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Lillooet River Channel Monitoring Program – 2021 Monitoring Report
Pemberton, BC

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EXECUTIVE SUMMARY

Northwest Hydraulic Consultants Ltd. (NHC) has prepared the following report for the Pemberton Valley Dyking District (PVDD) to summarize the results of the 2021 Lillooet River channel monitoring program, which is being conducted as part of an adaptive management strategy to manage channel sedimentation. On behalf of the PVDD, NHC implemented a monitoring program in 2021 to collect and record information that would be analyzed for two primary purposes:

- To evaluate the effectiveness of sediment removals to mitigate flood risk over time, and
- To inform an adaptive management approach for sediment removals; one that would consider changes to the channel over time as sediment management activities are implemented, and to respond to altered conditions as a result of future flood events or changed sediment supply.

The scope of work for the 2021 monitoring program are categorized into bathymetric and hydrometric monitoring. Channel bed elevation surveys (i.e., bathymetric monitoring) can be used to help indicate whether changes are occurring in the flood conveyance capacity of the channel and corresponding water surface elevation during flood events. Flooding is a direct result of high water, and changes in flood water elevation can still occur without a change in bed elevation if the channel roughness or energy gradient changes; therefore, a direct check on flood levels using water level sensors (i.e., hydrometric monitoring) is important.

Bathymetric monitoring

The bathymetry analysis is limited to locations where bathymetric monitoring data in 2017 and 2021 overlapped, which may introduce some degree of bias into the results. However, the sediment removal volumes at the management sites account for an order of magnitude more sediment volume than the end-area analysis using the thirty-three (33) historical monitoring sections. An analysis using the historical monitoring section data and 50 m transect data has been conducted at three sub-reaches to provide an order of magnitude understanding of the potential range in uncertainty for the channel bed level assessment for various resolutions datasets. Inherent, unresolved uncertainties exist when estimating bed elevation changes over time due to the mobile and unstable nature of the bed and presence of bedforms that can result in substantial fluctuations that cannot be resolved from survey error. A more detailed analysis of cumulative errors in the overall monitoring analysis has not been undertaken for this study and the error may be higher. Estimating average annual aggradation rates using sub-decadal to decadal scale data records can severely over or under predict the long-term sediment transport rate by an order of magnitude (Jordan and Slaymaker, 1991). Estimated aggradation rates should be refined over time as more data are obtained and additional analysis is undertaken.

An aggrading trend is apparent upstream of Highway 99, with a slight degrading trend apparent downstream of the Pemberton Creek confluence. Over the entire study reach there is a computed net volumetric change in the surveyed bed surface of approximately -7,000 m^3 between 2017 and 2021, indicating a net deficit. This corresponds to a net bed material surplus of 122,000 m^3 when accounting for the approximately 129,000 m^3 of sediment that was removed from the channel over this timeframe. By examining the cumulative volumetric changes in the study reach between 2017 and 2021, and considering uncertainty in the analyses, an upper bound rate of annual channel aggradation is estimated to be 40,000 m^3/year. This value represents approximately two-thirds of the annual target sediment removal rate over each of the past two years.

Between 2017 and 2021, the annual average unit channel bed elevation change over the study reach ranges from a lowering rate of less than 0.01 m/year to an infilling rate of 0.08 m/year, with an average infilling of 0.01 m/year. Had no sediment been removed from the channel, the values theoretically could have ranged between less than 0.01 to 0.12 m infilling/year with an average of 0.06 m/year.

The plotted 2011, 2017, and 2021 longitudinal channel bed profile data indicates the 2021 bed level remains substantially higher than the 2011 bed level. In the Lower Reach this represents a net reduction of dike freeboard overtime and a corresponding increase susceptibility to dike overtopping, and in the Middle Reach this represents a source of sediment that may continue to be transported and delivered to the Lower Reach, exacerbating the aggradation problem.

Considering the overall aggraded nature of the Lower Reach relative to 2011, the future potential for the Middle Reach to supply sediment to the Lower Reach, the inherent uncertainty associated with channel bed aggradation analyses, and the rationale for removals identified in the preliminary sediment management plan (NHC, 2019), there is no overwhelming evidence to alter the targeted annual sediment removal rate of 60,000 m^3/year over the next two to three years, unless sediment recruitment volumes at the sediment management sites substantially change or if other considering factors become emergent. In addition to the channel monitoring being conducted as part of a proposed multi-year Lillooet River gravel removal work program, the program should incorporate observations and assessment of biological parameters to inform the overall sediment management program.

Hydrometric monitoring

In April 2021, NHC established five hydrometric stations on the Lillooet River in the reach between Ryan River and Green River confluences. Each station is located downstream of one of the five sediment removal sites, for measuring and recording water level data over time. Each hydrometric station includes an archiving water level logger and at least three fixed elevation reference control points. In 2021, water level data was collected by NHC in conjunction with flow gauging conducted on the Lillooet River by Water Survey of Canada (WSC). Experimental crest stage gauges were installed to record the highest water level reached at each site, independently of the archiving water level sensors. The crest stage gauges were overtopped in the late June 2021 high water event and have since been raised and serviced in preparation for subsequent events. Station data sheets have been prepared and the hydrometric stations have been established in Aquarius; a software for data management, processing, and analysis. Baseline hydrometric conditions have been established at each site. For the 2021 year, the paired NHC site inspections and WSC discharge measurements are the primary data records due to logger deployment errors that led to substantial data gaps at all but one of the sites. NHC has since implemented additional internal procedures to mitigate for this deployment error during subsequent site visits.

NHC (2018) developed a specific gauge analysis approach that compares historical gauge elevations that coincide with discharge measurements to specific gauge elevations calculated from a reference rating curve. This method has been applied to the monitoring data and allows the effects of channel changes at all measured discharge magnitudes to be plotted. More importantly, this method is independent of how the rating curves are drawn by the hydrographers as the historic rating curves are not used, only the actual field measurements of stage and discharge. Reference rating curve and an initial shift diagram have been plotted for each monitoring location, and post-freshet conditions have been highlighted. A longer data record is needed to analyse potential channel geometry changes.

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1 INTRODUCTION

Northwest Hydraulic Consultants Ltd. (NHC) has prepared the following report for the Pemberton Valley Dyking District (PVDD) to summarize the results of the 2021 Lillooet River channel monitoring program, which is being conducted as part of an adaptive management strategy to manage channel sedimentation.

1.1 Background

Since the August 2010 Mount Meager landslide, sediment accumulation rates in the Lillooet River near Pemberton, BC have substantially increased. Sedimentation will reduce the flood-carrying capacity of the channel over time and increase the flood risk. In response, the PVDD has been removing sediment from the Lillooet River since 2013.

1.1.1 Historical channel monitoring

Fifty-six (56) historical channel monitoring sections were surveyed in 1985 and 2001 along a 44 km long reach of the Lillooet River, between the channel mouth and 4 km upstream of the Forest Service Road bridge. In 2011, following the landslide event, these monitoring sections were re-surveyed and twenty-eight (28) additional monitoring sections were established to document a base-line channel bed condition prior to substantial changes in sedimentation patterns in response to the large influx of sediment into the river system associated with the 2010 Mt. Meager slide event. The 2011 monitoring included a channel thalweg survey, from the mouth extending approximately 30 km upstream.

In 2017, the eighty-four (84) historical monitoring sections surveyed in 2011 were re-surveyed, in addition to supplemental 50-metre spacing transects. The 2017 monitoring included a 44 km long survey of the channel thalweg and alignments on either side of the channel upstream of the mouth.

1.1.2 Sediment removals since 2013

Since 2013, a total of five sediment bars in the lower reach of the Lillooet River have been targeted for sediment removals between the Miller Creek and Green River confluences (**Figure 1.1**): Voyageur, Beem, Belkin, Big Sky and Airport bars. These bars represent localized areas of sediment accumulation that are readily accessible, and where sediment removals can be conducted in isolation of flowing water during the winter low flow period.

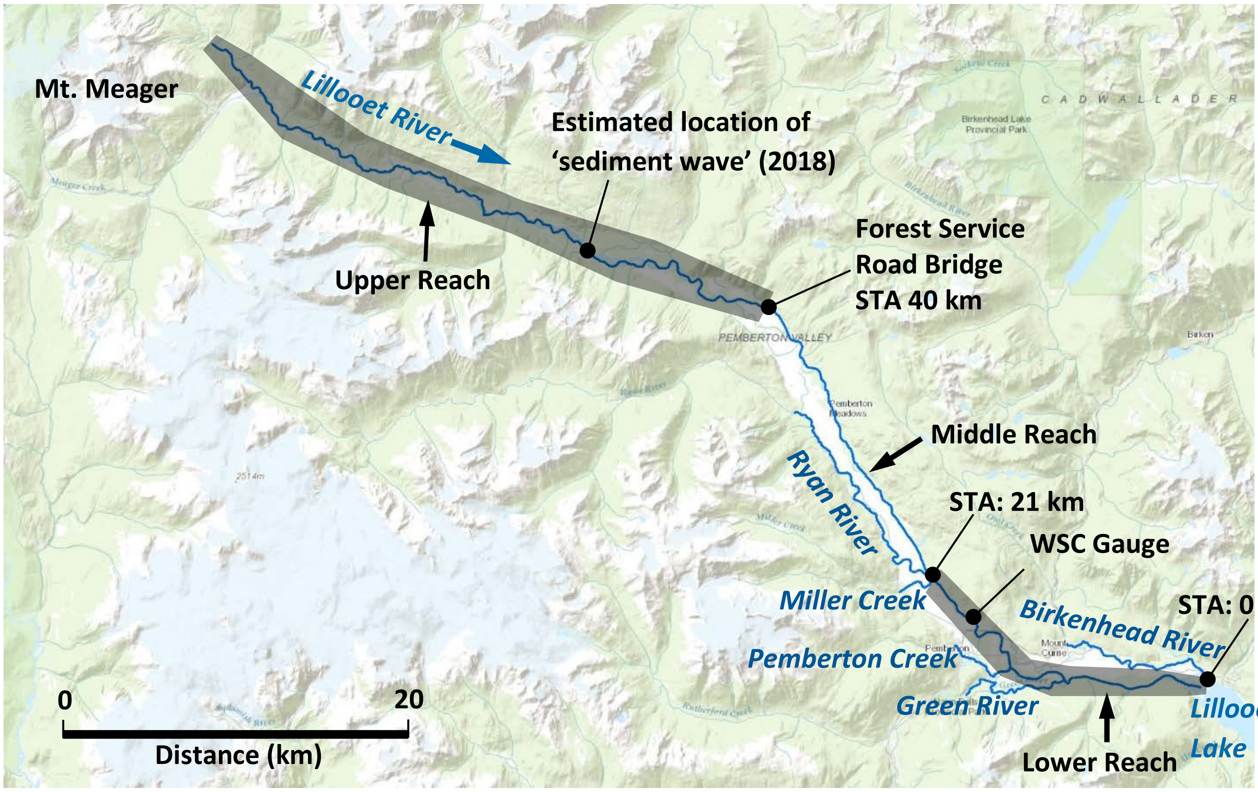


Figure 1.1 Schematic of the Lillooet River, tributaries and simplified reach breaks (after NHC, 2019).

Sediment removals at these bars are intended to offset the incoming sediment load, to reduce the overall rate of sediment accumulation along the channel bed. Since 2013 the PVDD has removed in the order of 199,000 m^3 of sediment from the Lillooet River (in 2013, 2016, 2017, 2019, 2020, and 2021), approximately 65% of which occurred in 2019, 2020, and 2021 (NHC, 2021a). Approximately 100% to 125% of the annual bed material influx has been targeted since a preliminary sediment management plan was prepared (NHC, 2019), with 60,000 m^3 was targeted in each of 2020 and 2021

1.2 Scope of Work

On behalf of the PVDD, NHC implemented a monitoring program in 2021 to collect and record information that would be analyzed for two primary purposes:

- To evaluate the effectiveness of sediment removals to mitigate flood risk over time, and
- To inform an adaptive management approach for sediment removals; one that would consider changes to the channel over time as sediment management activities are implemented, and to respond to altered conditions as a result of future flood events or changed sediment supply.

The scope of work for the 2021 monitoring program are categorized into bathymetric and hydrometric monitoring, as described in **Section 1.2.1** and **Section 1.2.2**, respectively. Channel bed elevation surveys (i.e., bathymetric monitoring) can be used to help indicate if the bed elevation is increasing or decreasing and there is a potential affect on the flood conveyance capacity of the channel and corresponding water surface elevation during flood events. Flooding is a direct result of high water, and changes in flood water elevation can still occur without a change in bed elevation if the channel roughness or energy gradient changes; therefore, a direct check on flood levels using water level sensors (i.e., hydrometric monitoring) is important.

1.2.1 Bathymetric Monitoring

Over time, the flood conveyance capacity of the channel can be inferred by evaluating changes in the channel cross sectional area at defined locations along the length of the channel. A bathymetry survey was conducted at each monitoring station in 2021 using a single beam sounder linked to a Real Time Kinematic Global Navigation Satellite System (RTK GNSS) base station to document a discrete 'snapshot' of the channel morphology at locations on the Lillooet River where historical monitoring data exists. The 2021 bathymetry included the following components:

- Thirty- three (33) historical monitoring sections were surveyed along a 12.7 km section of the Lower Reach between the Ryan River and Green River confluences (**Figure 1.2**).
- Two hundred and sixty-two (262) transects were surveyed spaced 50 m apart within the same channel reach (**Figure 1.3**). 50 m spacing transects were previously surveyed in this reach in 2017.
- Longitudinal profile alignments along the left and right channel edges were surveyed within the same channel reach. Similar alignments were previously surveyed in 2017.
- Longitudinal profile alignment along the channel centreline was surveyed, extending a distance of 37.5 km upstream of the channel mouth, including the entire Lower Reach and approximately 16.1 km of the Middle Reach. Similar alignments were previously surveyed in 2017 and partially surveyed in 2011.
- One hundred and four (104) transects spaced 50 m apart in the Middle Reach, between 34.2 and 39.4 km upstream of the mouth. 50 m spacing transects were previously surveyed in this reach in 2017 (**Figure 1.4**).

Select 2021 cross section data has been processed and plotted to compare to the 2017 dataset, focussing on the Lower Reach between the Ryan River and Green River confluences. Longitudinal channel bed profile data from 2021 has been compared with the 2017 and 2011 datasets. Analysis of the monitoring data has been used to assess for changes in average bed elevations and cross section area at each monitoring section, and volumetric and unit bed elevation changes over the study reach. The results have been used to infer general effectiveness of the sediment removals. The bathymetry survey is described in **Section 2.1**, the channel bed elevation analysis is described in **Section 3.1**, and the results are presented in **Section 4.1**.

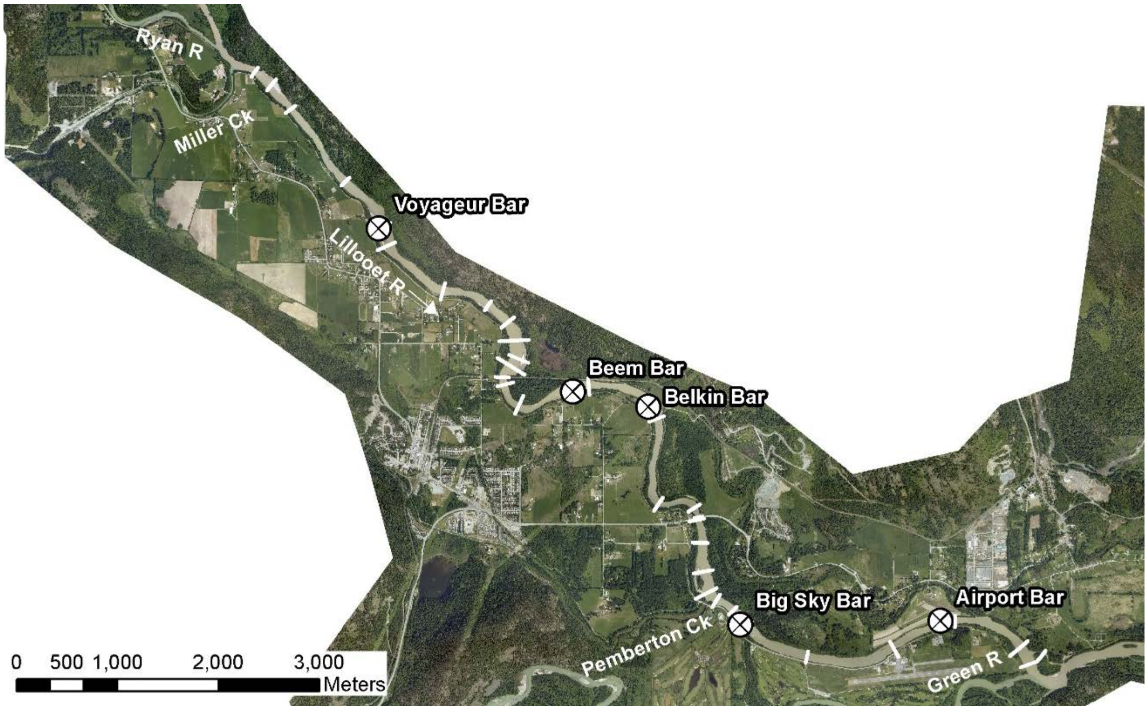


Figure 1.2 Lillooet River monitoring stations between the Ryan River and Green River confluences. Sediment removal sites and 2009 orthophoto background are shown for reference.

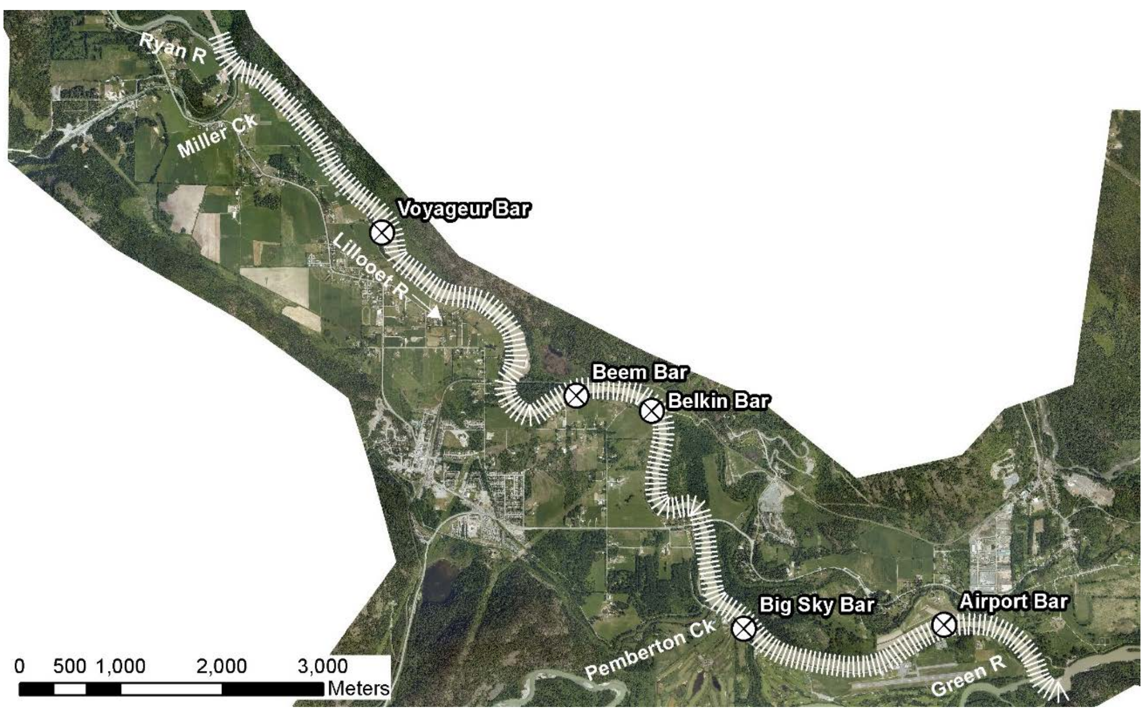


Figure 1.3 Lillooet River 50 metre transect spacing between the Ryan River and Green River confluences. Sediment removal sites and 2009 orthophoto background are shown for reference.

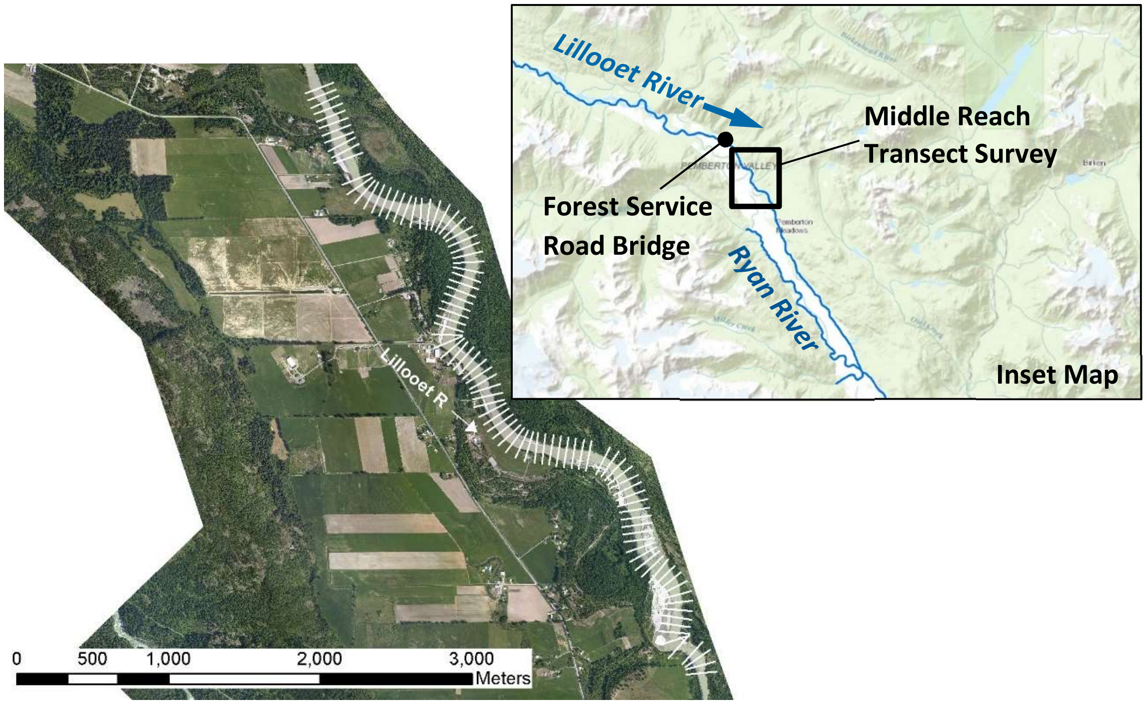


Figure 1.4 Lillooet River 50 metre transect spacing surveys carried out in the Middle Reach. 2009 orthophoto background is shown for reference.

1.2.2 Hydrometric Monitoring

In April 2021, NHC established five (5) hydrometric stations on the Lillooet River in the reach between Ryan River and Green River confluences (**Figure 1.5**). Each station is located nearby to of one of the five sediment removal sites for measuring and recording water level data over time. Water level data integrates changes in bed elevation with changes in the water surface gradient (energy gradient) and channel roughness to help understand the trajectory of flood levels. The water level data are intended to be used in conjunction with the Water Survey of Canada (WSC) Lillooet River gauge data to assess for long-term trends in water levels at each site. Hydrometric station 08MG005 is operated by the WSC branch of Environment and Climate Change Canada (ECCC).

Each hydrometric station includes a water level logger (i.e., levelogger) and at least three fixed elevation reference control points (i.e., hydrometric benchmarks), to record and archive water level time series and manually measured data. Station data sheets have been prepared and hydrometric stations have been established in Aquarius; a software for data management, processing, and analysis. The Aquarius database system that has been established for these sites will provide continued utility to the hydrometric monitoring program overtime.

The hydrometric monitoring activities are described in **Section 2.2**, the hydrometric analysis is described in **Section 3.2**, and the results are presented in **Section 4.2**.

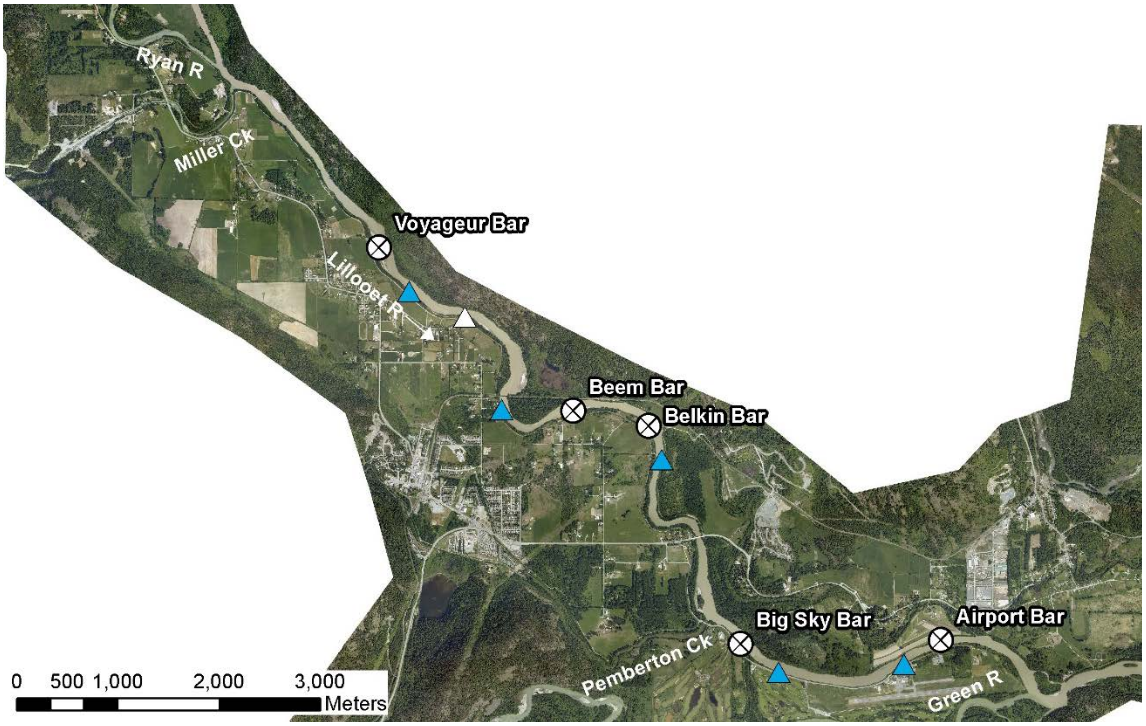


Figure 1.5 Location of water level logger monitoring sites between the Miller Creek and Green River confluences (blue triangles). The Water Survey of Canada gauge 08MG005 (white triangle), sediment removal sites (labelled white circles), and 2009 orthophoto background are shown for reference.

1.3 Applicable Guidelines

While there is no explicit set of guidelines for channel bed monitoring to evaluate changes associated with sediment removals and altered sediment supply rates, the following guidelines have been considered in the undertaking of this study:

- Ministry of Environment and Climate Change Strategy (MoECCS) 'Manual of British Columbia Hydrometric Standards' (MoECCS, 2018)
- Canadian Hydrographic Service Standards for Hydrographic Surveys. Edition 4, Feb. 2021. (Canadian Hydrographic Service, Fisheries and Oceans Canada, 2021)
- Guidelines for RTK/RTN GNSS Surveying in Canada. Version 1.1, July 2013. (Natural Resources Canada, 2015).
- Assessing Gravel Supply and Removals in Fisheries Streams (Sutek and Kellerhals, 1989).
- Legislated Flood Assessments in a Changing Climate in BC – Professional Practice Guidelines (EGBC, 2018).

2 FIELD ACTIVITIES

Field activities carried out include a bathymetric field program (**Section 2.1**) and a hydrometric field program (**Section 2.2**).

2.1 Bathymetric Field Program

The bathymetric field program was conducted by NHC personnel in two parts, firstly to establish geodetic control and secondly to perform the monitoring survey. The geodetic control survey activities were conducted on 5-6th July 2021 and the bathymetric monitoring was conducted between 12-17th July 2021. Based on WSC gauge 08MG005, the Lillooet River flow (i.e., discharge) ranged between 239 and 364 m^3/s over the duration of the bathymetric monitoring.

Data has been collected and processed relative to the following horizontal and vertical datums:

- Horizontal: North American Datum (NAD) 83; Canadian Spatial Reference System (CSRS) 2002 Projection: Universal Transverse Mercator (UTM) Zone 10 North
- Vertical: Canadian Geodetic Vertical Datum (CGVD) 2013; Geoid: Canadian Gravimetric Geoid (CGG) Model 2013a.

2.1.1 Control Point Survey

Control points from the 2017 bathymetry survey (NHC, 2018) were loaded into data collectors and searched in the field. Six (6) dual frequency survey grade GNSS receivers were used to statically occupy existing and newly established control monuments. Equipment used for control survey:

- Two (2) Trimble R12 GNSS receivers with a TSC3 data collector
- Two (2) Trimble R10 GNSS receivers with a TSC3 data collector
- Two (2) Trimble TDL 450 35w external radios
- Two (2) Emlid RS2 GNSS receivers with a smartphone app
- Six (6) external batteries
- Six (6) tripods and two (2) bipods

Three original control points, from 2017, were found and re-surveyed. The central control point (NHC1979) was occupied for nine (9) hrs. The second holding control point (NHC1191) was occupied for six (6) hrs. These two locations were applied as the anchor monitoring points (i.e., holding benchmarks) for the post-processing network adjustment that was applied using Trimble Business Center (TBC) post-processing software. All GNSS observables, raw static GNSS log files, have been uploaded into TBC. Antenna offsets and antenna reference points have been reconfirmed from fieldnotes taken during the control survey. All baselines have been computed using a static baseline processing style. All occupations have been submitted to Natural Resource Canada (NRCan) CSRS Precise Point Positioning (PPP) analysis. Positions for the holding benchmarks have been calculated from their NRCan PPP processing results (i.e., final IGS[1] ephemeris satellite positions). Four other benchmarks have been calculated using redundant baseline observations from all other stations, and the network adjustment has been calculated using the same parameters. Uncertainty values are estimated to be in the order of 0.01-0.02 m horizontally and 0.01-0.03 m vertically. The control points are summarized in **Table 2.1**, including individual control point residuals. **Figure 2.1** displays the control benchmarks and network connections.

Table 2.1 Summary of geomatic control points.

Control Point	Northing (m)	Easting (m)	Elevation CGVD2013 (m)	Description	Elevation Variance (m)
1	5588119.818	506066.003	224.74	NHC 1191	0.03
2	5578053.409	510897.169	217.43	NHC 1204	0.01
3	5574744.950	514609.787	207.96	NHC 1979	0.02
4	5572665.188	518840.232	204.31	NHC 3517	0.02
5	5582416.072	508616.959	216.67	NHC 4117	0.01
6	5572443.711	528969.968	231.45	NHC 4118	0.03

Figure 2.1 2021 Pemberton Valley control network.

[1] IGS refers to the International GNSS Service (https://igs.org/)

2.1.2 Bathymetry Monitoring

The monitoring survey was conducted with a RTK differential GNSS receiver that was radio-linked to base station receivers and synchronized to an echosounder. The following equipment was used for the survey:

- Trimble R12 rover and base station with a TSC3 data collector
- Trimble TDL 450 radio link
- Two Emlid RS2 base station receivers
- Toughbook with Hypack Hydrographic software
- Cee-Echo 200 kHz echosounder (5 Hz ping rate) with a 4 degree transducer
- Castaway conductivity, temperature, and depth (CTD) sensor to calculate sound velocity variations in the water column.

Historical monitoring sections and 50 metre transect lines were preloaded into the data collector for navigational reference. Some of the monitoring lines could only be partially replicated and others could not be replicated due to physical obstructions such as wood debris or sediment lobes. Accuracy of the echo sounder was checked against physical bed survey data and yielded sub decimetre to decimetre variances.

2.2 Hydrometric Field Program

NHC conducted regular inspections and maintenance of the NHC hydrometric stations throughout 2021 (**Table 2.2**). Station inspections and maintenance work included the following tasks:

- Inspection of instrumentation, including checking for damage and servicing, as necessary.
- Verification of water level sensor readings with manual water level measurements referenced to surveyed hydrometric benchmarks (i.e., level checks).
- Levelogger retrieval, download and redeployment as permitted by river water levels.
- Cleaning the sensor as needed.

When possible, hydrometric level surveys were collected in conjunction with station inspections and maintenance.

Table 2.2 Summary of 2021 Lillooet River monitoring hydrometric work.

Date	Work Conducted
09 April 2021	Initial reconnaissance GNSS survey of water levels
19-20 April 2021	Levelogger installation Control point installation GNSS and level survey of water levels and hydrometric benchmarks
14 May 2021	Levelogger retrieval, download, and redeployment Manual water level measurement
01 June 2021	Crest stage gauge installation Level survey of water levels and hydrometric benchmarks
02 June 2021	Manual water level measurements
30 June 2021	Manual water level measurements
21 October 2021	Manual water level measurements Extended and serviced crest stage gauges
28 October 2021	Levelogger retrieval, download, and redeployment Manual water level measurements Level survey (water levels, hydrometric benchmarks, crest stage gauge extensions)

2.2.1 Hydrometric station components

Each station includes a Solinst Levelogger 5 – M5 archiving total pressure sensor (levelogger), crest stage gauge, and a minimum of three (3) hydrometric benchmarks. Leveloggers are secured within 1.5” galvanized steel pipes bolted to pieces of rip rap with 3/8” expansion anchors (**Photo 2.1**).

Photo 2.1 Levelogger stilling well fastened to rip rap boulder at DS Airport Bar station.

Leveloggers record total pressure data (water and atmospheric pressure) at 5-minute intervals, which is consistent with other hydrometric stations in the Pemberton Valley. Hydrometric benchmarks are described in more detail in **Section 2.2.2**. The leveloggers and hydrometric benchmarks are intended as the primary source of water level data at each site. NHC also installed crest stage gauges at each site, to provide an experimental and low-tech contingency data source that records the maximum stage between successive station inspections.

Crest stage gauges are 15’ (4.5 m) long galvanized steel pipes with perforated caps at both ends and a wood staff inside the entire length of pipe (**Photo 2.2**). They are fastened to the bank similarly to the levelogger pipes. Granulated cork is sprinkled into the bottom of the crest stage gauge pipe during site inspections. The cork rises within the pipe as water levels rise and adheres to the wood staff as water levels fall, leaving a distinct line at the maximum water level reached since the last inspection. Station data are summarized in a series of station data sheets presented in **Appendix A**.

Photo 2.2 From left to right: Installed crest stage gauge; crest stage gauge with inner wood staff extending out; high water mark on wood staff left by cork.

2.2.2 Hydrometric benchmarks

Hydrometric benchmarks are fixed elevation reference points that have been surveyed to the CGVD 2013 datum and are used to directly measure water levels with either a tape measure or surveyor’s level. Direct water level measurements that reference the hydrometric benchmarks are used to verify levelogger data and provide discrete ‘snapshot’ water level records. They are either 0.5 m long sections of rebar driven into the ground adjacent to the top of the dike, or ¼” expansion anchors installed on the rip rap adjacent to the levelogger or crest stage gauge.

The hydrometric benchmarks were established on 19-20th April 2021 using a combination of Emlid Reach RS2 RTK GNSS receivers with a Samsung S20+ data collector, and a survey level. The base GNSS receiver was set up on the previously established control point NHC 1979. A check shot was performed at a nearby survey spike. The hydrometric benchmarks are summarized in **Table 2.3.**

At each station, one benchmark has been assigned a geodetic elevation based on the RTK GNSS data and the other benchmarks have been tied to this benchmark using closed level loops. The GNSS surveys will have absolute accuracies on the order of a few centimetres, while the level surveys enable the benchmarks to be tracked relative to each other to within a few millimetres.

In general, the elevation does not need to be resurveyed with a GNSS after the value has been assigned, and instead the elevation of the benchmarks relative to each other need to be confirmed with level surveys. Benchmarks are thereby used to determine if the local water level is rising or dropping relative to the local ground level.

Repeated geodetic surveys would be useful at time scales on the order of a decade or more to assess for subsidence or uplift along the valley. For the purpose of this study, the benchmarks will retain the 'assigned datum' established by the initial 2021 geodetic survey so that the water level can be tracked relative to the local elevation of the benchmarks. If the benchmarks are shown to move geodetically at a future point in time, this should be tracked separately as tectonic movement and the local benchmark elevations should not be updated. Adjusting the benchmark elevations could result in false shifts in the record.

Table 2.3 Summary of hydrometric benchmarks.

Station No.	Station Name	Hydrometric Benchmark Elevation (m, assigned datum)								
		BM 1	BM 2	BM 3	BM 4	BM 5	BM 6	BM 7	BM 8	BM 9
1	Downstream of Airport Bar	**NHC 3538 = 205.653**	**NHC 3537 = 205.146**	NHC 5043 = 202.600	NHC 5038 = 202.856	NHC 5050 = 203.544	NHC 5051 = 203.392	NHC LRLB = 202.334	NHC ULRB = 202.620	NHC TCGP = 205.151
2	Downstream of Big Sky Bar	**NHC 3535 = 206.145**	**NHC 3536 = 206.159**	NHC 5039 = 205.287	NHC 5036 = 204.198	NHC 5045 = 203.134	NHC TCGP = 206.703	NHC 5049 = 204.385	NHC 5048 = 204.354	
3	Downstream of Belkin Bar	**NHC 3533 = 208.956**	**NHC 3534 = 209.317**	NHC 5018 = 205.757	NHC 5017 = 205.134	NHC 5035 = 207.189	NHC 5046 = 206.230	NHC 5047 = 206.105	NHC TCGP = 208.553	
4	Uptream of Beem Bar	**NHC 3532 = 209.389**	**NHC 3531 = 209.409**	NHC 5020 = 207.596	NHC 5019 = 206.382	NHC DS LRB = 206.370	NHC DS HRB = 206.729	NHC TCGP = 209.664		
5	Downstream of Voyageur Bar	**NHC 3539 = 212.663**	NHC 3540 = 210.848	NHC 5044 = 208.147	NHC 5037 = 208.148	NHC LRRB = 208.045	NHC TCGP = 210.854	NHC LRLB = 209.529		

Notes:
1. BM 1 refers to the primary hydrometric benchmark at each station, and was derived using GNSS survey methods. Elevation values of all other hydrometric benchmarks were established based on a level survey that references BM 1.
2. Benchmarks in **bold** were surveyed with GNSS. **Bold** non-primary benchmark elevations in this table have still been established via level survey, though may function as a redundant primary benchmark if BM 1 is damaged.

3 ANALYSES

Analyses conducted include a channel bed elevation change analysis (**Section 3.1**) and a hydrometric analysis (**Section 3.2**).

3.1 Channel Bed Elevation Change Analysis

Changes in bed elevation have been analyzed by comparing the 2021 bathymetric survey data with survey data collected in 2011 (Atek Hydrographic Surveys Ltd.) and 2017 (NHC). Methods used to conduct the 2011 and 2017 surveys are described in KWL, 2011 and NHC, 2018, respectively. The methodology applied for the bed elevation change analysis is described below and the results of the analyses are presented in **Section 4.1**.

3.1.1 Methodology

Bathymetry post-processing has been conducted using Hypack single beam editor software. This hydrographic software allows the user to interface graphically with all individual soundings in profile. Geodetic parameters, sound velocities and sounder field checks have been confirmed. Sounder field checks involve logging a sounding file in Hypack and confirming the final elevation with an RTK GNSS topographic survey point in the same spot on the river. The purpose is to conduct an independent check that the hydrographic software is properly calculating the geodetic position and combining it with the depth sounding value to generate a final channel bed elevation. All checks are within ±0.05 m. If possible, errant soundings, caused by instantaneous disconnections with the RTK GNSS, have been either interpolated to align with the vessel track or deleted. Exported processed bathymetry data and the raw RTK GNSS and sounding data information has been reviewed and compared for quality checking purposes.

Bathymetric point data from each survey have been compiled, plotted, and compared using a set of proprietary spreadsheets. Cross sectional changes have been computed at each of the thirty-three (33) historical monitoring sections in the Lower Reach, between the Ryan River and Green River confluences (referred to hereafter as 'historical monitoring sections'). The computed results at each of the historical monitoring sections have been derived by determining the area between the surveyed bed and a simulated 2-year return period water surface elevation. Volumetric changes have been estimated based on an end-area approach, by multiplying the cross sectional changes at each monitoring section by one-half the length of channel distance between each of the upstream and downstream monitoring sections and summing the total over the study reach. Channel aggradation rates between 2017 and 2021 have been estimated by cumulatively summing the computed end-area volumetric changes and accounting for the volume of sediment removed by excavation.

Net and cumulative volume changes and unit bed elevation changes through the study reach have been computed. Cumulative analyses provide a useful indicator of the total accumulation upstream of a given location on the channel, whereas net analyses represent the change through the entire study reach. Unit bed elevation changes have been computed by dividing the computed end-area volume for each monitoring section by the corresponding computed surface area. Each unit bed elevation change represents a 'channel unit' that is based on changes at one of the monitoring sections. Total estimated sediment removal volumes at each of the five management sites have been included into the calculations. For this, we have assumed sediment removal volumes at each management site are applied to the nearest monitoring section to each site.

Aside from the monitoring stations on either side of the Highway 99 crossing, the historical monitoring sections included in the analysis are spaced between 82 and 907 m apart, or 376 m on average. Volumetric comparisons have been conducted for three sub-reaches using survey data collected at each of the transects spaced 50 m apart. To assess how the results vary depending on the spacing of the monitoring sections applied, these results have been compared to the results of the analysis conducted for these same reaches using data from the more distally spaced historical monitoring sections. **Figure 3.1** shows the three sub reaches:

- Sub-reach A covers historical monitoring sections 44 and 45, a distance of 907 m
- Sub-reach B covers historical monitoring sections 54 to 57, a distance of 1,005 m
- Sub-reach C covers historical monitoring sections 70 to 71, a distance of 901 m

To evaluate the variances in the results, the sub-reach analysis replicated the same end-area approach using the 50 m transects and conducted a grid raster analysis using the same data. For the grid raster analysis, a DEM was generated for each sub-reach using GIS software and converted to a series of 5 m resolution grid cells. For this approach, volume change within the sub-reach is the summed total of the computed volume of each raster cell.

