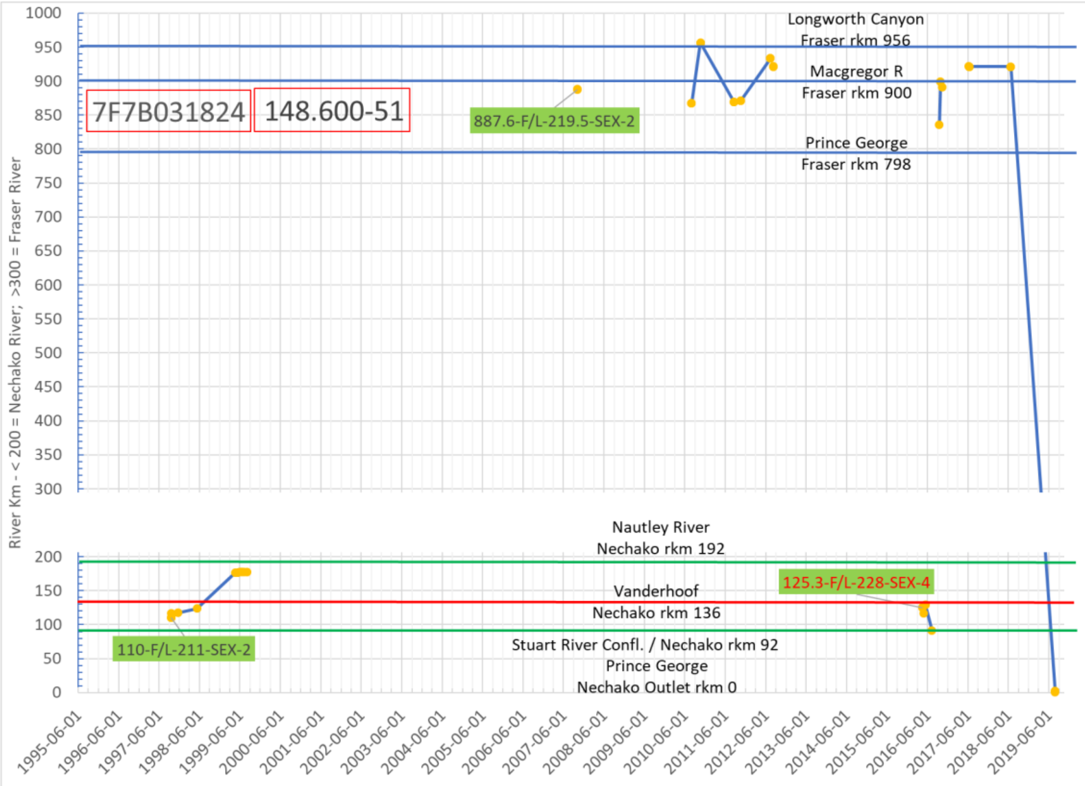
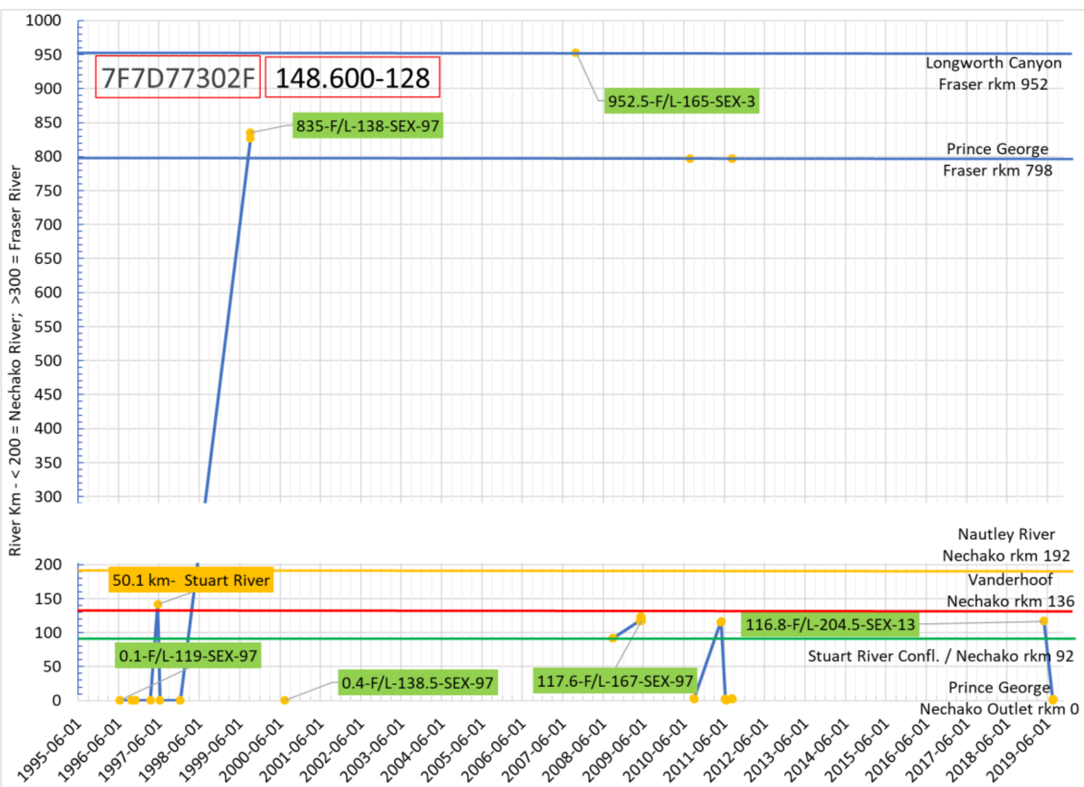


Appendix A Figure 38. PIT 7F7B031824.



Appendix A Figure 39. PIT 7F7D77302F.