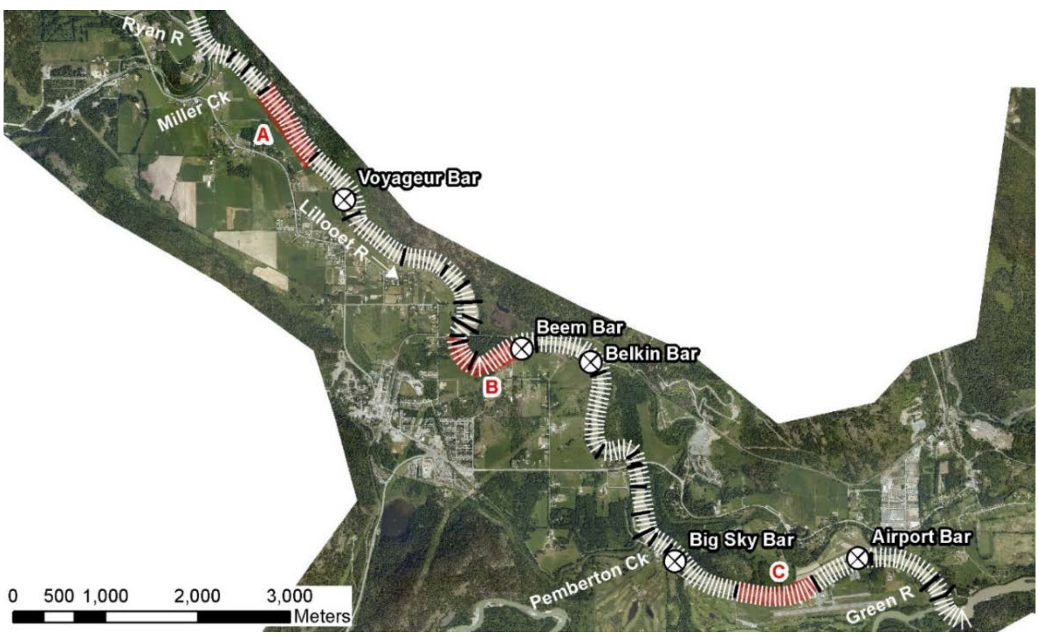


Figure 3.1 Location of three sub-reaches used to evaluate volumetric (labelled as 'A', 'B', and 'C'). Historical monitoring sections are shown in black and 50 metre transects are shown in white. 2009 orthophoto background is shown for reference.

Longitudinal channel bed profile changes between 2011, 2017 and 2021 have been compared by snapping data points from each survey to a defined channel centreline alignment using GIS software and plotting the bed elevations against the channel distance upstream of the mouth. Estimated average channel bed elevations at each cross section location have been computed by integrating the elevation of the channel bed at the deepest parts of the channel, on the sediment bars, and at all points in between.

The 2021 monitoring survey data was conducted using an echo-sounder, limiting the survey to locations that were submerged and accessible by boat during the field program. Therefore, exposed bars or other areas that were too shallow or treacherous to survey during the boat-based 2021 bathymetry survey are excluded, and the 2017 to 2021 analysis has been limited to those portions of the monitoring sections where data exists for both datasets.

3.1.2 Uncertainty

The overall uncertainty associated with the channel bed elevation change analysis is a function of the vertical accuracy of each survey used in the comparison, the completeness and proximity of the surveyed points relative to the defined monitoring section alignment, the density of the survey points, the number of monitoring sections used to conduct the end area analysis, and the complexity of bed formations and mobility of the bed during the survey.

Similar to the 2017 dataset, the vertical accuracy of the 2021 bathymetry data is estimated to be in the order of ± 0.15 m; however, accuracy may be in the order of ± 0.3 m in locations due to challenging conditions on the Lillooet River. Fluctuations in the channel bed were detected on different days during each of the 2011 (KWL, 2011), 2017 (NHC, 2018) and 2021 surveys, based on comparison of overlapping survey points. These bed elevation differences vary across the channel and along its length and typically range from less than 0.1 m to several decimetres; in some locations the variances are in the order of 1 m or more. Observed fluctuations in the bed surface may be associated with mobile bed forms, in addition to bathymetry error associated with vessel pitch and roll.

Since the 2017 monitoring survey was carried out (NHC, 2018), NHC has acquired a new single beam sounder (i.e., Cee Hydrosystems Cee-Echo), with a much higher ping rate (5-20Hz) and narrower beam angle (3^0). In 2017, an Ohmex Sonarmite 200 kHz ranging beam angle ($6\text{-}10^0$) was used. As a result, the 2021 dataset has much less noise, a narrower beam angle, and more along-line detail.

The analysis is limited to locations where bathymetric monitoring data in 2017 and 2021 overlapped, which may introduce some degree of bias into the results. However, the sediment removal volumes at the management sites account for an order of magnitude more sediment volume than the end-area analysis using the historical monitoring sections. The results of the sub-reach analyses are presented in **Section 4.1.2**. In our opinion, the variation in the computed results of the sub-reach analyses provides an order of magnitude understanding of the potential range in uncertainty for the channel bed level assessment, depending on the resolution of data being compared. A more detailed analysis of cumulative errors in the overall monitoring analysis has not been undertaken for this study, and as such, the error may be higher.

Inherent, unresolved uncertainties exist when estimating bed elevation change over time due to the mobile and unstable nature of the bed and presence of bedforms that can result in substantial fluctuations that cannot be resolved from survey error. Furthermore, estimating average annual aggradation rates using sub-decadal to decadal scale data records can severely over or under predict the long-term sediment transport rate by an order of magnitude (Jordan and Slaymaker, 1991). Estimated aggradation rates should be refined over time as more data are obtained and additional analysis is undertaken.

3.2 Hydrometric Analysis

Eventually, once the water level data record is more extensive, a specific gauge analysis will be conducted to determine potential channel geometry changes at each monitoring station. To date, the dataset includes 2021 pre-freshet, freshet, and post-freshet conditions, as summarized in **Section 4.2**. Changes to the channel geometry are most clearly observed at low flows, but channel conveyance is of most concern during high flows. Low to moderate flows have occurred twice in the existing data record. High flows have only occurred once.

3.2.1 Specific Gauge Analysis

This section describes the specific gauge analysis methodology that will be used to establish changes to the channel geometry at each site. For any one river gauge location, Blench (1966) defined the "specific gauge" as the staff gauge elevation at a specific discharge. As the relationship between gauge elevation and discharge is only known for a limited number of measured discharge values, a rating curve equation is developed that represents the interpolation of gauge elevations for all discharge values. The rating curve then allows one to back-calculate the specific gauge for any discharge at this location, even though it was not measured directly. If geomorphic or hydraulic changes occur, this specific gauge height might shift for a given discharge, as sediment might accumulate or erode or the hydraulic geometry changes due to natural or human causes (Klingeman, 1973).

NHC (2018) developed a slightly different approach to the specific gauge analysis. NHC's approach compares historical gauge elevations that coincide with discharge measurements to specific gauge elevations calculated from a reference rating curve. This method allows the effects of channel changes at all measured discharge magnitudes to be plotted. More importantly, this method is independent of how the rating curves are drawn by the hydrographers as the historic rating curves are not used, only the actual field measurements of stage and discharge. If there are no differences between measured and rating-curve-predicted stage, the rating curve represents the measured conditions well. If past measurements show a systematic difference to the current rating curve, it means that the relationship between stage and discharge has changed, which could be caused by changes in the hydraulic geometry of the river (e.g., due to erosion or accumulation, or construction activity that changed the hydraulics at the gauge).

3.2.2 Reference Rating Curves

NHC created a reference rating curve for each monitoring location using NHC-measured stage and ECCC-calculated discharge. The rating curves have been fit using data from 09 April 2021 to 28 October 2021.

As the program continues, it is proposed that new stage-discharge field measurements would be plotted with these curves to determine whether a given future discharge measurement corresponds to a higher or lower stage at each location.

3.2.3 Crest Gauges

The crest stage gauges are experimental but may provide additional contingency. They record the highest water level reached at each site, independently of the archiving water level sensors. The crest stage gauges were overtopped in the late June high water event and have since been raised and serviced in preparation for subsequent events.

3.2.4 Quality assurance, quality control, compliance with hydrometric quality standards

NHC observes strict protocols for data quality assurance (QA) and quality control (QC) and uses Aquarius software for data management, processing, and analysis. QA/QC procedures include:

- Onsite inspection of sensors when safe access is permitted
- Removal of stage discontinuities related to sensor maintenance, and replacement with interpolated data
- Comparison of sensor records to manual water level measurements
- Assignment of grade levels to stage series;
- Comparison and correlation of stage series in order to identify and correct anomalies or erroneous values.

The Manual of British Columbia Hydrometric Standards (MoECCS, 2018) framework for quantifying hydrometric data quality in the form of data grades has been used to assess the Lillooet River stage data. Assigned grades represent the current station conditions, and grades may change as additional data is collected.

3.2.5 Data risks and program contingencies

There are several data quality or data loss risks associated with the continuous water level monitoring in this study. Risks to the continuous water level data include sensor damage or loss from sediment transport in the river, and sensor malfunction or deployment errors. The consequences of these issues are increased due to the archiving nature of the sensors rather than real-time sensors, and due to the fact that they are only accessible at low flows. As such, sensor issues are not discovered until they are physically inspected and downloaded, which cannot be done during spring and summer flow conditions.

Another potential data issue in the study relates to the calculated discharge in the Lillooet River. ECCC estimates Lillooet River discharge using a rating curve, which describes the relation between stage and discharge at a given location. Rating curves are used to estimate discharge because it is practical to measure stage continuously but not discharge. However, rating curves are subject to change based on changes to the channel geometry. The high rate of sediment transport in the Lillooet River means the channel geometry is subject to frequent changes, which lowers confidence in rating curve-derived discharges. NHC's proposed analysis accounts for these changes and is described in **Section 3.2.1**.

During the 2021 program NHC strived to coordinate field excursions with ECCC staff to ensure the NHC station inspections coincided on the same day as the ECCC discharge measurements. This provided reliable stage and discharge measurements at each site independent of the water level sensor errors, and with minimal ECCC rating curve errors. Because the manual water level measurements and discharge measurement do not happen at the exact same time during the day, the stage-discharge data point for each station is based on a minor interpolation of the calculated discharge. However, because the interpolated discharge is close to the measured discharge, this discharge error is considered to be very minor.

Overtime, the physically collected water level data points that coincide with each ECCC discharge measurement can meet the study's data needs if they are collected over a long enough time period. For the 2021 year, the paired NHC site inspections and ECCC discharge measurements are the primary data records due to logger deployment errors that led to substantial data gaps at all but one of the sites (Lillooet River 3 – Lillooet River Downstream of Belkin Bar). NHC has since implemented additional internal procedures to mitigate for this deployment error during subsequent site visits.

4 RESULTS

The results of the channel bed elevation change analyses are presented in **Section 4.1** and the hydrometric analyses are presented in **Section 4.2**.

4.1 Channel Bed Elevation Change Results

Based on the analyses and uncertainty described in **Section 3.1**, the results are described herein. As described in detail in **Section 4.1.1**, an aggrading trend is apparent upstream of Highway 99, with a slight degrading trend apparent downstream of the Pemberton Creek confluence. Over the entire study reach there is a computed net volumetric change in the surveyed bed surface of approximately -7,000 m^3 between 2017 and 2021, indicating a net deficit. This corresponds to a net bed material surplus of 122,000 m^3 when accounting for the approximately 129,000 m^3 of sediment that was removed from the channel over this timeframe.

By examining the cumulative volumetric changes in the study reach between 2017 and 2021, and considering uncertainty in the analyses, an upper bound rate of annual channel aggradation is estimated to be 40,000 m^3/year. This value represents approximately two-thirds of the annual target sediment removal rate over each of the past two years.

In general, the results support our opinion that the magnitude of the sediment removal program between 2017 and 2021 has been effective in managing reach-scale channel aggradation within the Lower Reach, and widespread lowering of the channel bed profile is not apparent. Between 2017 and 2021, the annual average unit channel bed elevation change over the study reach ranges from a lowering rate of less than 0.01 m/year to an infilling rate of 0.08 m/year, with an average infilling of 0.01 m/year. Had no sediment been removed from the channel, the values theoretically could have ranged between less than 0.01 to 0.12 m infilling/year with an average of 0.06 m/year.

A sub-reach analysis undertaken at three locations along the study reach (presented in **Section 4.1.2**) indicates variances in the computed changes in bed volume within those sub-reaches of between 33% to 392% of the estimated values. For context, this degree of uncertainty equates to a ±0.06 m variance in the computed unit bed elevation rate, or less than 0.02 m/year. The sub-reach analysis illustrates the substantial degree of uncertainty associated with the application of the more distally spaced historical monitoring sections for end-area volumetric calculations. A more detailed analysis of cumulative errors in the overall monitoring analysis has not been undertaken for this study and the error may exceed these computed variances.

As presented in **Section 4.1.3**, a comparison of the 2011, 2017, and 2021 longitudinal channel bed profiles indicates the channel bed profile generally remains similar to the 2017 channel bed condition, and both the 2017 and 2021 channel bed profiles are substantially higher than the 2011 profile, representing net aggradation since 2011. Between the Pemberton Creek and Green River confluences, where a slight, predominant degrading trend has been observed since 2017, the longitudinal profile survey data indicates the 2021 channel bed elevation is often higher than the 2011 channel bed by more than 1 m, with several locations that between 2 to 3 m higher.

Cross section plots of 2017 and 2021 channel bathymetry data are presented in **Appendix B** (Lower Reach, between Ryan River and Green River confluences) and **Appendix C** (Middle Reach, between 34.15 and 39.40 km upstream of the mouth)**.** The results of the bed elevation change analyses are presented below.

4.1.1 Historical Monitoring Section Analysis

The results of the analysis of historical monitoring sections on the Lillooet River, in the Lower Reach, between the Ryan River and Green River confluences are presented in a series of plots and discussed below. Each includes labels that refer to the locations of the Green River, Pemberton Creek, and Ryan River confluences; the Highway 99 and railway bridge crossings; and the five channel bars being actively managed by the PVDD.

Figure 4.1 presents the 2017 and 2021 estimated average channel bed elevation, based on a comparison of the two survey datasets. The average bed elevation change plot represents changes at a given monitoring section location only, so while this plot provides an indication of changes at a particular channel cross section it does not necessarily represent changes along the channel (this is represented in a series of unit bed elevation plots presented later in this section). Over the 2017 and 2021 monitoring period, computed average bed elevation changes at specific monitoring sections range between 0.49 m (at the left bank bar upstream of the railway bridge) and -0.40 m (upstream of Highway 99). Larger negative changes (i.e., scour) occurred at the highway and railway bridges (-0.65 m and -0.57 m respectively); however, it is our opinion that hydraulic influences at these bridge openings may be associated with scour and fill processes that are not indicative of reach-scale bed level changes.

Downstream of the Pemberton Creek confluence, average bed elevation changes range between -0.09 to 0.01 m, representing a predominant pattern of degradation within this sub-reach. For context, **Figure 4.2** presents a longitudinal profile plot of 2011, 2017 and 2021 survey data between Airport Bar and the Green River confluence. This plot illustrates that the surveyed 2021 channel bed level remains substantially higher than the 2011 channel bed condition, despite observed channel lowering since 2017.

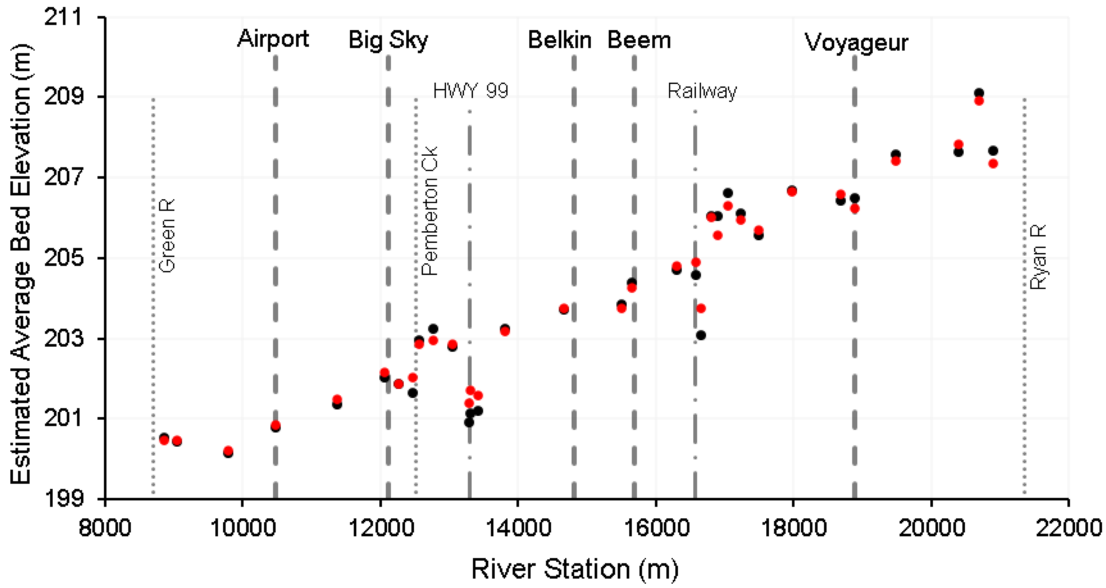


Figure 4.1 2017 (red dots) and 2021 (black dots) estimated average channel bed elevation at the historical monitoring sections on the Lillooet River Lower Reach, between Ryan River and Green River confluences.

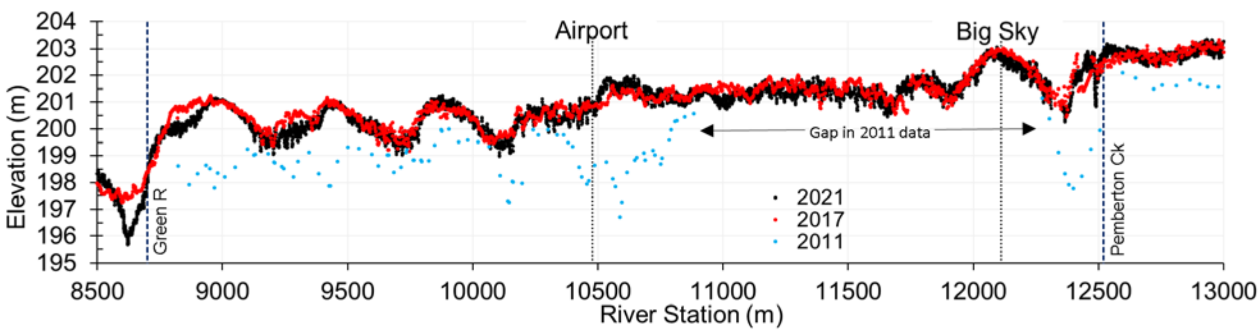


Figure 4.2 Lillooet River 2017 and 2021 channel bed longitudinal profile between Pemberton Creek and Green River confluence.

Figure 4.3 presents the estimated cumulative volume of channel bed infilling for two conditions: one represents the cumulative changes based on the survey data only, and one represents changes assuming no sediment removals had occurred over the monitoring period (i.e., includes sediment removal volumes). Positive values represent infilling of the channel bed (i.e., a net increase in the channel bed volume) and negative values represent scour. The plotted line that includes the sediment volumes is a theoretical representation of the total potential for channel bed infilling since 2017. Actual aggradation rates along the study reach are expected to vary compared to the theoretical values presented herein, because of the tendency for sediment to accumulate at localized zones of deposition.

Figure 4.4 replots the estimated cumulative volume of channel bed infilling (based on the survey data only) along with the estimated upper and lower error bounds. The error bounds are based on the results of a sub-area analysis, described in **Section 4.1.2**. The theoretical maximum aggradation over the study period occurs at a bar upstream of the railway crossing; it is presently inaccessible and has not yet been targeted for sediment removals. Overtime, sediment removals at Voyageur Bar may reduce the rate of aggradation at this bar. However, due to the hydraulic influences of the railway crossing on the channel morphology, sediment removals at Beem and Belkin Bars may be limited in their effectiveness to induce a geomorphic channel response that would substantially reduce the bar upstream of the railway bridge.

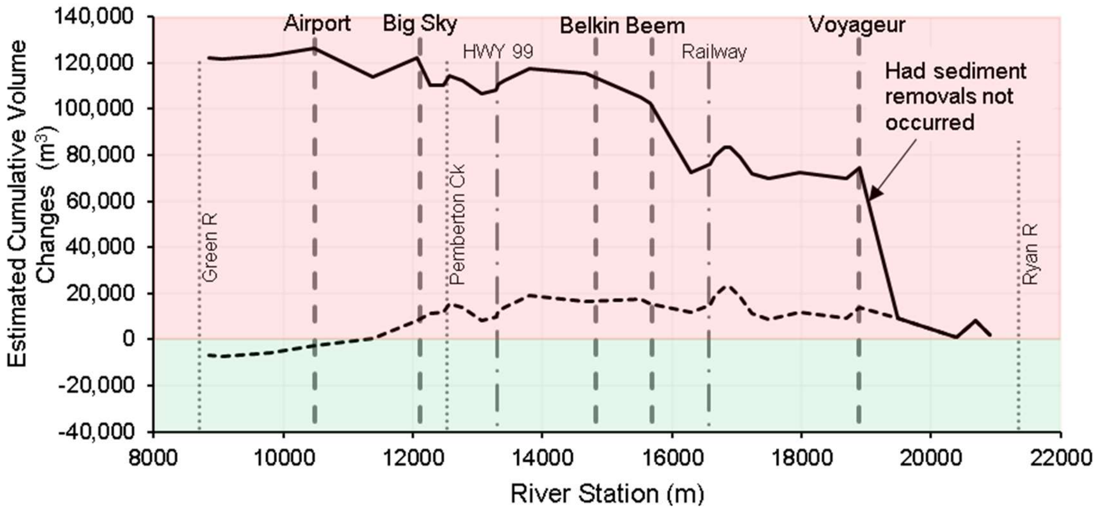


Figure 4.3 2017 to 2021 estimated cumulative volumes of channel bed infilling (positive values) and scour (negative values). Line plotted for the condition 'had sediment removals not occurred' is theoretical.

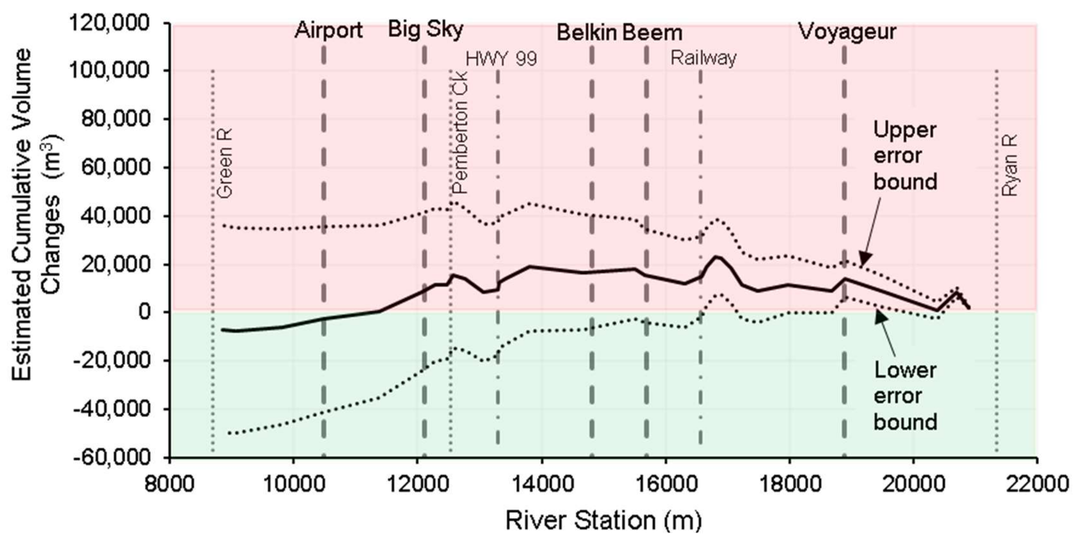


Figure 4.4 2017 to 2021 estimated cumulative volume of observed channel bed infilling (positive values) and scour (negative values), excluding sediment volumes that have been removed over the monitoring period. Upper and error bound estimates are shown for context.

Figure 4.5 presents the theoretical average annual estimated cumulative volume of channel bed infilling that could have occurred had no sediment been removed, including upper and lower error bound. Data from this plot has been used to estimate the annual average channel aggradation rate.

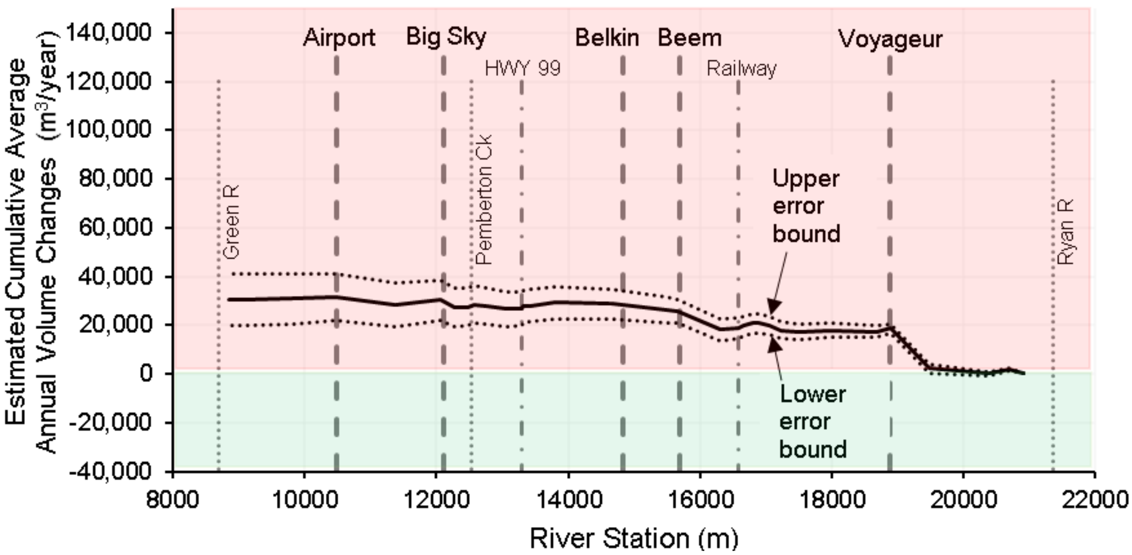


Figure 4.5 Estimated theoretical annual average cumulative channel bed infilling (positive values) and scour (negative values) rates between 2017 and 2021, had no sediment removals occurred. Upper and error bound estimates are shown for context.

Figure 4.6 presents the estimated change in unit bed elevation between 2017 and 2021 for two conditions: one representing observed channel infilling and one representing a theoretical infilling assuming no sediment removals had occurred over the monitoring period. Unit bed elevation changes are a representative value of the channel infilling that could occur assuming aggradation occurred uniformly over the area being represented (i.e., for this study the channel is comprised of a series of 'units,' each represented by one of the monitoring sections). For a given volumetric change at a monitoring section, larger unit bed elevation changes would occur at narrower channel locations. This metric provides useful context to illustrate the potential responsiveness of the channel bed to sediment volume accumulations. The plotted line that shows the condition 'had sediment removals not occurred' is a theoretical representation of the total potential that the channel bed could have infilled since 2017. Over the monitoring period, the unit channel bed within the study reach theoretically could have aggraded by an average of 0.2 and as much as 0.5 m, had no sediment removals occurred during the course of the monitoring period. The plot shows the apparent influences of the sediment removals increase farther upstream, reaching a theoretical maximum at Voyageur Bar.

Figure 4.7 presents the estimated average annual change in unit bed elevation between 2017 and 2021, had sediment removals not occurred, including the upper and lower error bound estimates for context. This plot represents the same data that is presented in the previous plot, with the data averaged over the monitoring period. The plot provides context on theoretical annual bed infilling rates.

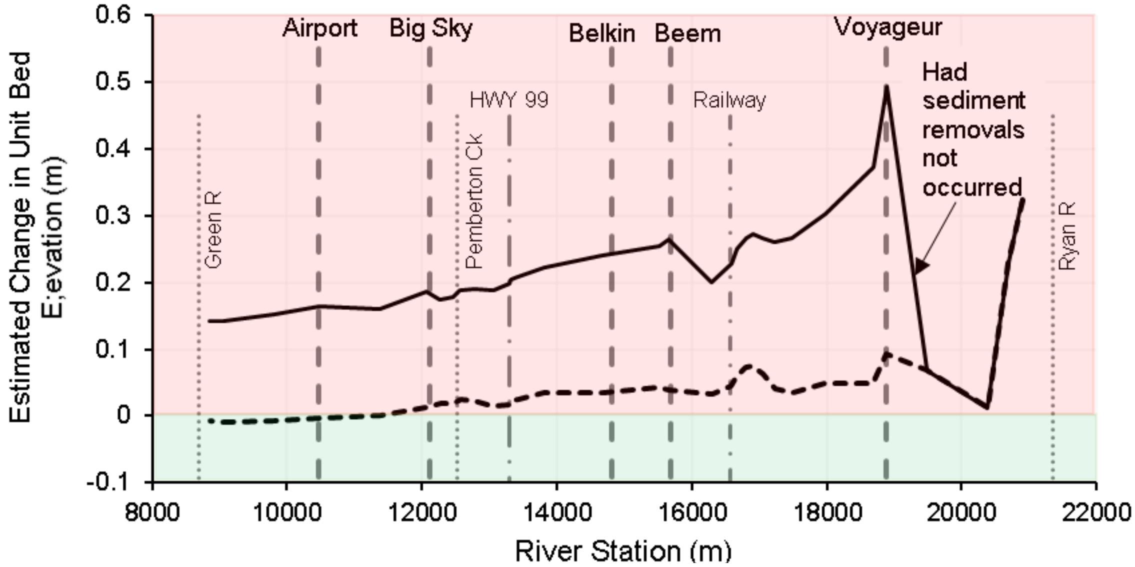


Figure 4.6 Estimated change in unit bed elevation between 2017 and 2020. Upper and error bound estimates are shown for context.

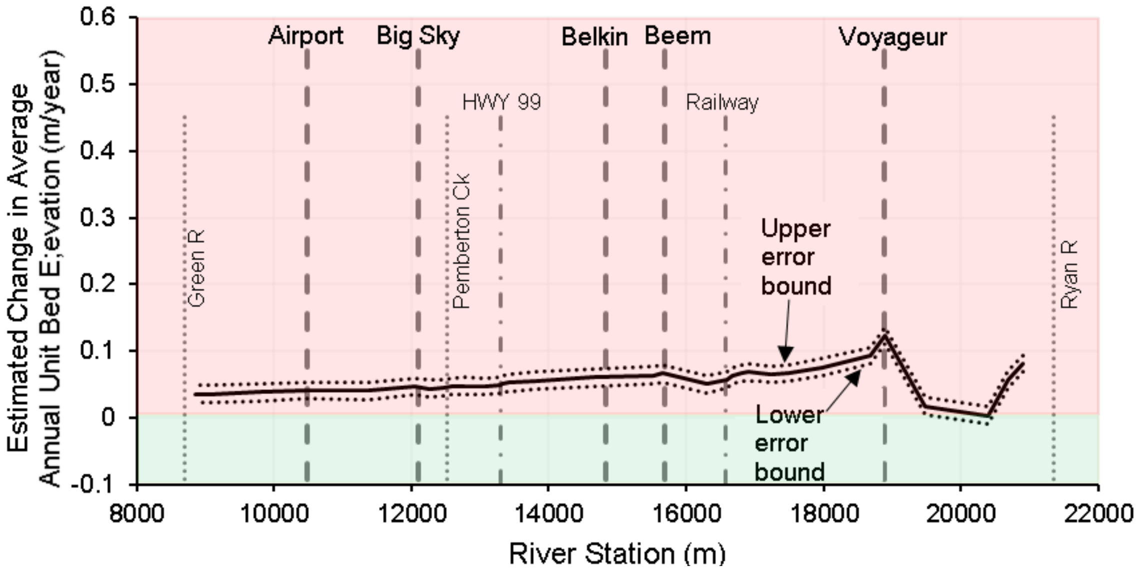


Figure 4.7 Estimated average annual rate of change in unit bed elevation between 2017 and 2020 had sediment removals not occurred. Upper and error bound estimates are shown for context.

4.1.2 Sub-Reach Analyses

Figure 4.8 compares the results of end-area and grid raster analyses using the 50 m transect data to the results of an end-area analysis that relies on the historical monitoring sections. The analyses have been conducted for three sub-reaches, as described in **Section 3.1.1**. The analyses are limited to data collected via bathymetric surveys and exclude any channel areas that were too shallow or located above water. The uncertainty analysis reflects the variation in the computed results and provides an order of magnitude understanding of the potential range in values depending on the resolution of the data being included in the analysis.

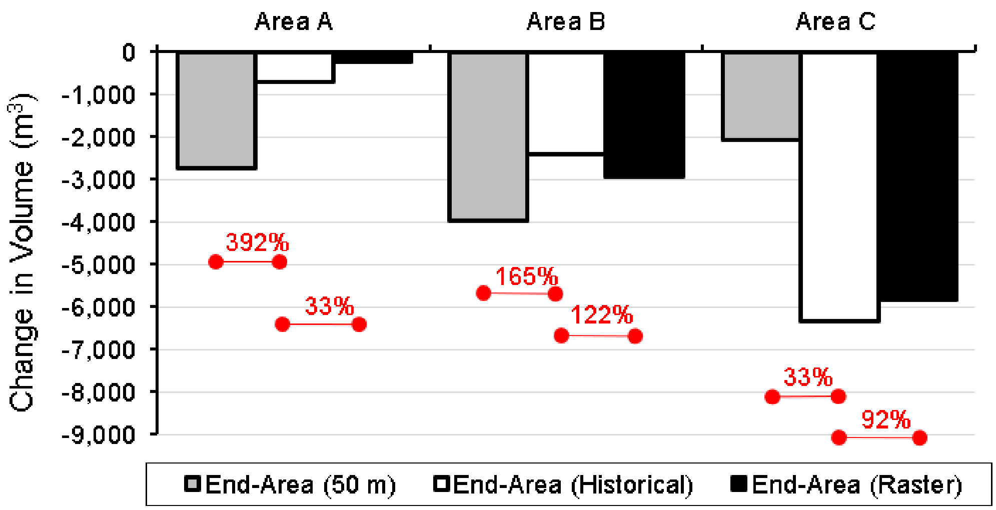
The results of the sub-reach analyses indicate the end-area volumetric calculations at the sub-reach scale vary by between 33% and 392%, depending on whether the 50 m transect or more distally spaced historical monitoring sections have been applied. These variances are assumed to represent plausible lower and upper bound variances in the overall results of the analysis conducted for the reach between the Ryan River and Green River confluences. These volumetric variances correlate to a variance in estimated unit bed elevation changes of ±0.06 m, or less than 0.02 m/year. For context, this value is less than one-third of the average and one-eighth of the maximum estimated unit bed elevation changes between 2017 and 2021, had no sediment removals occurred.

The results of the end-area volume calculations using the monitoring sections and grid raster calculations ranged between 33% and 122%, corresponding to a unit bed elevation variance of 0.05 m, or approximately 0.01 m/year. The grid raster approach offers a relatively lower level of effort to compute bed elevation changes using the 50 m transect data, compared to the end-area approach.

Sub-reach A includes nineteen (19) 50 m transects between historical monitoring sections L44 and L45, located upstream of Voyageur Bar. **Figure 4.9** presents a plan view showing the distribution of data used for the end-area and grid analyses, and **Figure 4.10** presents a grid raster map showing the difference between the 2021 and 2017 datasets. Red colours on the difference map represents infilling and blue represents scour.

Sub-reach B includes twenty-one (21) 50 m transects between historical monitoring sections L54 and L57, located upstream of Beem Bar. **Figure 4.11** presents a plan view showing the distribution of data used for the end-area and grid analyses, and **Figure 4.12** presents a grid raster map showing the difference between the 2021 and 2017 datasets.

Sub-reach C includes eighteen (18) 50 m transects between historical monitoring sections L70 and L71, located upstream of Airport Bar. **Figure 4.13** presents a plan view showing the distribution of data used for the end-area and grid analyses, and **Figure 4.14** presents a grid raster map showing the difference between the 2021 and 2017 datasets.



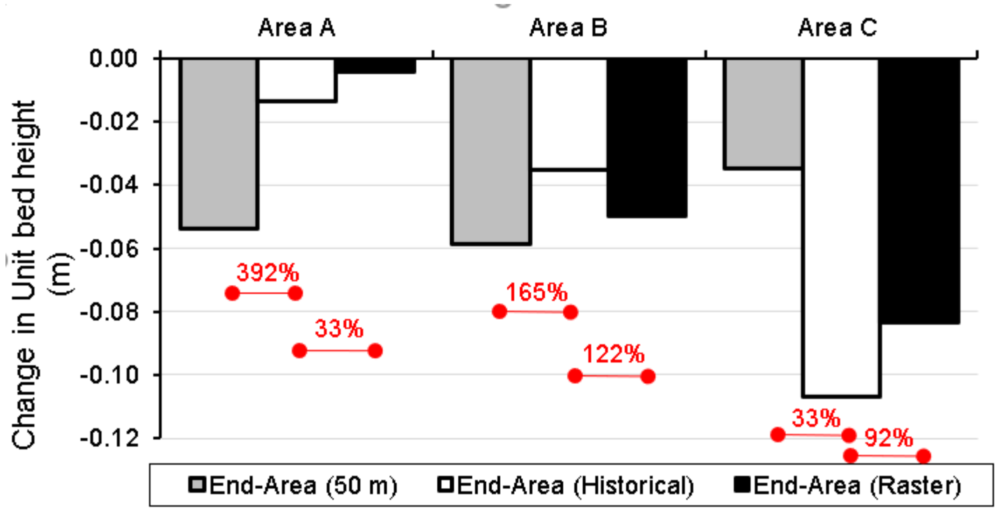


Figure 4.8 2017 to 2021 comparisons of changes in channel bed volume and unit bed height for three analytical approaches.

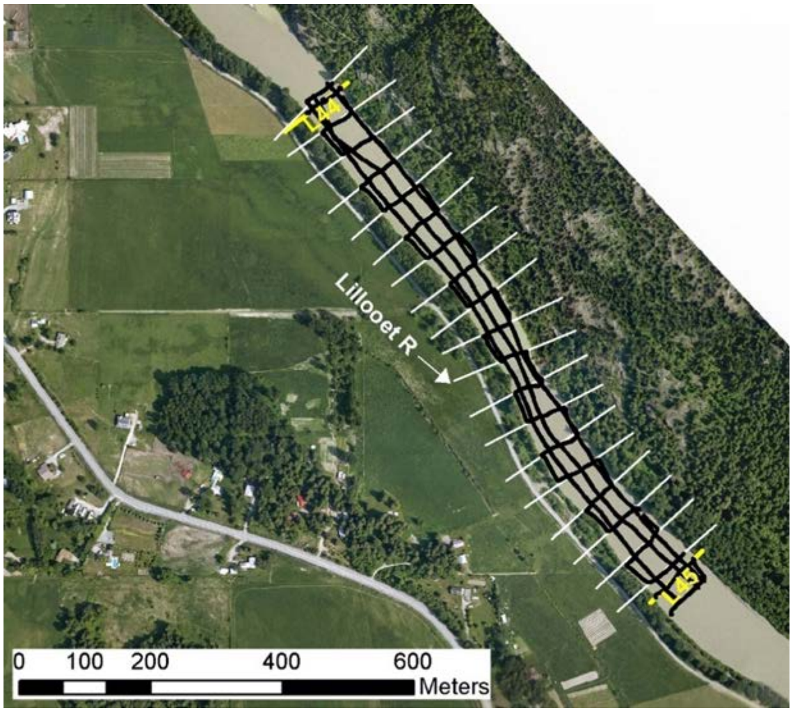


Figure 4.9 2021 sub-reach A monitoring section data. Historical monitoring sections L44 and L45, 50 metre spacing transect lines, and 2016 EMBC orthophoto are shown for reference.

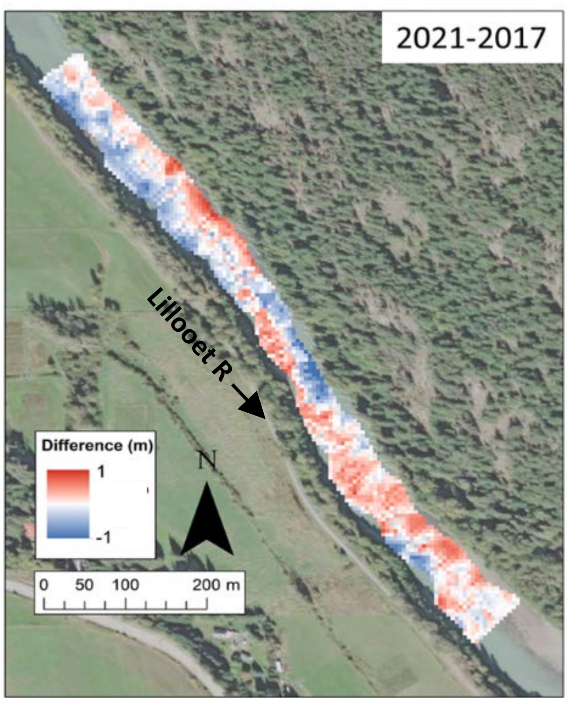


Figure 4.10 Sub-reach A grid raster analysis. Red indicates bed infilling and blue indicates bed lowering between 2017 and 2021.

Figure 4.11 2021 sub-reach B monitoring sections. Historical monitoring sections L54 to L57, 50 metre spacing transect lines, and 2016 EMBC orthophoto are shown for reference.

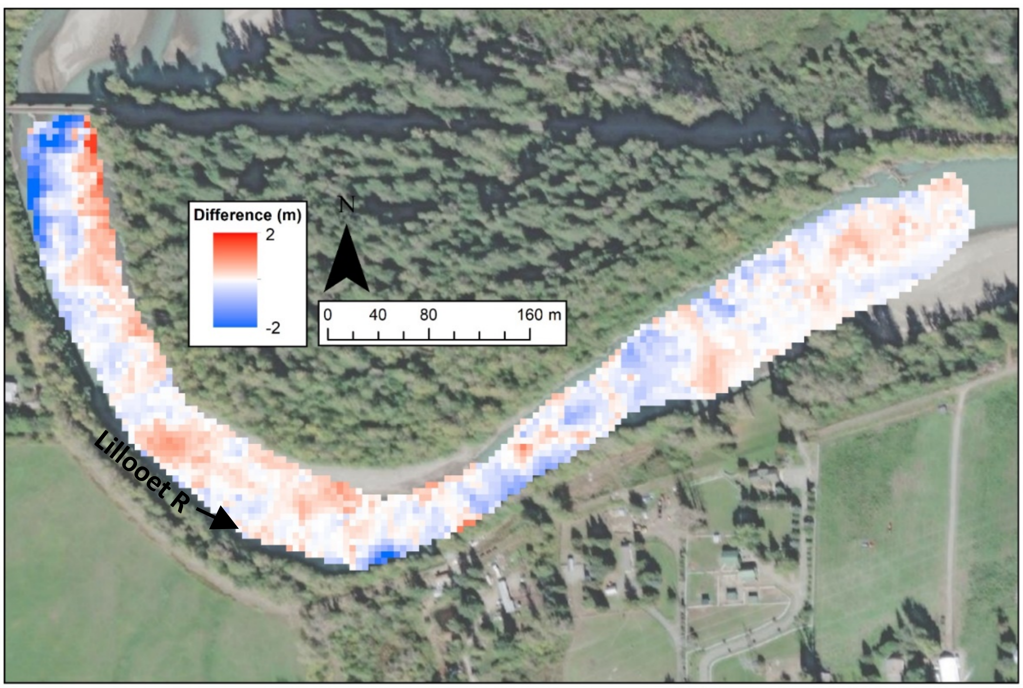


Figure 4.12 Sub-reach B grid raster analysis. Red indicates bed infilling and blue indicates bed lowering between 2017 and 2021.

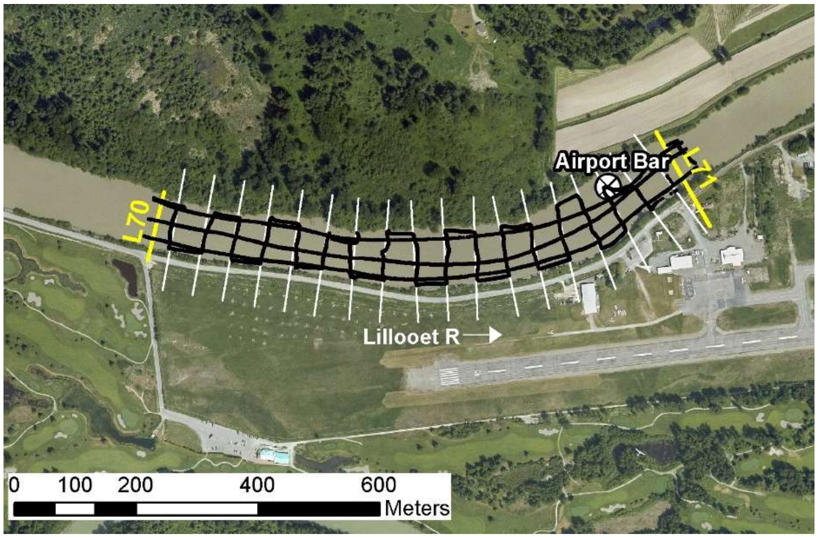


Figure 4.13 2021 sub-reach C monitoring section data. Historical monitoring sections L70 and L71, 50 metre spacing transect lines, and 2016 EMBC orthophoto are shown for reference.

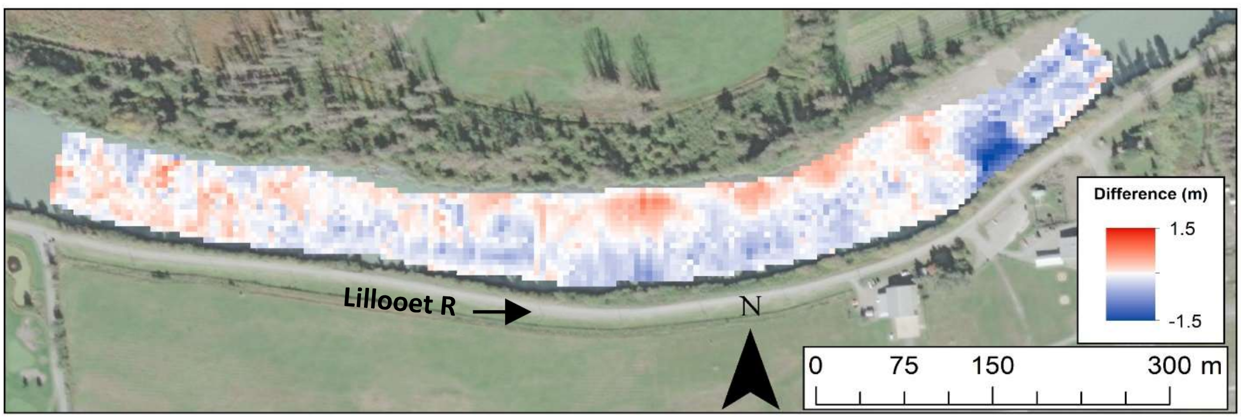


Figure 4.14 Sub-reach C grid raster analysis. Red indicates bed infilling and blue indicates bed lowering between 2017 and 2021.

4.1.3 Longitudinal Channel Bed Profiles

The 2011, 2017, and 2021 longitudinal channel bed profile is plotted below. **Figure 4.15** presents data for the Lower Reach, between the Ryan River and Green River confluences; included are labels referring to the locations of the Green River, Pemberton Creek, and Ryan River confluences; the Highway 99 and railway bridge crossings; and the five channel bars being actively managed by the PVDD. **Figure 4.16** presents data for the downstream-most section of the Middle Reach. **Figure 4.17** presents 2017 and 2021 data in the Middle Reach, extending 10 km farther upstream.

At the reach-scale, the 2021 and 2017 channel bed profile and gradient are relatively similar, and both profiles are substantially higher than the 2011 profile. The aggraded condition of the Middle Reach represents a future sediment supply source to the Lower Reach.

The 2021 longitudinal profiles show that the bed is typically populated with dune bedforms that can have lengths and heights (trough to crest) up to 20 m and 1 m, respectively. However, dune presence, size, and shape vary over the length of the river and most bedforms occur at a scale less than 10 m. The resolution of the 2017 data is too coarse to examine dune dynamics because longitudinal data points must occur at 1 m or less to accurately characterize the features. Dunes migrate and transport substantial volumes of bed material, add roughness that modulates water surface levels, and adds uncertainly to bed level measurements (described in **Section 3.1.2**). Should future monitoring data be collected with the appropriate resolution, it would be feasible to examine how and where dunes appear under different sediment transport conditions, to better understand how they are impacted sediment transport, flood levels and measurement uncertainty.

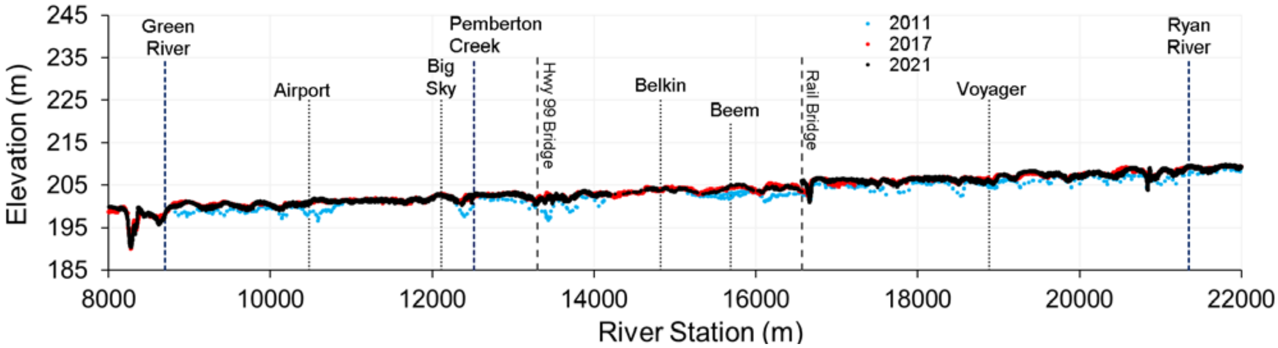


Figure 4.15 Lillooet River 2011, 2017, and 2021 channel bed longitudinal profile along the Lower Reach between Ryan River and Green River.

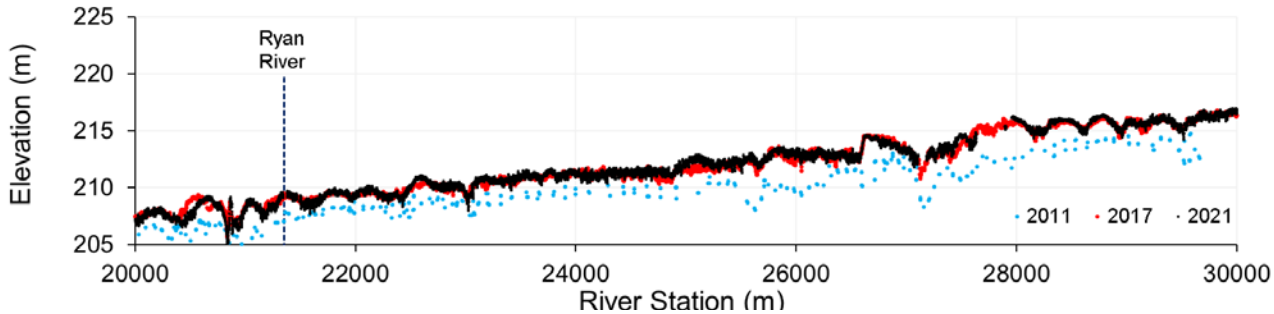


Figure 4.16 Lillooet River 2011, 2017, and 2021 channel bed longitudinal profile along the Middle Reach upstream of Ryan River.

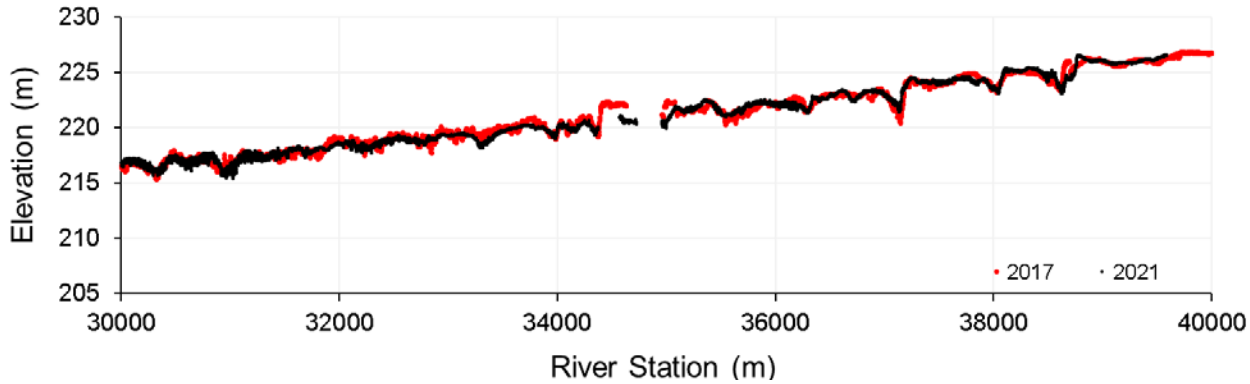


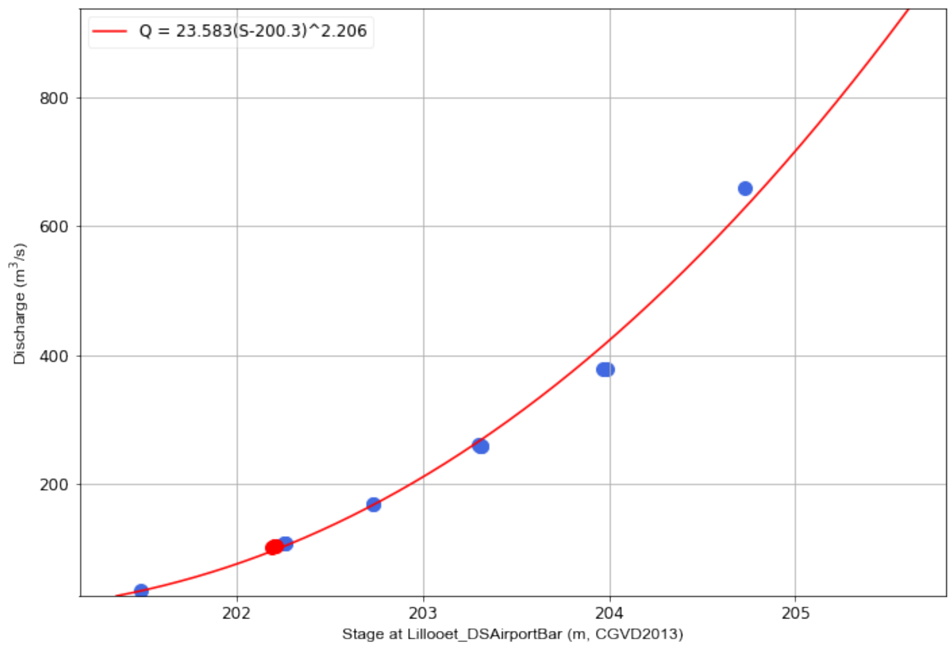
Figure 4.17 Lillooet River 2017 and 2021 channel bed longitudinal profile along the Middle Reach downstream of the Forest Service Road Bridge (located at approx. river station 40.2 km).

4.2 Hydrometric Monitoring Results

The 2021 hydrometric monitoring data for each monitoring station is plotted in **Figure 4.18** to **Figure 4.22**. The stations are numbered from one to five from downstream to upstream (i.e., Lillooet 1 – downstream of Airport Bar to Lillooet 5 – downstream of Voyageur Bar). Each figure includes a reference rating curve and an initial shift diagram for each monitoring location. Red points in both diagrams correspond to post-freshet conditions.

The shift diagram shows the change in stage required for the discharge measurement to fit the rating curve. Consistent departures on the shift diagram indicate a change in the specific gauge. Data collected so far do not show any significant shifts at any of the sites, indicating that the extended melt associated with the heat dome did not create a rapid change in the geometry of the river. It is worth emphasizing that the hydrometric analysis is meant to compare conditions at the sites over multiple high flow events. Baseline conditions have been established at each site but a longer data record is needed to analyse potential channel geometry changes.

Lillooet 1 – Downstream of Airport Bar



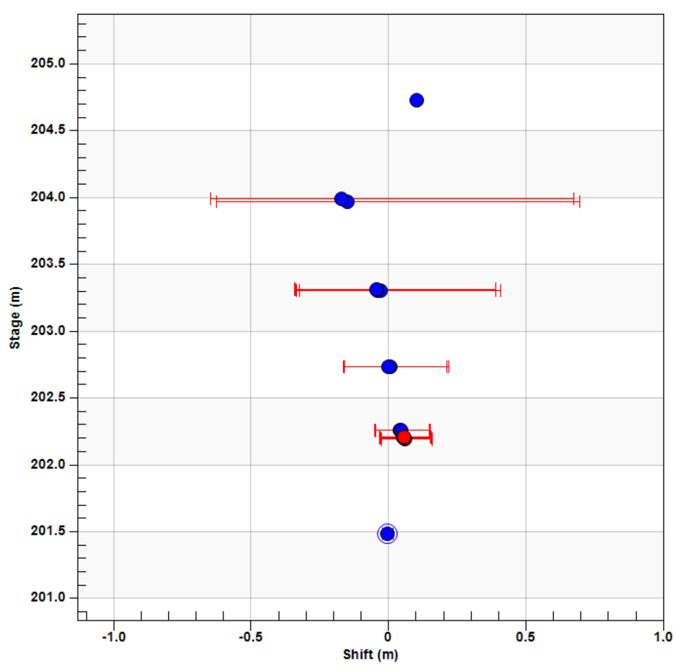
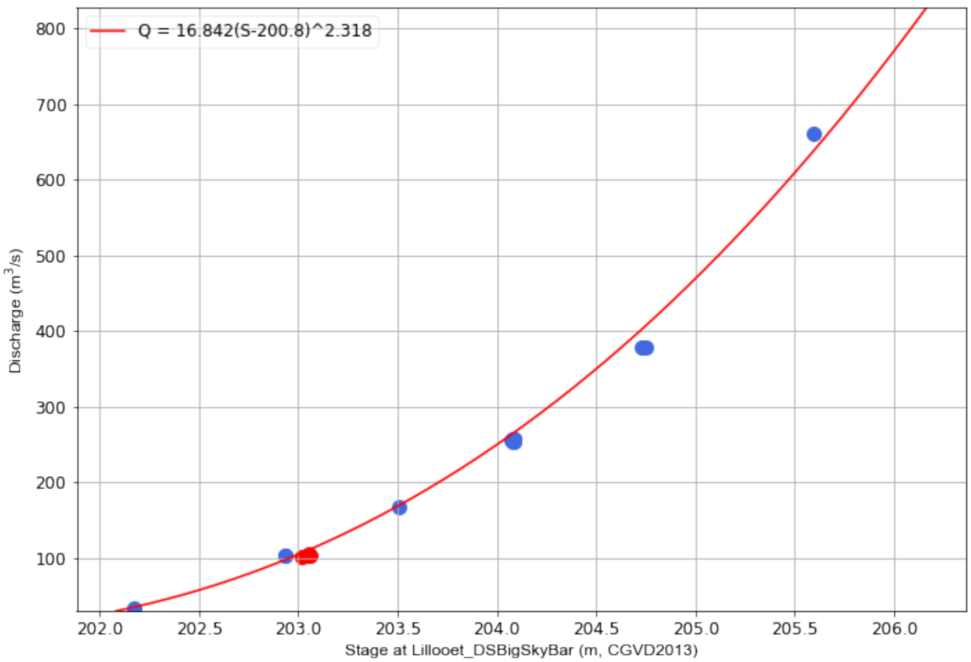


Figure 4.18 Rating curve and shift diagram for Lillooet 1 – Lillooet River Downstream of Airport Bar. Red points in both diagrams correspond to post-freshet conditions. They are very similar to pre-freshet conditions at this site.

Lillooet 2 – Downstream of Big Sky Bar



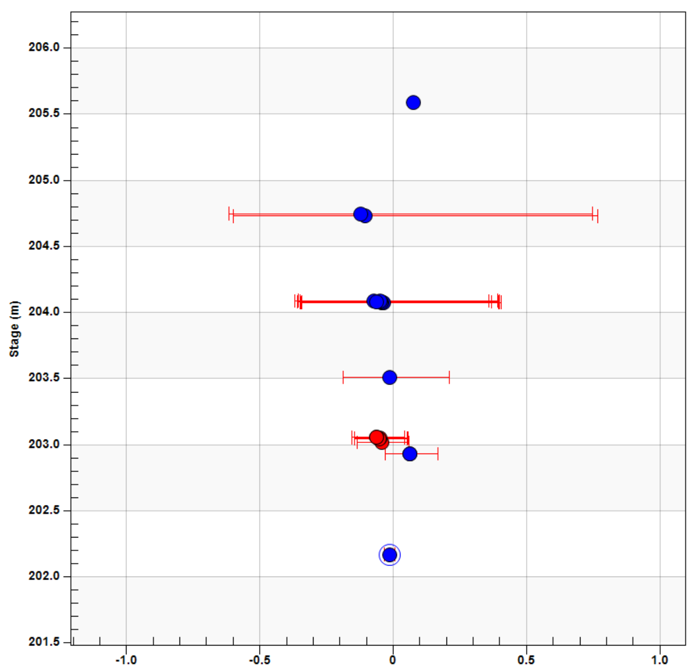


Figure 4.19 Rating curve and shift diagram for Lillooet 2 – Lillooet River Downstream of Big Sky Bar. Red points in both diagrams correspond to post-freshet conditions. There appears to be a minor negative shift at this site which would correspond to a higher specific gauge. However, the shift is within measurement error and is therefore inconclusive.

Lillooet 3 – Downstream of Belkin Bar

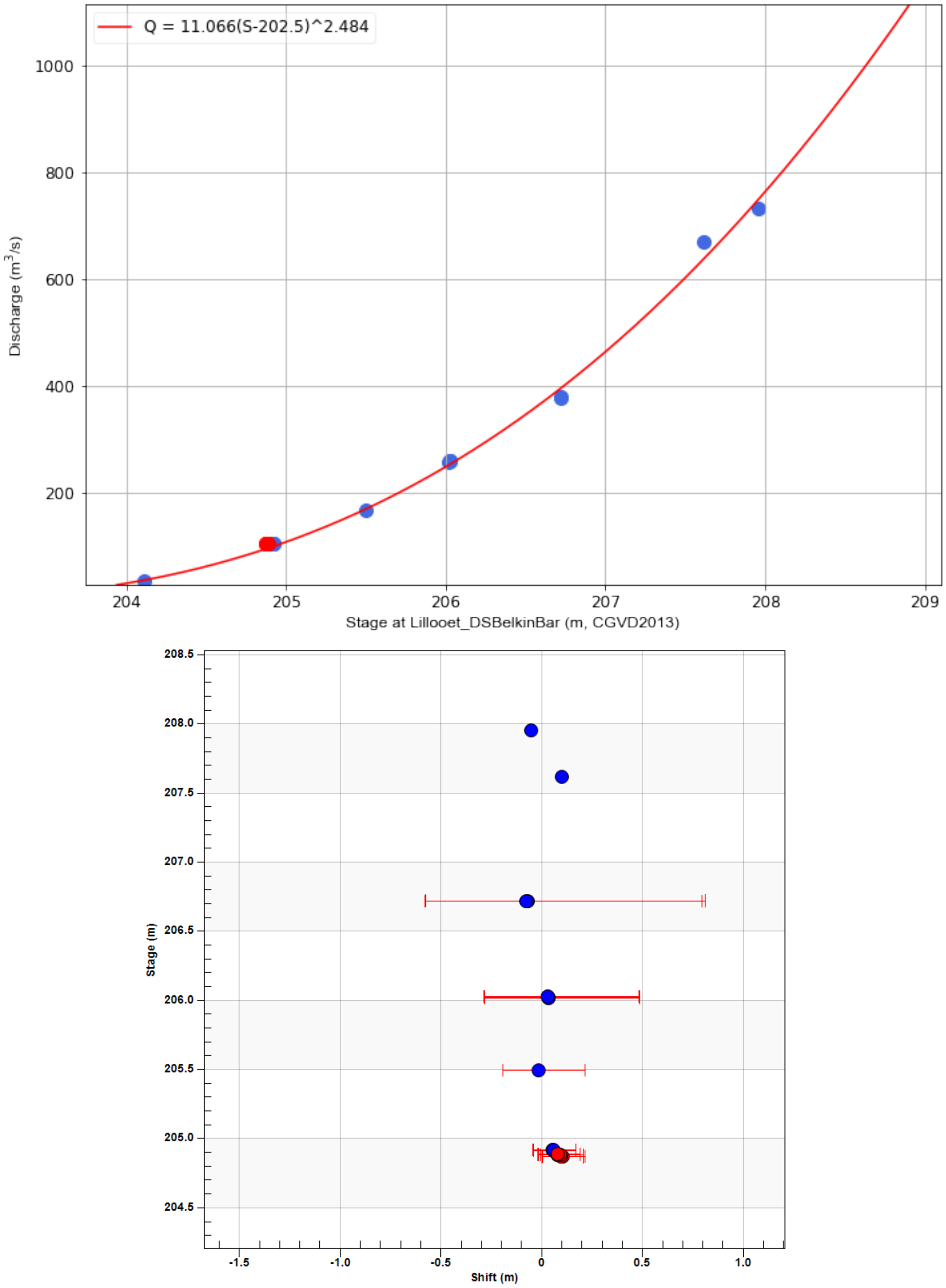


Figure 4.20 Rating curve and shift diagram for Lillooet 3 – Lillooet River Downstream of Belkin Bar. Red points in both diagrams correspond to post-freshet conditions, which are very similar to pre-freshet conditions at this site.

Lillooet 4 – Upstream of Beem Bar

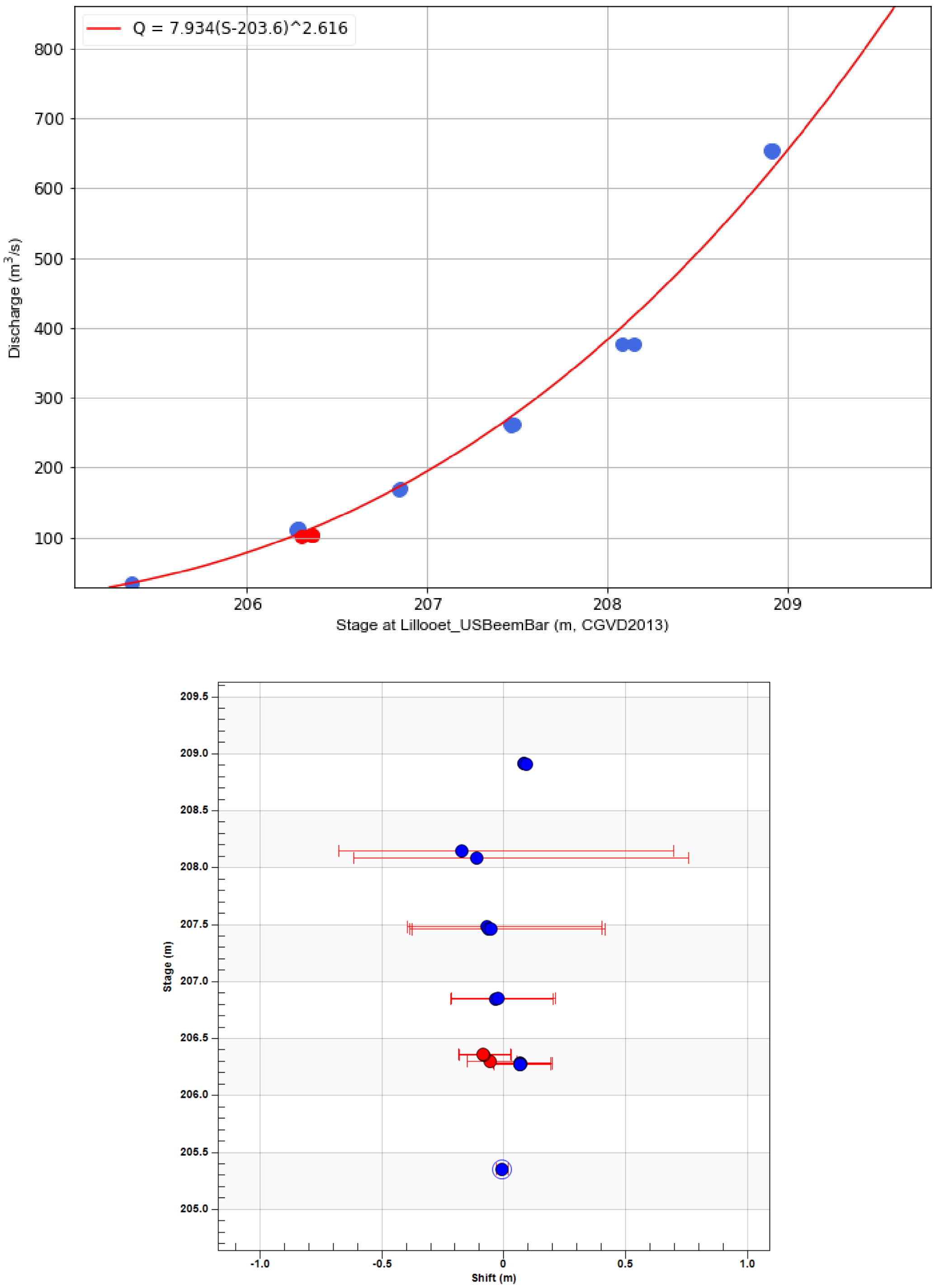
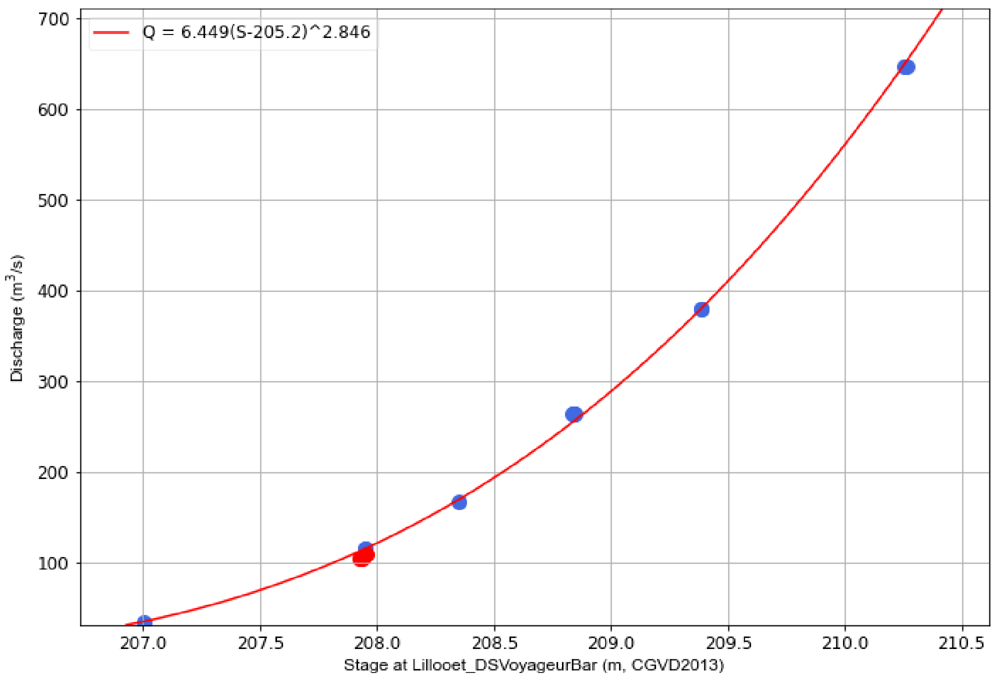


Figure 4.21 Rating curve and shift diagram for Lillooet 4 – Lillooet River Upstream of Beem Bar. Red points in both diagrams correspond to post-freshet conditions.

Lillooet 5 – Downstream of Voyageur Bar



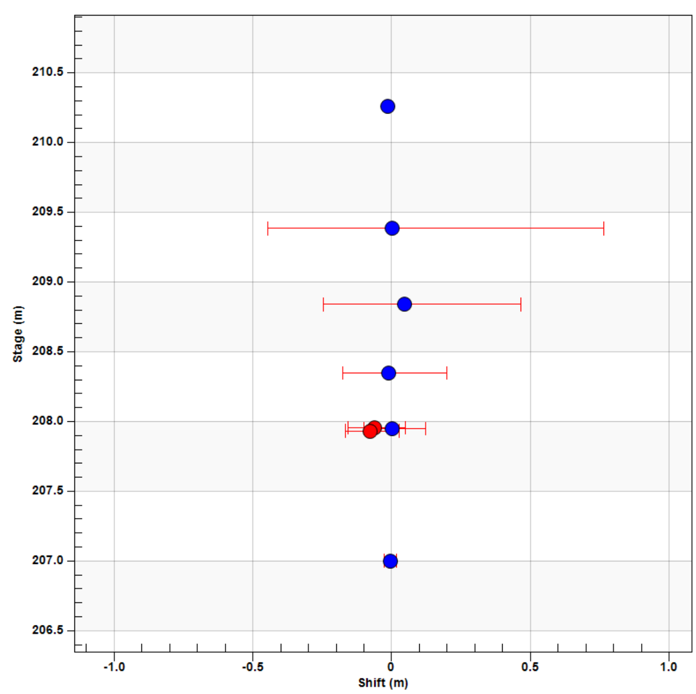


Figure 4.22 Rating curve and shift diagram for Lillooet 5 – Lillooet River Downstream of Voyageur Bar. Red points in both diagrams correspond to post-freshet conditions. They are very similar to pre-freshet conditions at this site.

5 CONCLUSION

An aggrading trend is apparent upstream of Highway 99, with a slight degrading trend apparent downstream of the Pemberton Creek confluence. Over the entire study reach there is a computed net volumetric change in the surveyed bed surface of approximately -7,000 m^3 between 2017 and 2021, indicating a net deficit. This corresponds to a net bed material surplus of 122,000 m^3 when accounting for the approximately 129,000 m^3 of sediment that was removed from the channel over this timeframe.

By examining the cumulative volumetric changes in the study reach between 2017 and 2021, and considering uncertainty in the analyses, an upper bound rate of annual channel aggradation is estimated to be 40,000 m^3/year. This value represents approximately two-thirds of the annual target sediment removal rate over each of the past two years.

The plotted 2011, 2017, and 2021 longitudinal channel bed profile data indicates the 2021 bed level remains substantially higher than the 2011 bed level. In the Lower Reach this represents a net reduction of dike freeboard overtime and a corresponding increase susceptibility to dike overtopping, and in the Middle Reach this represents a source of sediment that may continue to be transported and delivered to the Lower Reach, exacerbating the aggradation problem.

Considering the overall aggraded nature of the Lower Reach relative to 2011, the future potential for the Middle Reach to supply sediment to the Lower Reach, the inherent uncertainty associated with channel bed aggradation analyses, and the rationale for removals identified in the preliminary sediment management plan (NHC, 2019), there is no overwhelming evidence to alter the targeted sediment removal rate of 60,000 m^3/year over the next two to three years, unless sediment recruitment volumes at the sediment management sites substantially change or if other considering factors become emergent. In addition to the channel monitoring being carried out as part of a proposed multi-year Lillooet River gravel removal work program (NHC, 2021b), the program should incorporate observations and assessment of biological parameters to inform the overall sediment management program.

Baseline hydrometric conditions have been established at each site but a longer data record is needed to analyse potential channel geometry changes.

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APPENDIX A

HYDROMETRIC STATION DATA

LILLOOET RIVER DOWNSTREAM OF AIRPORT

STATION SUMMARY

Lillooet River downstream of Airport	
Aquarius ID	Lillooet_DSAirportBar
Client	Pemberton Valley Dyking District
Client Contact	Kevin Clark (kclark@pvdd.ca)
Installation Date	2021-04-19
Installed By	MWH JRR
Parameters Logged	Stage, water temperature
Station Location Lat./Long	50.304883, -122.739236
Survey Geoid and Datum	NAD83, CVGD2013
Elevation	202
Time Zone	PST
Archiving Sensor Sample Frequency	5 min
Barologger location	North Arm Channel Outlet, Arn Canal Outlet

Station Description:

- Archiving pressure transducer is located on right bank of Lillooet River
- Crest gauge is installed downstream of the archiving pressure transducer

Access Requirements:

- Accessible by all vehicles. Station is right before the fire base sign as the road turns to dirt at the airport.
- Levelogger pipe only visible and accessible when wsc flows are below ~160 m^3/s. (geodetic stage in cvgd2013 at 08MG005 is 207.8 or below)
- Crest gage pipe was installed when wsc flows were 241 m^3/s and would be accessible well above that.
- Pin finder required to locate rebar bms.

Safety Requirements:

- Bank is steep and drops off quickly. Tall grass during summer obscures this.

Last Updated:	November 5, 2021 11:57

LILLOOET RIVER DOWNSTREAM OF AIRPORT

BENCHMARKS

Horizontal	NAD 1983 CSRS	Vertical	CGVD2013	Geoid: CCG2013A
BM	Lat	Lon	Elevation	Description
NHC 3538	50.30473018	-122.73939127	205.653	Pl. Rebar
NHC 3537	50.30485853	-122.73907244	205.146	Pl. Rebar
NHC 5043			202.600	Pl. 1/4" Rockbolt D/S
NHC 5038			202.856	Pl. 1/4" Rockbolt U/S
NHC 5050			203.544	Rock bolt near bottom of crest stage
NHC 5051			203.392	Rock bolt
LRLB			202.334	Bottom River Left Rock Bolt
ULRB			202.620	Top River Left Rock Bolt
TCGP			205.151	Top of Crest Gauge Pipe. Raised 2021-10-21.

SENSORS

Location	Make	Model	Serial Number	Date Installed	Date Removed
	Solinst	Levelogger5 M5	2134081	2021-04-19	2021-10-28
	Solinst	Levelogger5 M5	2134089	2021-10-28	

PHOTOS

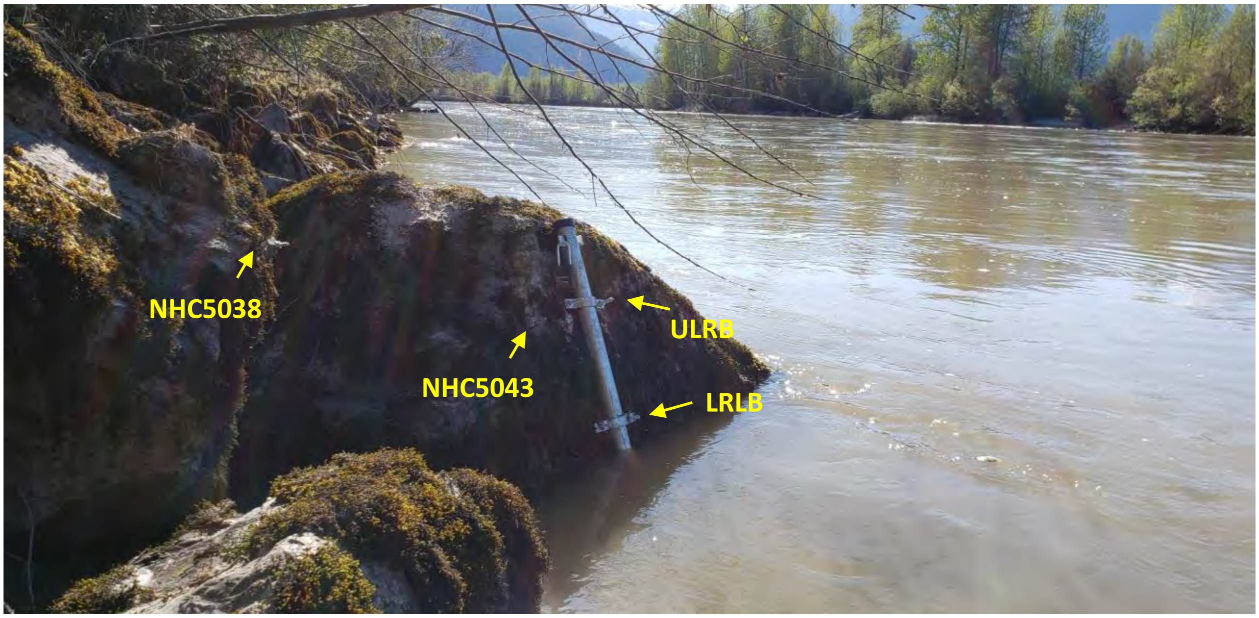

Photo 1 Benchmarks NHC5038, NHC5043, ULRB, and LRLB.

Photo 2 Benchmark NHC3535

Photo 0.3 Crest gauge with benchmarks NHC5050 and TCGP (Top of crest gauge pipe).

LILLOOET RIVER
DOWNSTREAM OF BIG SKY BAR

STATION SUMMARY

Lillooet River downstream of Airport	
Aquarius ID	Lillooet_DSBigSkyBar
Client	Pemberton Valley Dyking District
Client Contact	Kevin Clark (kclark@pvdd.ca)
Installation Date	2021-04-19
Installed By	MWH JRR
Parameters Logged	Stage, water temperature
Station Location Lat./Long	50.304215, -122.756662
Survey Geoid and Datum	NAD83, CVGD2013
Elevation	203.000 m
Time Zone	PST
Archiving Sensor Sample Frequency	5 min
Barologger location	North Arm Channel Outlet, Arn Canal DS Outlet, EC station @ Airport

Station Description:

- Archiving pressure transducer is located on right bank of Lillooet River
- Crest gauge located approx. 20m downstream of archiving pressure transducer on right bank of Lillooet River

Access Requirements:

- Will not be able to retrieve levelogger unless stage at 08MG005 (geodetic cvgd2013) is below ~207.5m.
- Crest gauge accessible at very high flows.
- Accessible by any vehicle, parking along road.
- Pin finder required to find rebar bms.

Safety Requirements:

Last Updated:	November 5, 2021 12:04

LILLOOET RIVER

DOWNSTREAM OF BIG SKY BAR

BENCHMARKS

Horizontal datum	NAD83 CSRS	Vertical datum	CGVD2013	Geoid: CCG2013A
BM	Lat	Lon	Elevation	Description
NHC3535	50.30403157	-122.75628096	206.145	Pl. Rebar
NHC3536	50.30408128	-122.75653628	206.159	Pl. Rebar
NHC5039			205.287	Pl. 1/4" Rockbolt
NHC5036			204.198	Pl. 1/4" Rockbolt
NHC5045			203.134	Pl. 1/4" Rockbolt
Crest Gauge			206.703	Top of Crest Gauge Pipe/Wood
NHC5049			204.385	3/8" Rockbolt bottom Pipe Clamp
NHC5048			204.354	1/4" Rockbolt

SENSORS

Location	Make	Model	Serial Number	Date Installed	Date Removed
	Solinst	Levelogger 5 M5	2134099	2021-04-19	

LILLOOET RIVER
DOWNSTREAM OF BIG SKY BAR

PHOTOS

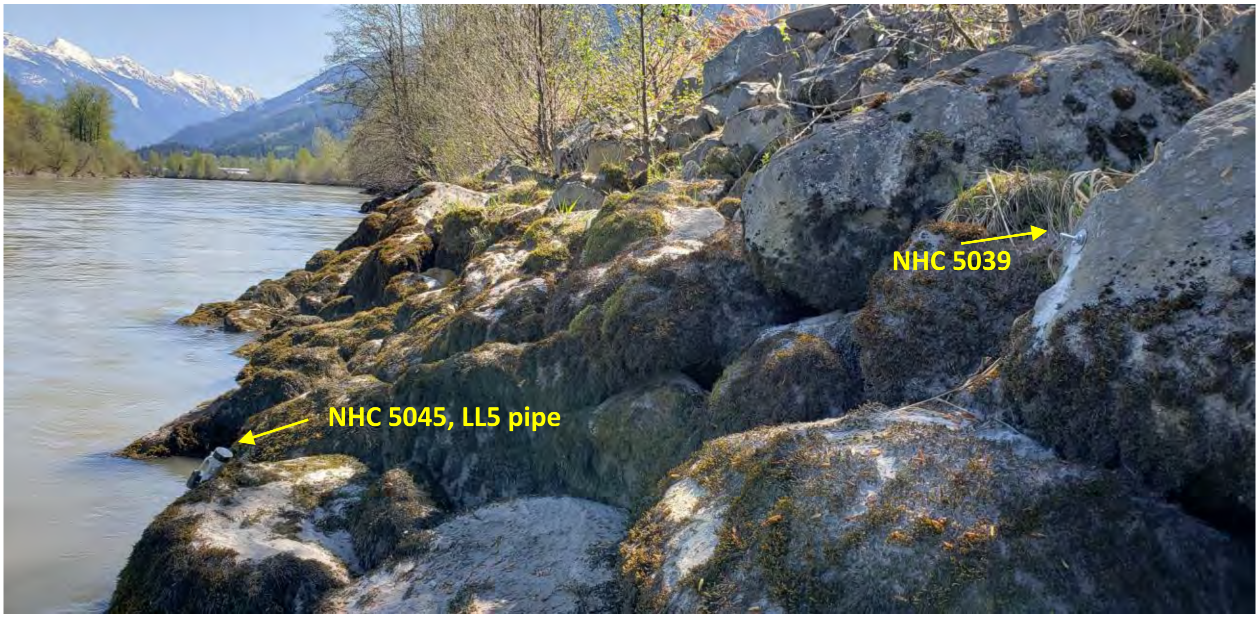

Photo 1 Benchmark NHC5039 upslope from the archiving pressure transducer

Photo 2 Benchmark NHC 5045

Photo 3 Crest gauge

LILLOOET RIVER
DOWNSTREAM OF BIG SKY BAR

Photo 4 Benchmark NHC 3536 on top of placed rebar

LILLOOET RIVER
UPSTREAM OF BEEM BAR

STATION SUMMARY

Lillooet River downstream of Airport	
Aquarius ID	Lillooet_USBeemBar
Client	Pemberton Valley Dyking District
Client Contact	Kevin Clark (kclark@pvdd.ca)
Installation Date	2021-04-19
Installed By	MWH JRR
Parameters Logged	Stage, water temperature
Station Location Lat./Long	50.327717, -122.795099
Survey Geoid and Datum	NAD83, CVGD2013
Elevation	206.000 m
Time Zone	PST
Archiving Sensor Sample Frequency	5 min
Barologger location	North Arm Channel Outlet, Arn Canal Outlet, EC station @ airport

Station Description:

- Archiving pressure transducer located on right bank of Lillooet River
- Crest gauge approximately 5 m downstream of archiving sensor

Access Requirements:

- Best way is through Tom's (778-793-4033) yard. He is happy to let us through but mind the gate in the back so dogs don't escape.
- At winter low flows site can be accessed by walking to railway bridge and then south along river bank rip rap.
- Flagging tape hanging from branches marks the spot where the gauge is.
- Machete for clearing brush at top of bank is going to be a good idea.
- Pin finder needed to find rebar benchmarks
- Will not be able to retrieve levelogger unless stage at 08MG005 (geodetic cvgd2013) is below ~207.7m.

Safety Requirements:

Last Updated:	January 21, 2022 08:28

LILLOOET RIVER
UPSTREAM OF BEEM BAR

BENCHMARKS

Horizontal	NAD83 CSRS	Vertical	CGVD2013	Geoid: CCG2013A
BM	**Lat**	**Lon**	**Elevation**	**Description**
NHC3532	50.32768888	-122.79533423	209.389	Pl. Rebar
NHC3531	50.32777771	-122.79537356	209.409	Pl. Rebar
NHC5020			207.596	Pl. 1/4" Rockbolt High
NHC5019			206.382	Pl. 1/4" Rockbolt Low
DS Low Pipe Rock Bolt			206.370	DS Low Pipe Rock Bolt
DS High Pipe Rock Bolt			206.729	DS High Pipe Rock Bolt
Crest Gauge			209.664	Top of Crest Gauge Pipe

SENSORS

Location	Make	Model	Serial Number	Date Installed	Date Removed
	Solinst	Levelogger5	20134074	2021-04-19	

PHOTOS

Photo 1 PT stilling well at Lillooet River downstream of Beam Bar (2021-04-19)

Photo 2 Low Benchmark NHC5019 on rock bolt near pressure transducer pipe.

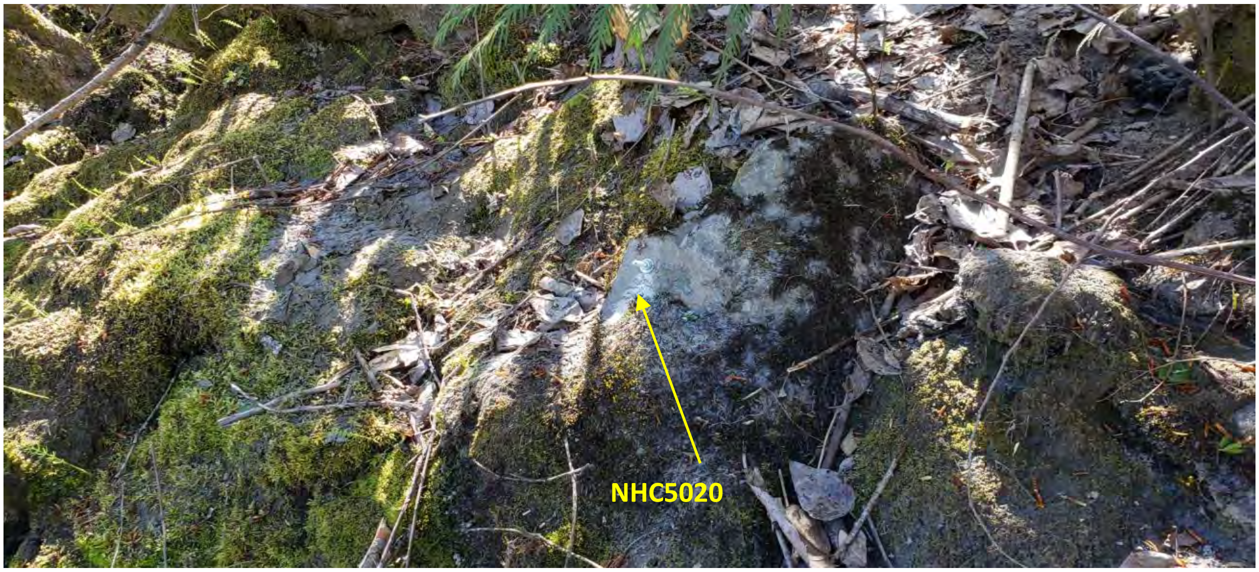

Photo 3 High Benchmark NHC5020

Photo 4 **Access to DS Beam Bar. Red is through Tom's yard. Blue is only an option during winter low flows as it means walking along the rip rap at the river's edge.**

Photo 5 Crest Gauge pipe.

LILLOOET RIVER
DOWNSTREAM OF BELKIN BAR

STATION SUMMARY

Lillooet River downstream of Airport	
Aquarius ID	Lillooet_DSBelkinBar
Client	Pemberton Valley Dyking District
Client Contact	Kevin Clark (kclark@pvdd.ca)
Installation Date	2021-04-20
Installed By	MWH JRR
Parameters Logged	Stage, water temperature
Station Location Lat./Long	50.323216, -122.772858
Survey Geoid and Datum	NAD83, CVGD2013
Elevation	205.000
Time Zone	PST
Archiving Sensor Sample Frequency	5 min
Barologger location	North Arm Channel Outlet, Arn Canal Outlet, EC wx station @ Airport

Station Description:

- Archiving pressure transducer located on left bank of Lillooet River
- Crest gauge immediately above archiving pressure transducer.
- Need pin finder for placed rebar benchmarks.

Access Requirements:

- High clearance a definite asset to get to this site. It can be done in a normal car but odds of scraping are very high.
- Requires Lillooet EWS gate key. Same key as Lillooet FSR EWS station.
- Wont be able to access levelogger pipe unless wsc flows are below ~150 m^3/s at 08MG005 (geodetic cvgd2013 stage at that site below 207.8).
- Crest gauge accessible at very high flows.

Safety Requirements:

Last Updated:	November 5, 2021 12:08

LILLOOET RIVER
DOWNSTREAM OF BELKIN BAR

BENCHMARKS

Horizontal	NAD83 CSRS	Vertical	CGVD2013	Geoid: CCG2013A
BM	**Lat**	**Lon**	**Elevation**	**Description**
NHC3533	50.32324516	-122.77261269	208.956	Pl. Rebar
NHC3534	50.32309437	-122.77274385	209.317	Pl. Rebar
NHC5018			205.757	Pl. 1/4" Rockbolt
NHC5017			205.134	Pl. 1/4" Rockbolt
NHC5035			207.189	Pl. 1/4" Rockbolt
NHC5046			206.230	Pl. 1/4" Rockbolt near crest gauge
NHC5047			206.105	Lowest Pipe Clamp 3/8" Rockbolt of Crest Gauge
Crest Gauge			208.553	Top of Crest Gauge Pipe/Wood

SENSORS

Location	Make	Model	Serial Number	Date Installed	Date Removed
	Solinst	Levelogger5	2134088	2021-04-20	

PHOTOS

Photo 1 Benchmark NHC5039 upslope from the archiving pressure transducer

Photo 2 Benchmark NHC 5035 on rock bolt near pressure transducer pipe.

Photo 3 Primary Benchmark NHC3533 on top of placed rebar on dike.

LILLOOET RIVER
DOWNSTREAM OF BELKIN BAR

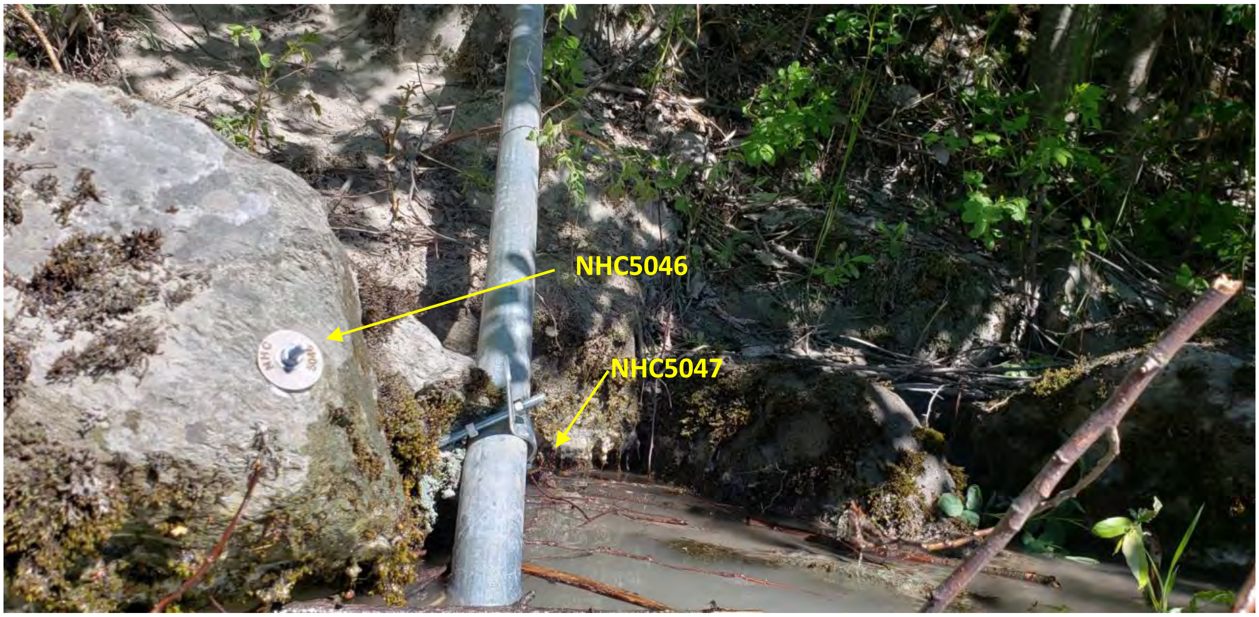

Photo 4 Benchmarks NHC5046 and NHC5047 at Crest Gauge pipe.

Photo 5 Access to station. Blue line indicates location of locked gate. Truck advised for this road.

LILLOOET RIVER
DOWNSTREAM OF VOYAGEUR BAR

STATION SUMMARY

Lillooet River downstream of Voyager Bar	
Aquarius ID	Lillooet_DSVoyageurBar
Client	Pemberton Valley Dyking District
Client Contact	Kevin Clark (kclark@pvdd.ca)
Installation Date	2021-04-19
Installed By	MWH JRR
Parameters Logged	Stage, water temperature
Station Location Lat./Long	50.3385333, -122.8082905
Survey Geoid and Datum	NAD83, CVGD2013
Elevation	208.000
Time Zone	PST
Archiving Sensor Sample Frequency	5 min
Barologger location	North Arm Channel Outlet, Arn Canal Outlet, EC weather station @ airport

Station Description:

- Levelogger 5 in pipe mounted to rip rap; crest stage gauge mounted vertically to tree adjacent to it.

Access Requirements:

- Need Lillooet EWS gate key to access dike. We have this key for the Lillooet FSR EWS station.
- Will not be able to access levelogger at flows above ~150 cms at 08MG005 (geodetic cvgd2013 stage at 08MG005 below ~207.6m).
- Pin finder needed to find rebar bm on side of dike

Safety Requirements:

- Bank is very undercut here. Use caution getting down to water's edge at high flows.
- Machete for brush clearing going to be a good idea for accessing site from dike.

Last Updated:	January 21, 2022 08:34

LILLOOET RIVER
DOWNSTREAM OF VOYAGEUR BAR

BENCHMARKS

Horizontal	NAD83 CSRS	Vertical	CGVD2013	Geoid: CCG2013A
BM	Lat	Lon	Elevation	Description
NHC3539	50.33813330	-122.80846666	212.663	Pl. Rebar
NHC3540			210.848	Pl. Rebar
NHC5044			208.147	Pl. 1/4" Rockbolt D/S
NHC5037			208.148	Pl. 1/4" Rockbolt U/S
LRRB			208.045	Lower Right Pipe Clamp Rockbolt on PT pipe
TCGP			210.854	Top of Crest Gauge Pipe/Wood
LRLB			209.529	Lower right lag bolt on crest gauge pipe

SENSORS

Location	Make	Model	Serial Number	Date Installed	Date Removed
	Solinst	Levelogger5 M5	2134094	2021-04-19	

PHOTOS

Photo 1 Access to DS Voyager Bar. Blue line shows location of gate.

Photo 2 Pressure transducer pipe

Photo 3 Rockbolt benchmarks NHC5044, NHC5037 and LRRB (lower right rock bolt) near PT pipe

Photo 4 Primary benchmark NHC3539 on top of placed rebar

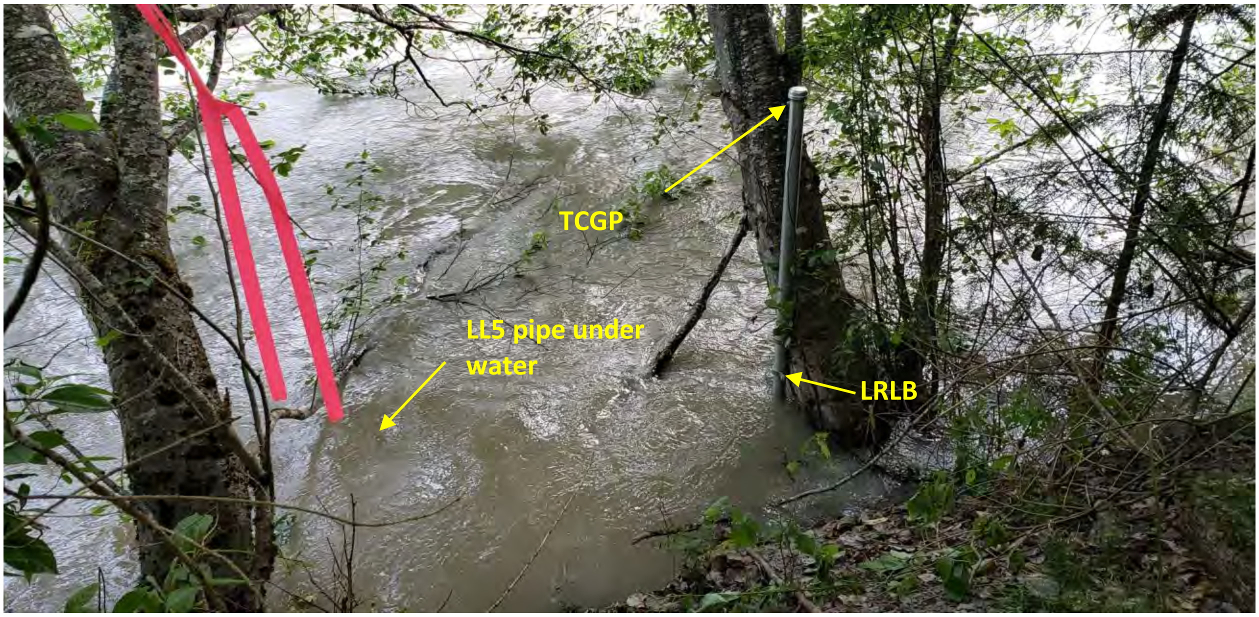

Photo 5 **Crest gauge pipe with benchmarks TCGP (top of crest gauge pipe) and LRLB (lower right lag bolt). Photo from 2021-06-01.**

APPENDIX B

2017 AND 2021 LILLOOET RIVER HISTORICAL MONITORING SECTIONS BETWEEN RYAN RIVER AND GREEN RIVER CONFLUENCES

TABLE OF CONTENTS

Figure 1 **Lillooet River Lower Reach Historical Monitoring Section L42 to L50. 2016 EMBC orthophoto for reference. 2021 data shown as black dots and 2017 data shown as smaller red dots. Flow direction is from top to bottom.**

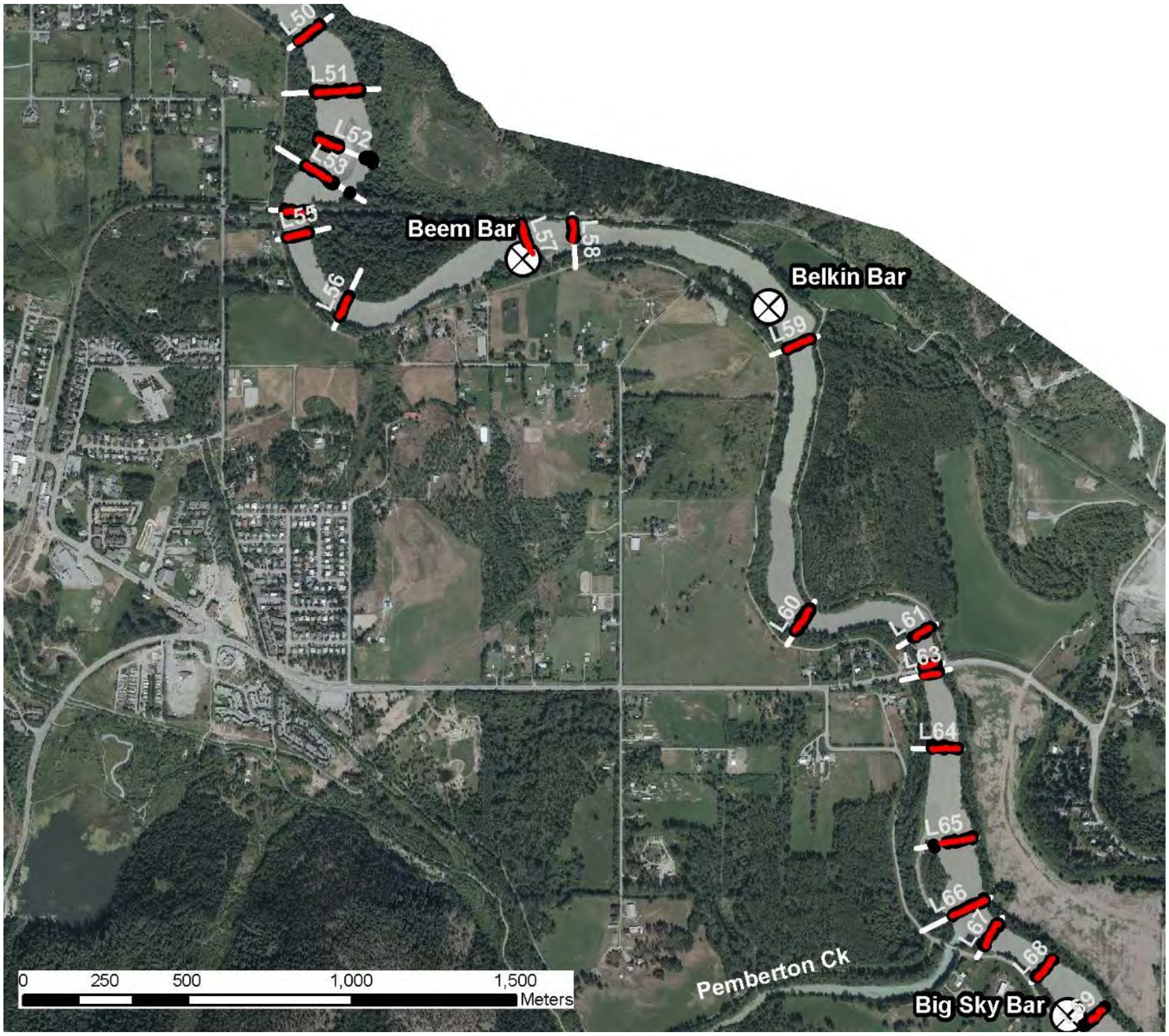

Figure 2 Lillooet River Lower Reach Historical Monitoring Section L50 to L69. 2021 data shown as black dots and 2017 data shown as smaller red dots. Flow direction is from top to bottom.

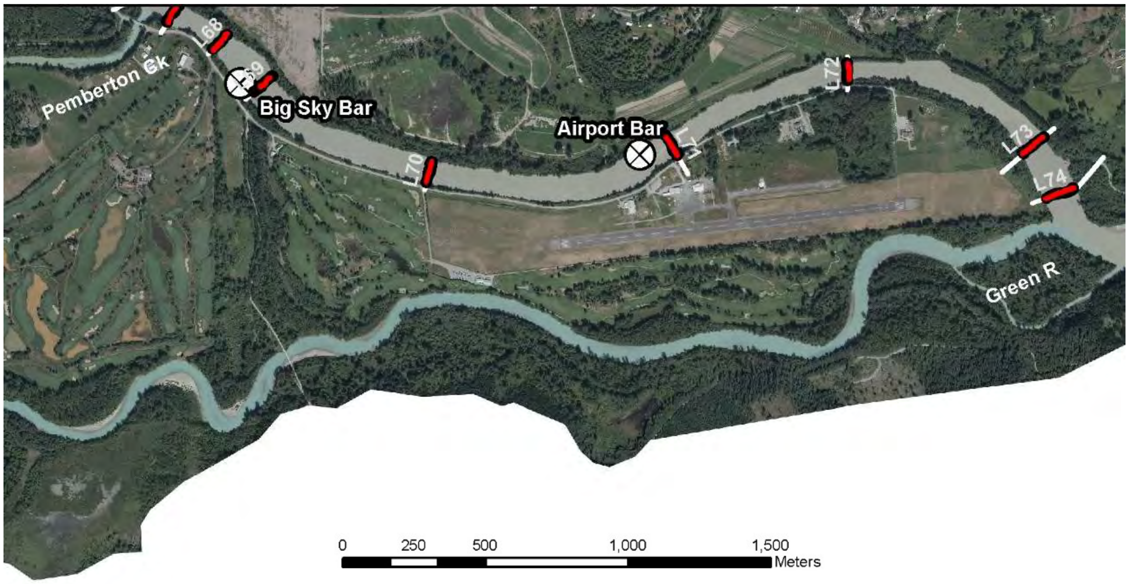

Figure 3 Lillooet River Lower Reach Historical Monitoring Section L66 to L74. 2021 data shown as black dots and 2017 data shown as smaller red dots. Flow direction is from top to bottom

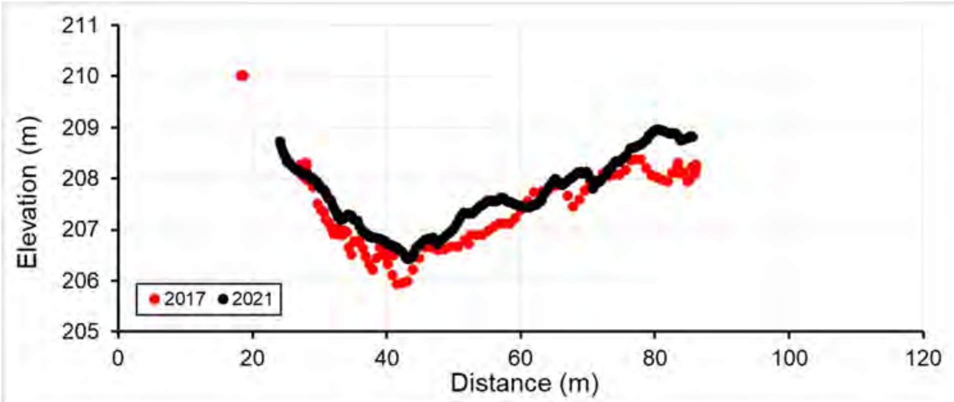

Figure 4 **Lillooet River Lower Reach: Historical Monitoring Section L42 (Located 20,901 m upstream of the mouth). Section is plotted in a downstream viewed perspective.**

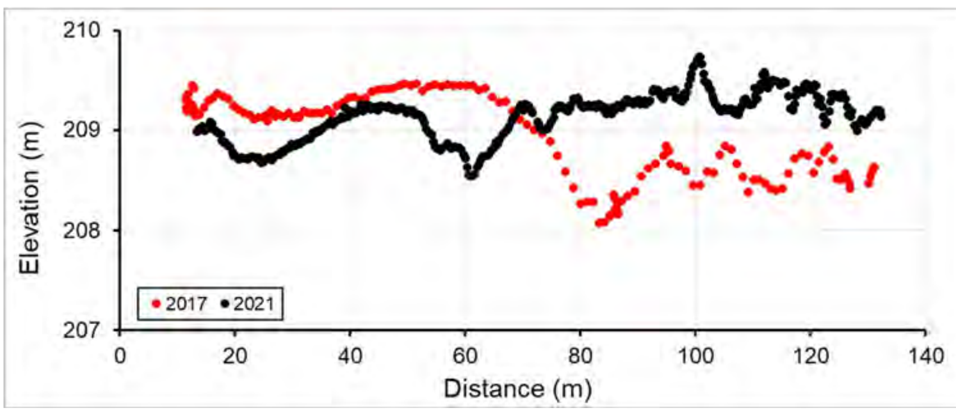

Figure 5 **Lillooet River Lower Reach: Historical Monitoring Section L43 (Located 20,691 m upstream of the mouth). Section is plotted in a downstream viewed perspective.**

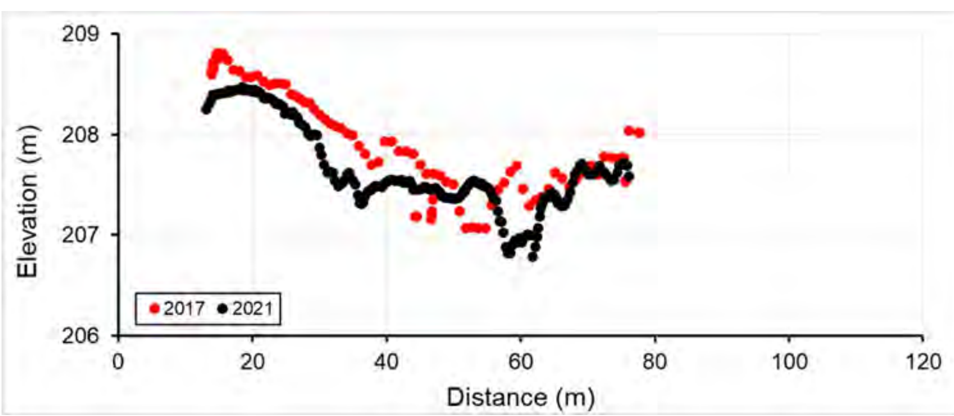

Figure 6 **Lillooet River Lower Reach: Historical Monitoring Section L44 (Located 20,387 m upstream of the mouth). Section is plotted in a downstream viewed perspective.**

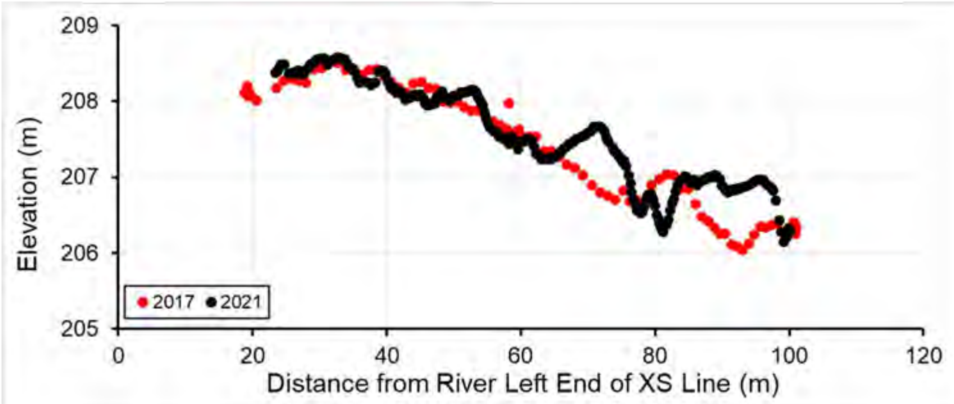

Figure 7 Lillooet River Lower Reach: Historical Monitoring Section L45 (Located 19,480 m upstream of the mouth). Section is plotted in a downstream viewed perspective.

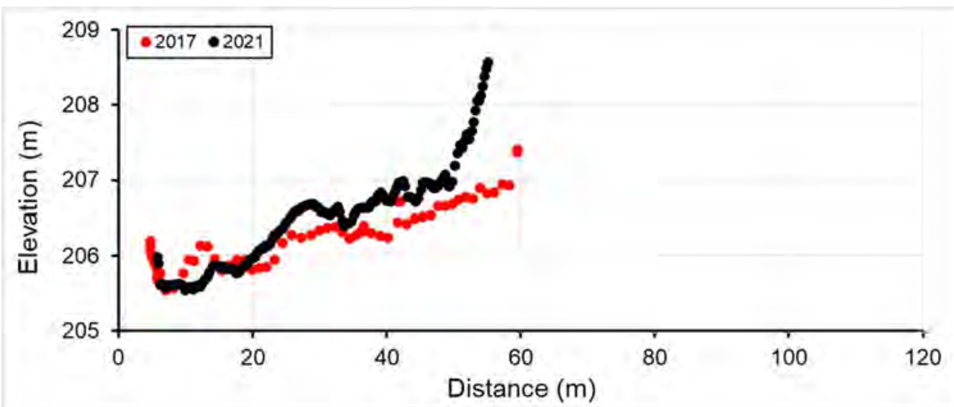

Figure 8 Lillooet River Lower Reach: Historical Monitoring Section L46 (Located 18,888 m upstream of the mouth). Section is plotted in a downstream viewed perspective.

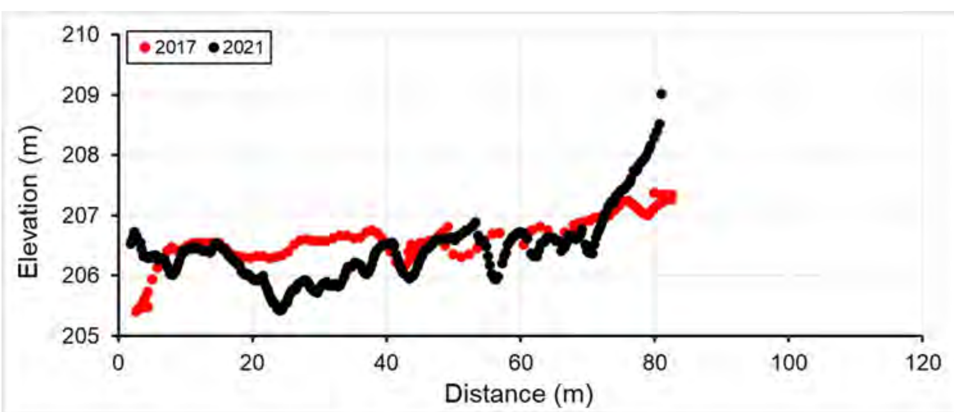

Figure 9 Lillooet River Lower Reach: Historical Monitoring Section L47 (Located 18,684 m upstream of the mouth). Section is plotted in a downstream viewed perspective.

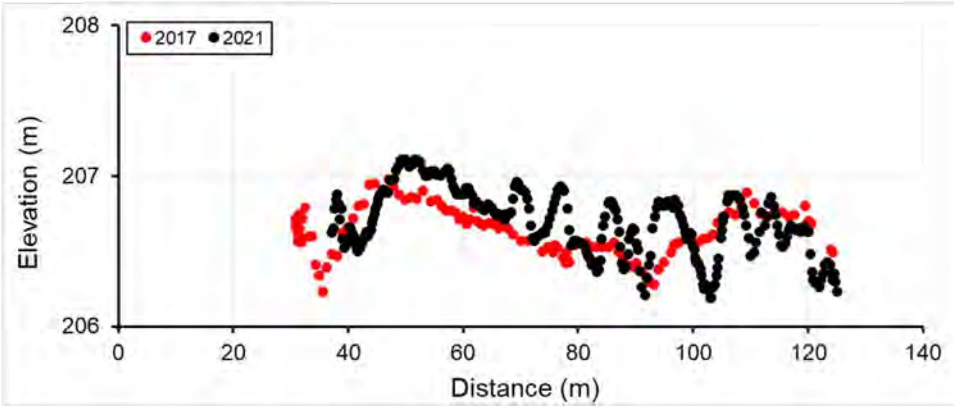

Figure 10 Lillooet River Lower Reach: Historical Monitoring Section L48 (Located 17,975m upstream of the mouth). Section is plotted in a downstream viewed perspective.

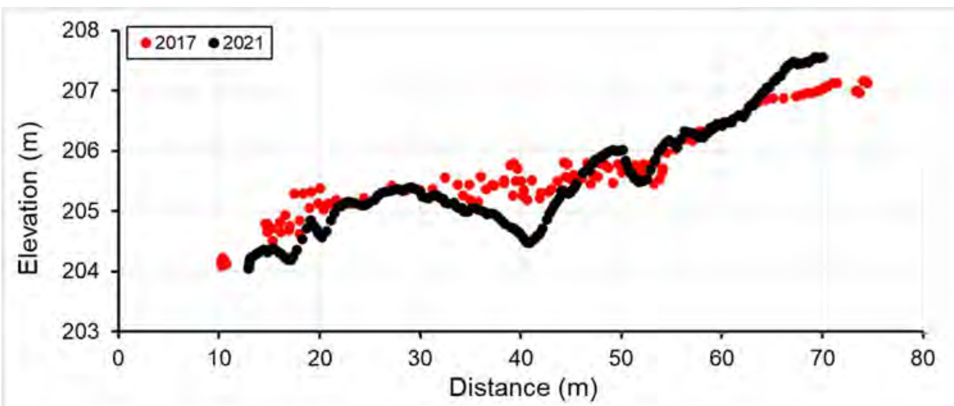

Figure 11 Lillooet River Lower Reach: Historical Monitoring Section L49 (Located 17,492 m upstream of the mouth). Section is plotted in a downstream viewed perspective.

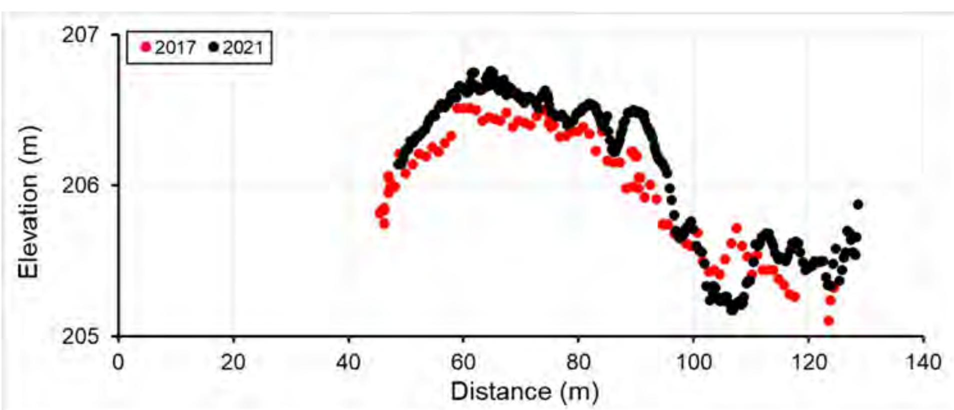

Figure 12 Lillooet River Lower Reach: Historical Monitoring Section L50 (Located 17,232 m upstream of the mouth). Section is plotted in a downstream viewed perspective.

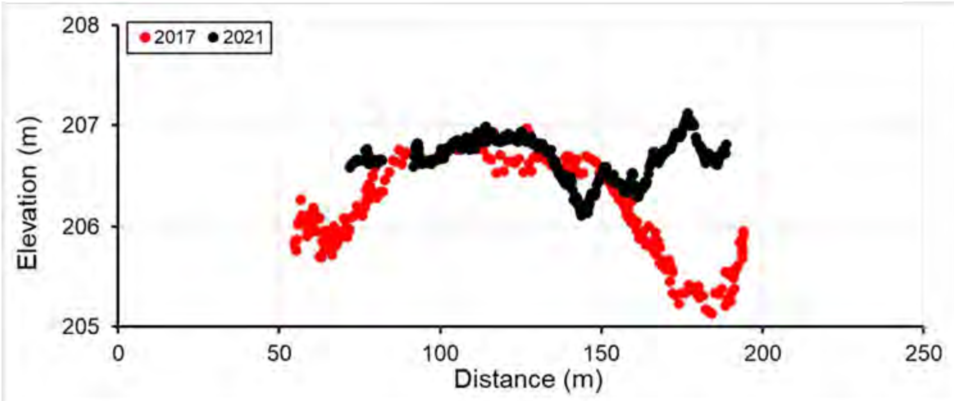

Figure 13 **Lillooet River Lower Reach: Historical Monitoring Section L51 (Located 17,054 m upstream of the mouth). Section is plotted in a downstream viewed perspective.**

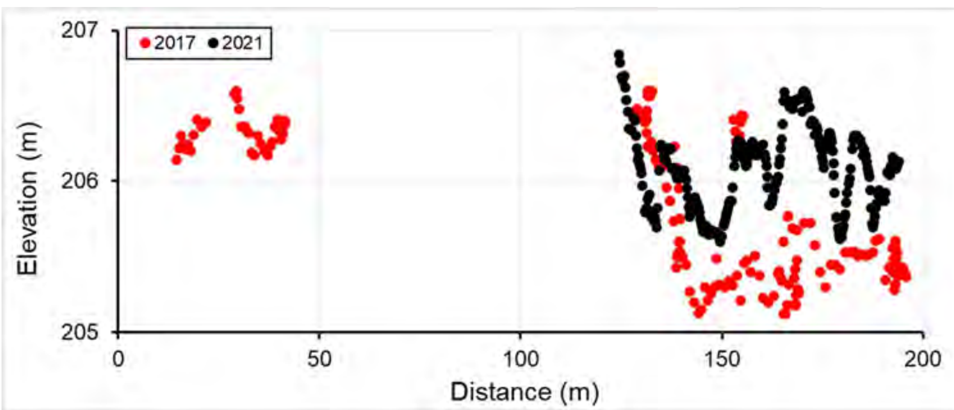

Figure 14 **Lillooet River Lower Reach: Historical Monitoring Section L52 (Located 16,900 m upstream of the mouth). Section is plotted in a downstream viewed perspective.**

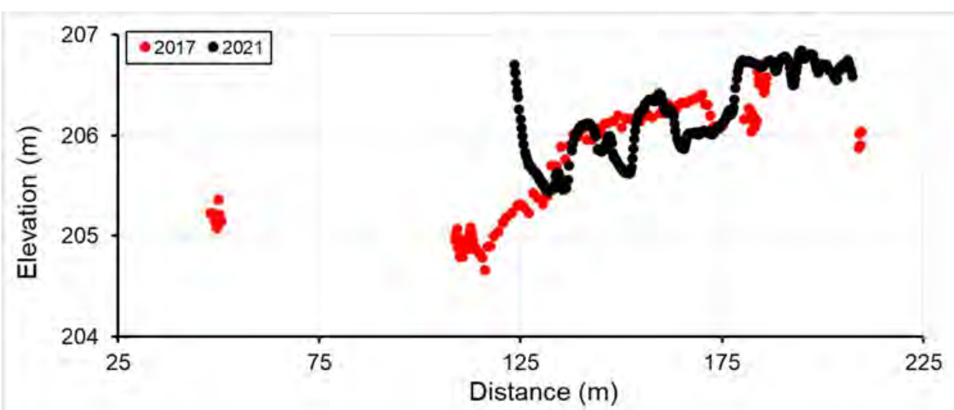

Figure 15 **Lillooet River Lower Reach: Historical Monitoring Section L53 (Located 16,804 m upstream of the mouth). Section is plotted in a downstream viewed perspective.**

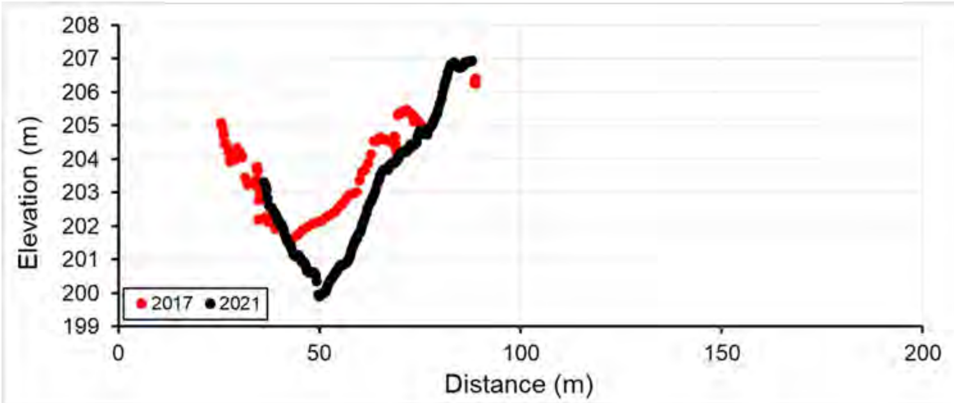

Figure 16 Lillooet River Lower Reach: Historical Monitoring Section L54 (Located 16,665 m upstream of the mouth). Section is plotted in a downstream viewed perspective.

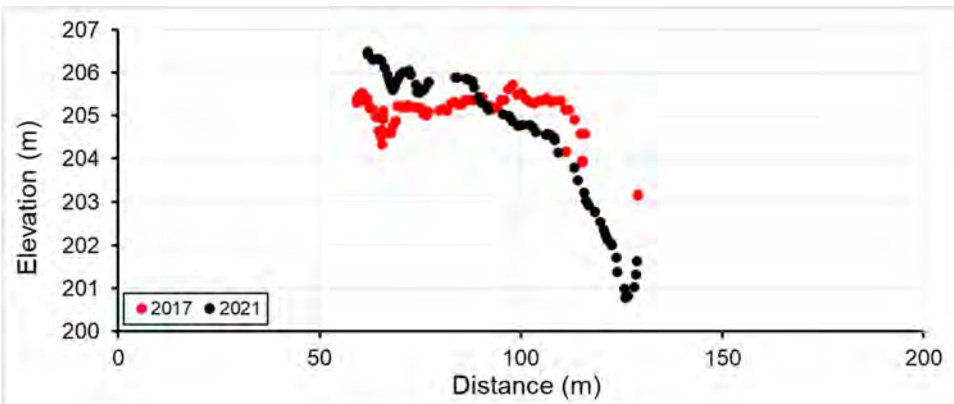

Figure 17 Lillooet River Lower Reach: Historical Monitoring Section L55 (Located 16,583 m upstream of the mouth). Section is plotted in a downstream viewed perspective.

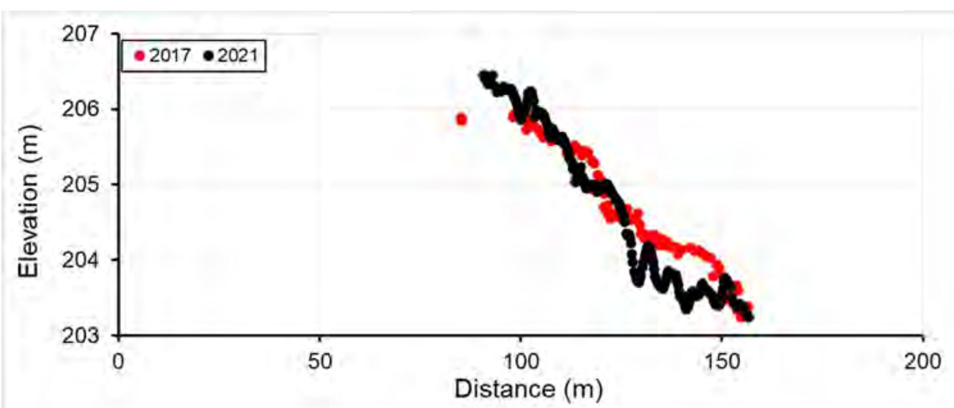

Figure 18 Lillooet River Lower Reach: Historical Monitoring Section L56 (Located 16,300 m upstream of the mouth). Section is plotted in a downstream viewed perspective.

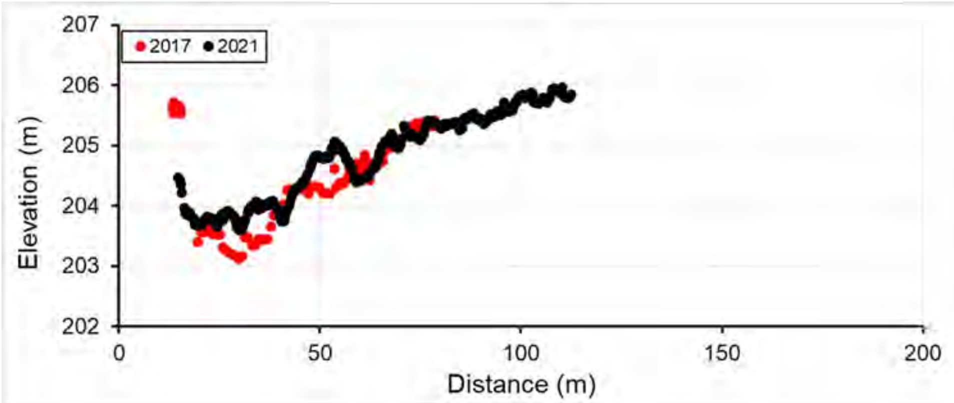

Figure 19 Lillooet River Lower Reach: Historical Monitoring Section L57 (Located 15,660 m upstream of the mouth). Section is plotted in a downstream viewed perspective.

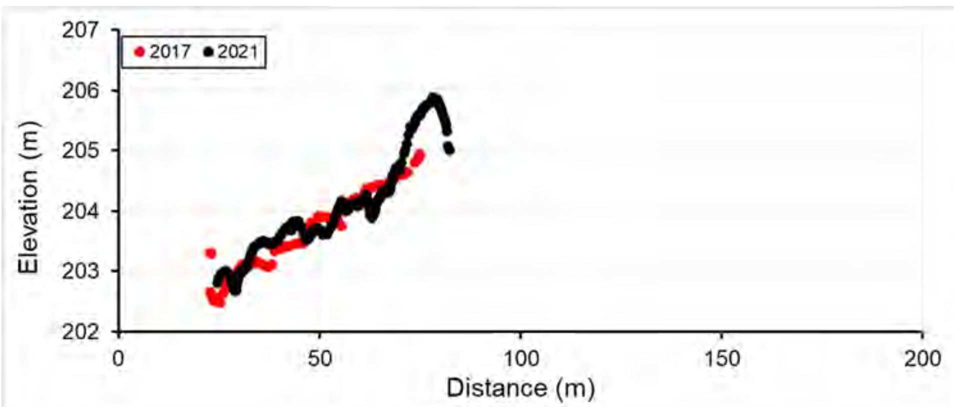

Figure 20 Lillooet River Lower Reach: Historical Monitoring Section L58 (Located 15,513 m upstream of the mouth). Section is plotted in a downstream viewed perspective.

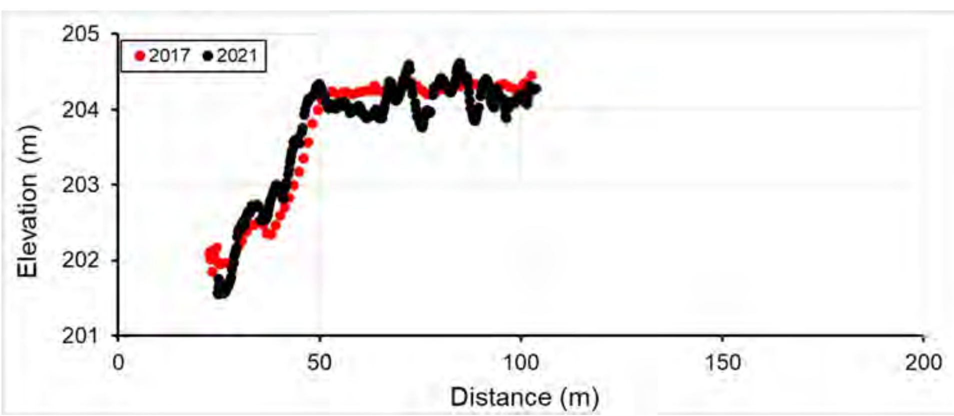

Figure 21 Lillooet River Lower Reach: Historical Monitoring Section L59 (Located 14,668 m upstream of the mouth). Section is plotted in a downstream viewed perspective.

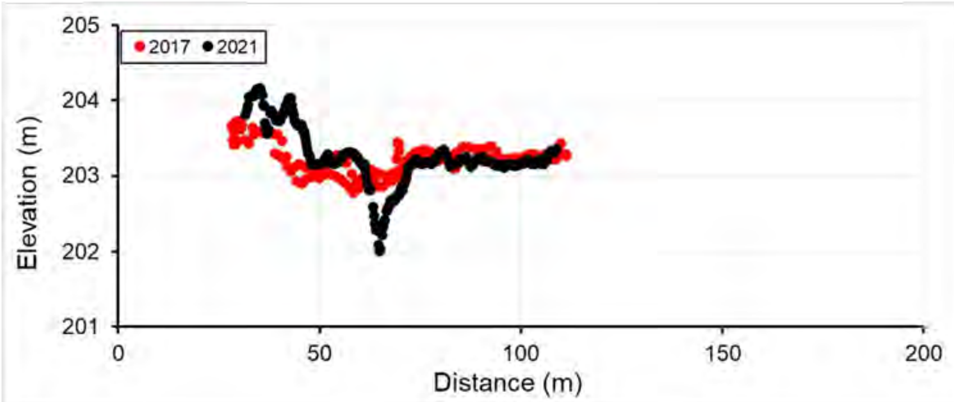

Figure 22 Lillooet River Lower Reach: Historical Monitoring Section L60 (Located 13,805 m upstream of the mouth). Section is plotted in a downstream viewed perspective.

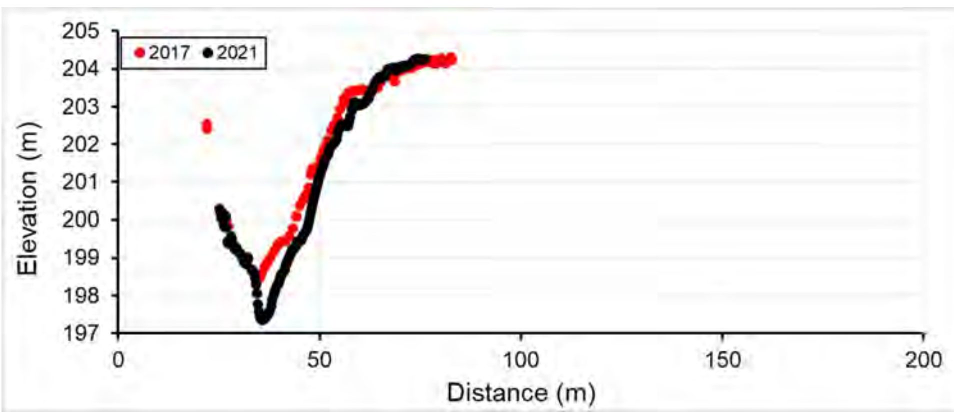

Figure 23 Lillooet River Lower Reach: Historical Monitoring Section L61 (Located 13,419 m upstream of the mouth). Section is plotted in a downstream viewed perspective.

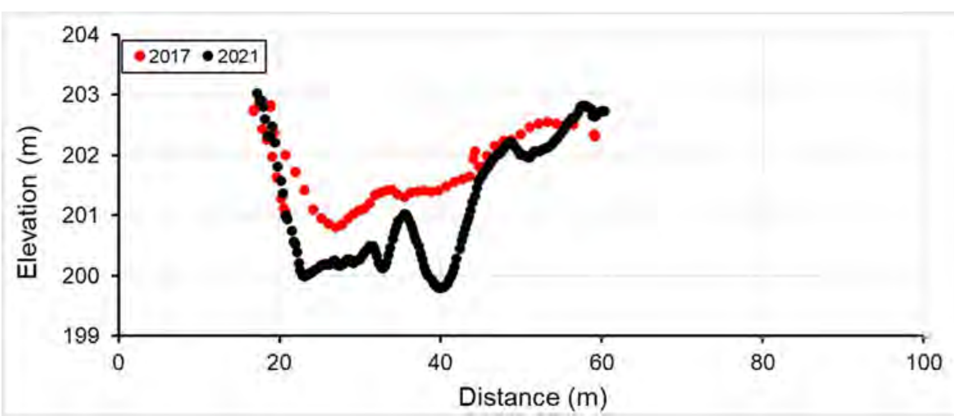

Figure 24 Lillooet River Lower Reach: Historical Monitoring Section L62 (Located 13,314 m upstream of the mouth). Section is plotted in a downstream viewed perspective.

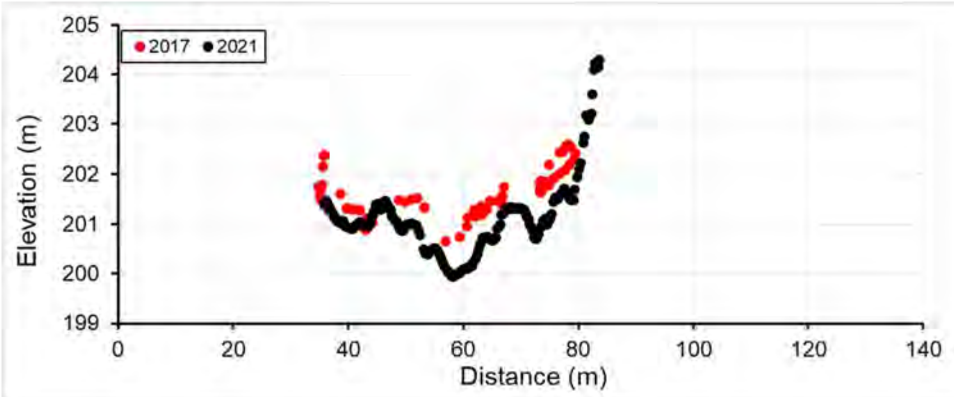

Figure 25 **Lillooet River Lower Reach: Historical Monitoring Section L63 (Located 13,290 m upstream of the mouth). Section is plotted in a downstream viewed perspective.**

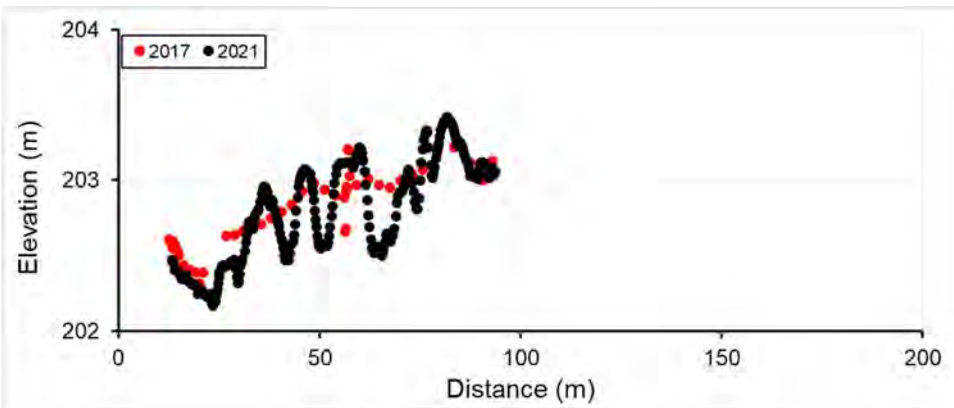

Figure 26 **Lillooet River Lower Reach: Historical Monitoring Section L64 (Located 13,056 m upstream of the mouth). Section is plotted in a downstream viewed perspective.**

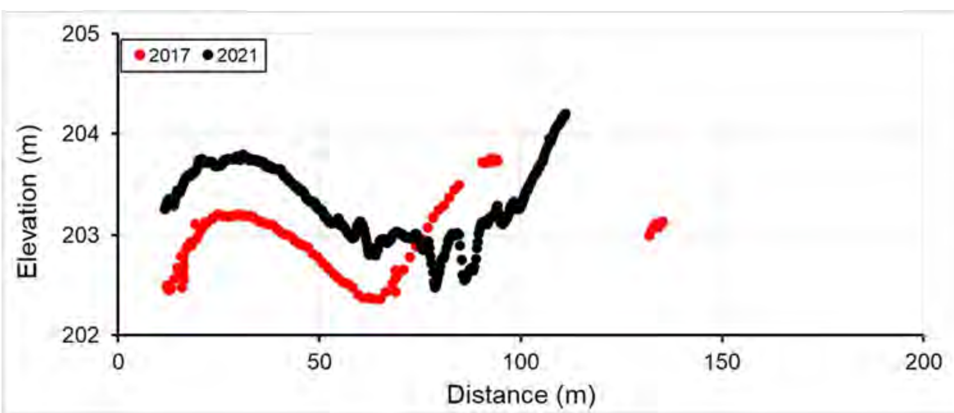

Figure 27 **Lillooet River Lower Reach: Historical Monitoring Section L65 (Located 12,773m upstream of the mouth). Section is plotted in a downstream viewed perspective.**

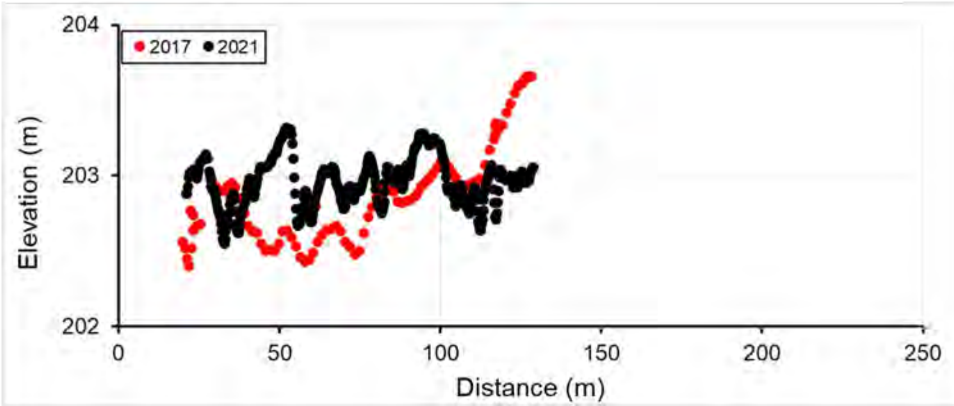

Figure 28 **Lillooet River Lower Reach: Historical Monitoring Section L66 (Located 12,570 m upstream of the mouth). Section is plotted in a downstream viewed perspective.**

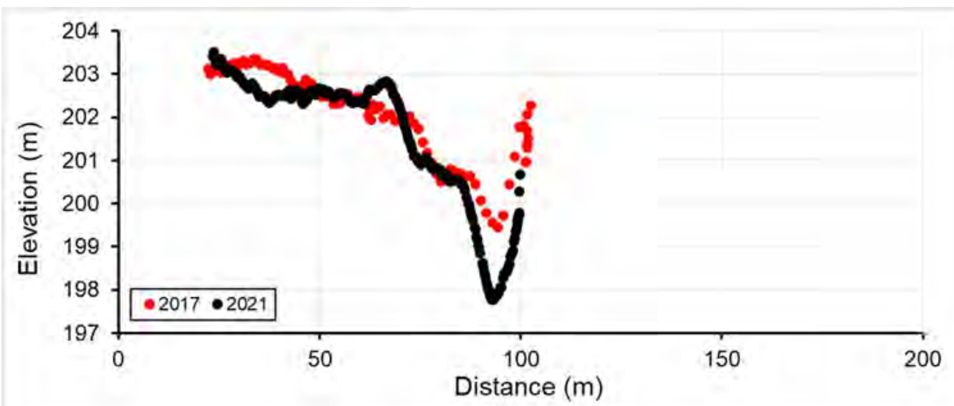

Figure 29 **Lillooet River Lower Reach: Historical Monitoring Section L67 (Located 12,466 m upstream of the mouth). Section is plotted in a downstream viewed perspective.**

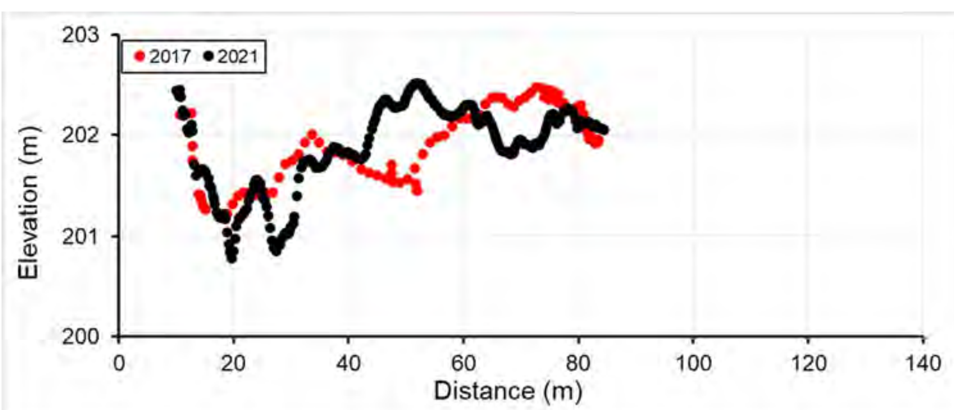

Figure 30 **Lillooet River Lower Reach: Historical Monitoring Section L68 (Located 12,273 m upstream of the mouth). Section is plotted in a downstream viewed perspective.**

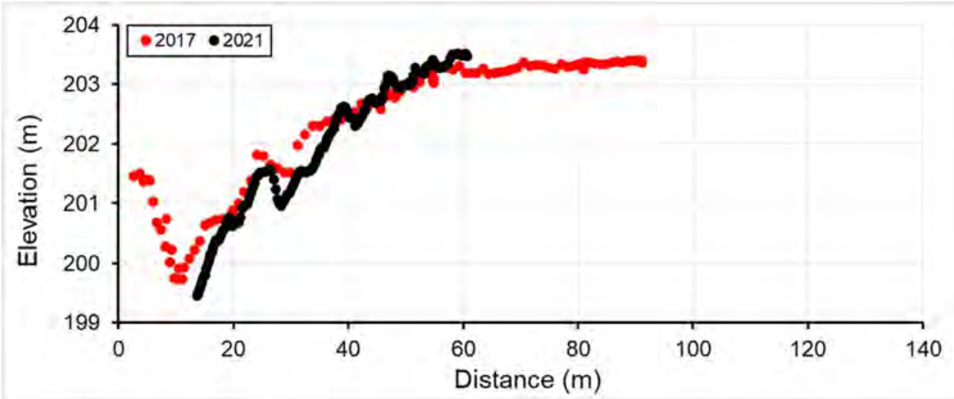

Figure 31 Lillooet River Lower Reach: Historical Monitoring Section L69 (Located 12,061 m upstream of the mouth). Section is plotted in a downstream viewed perspective.

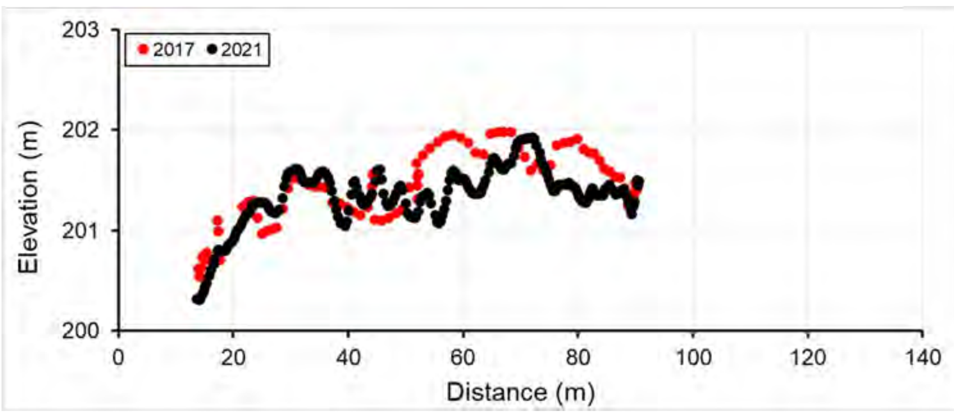

Figure 32 Lillooet River Lower Reach: Historical Monitoring Section L70 (Located 11,379 m upstream of the mouth). Section is plotted in a downstream viewed perspective.

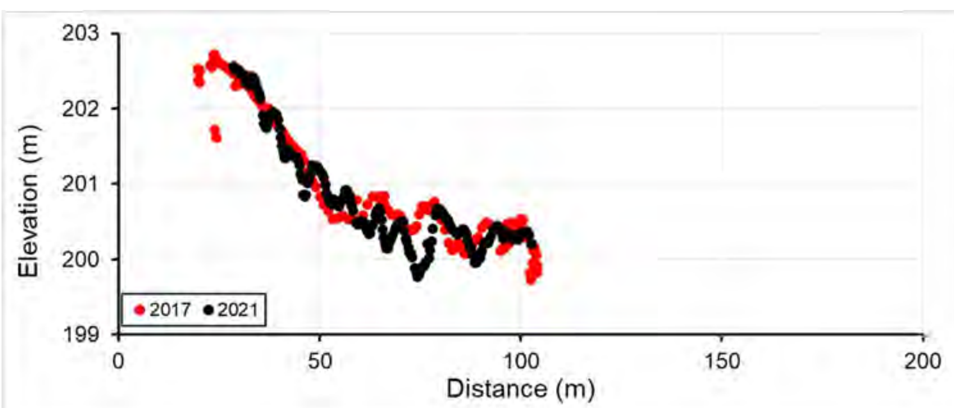

Figure 33 Lillooet River Lower Reach: Historical Monitoring Section L71 (Located 10,478 m upstream of the mouth). Section is plotted in a downstream viewed perspective.

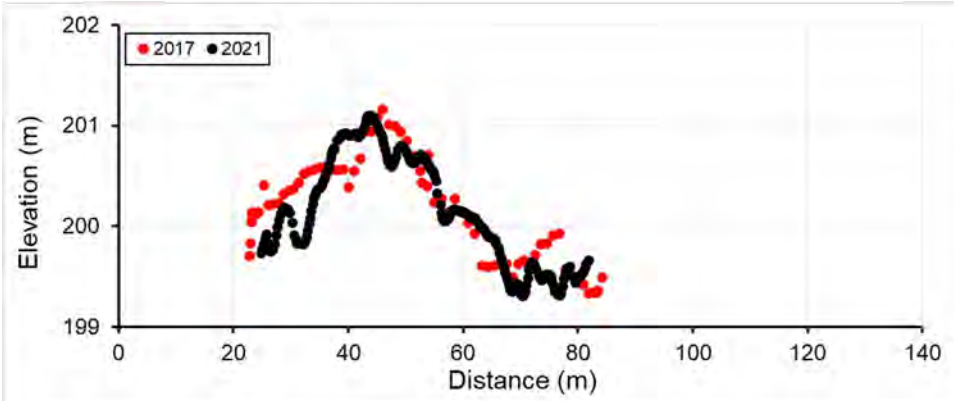

Figure 34 Lillooet River Lower Reach: Historical Monitoring Section L72 (Located 9,803 m upstream of the mouth). Section is plotted in a downstream viewed perspective.

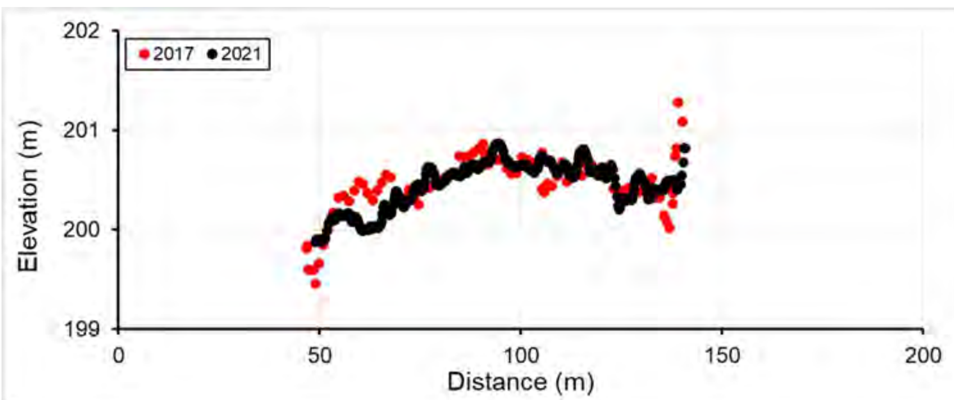

Figure 35 Lillooet River Lower Reach: Historical Monitoring Section L73 (Located 9,057 m upstream of the mouth). Section is plotted in a downstream viewed perspective.

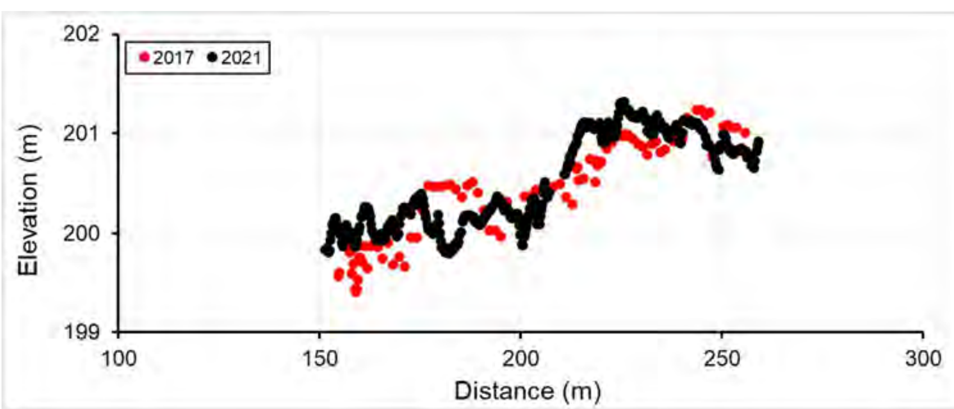

Figure 36 Lillooet River Lower Reach: Historical Monitoring Section L74 (Located 8,857 m upstream of the mouth). Section is plotted in a downstream viewed perspective.

APPENDIX C

2017 AND 2021 LILLOOET RIVER 50 M TRANSECTS AT SELECT LOCATIONS IN THE MIDDLE REACH

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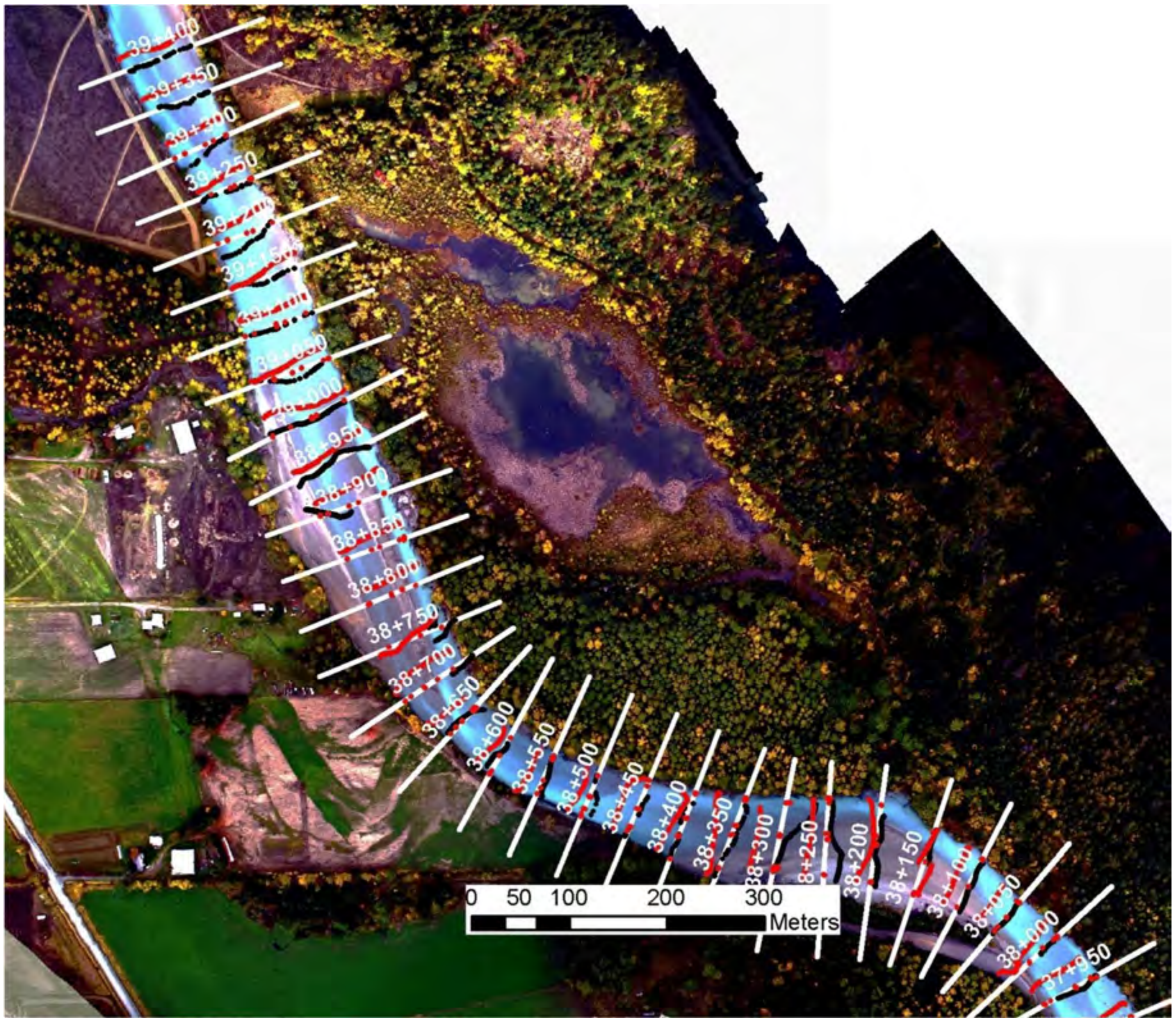

Figure 1 Lillooet River Middle Reach 50 m transects 39+400 to 37+950. 2017 NHC orthophoto for reference. 2021 data shown as black dots and 2017 data shown as red dots. Flow direction is from top to bottom.

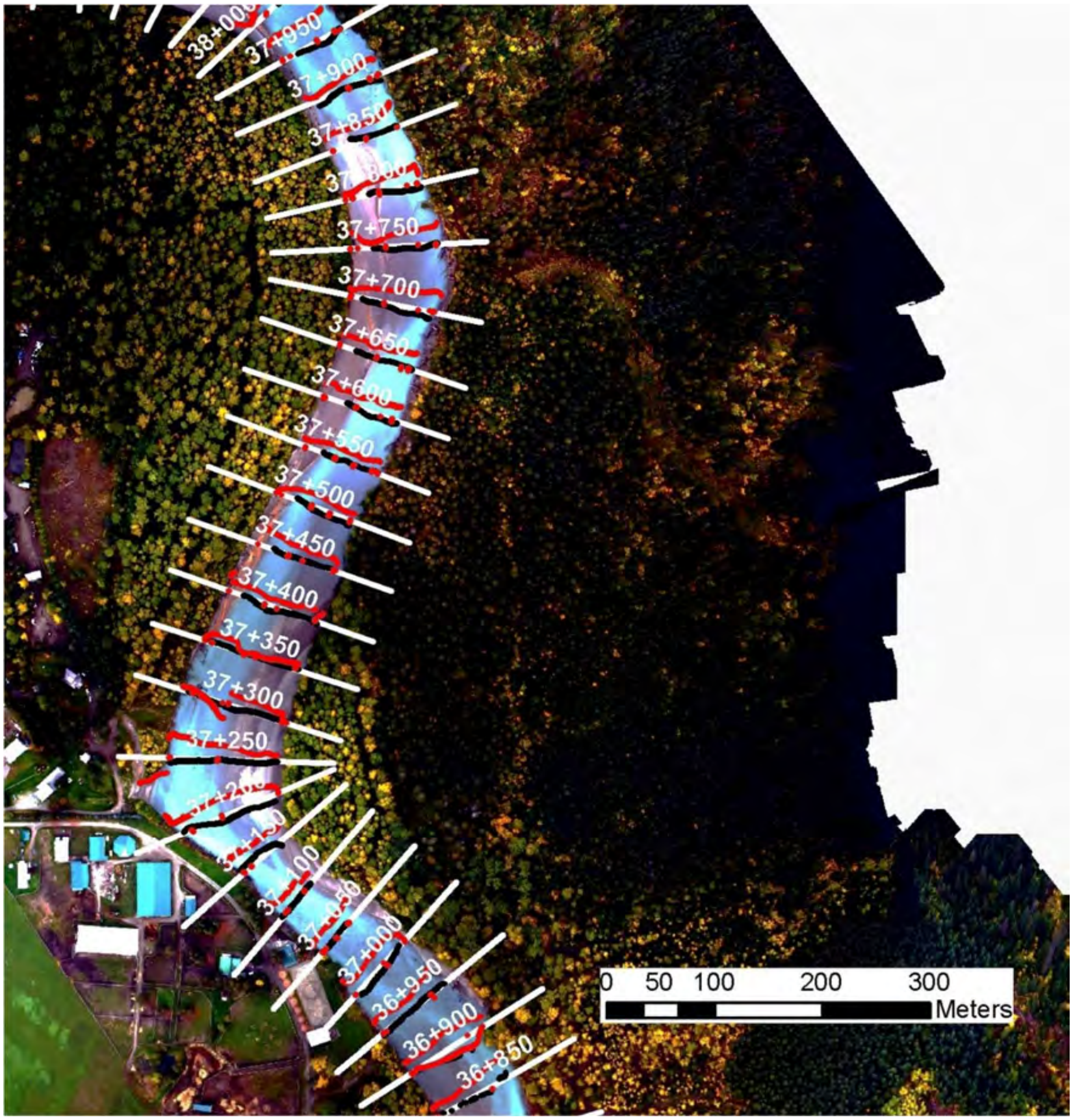

Figure 2 Lillooet River Middle Reach 50 m transects 37+950 to 36+850. 2017 NHC orthophoto for reference. 2021 data shown as black dots and 2017 data shown as red dots. Flow direction is from top to bottom.

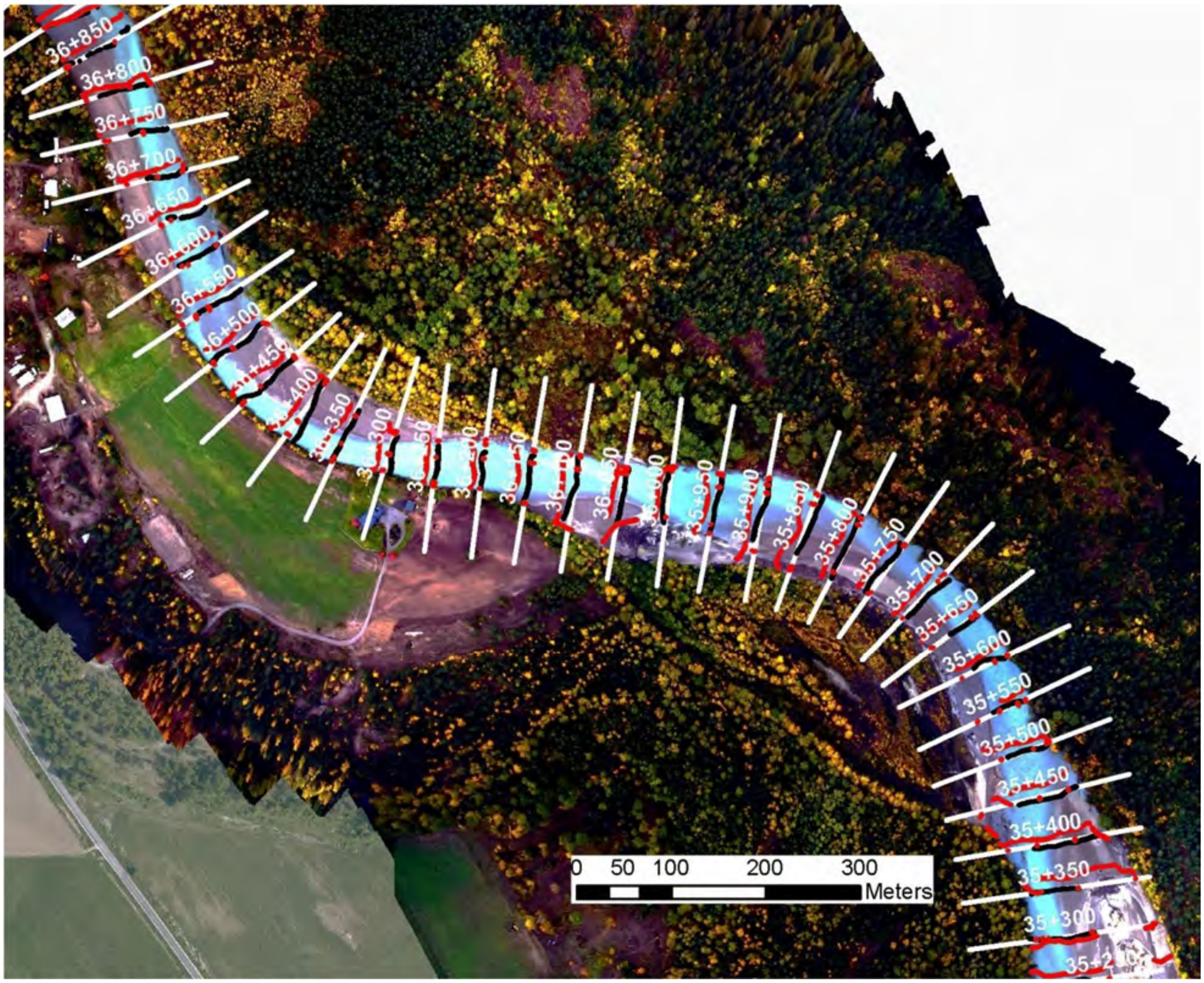

Figure 3 **Lillooet River Middle Reach 50 m transects 36+850 to 35+250. 2017 NHC orthophoto for reference. 2021 data shown as black dots and 2017 data shown as red dots. Flow direction is from top to bottom.**

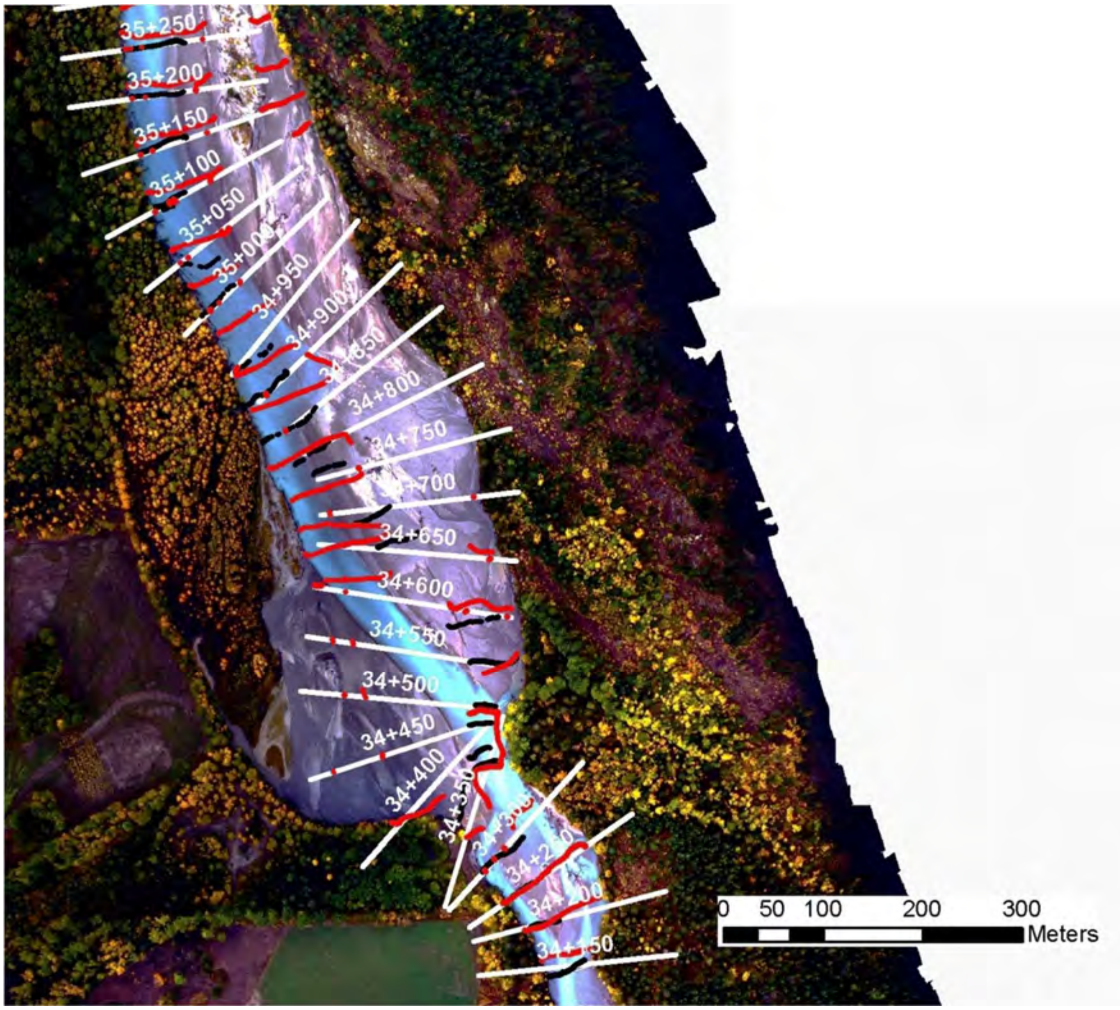

Figure 4 **Lillooet River Middle Reach 50 m transects 35+250 to 34+150. 2021 data shown as black dots and 2017 data shown as red dots. Flow direction is from top to bottom.**

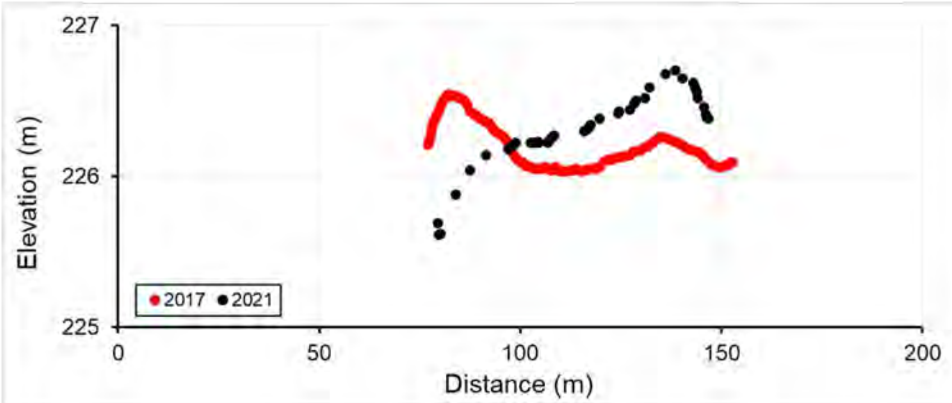

Figure 5 Lillooet River Middle Reach 50-metre transects – River Station 39+400 (i.e., located 39,400 m upstream of the mouth). Section is plotted in a downstream viewed perspective.

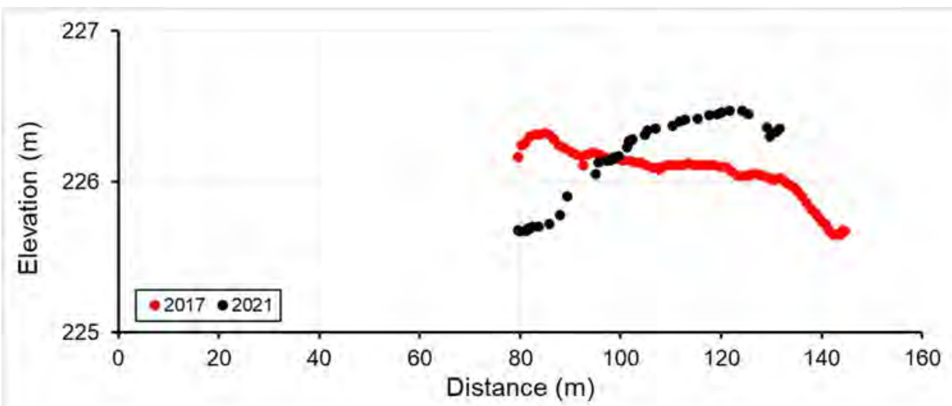

Figure 6 Lillooet River Middle Reach 50-metre transects – River Station 39+350. Section is plotted in a downstream viewed perspective.

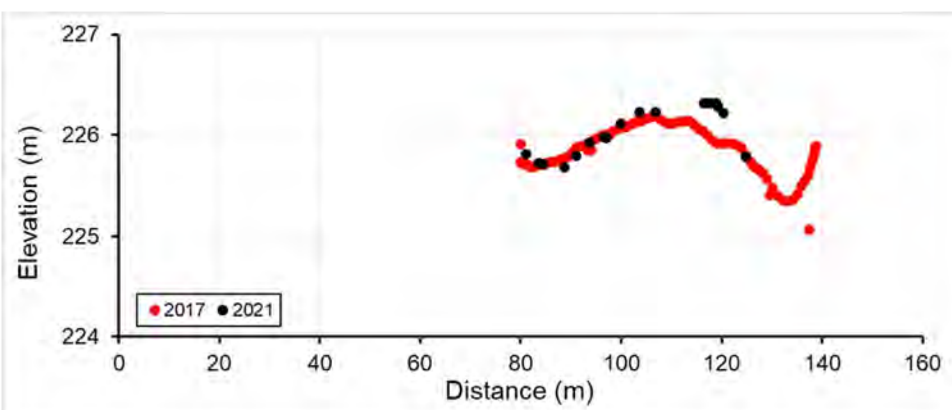

Figure 7 Lillooet River Middle Reach 50-metre transects – River Station 39+300. Section is plotted in a downstream viewed perspective.

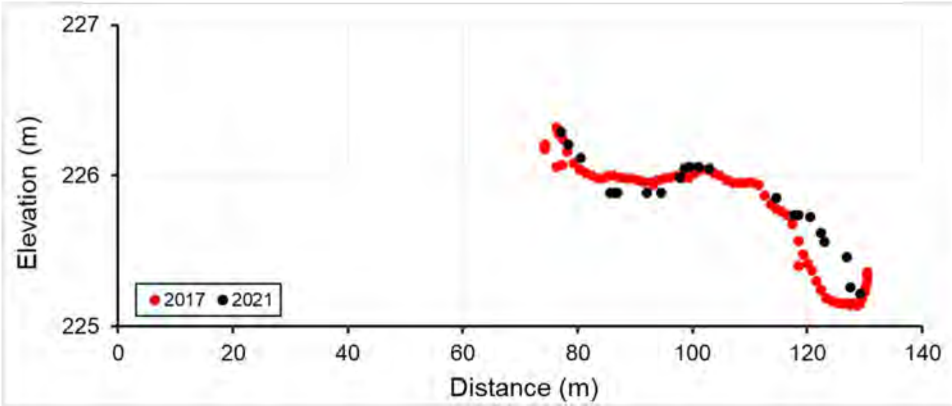

Figure 8 Lillooet River Middle Reach 50-metre transects – River Station 39+250. Section is plotted in a downstream viewed perspective.

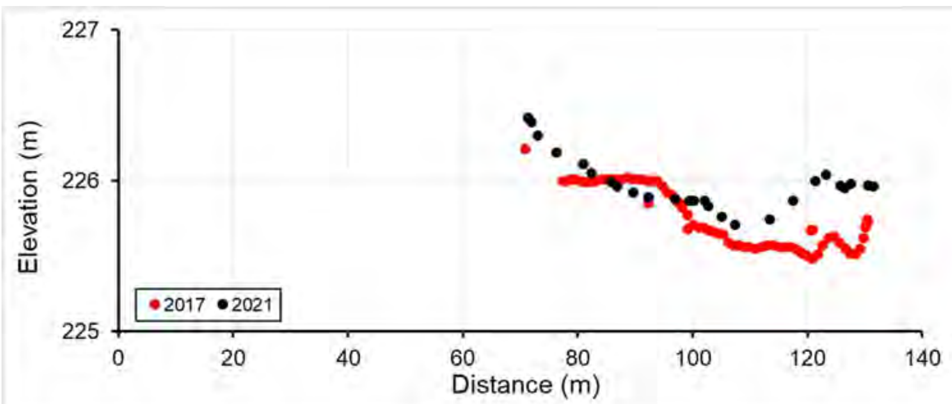

Figure 9 Lillooet River Middle Reach 50-metre transects – River Station 39+200. Section is plotted in a downstream viewed perspective.

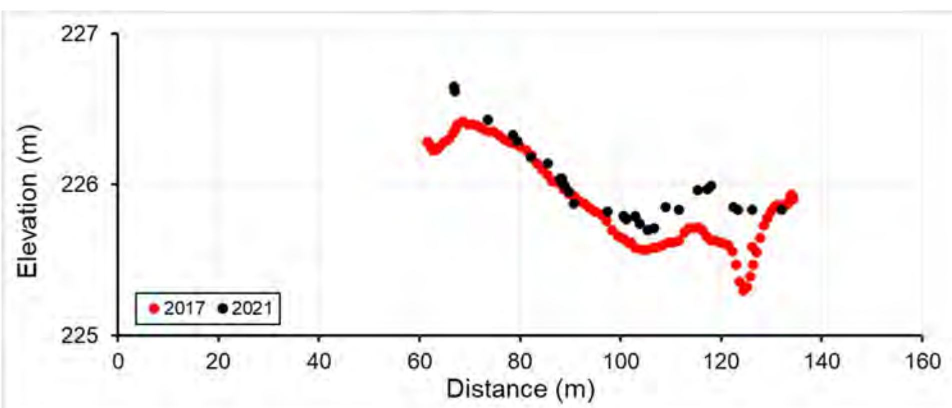

Figure 10 Lillooet River Middle Reach 50-metre transects – River Station 39+150. Section is plotted in a downstream viewed perspective.

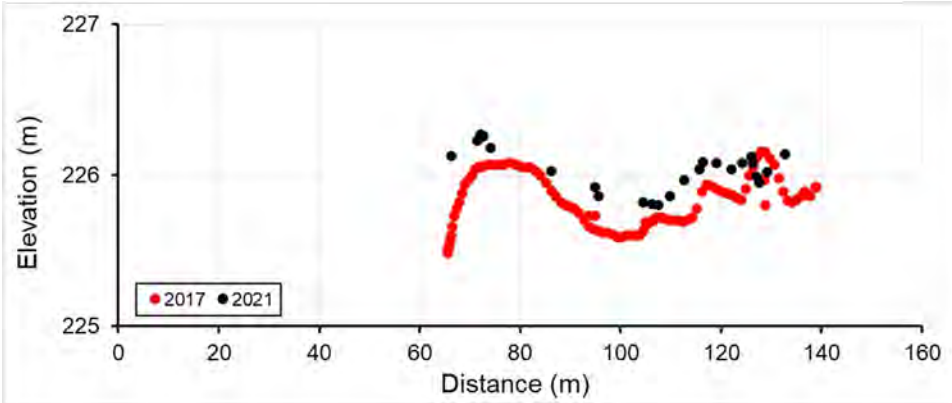

Figure 11 **Lillooet River Middle Reach 50-metre transects – River Station 39+100. Section is plotted in a downstream viewed perspective.**

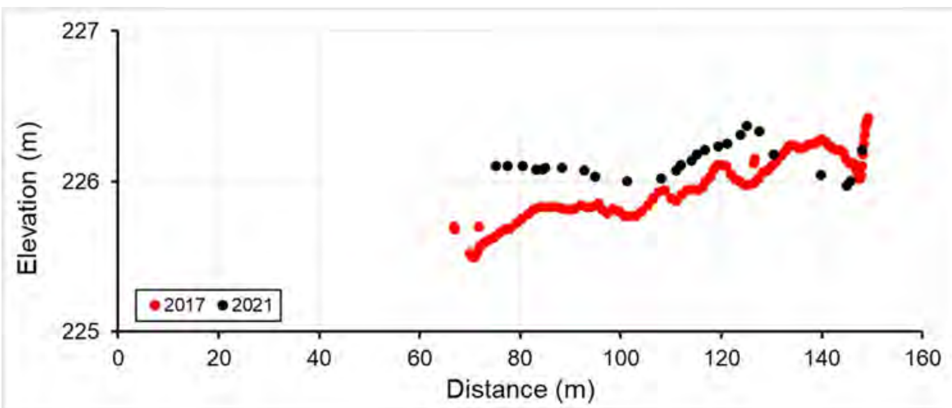

Figure 12 **Lillooet River Middle Reach 50-metre transects – River Station 39+050. Section is plotted in a downstream viewed perspective.**

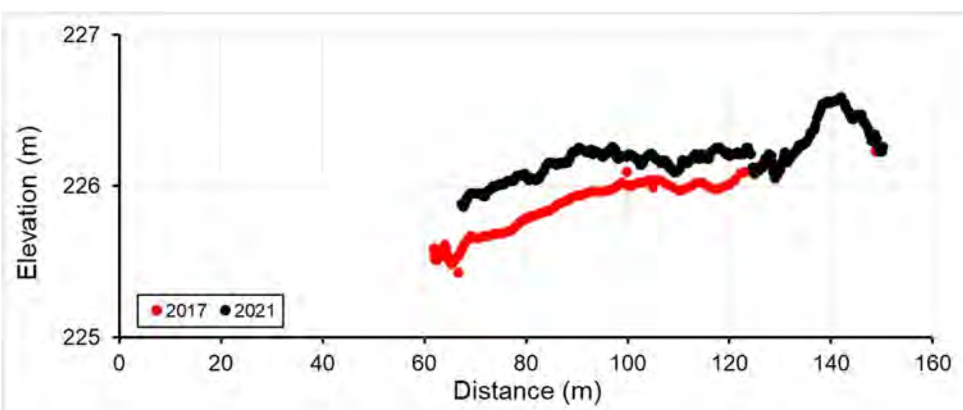

Figure 13 **Lillooet River Middle Reach 50-metre transects – River Station 39+000. Section is plotted in a downstream viewed perspective.**

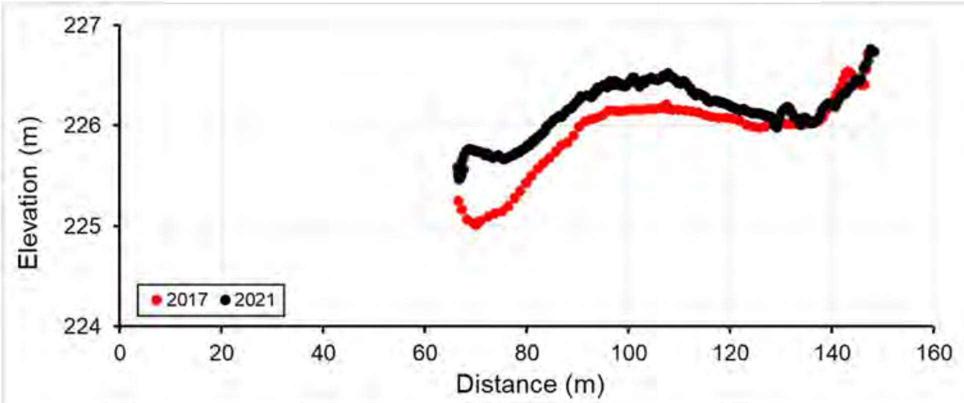

Figure 14 Lillooet River Middle Reach 50-metre transects – River Station 38+950. Section is plotted in a downstream viewed perspective.

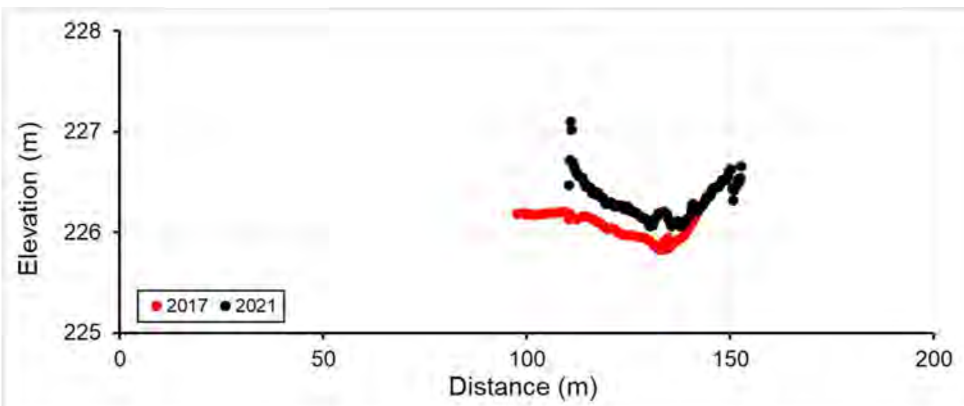

Figure 15 Lillooet River Middle Reach 50-metre transects – River Station 38+900. Section is plotted in a downstream viewed perspective.

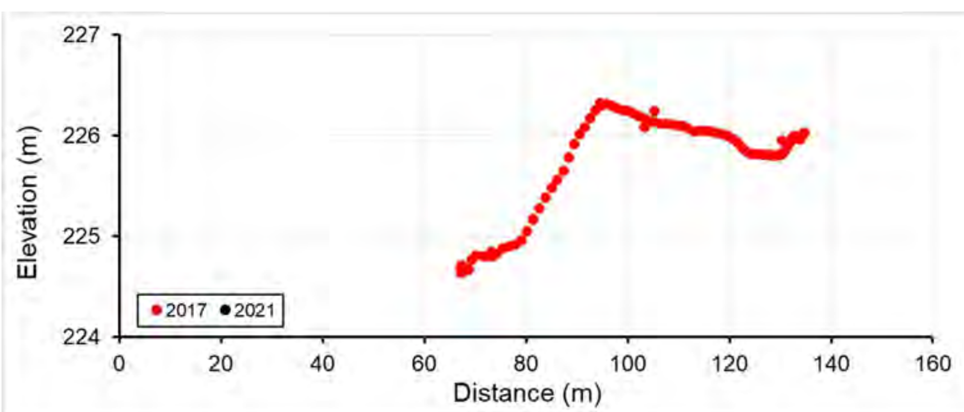

Figure 16 Lillooet River Middle Reach 50-metre transects – River Station 38+850. Section is plotted in a downstream viewed perspective.

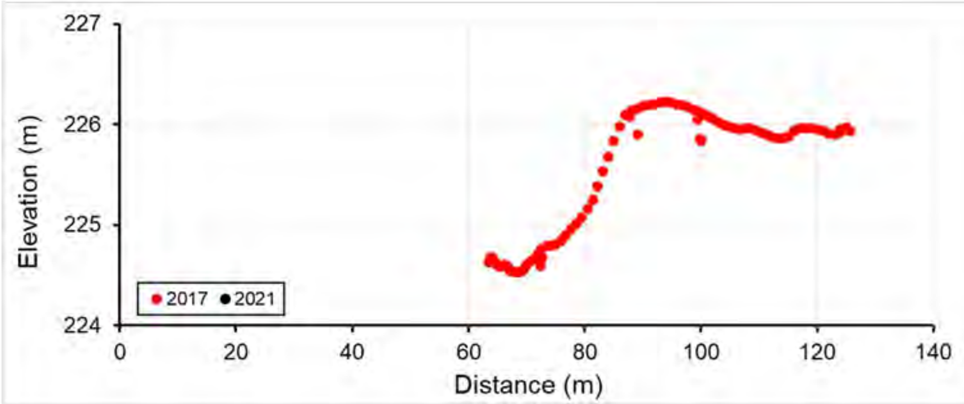

Figure 17 Lillooet River Middle Reach 50-metre transects – River Station 38+380. Section is plotted in a downstream viewed perspective.

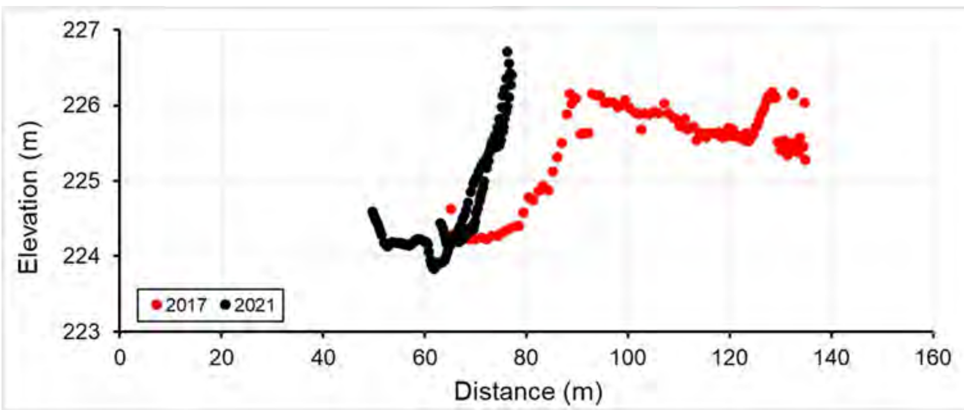

Figure 18 Lillooet River Middle Reach 50-metre transects – River Station 38+750. Section is plotted in a downstream viewed perspective.

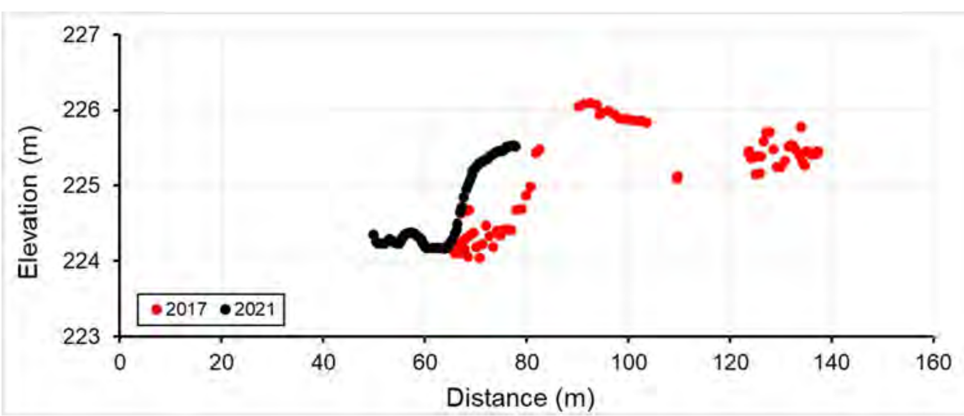

Figure 19 Lillooet River Middle Reach 50-metre transects – River Station 38+700. Section is plotted in a downstream viewed perspective.

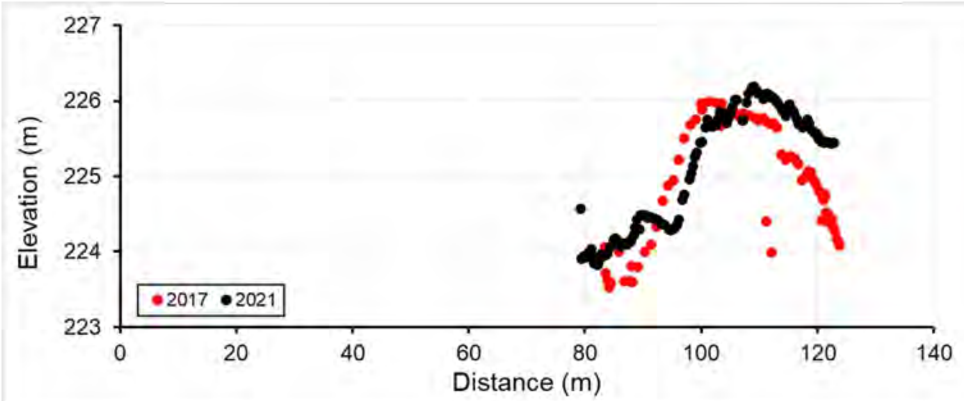

Figure 20 Lillooet River Middle Reach 50-metre transects – River Station 38+650. Section is plotted in a downstream viewed perspective.

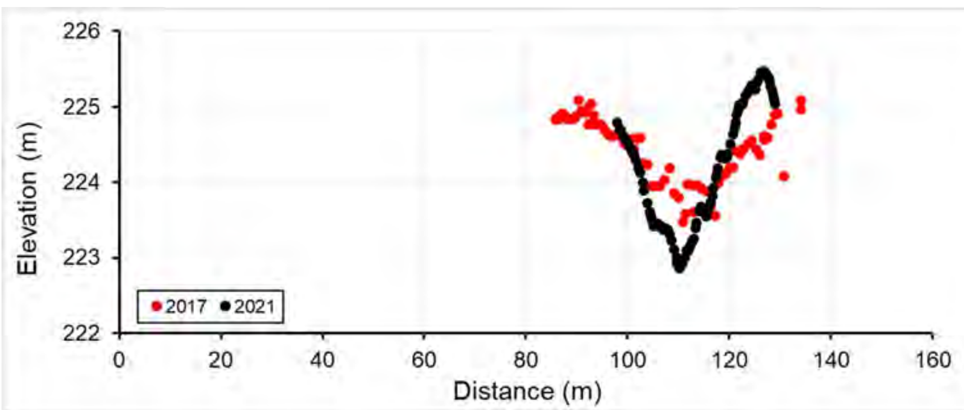

Figure 21 Lillooet River Middle Reach 50-metre transects – River Station 38+600. Section is plotted in a downstream viewed perspective.

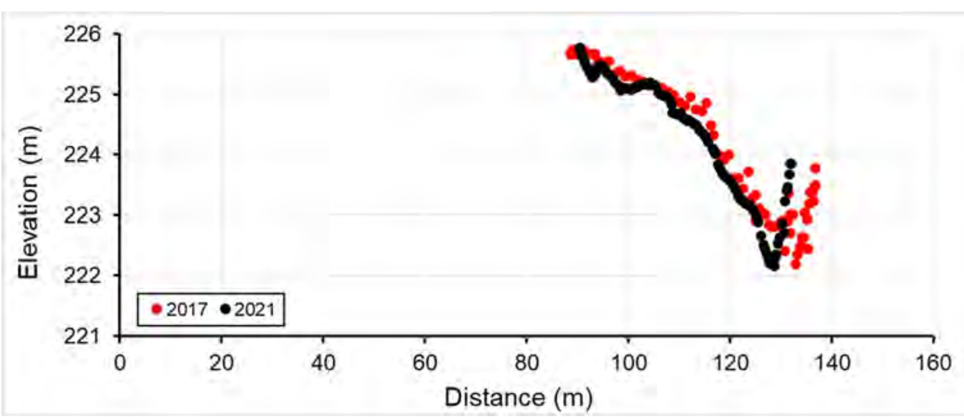

Figure 22 Lillooet River Middle Reach 50-metre transects – River Station 38+550. Section is plotted in a downstream viewed perspective.

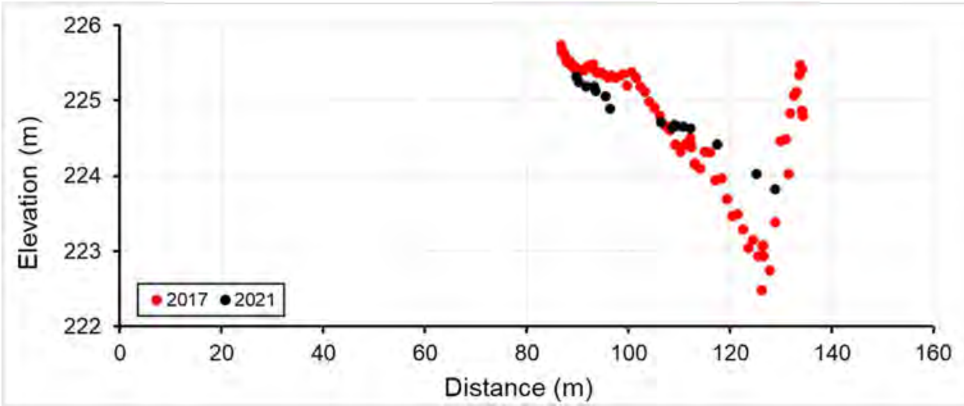

Figure 23 Lillooet River Middle Reach 50-metre transects – River Station 38+500. Section is plotted in a downstream viewed perspective.

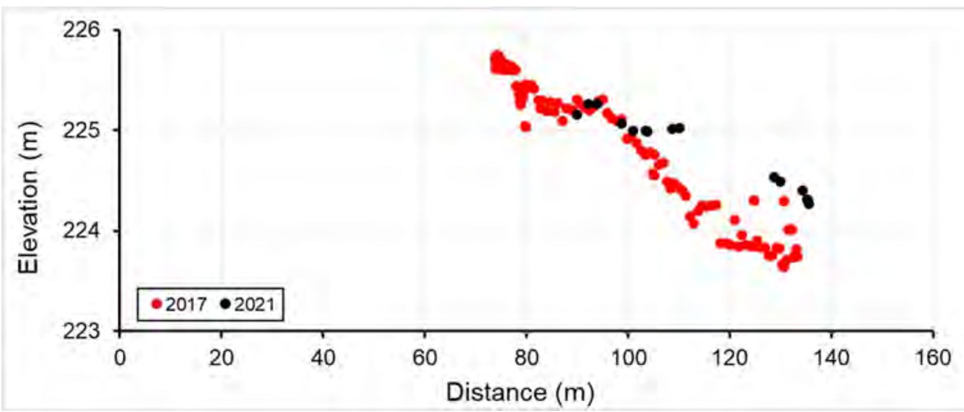

Figure 24 Lillooet River Middle Reach 50-metre transects – River Station 38+450. Section is plotted in a downstream viewed perspective.

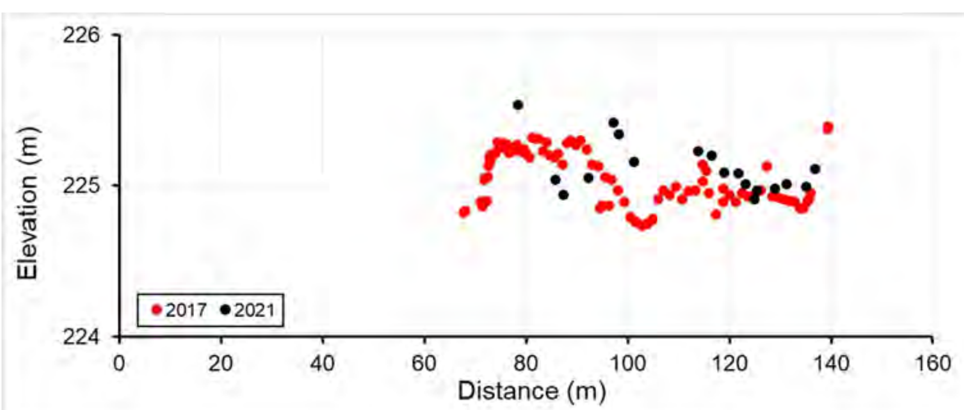

Figure 25 Lillooet River Middle Reach 50-metre transects – River Station 38+400. Section is plotted in a downstream viewed perspective.

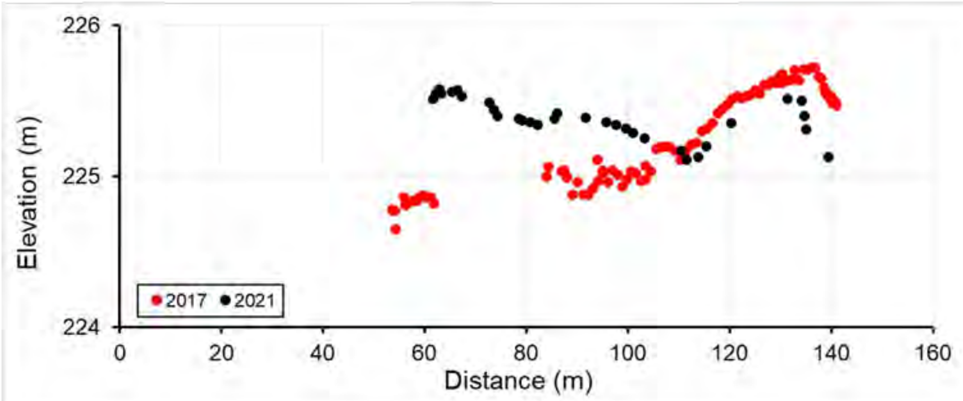

Figure 26 Lillooet River Middle Reach 50-metre transects – River Station 38+350. Section is plotted in a downstream viewed perspective.

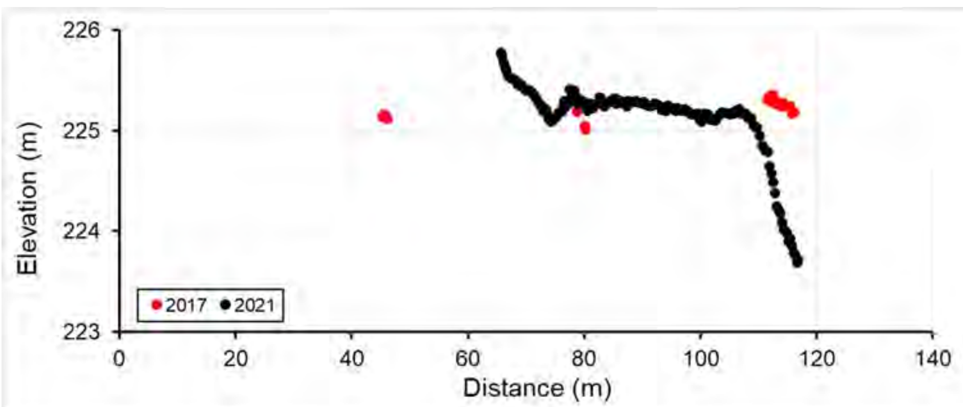

Figure 27 Lillooet River Middle Reach 50-metre transects – River Station 38+300. Section is plotted in a downstream viewed perspective.

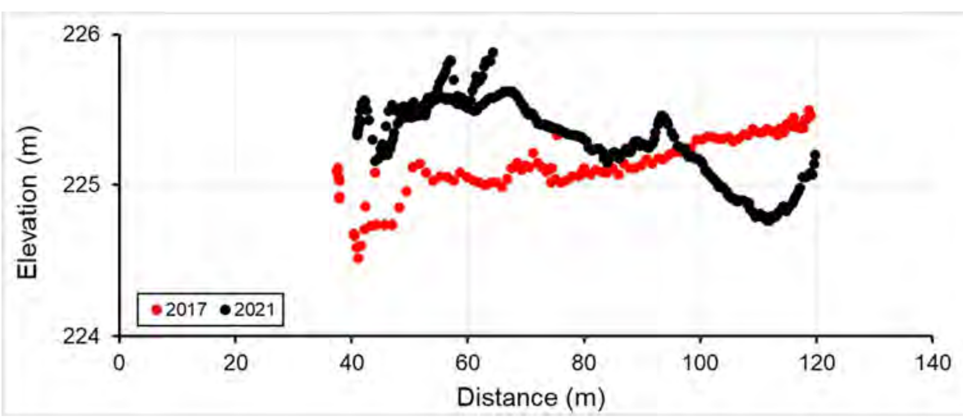

Figure 28 Lillooet River Middle Reach 50-metre transects – River Station 38+250. Section is plotted in a downstream viewed perspective.

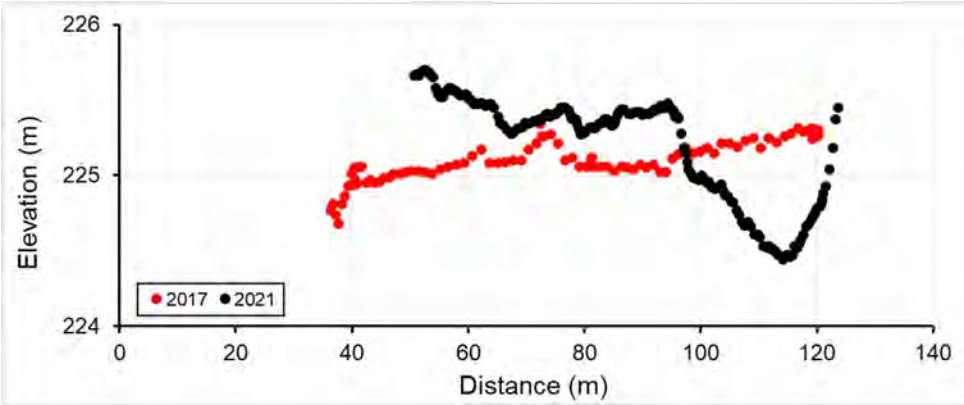

Figure 29 **Lillooet River Middle Reach 50-metre transects – River Station 38+200. Section is plotted in a downstream viewed perspective.**

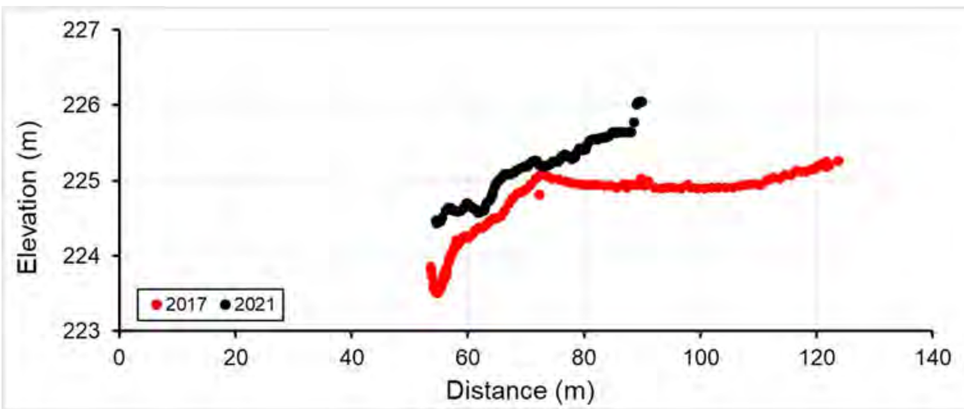

Figure 30 **Lillooet River Middle Reach 50-metre transects – River Station 38+150. Section is plotted in a downstream viewed perspective.**

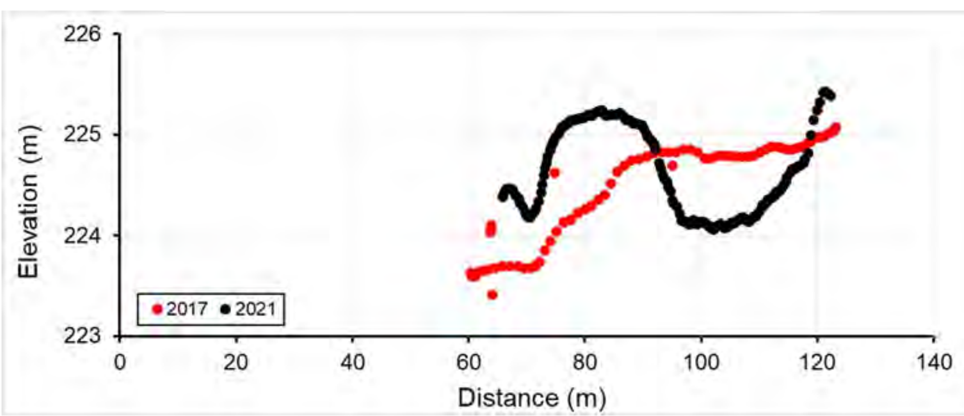

Figure 31 **Lillooet River Middle Reach 50-metre transects – River Station 38+100. Section is plotted in a downstream viewed perspective.**

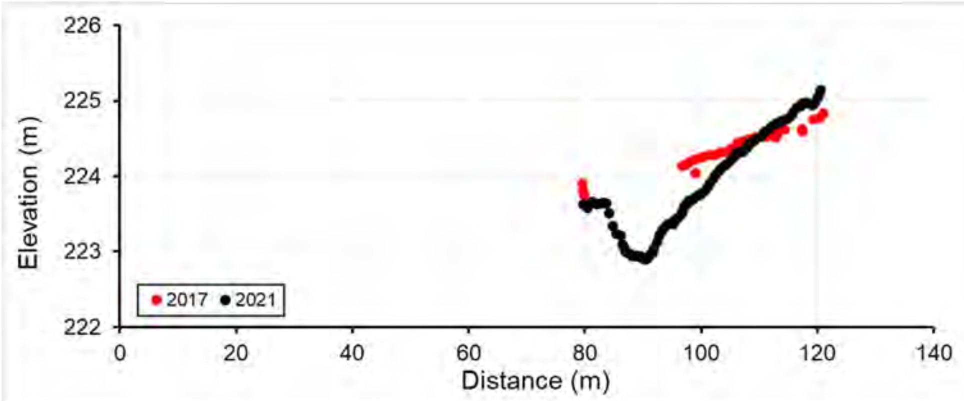

Figure 32 Lillooet River Middle Reach 50-metre transects – River Station 38+050. Section is plotted in a downstream viewed perspective.

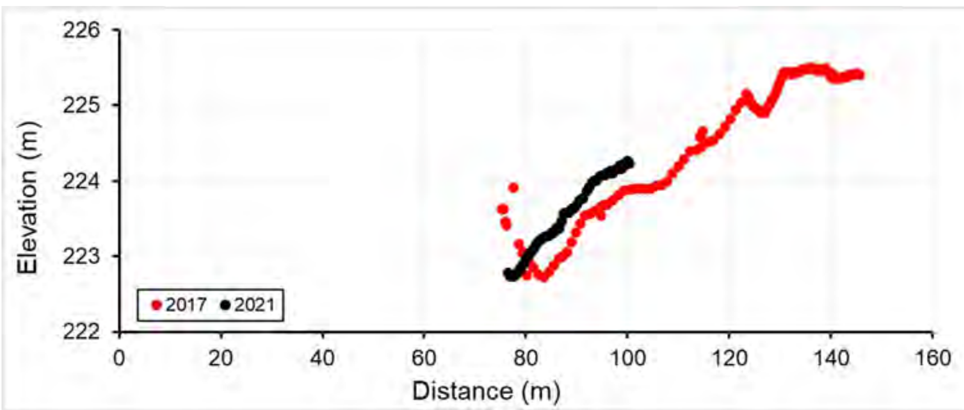

Figure 33 Lillooet River Middle Reach 50-metre transects – River Station 38+000. Section is plotted in a downstream viewed perspective.

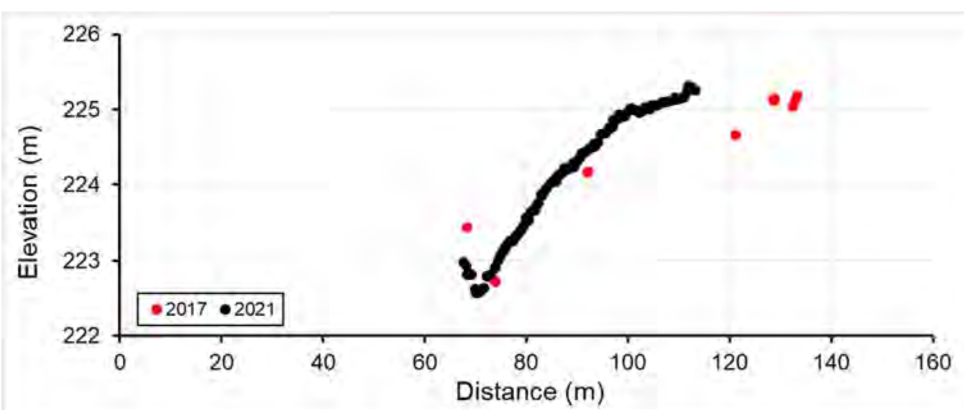

Figure 34 Lillooet River Middle Reach 50-metre transects – River Station 37+950. Section is plotted in a downstream viewed perspective.

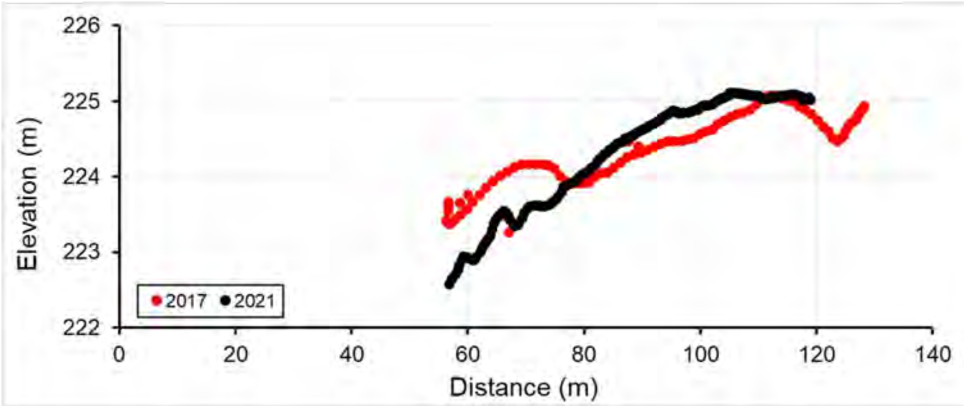

Figure 35 Lillooet River Middle Reach 50-metre transects – River Station 37+900. Section is plotted in a downstream viewed perspective.

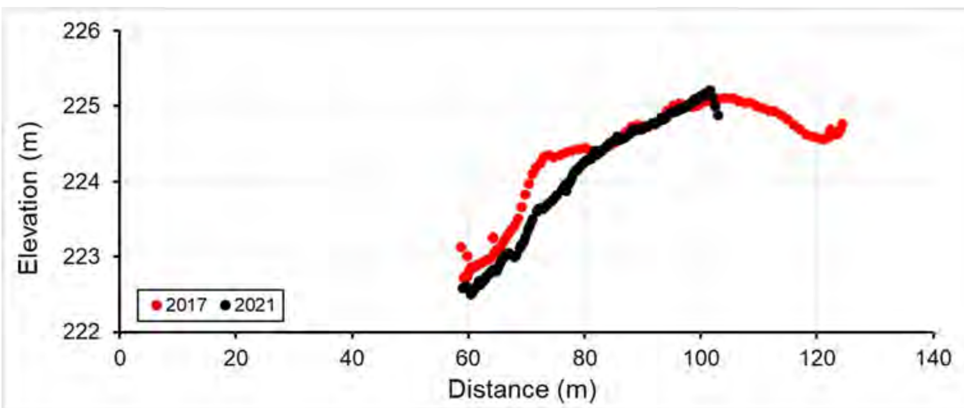

Figure 36 Lillooet River Middle Reach 50-metre transects – River Station 37+850. Section is plotted in a downstream viewed perspective.

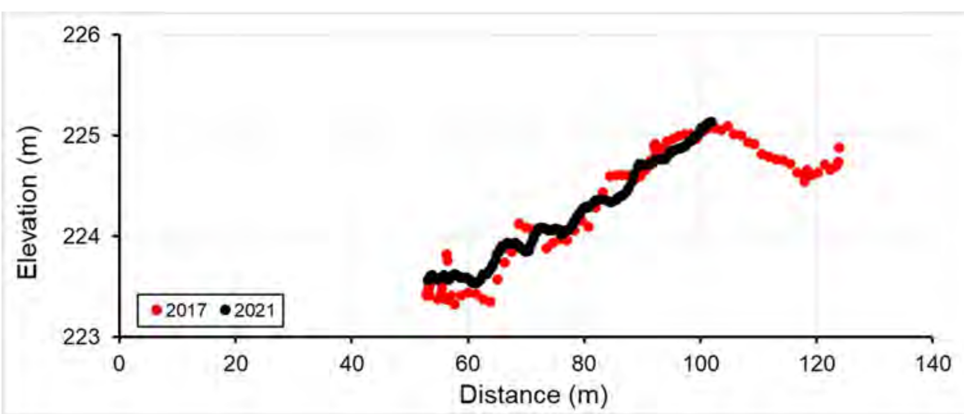

Figure 37 Lillooet River Middle Reach 50-metre transects – River Station 37+800. Section is plotted in a downstream viewed perspective.

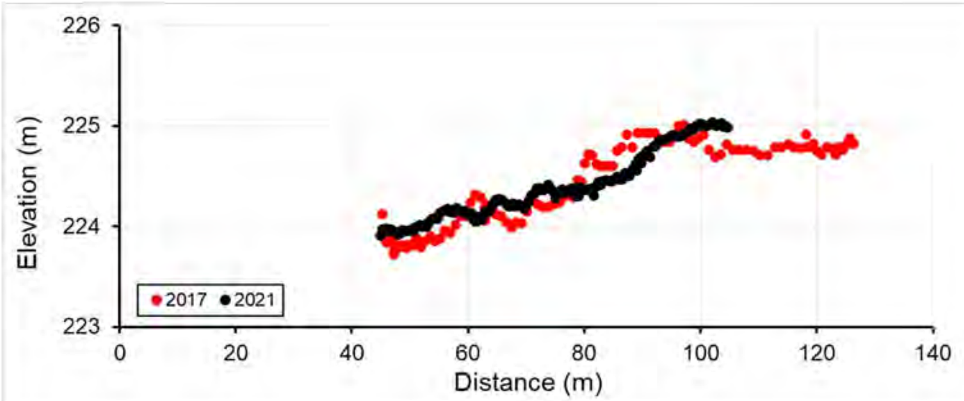

Figure 38 **Lillooet River Middle Reach 50-metre transects – River Station 37+750. Section is plotted in a downstream viewed perspective.**

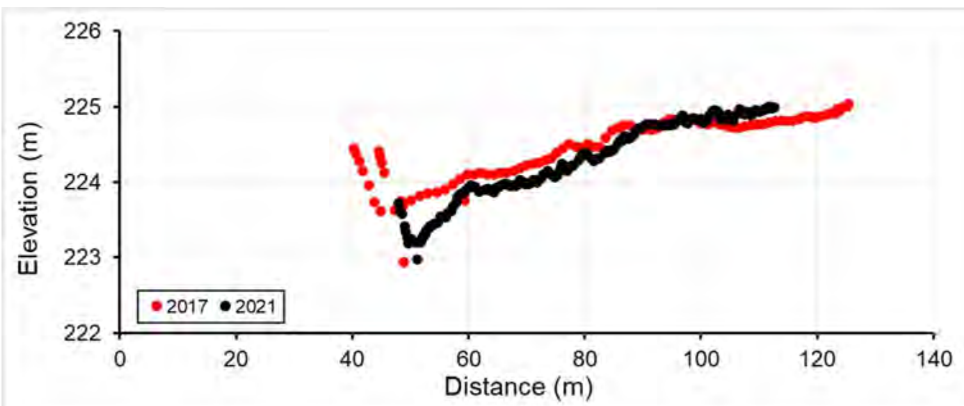

Figure 39 **Lillooet River Middle Reach 50-metre transects – River Station 37+700. Section is plotted in a downstream viewed perspective.**

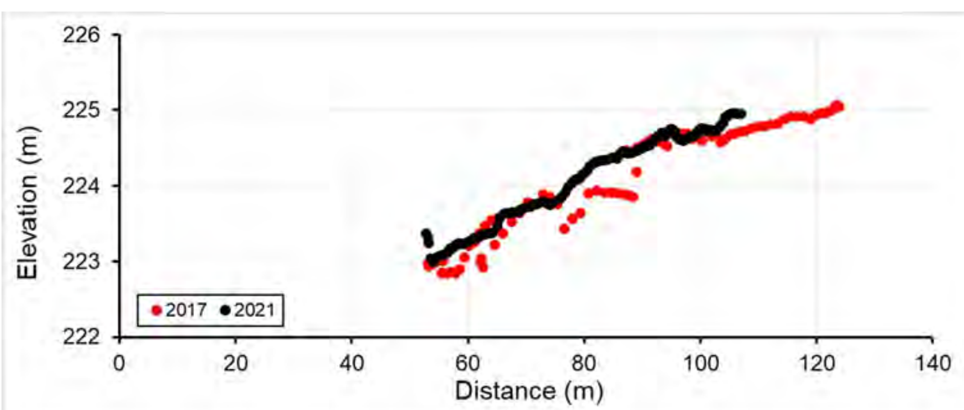

Figure 40 **Lillooet River Middle Reach 50-metre transects – River Station 37+650. Section is plotted in a downstream viewed perspective.**

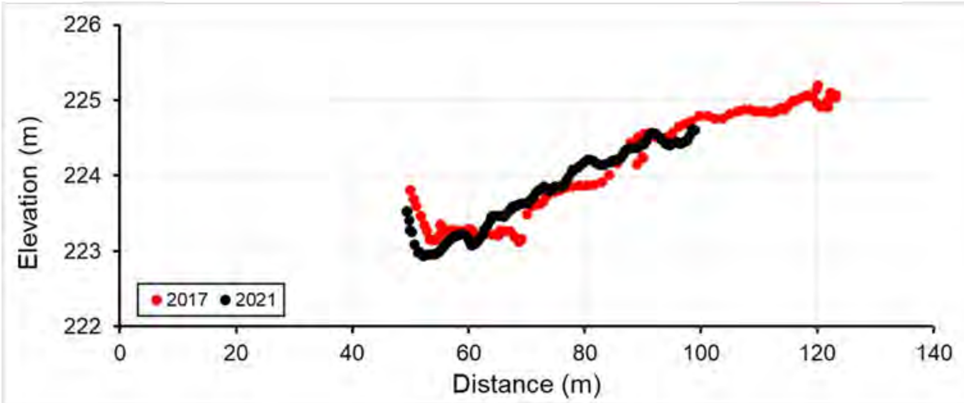

Figure 41 **Lillooet River Middle Reach 50-metre transects – River Station 37+600. Section is plotted in a downstream viewed perspective.**

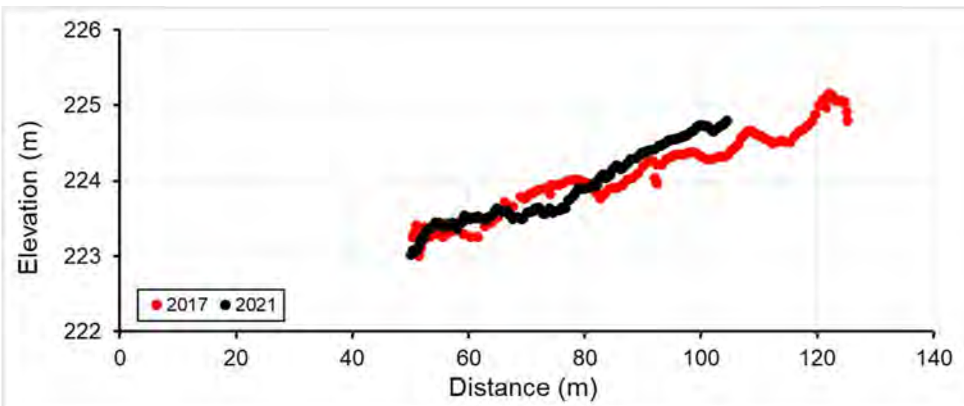

Figure 42 **Lillooet River Middle Reach 50-metre transects – River Station 37+550. Section is plotted in a downstream viewed perspective.**

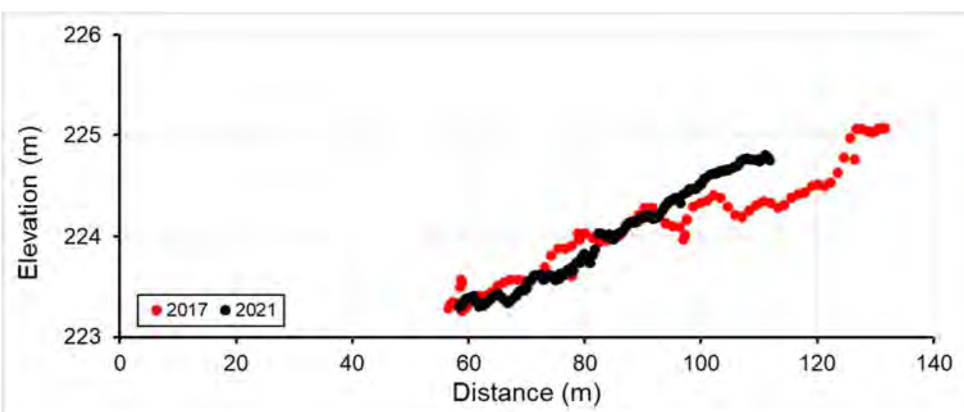

Figure 43 **Lillooet River Middle Reach 50-metre transects – River Station 37+500. Section is plotted in a downstream viewed perspective.**

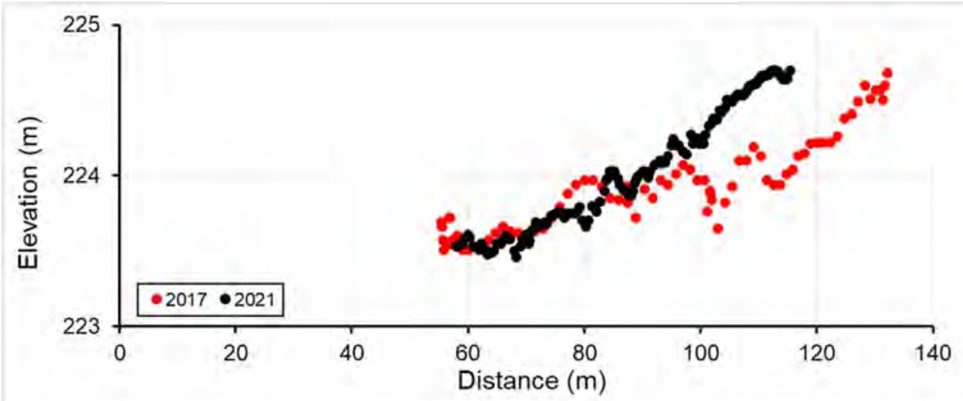

Figure 44 Lillooet River Middle Reach 50-metre transects – River Station 37+450. Section is plotted in a downstream viewed perspective.

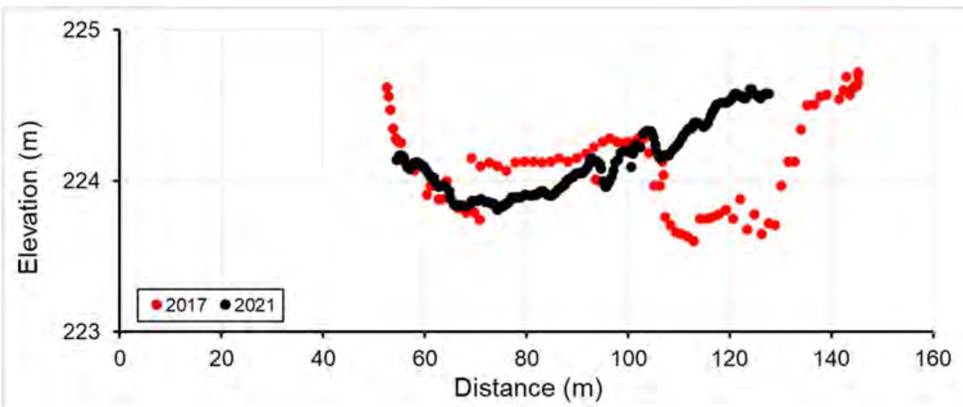

Figure 45 Lillooet River Middle Reach 50-metre transects – River Station 37+400. Section is plotted in a downstream viewed perspective.

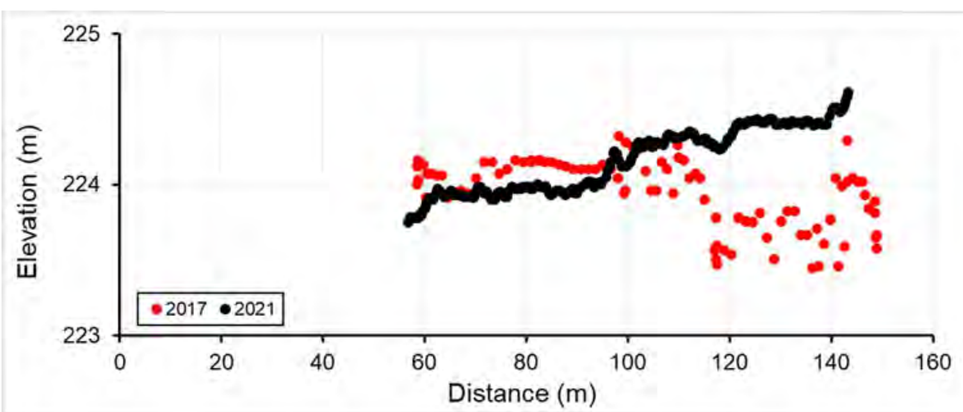

Figure 46 Lillooet River Middle Reach 50-metre transects – River Station 37+350. Section is plotted in a downstream viewed perspective.

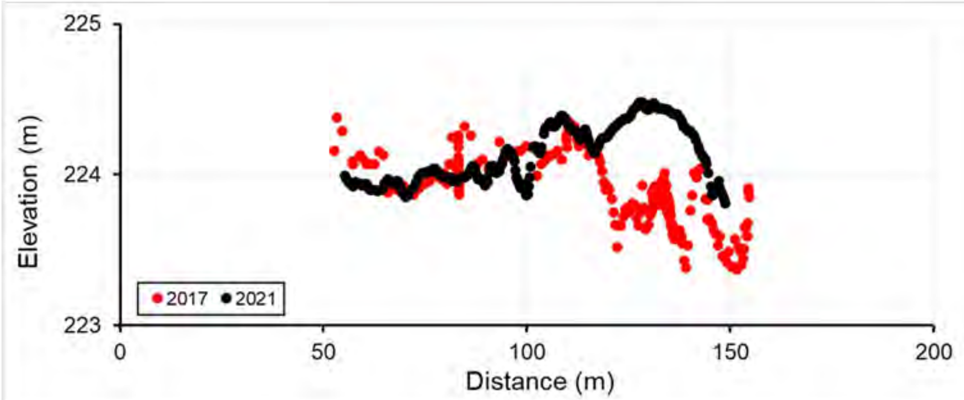

Figure 47 Lillooet River Middle Reach 50-metre transects – River Station 37+300. Section is plotted in a downstream viewed perspective.

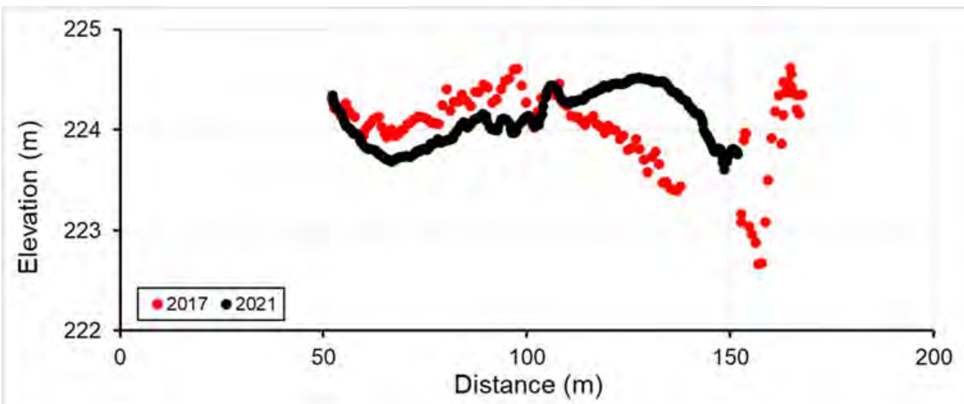

Figure 48 Lillooet River Middle Reach 50-metre transects – River Station 37+250. Section is plotted in a downstream viewed perspective.

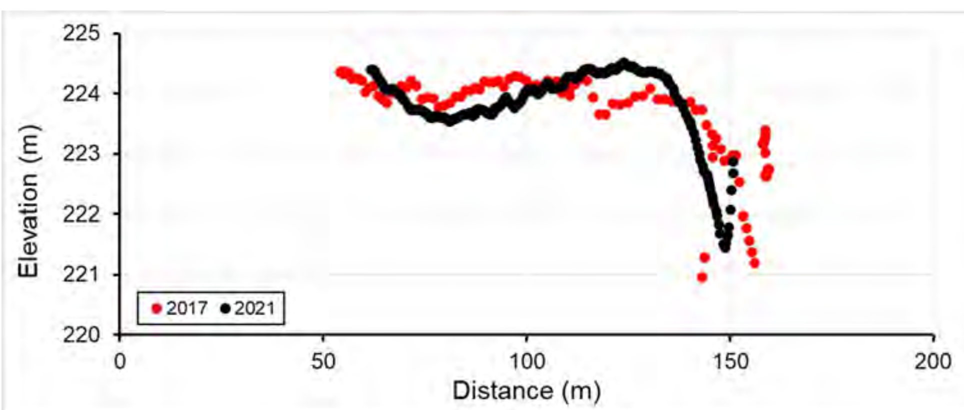

Figure 49 Lillooet River Middle Reach 50-metre transects – River Station 37+200. Section is plotted in a downstream viewed perspective.

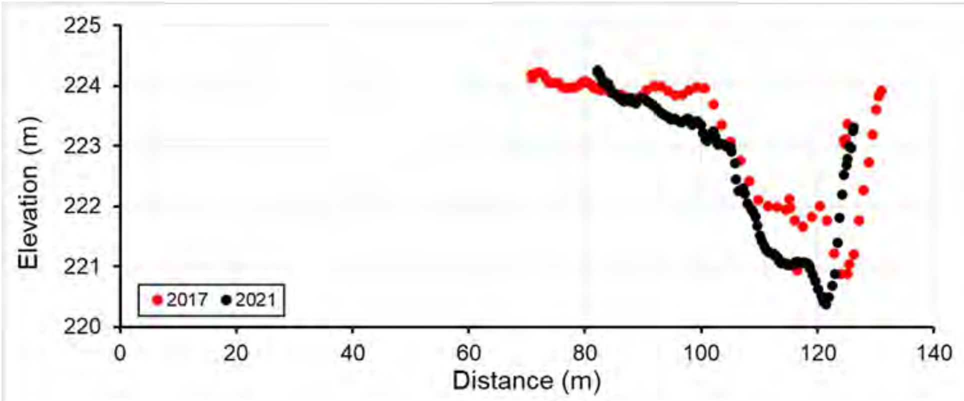

Figure 50 Lillooet River Middle Reach 50-metre transects – River Station 37+150. Section is plotted in a downstream viewed perspective.

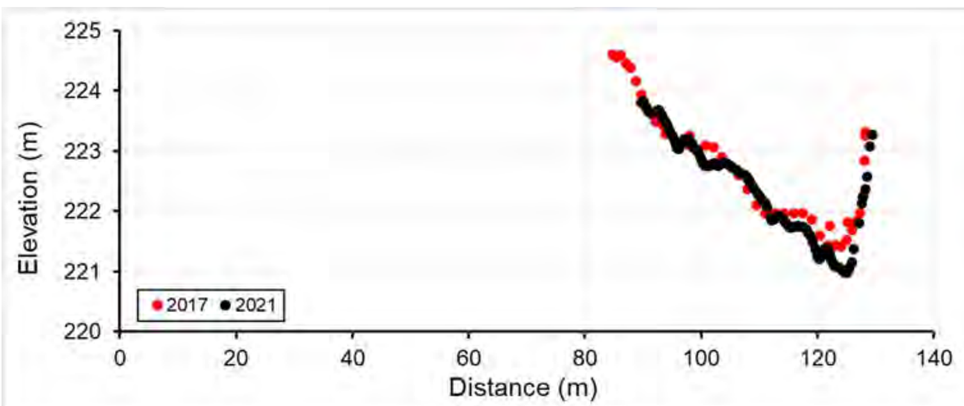

Figure 51 Lillooet River Middle Reach 50-metre transects – River Station 37+100. Section is plotted in a downstream viewed perspective.

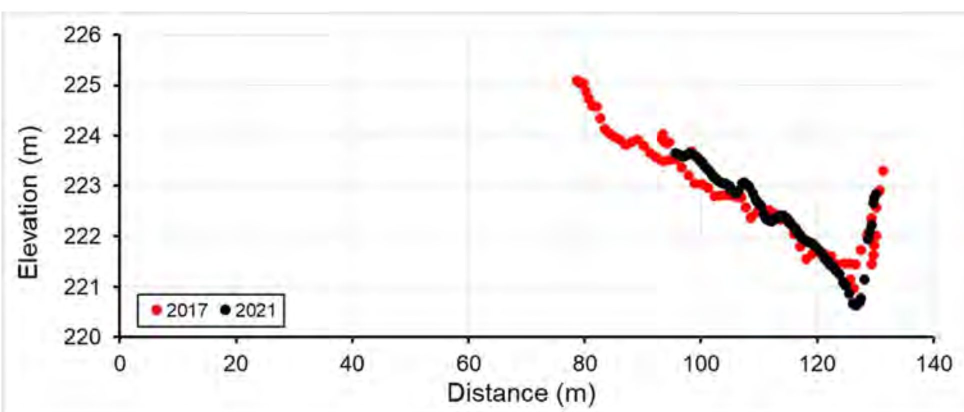

Figure 52 Lillooet River Middle Reach 50-metre transects – River Station 37+050. Section is plotted in a downstream viewed perspective.

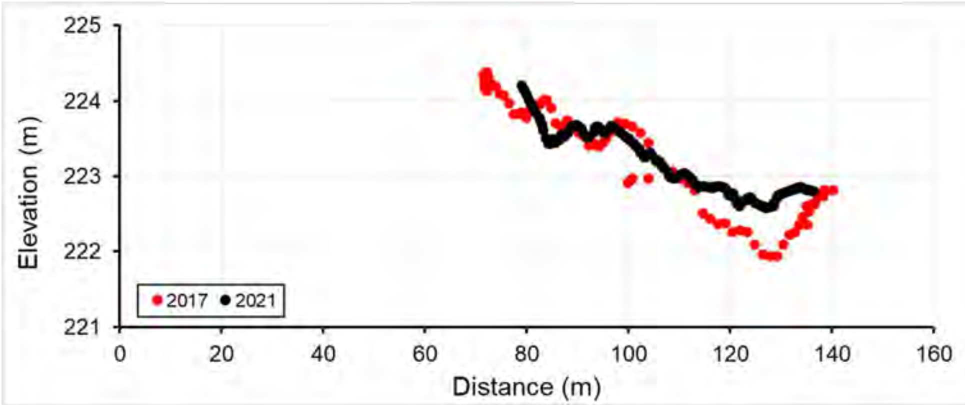

Figure 53 **Lillooet River Middle Reach 50-metre transects – River Station 37+000. Section is plotted in a downstream viewed perspective.**

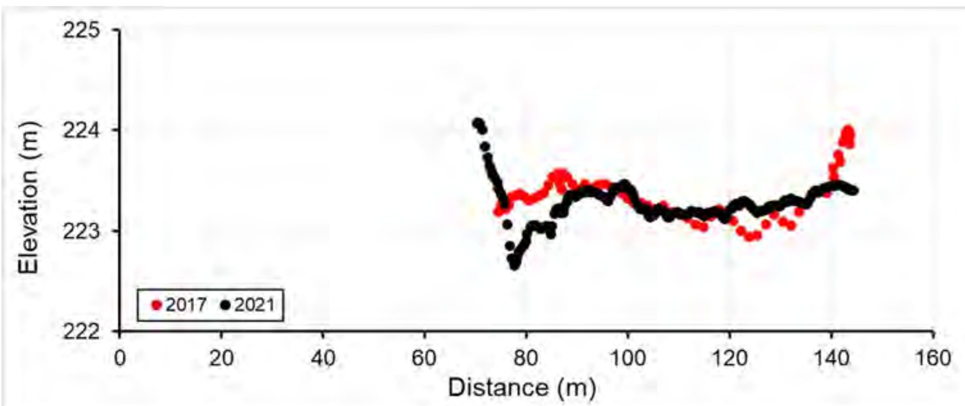

Figure 54 **Lillooet River Middle Reach 50-metre transects – River Station 36+950. Section is plotted in a downstream viewed perspective.**

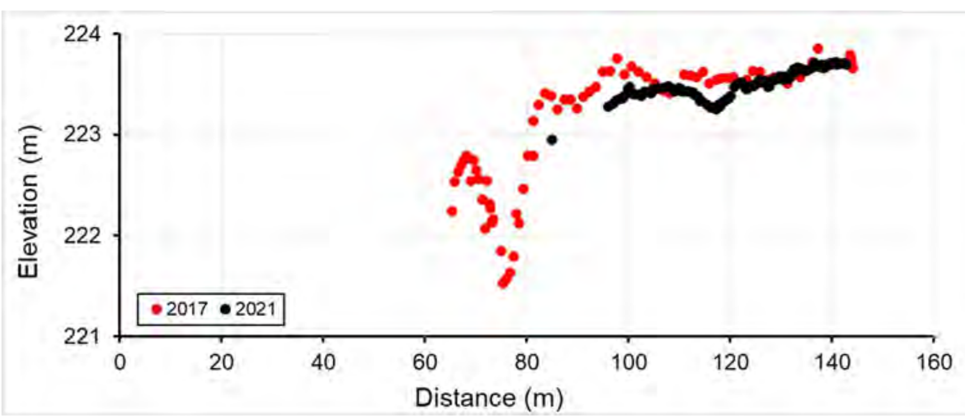

Figure 55 **Lillooet River Middle Reach 50-metre transects – River Station 36+900. Section is plotted in a downstream viewed perspective.**

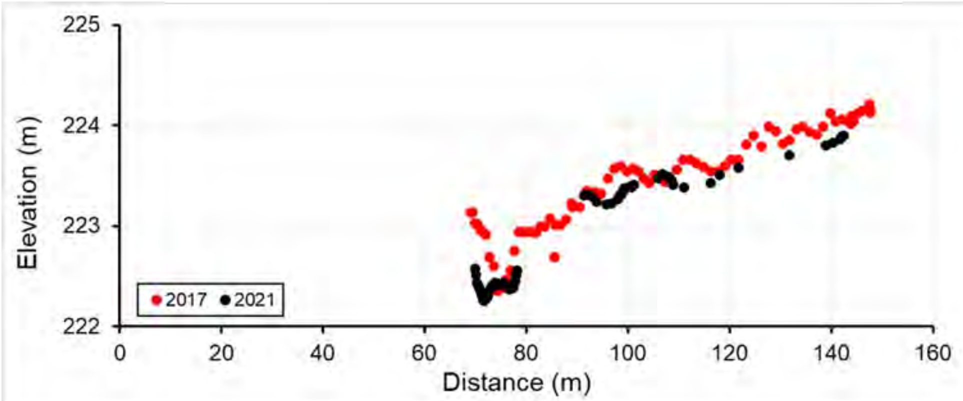

Figure 56 **Lillooet River Middle Reach 50-metre transects – River Station 36+850. Section is plotted in a downstream viewed perspective.**

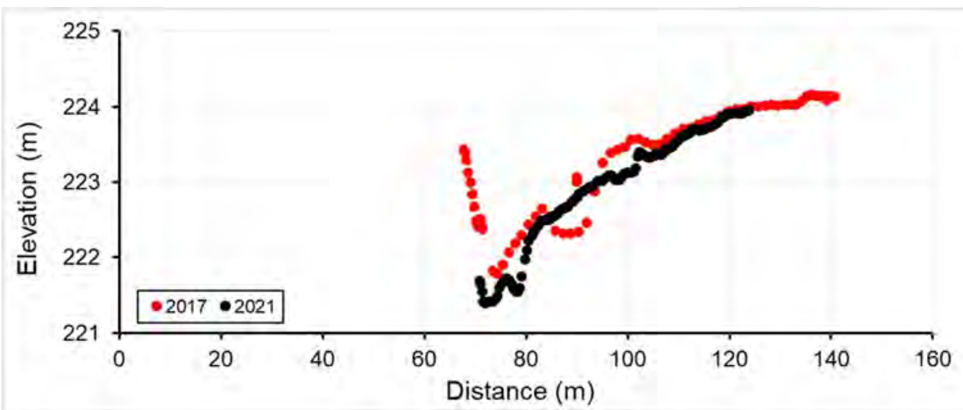

Figure 57 **Lillooet River Middle Reach 50-metre transects – River Station 36+800. Section is plotted in a downstream viewed perspective.**

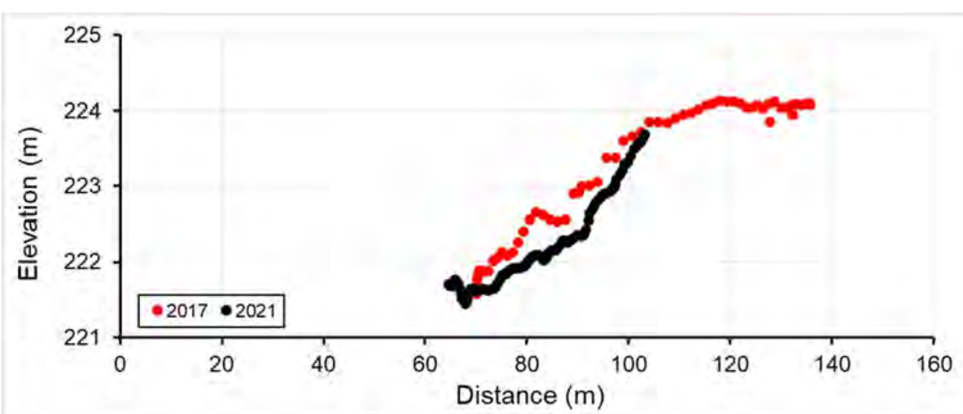

Figure 58 **Lillooet River Middle Reach 50-metre transects – River Station 36+750. Section is plotted in a downstream viewed perspective.**

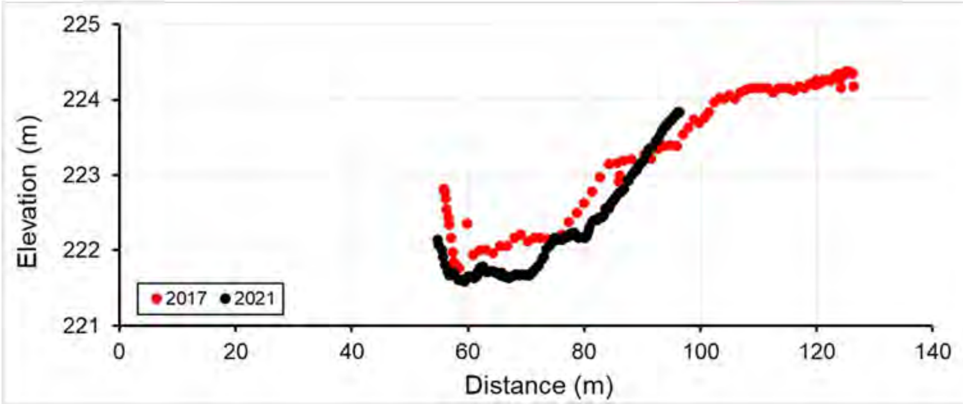

Figure 59 **Lillooet River Middle Reach 50-metre transects – River Station 36+700. Section is plotted in a downstream viewed perspective.**

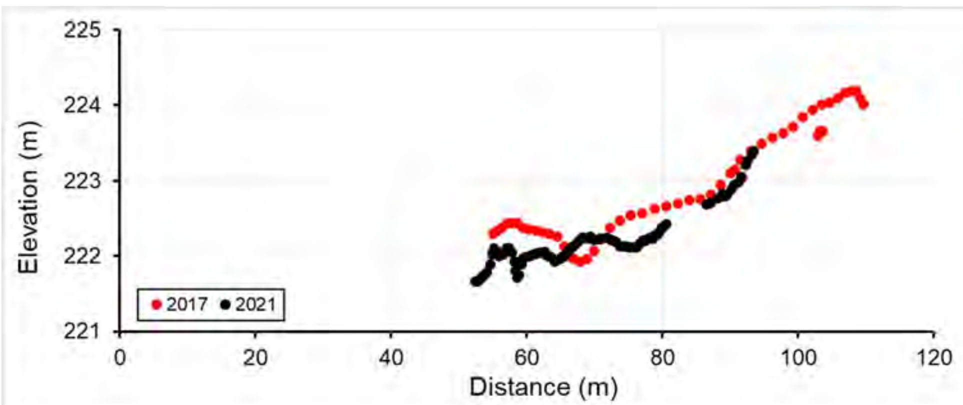

Figure 60 **Lillooet River Middle Reach 50-metre transects – River Station 36+650. Section is plotted in a downstream viewed perspective.**

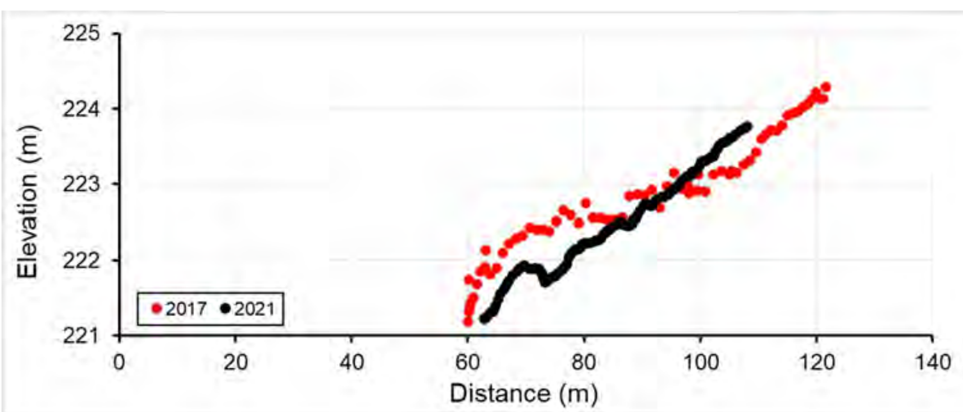

Figure 61 **Lillooet River Middle Reach 50-metre transects – River Station 36+600. Section is plotted in a downstream viewed perspective.**

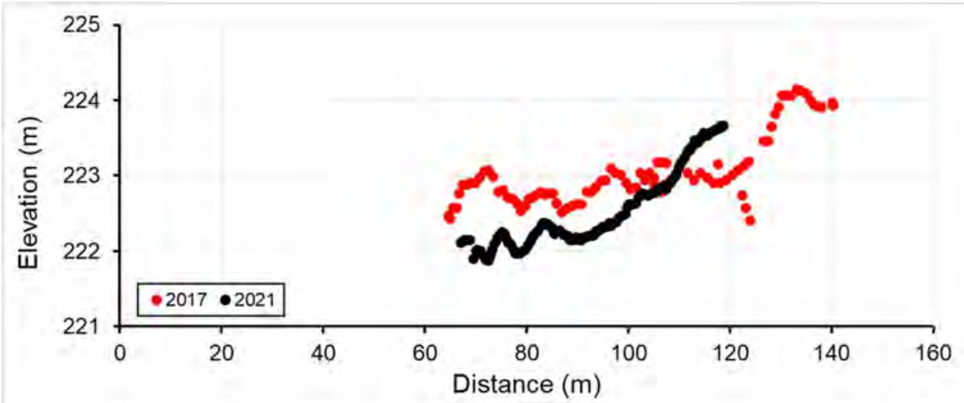

Figure 62 Lillooet River Middle Reach 50-metre transects – River Station 36+550. Section is plotted in a downstream viewed perspective.

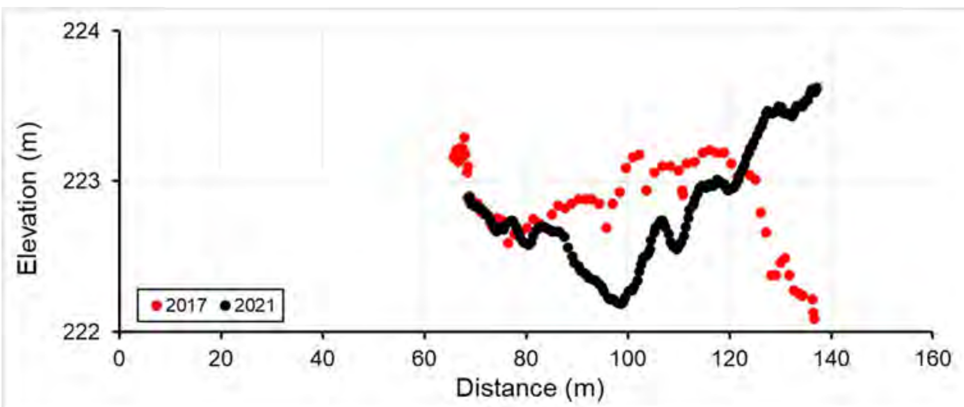

Figure 63 Lillooet River Middle Reach 50-metre transects – River Station 36+500. Section is plotted in a downstream viewed perspective.

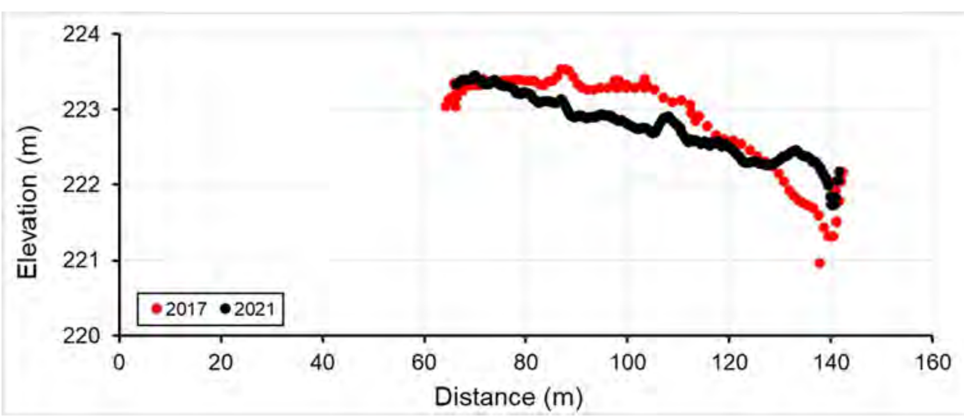

Figure 64 Lillooet River Middle Reach 50-metre transects – River Station 36+450. Section is plotted in a downstream viewed perspective.

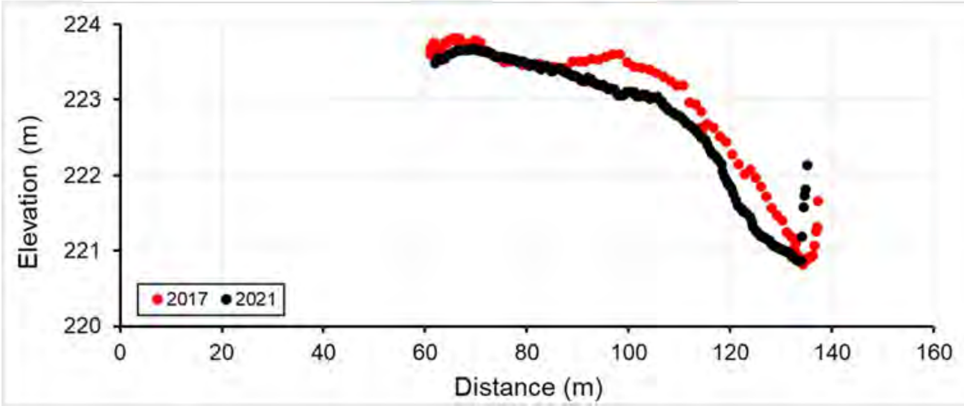

Figure 65 Lillooet River Middle Reach 50-metre transects – River Station 36+400. Section is plotted in a downstream viewed perspective.

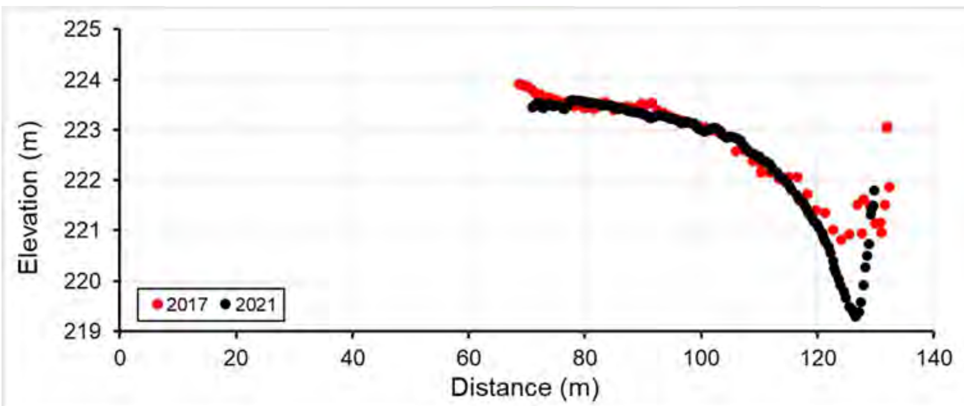

Figure 66 Lillooet River Middle Reach 50-metre transects – River Station 36+350. Section is plotted in a downstream viewed perspective.

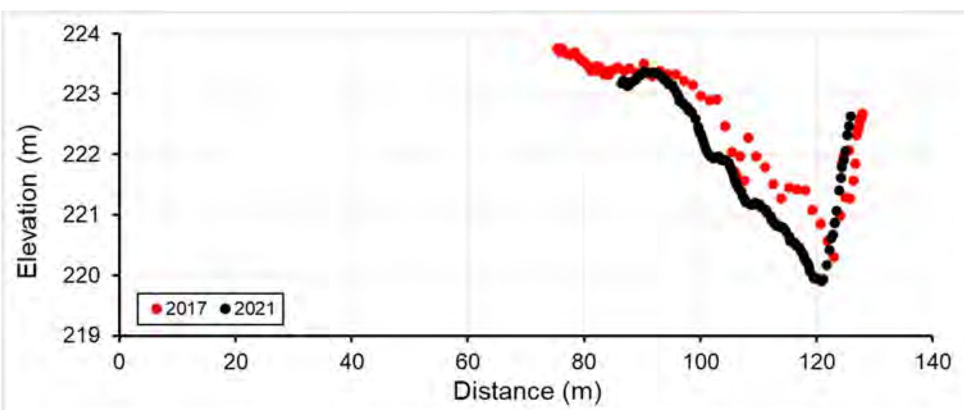

Figure 67 Lillooet River Middle Reach 50-metre transects – River Station 36+300. Section is plotted in a downstream viewed perspective.

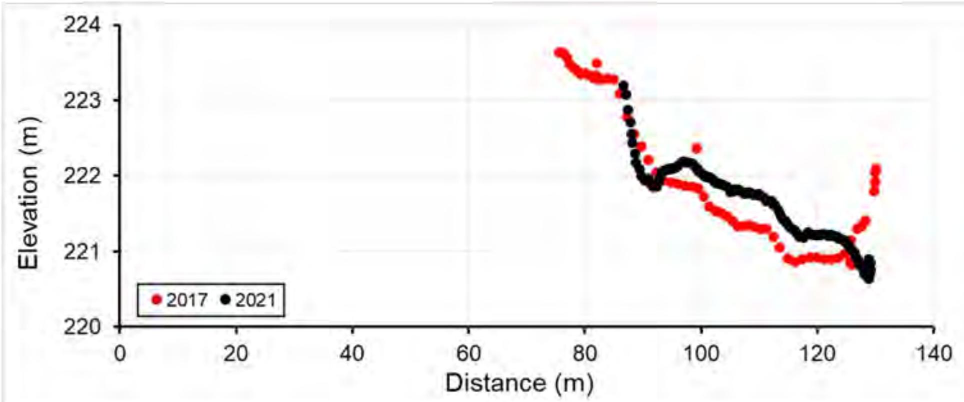

Figure 68 **Lillooet River Middle Reach 50-metre transects – River Station 36+250. Section is plotted in a downstream viewed perspective.**

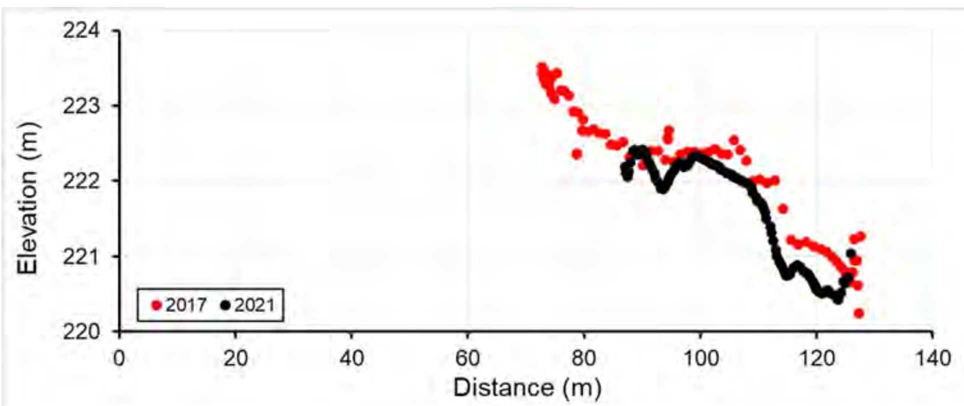

Figure 69 **Lillooet River Middle Reach 50-metre transects – River Station 36+200. Section is plotted in a downstream viewed perspective.**

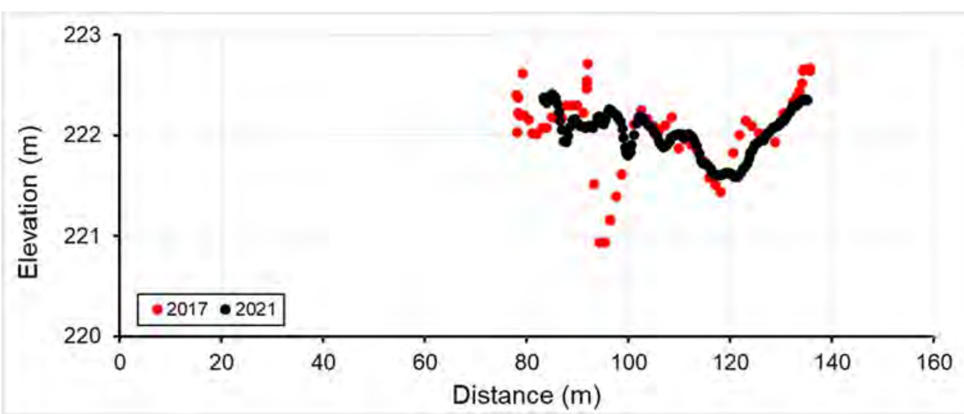

Figure 70 **Lillooet River Middle Reach 50-metre transects – River Station 36+150. Section is plotted in a downstream viewed perspective.**

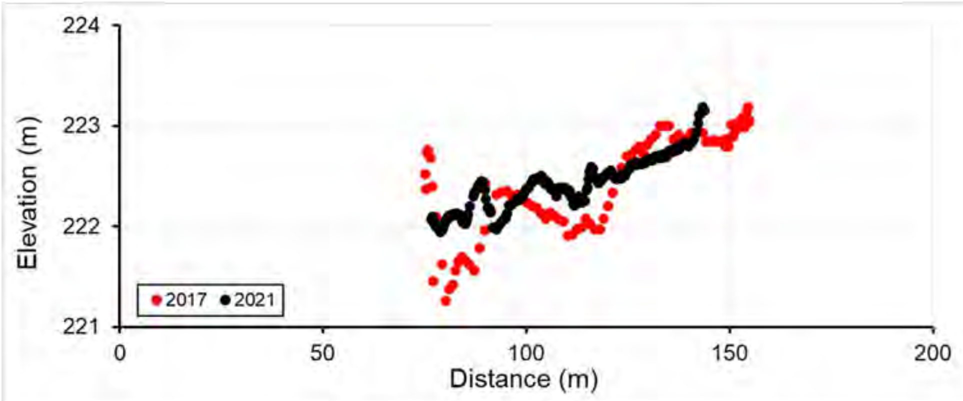

Figure 71 **Lillooet River Middle Reach 50-metre transects – River Station 36+100. Section is plotted in a downstream viewed perspective.**

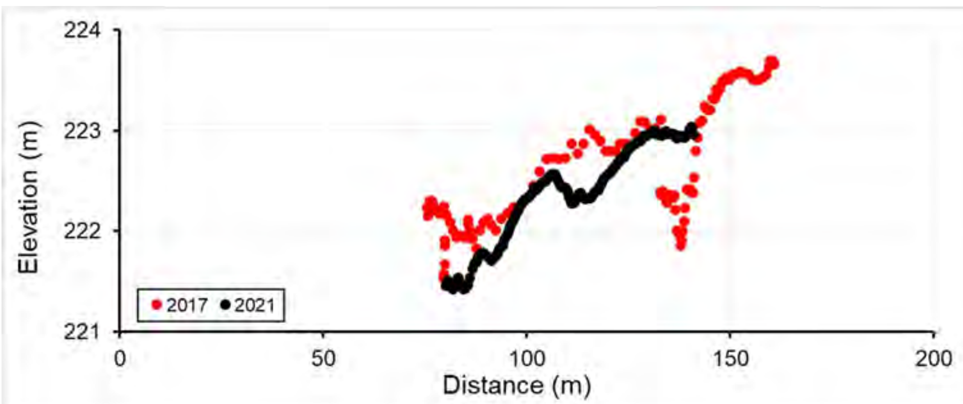

Figure 72 **Lillooet River Middle Reach 50-metre transects – River Station 36+050. Section is plotted in a downstream viewed perspective.**

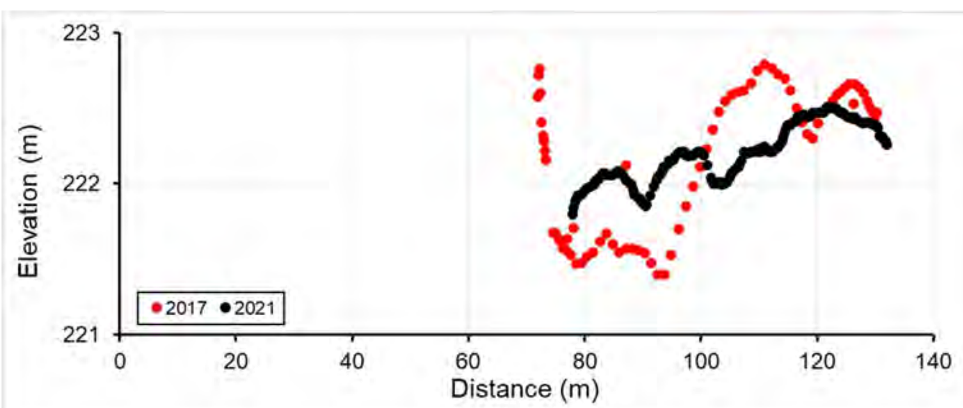

Figure 73 **Lillooet River Middle Reach 50-metre transects – River Station 36+000. Section is plotted in a downstream viewed perspective.**

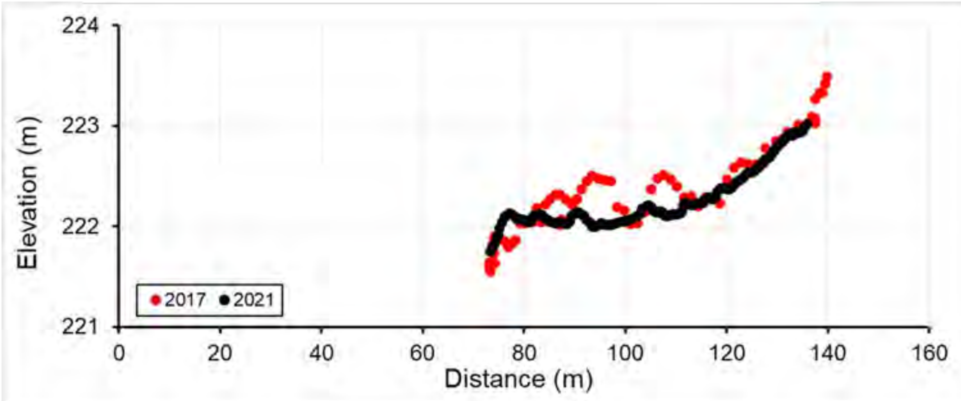

Figure 74 **Lillooet River Middle Reach 50-metre transects – River Station 35+950. Section is plotted in a downstream viewed perspective.**

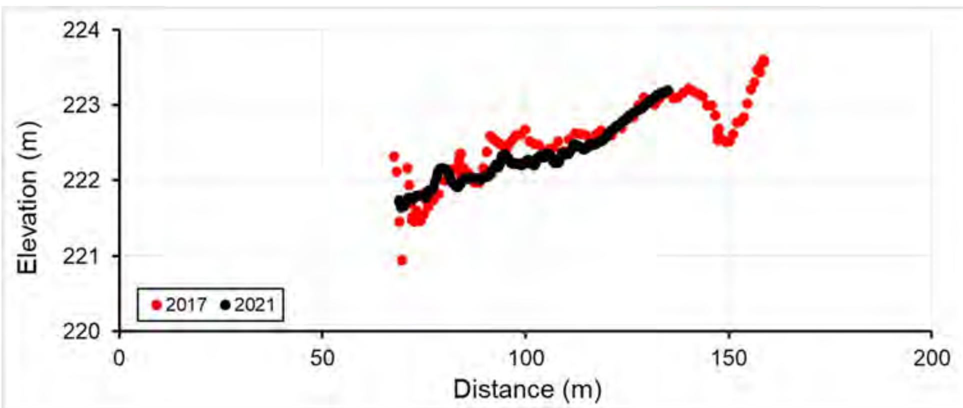

Figure 75 **Lillooet River Middle Reach 50-metre transects – River Station 35+900. Section is plotted in a downstream viewed perspective.**

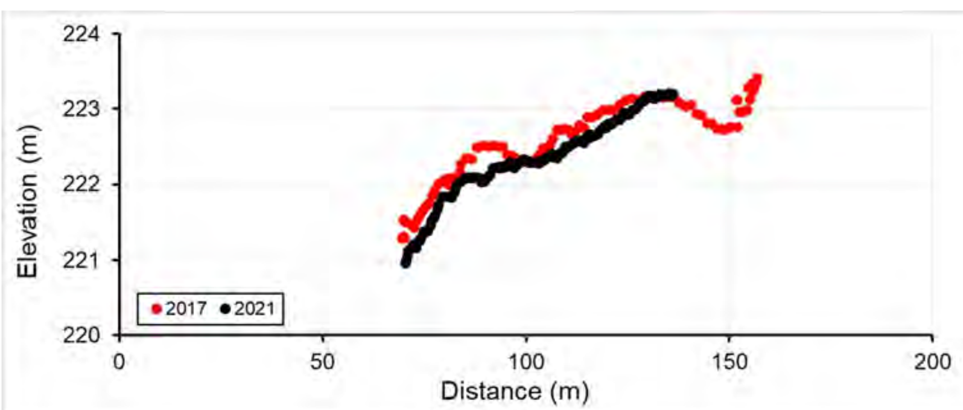

Figure 76 **Lillooet River Middle Reach 50-metre transects – River Station 35+850. Section is plotted in a downstream viewed perspective.**

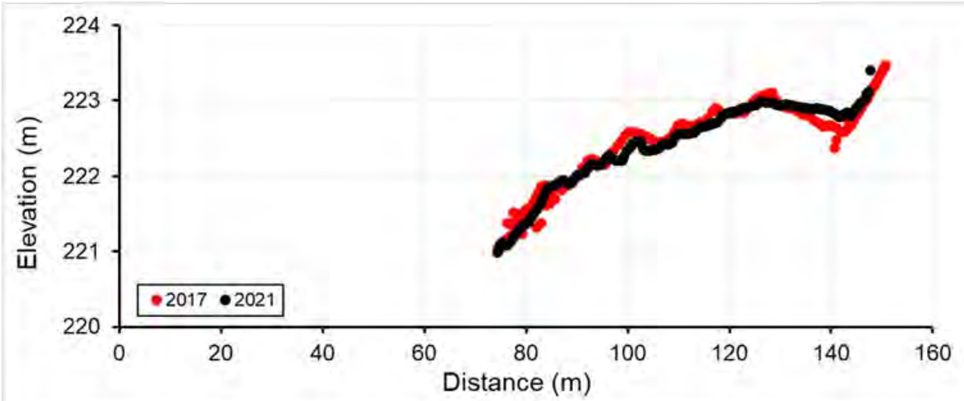

Figure 77 Lillooet River Middle Reach 50-metre transects – River Station 35+800. Section is plotted in a downstream viewed perspective.

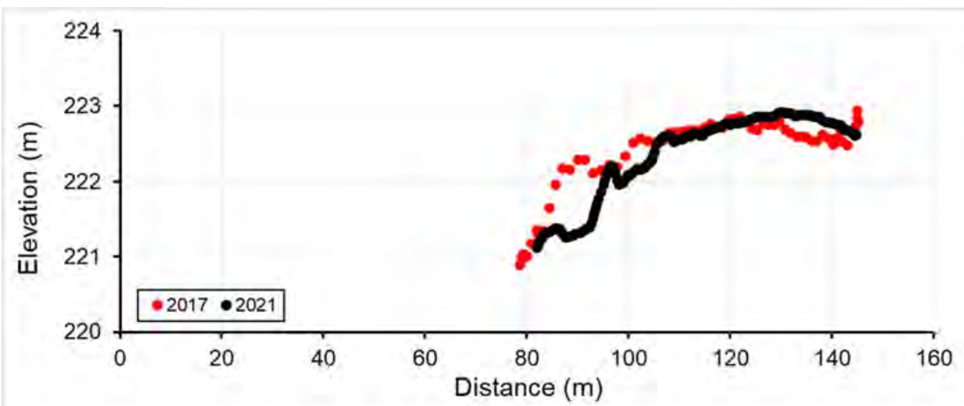

Figure 78 Lillooet River Middle Reach 50-metre transects – River Station 35+750. Section is plotted in a downstream viewed perspective.

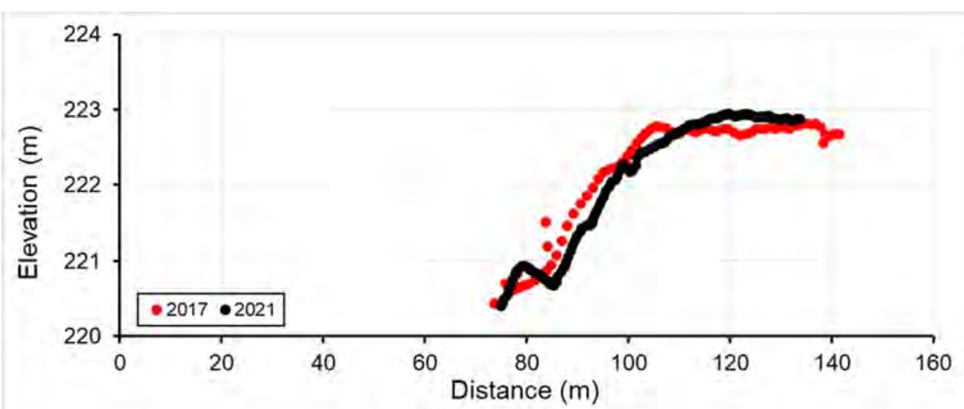

Figure 79 Lillooet River Middle Reach 50-metre transects – River Station 35+700. Section is plotted in a downstream viewed perspective.

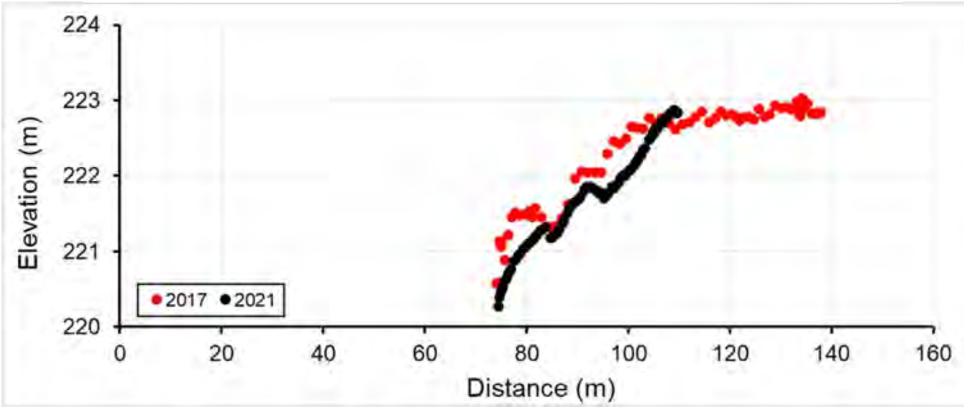

Figure 80 Lillooet River Middle Reach 50-metre transects – River Station 35+650. Section is plotted in a downstream viewed perspective.

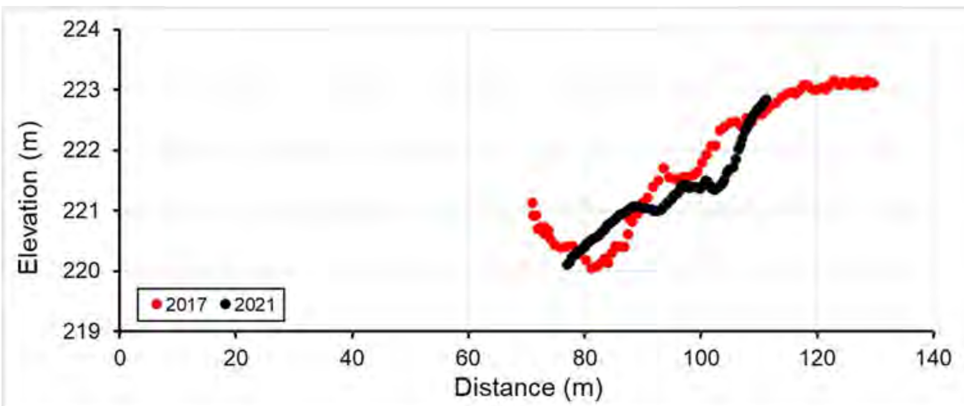

Figure 81 Lillooet River Middle Reach 50-metre transects – River Station 35+600. Section is plotted in a downstream viewed perspective.

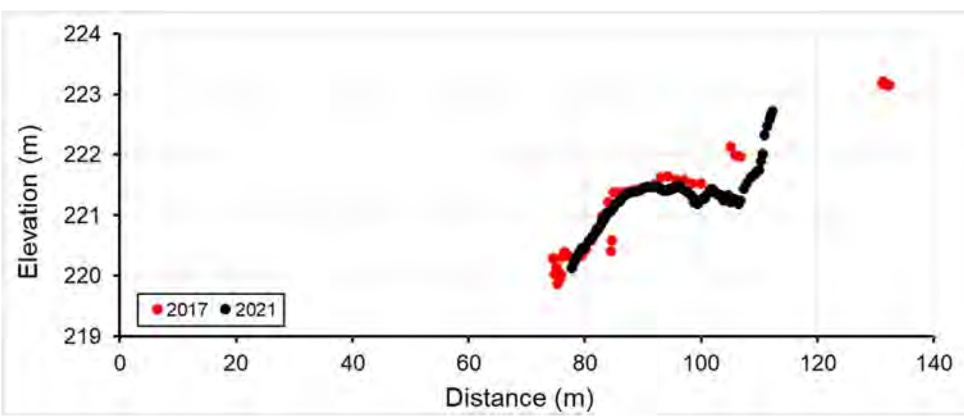

Figure 82 Lillooet River Middle Reach 50-metre transects – River Station 35+550. Section is plotted in a downstream viewed perspective.

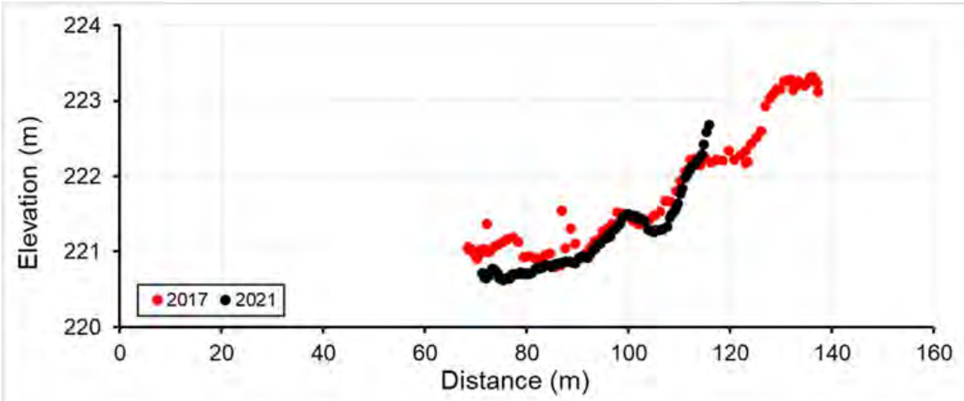

Figure 83 **Lillooet River Middle Reach 50-metre transects – River Station 35+500. Section is plotted in a downstream viewed perspective.**

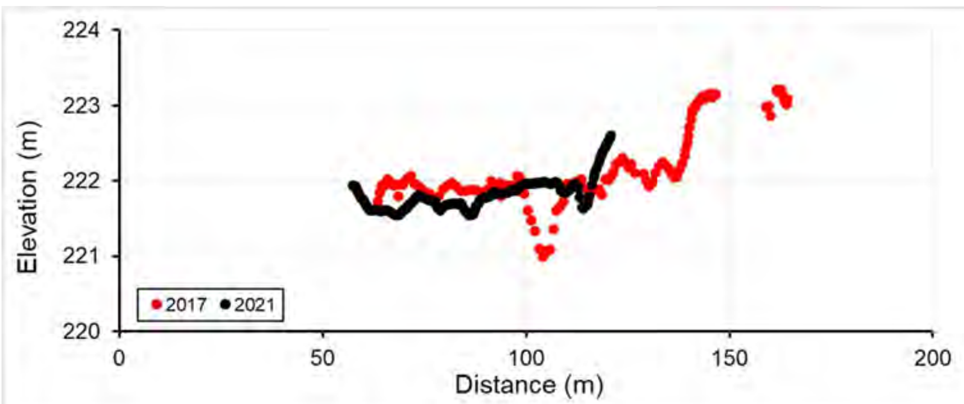

Figure 84 **Lillooet River Middle Reach 50-metre transects – River Station 35+450. Section is plotted in a downstream viewed perspective.**

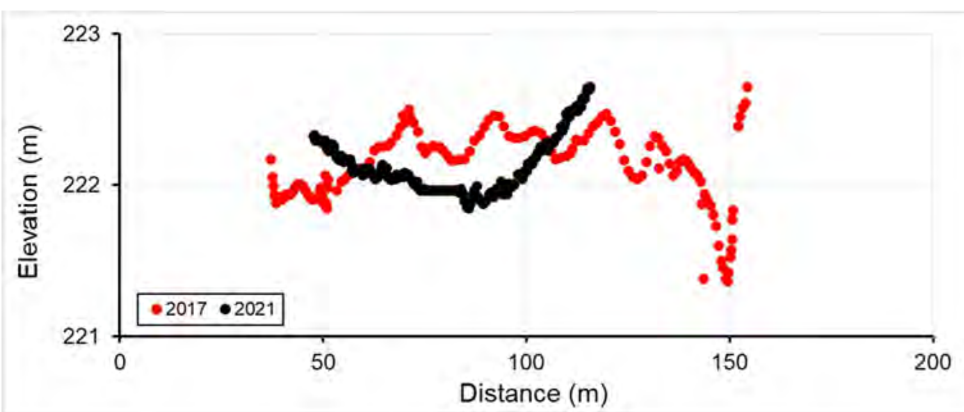

Figure 85 **Lillooet River Middle Reach 50-metre transects – River Station 35+400. Section is plotted in a downstream viewed perspective.**

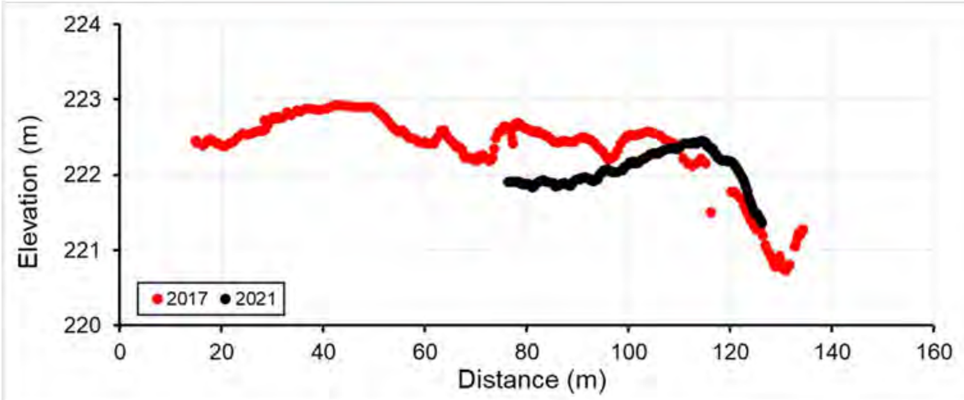

Figure 86 Lillooet River Middle Reach 50-metre transects – River Station 35+350. Section is plotted in a downstream viewed perspective.

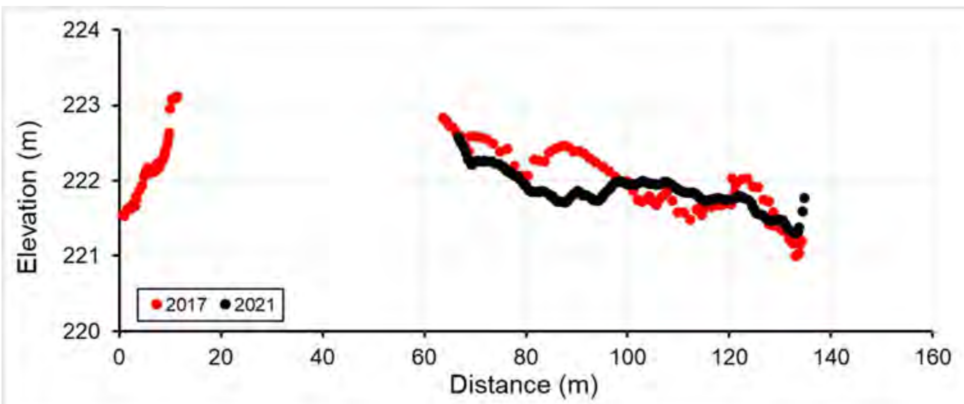

Figure 87 Lillooet River Middle Reach 50-metre transects – River Station 35+300. Section is plotted in a downstream viewed perspective.

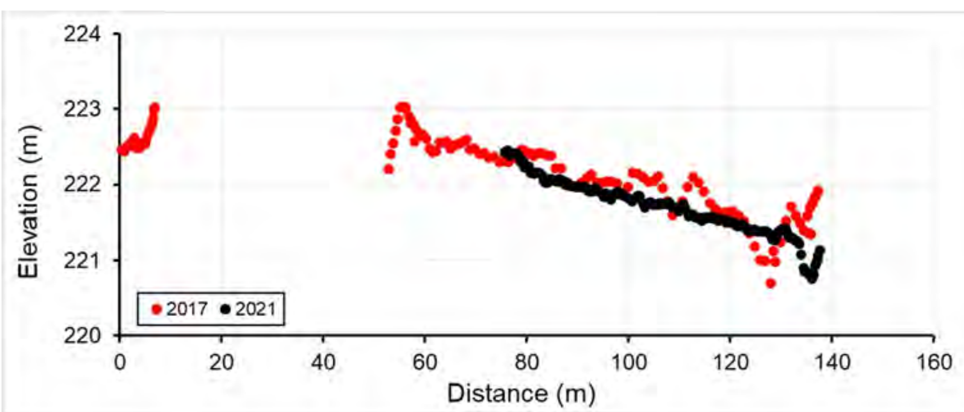

Figure 88 Lillooet River Middle Reach 50-metre transects – River Station 35+250. Section is plotted in a downstream viewed perspective.

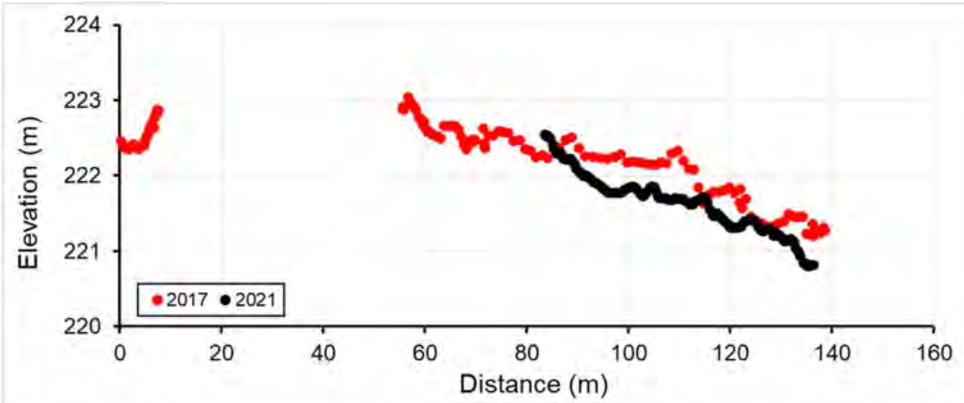

Figure 89 **Lillooet River Middle Reach 50-metre transects – River Station 35+200. Section is plotted in a downstream viewed perspective.**

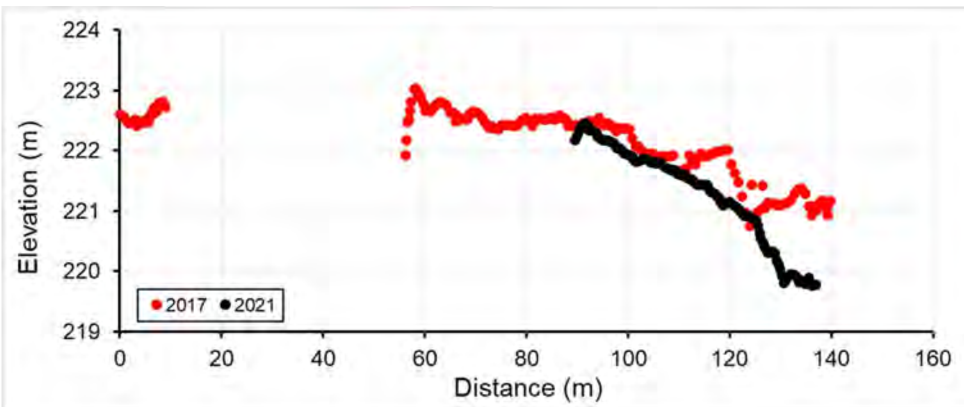

Figure 90 **Lillooet River Middle Reach 50-metre transects – River Station 35+150. Section is plotted in a downstream viewed perspective.**

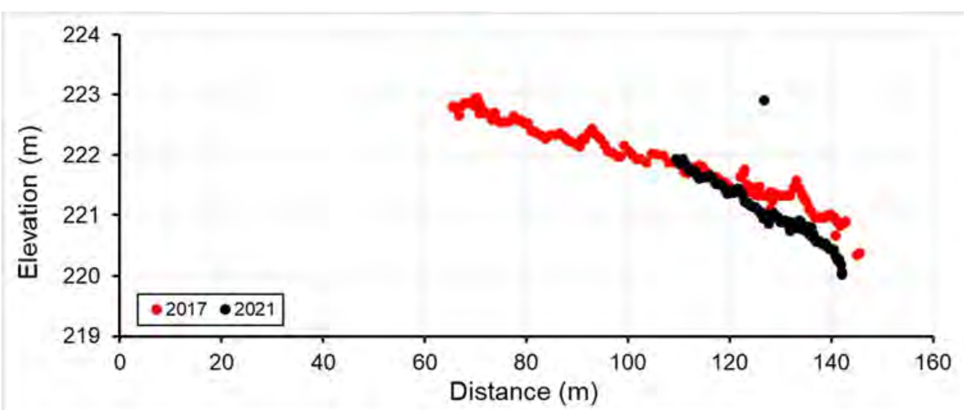

Figure 91 **Lillooet River Middle Reach 50-metre transects – River Station 35+100. Section is plotted in a downstream viewed perspective.**

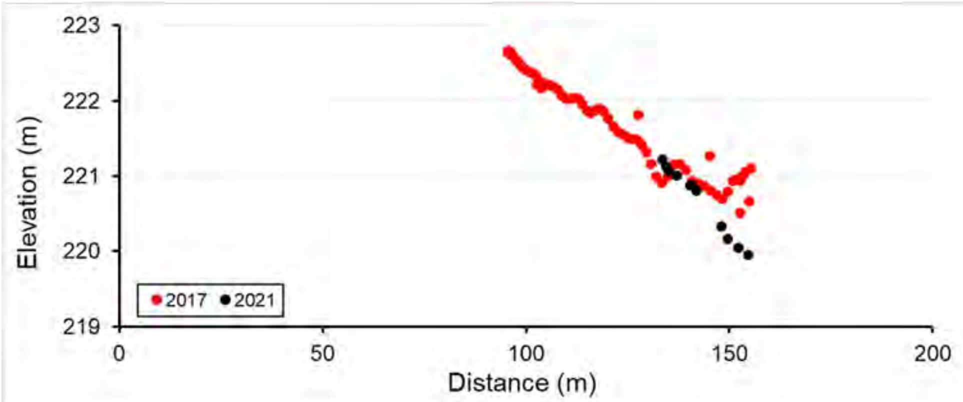

Figure 92 Lillooet River Middle Reach 50-metre transects – River Station 35+050. Section is plotted in a downstream viewed perspective.

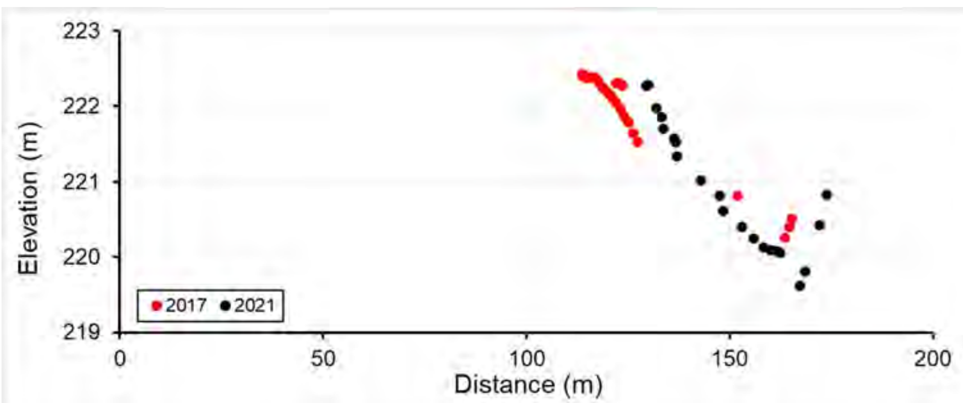

Figure 93 Lillooet River Middle Reach 50-metre transects – River Station 35+000. Section is plotted in a downstream viewed perspective.

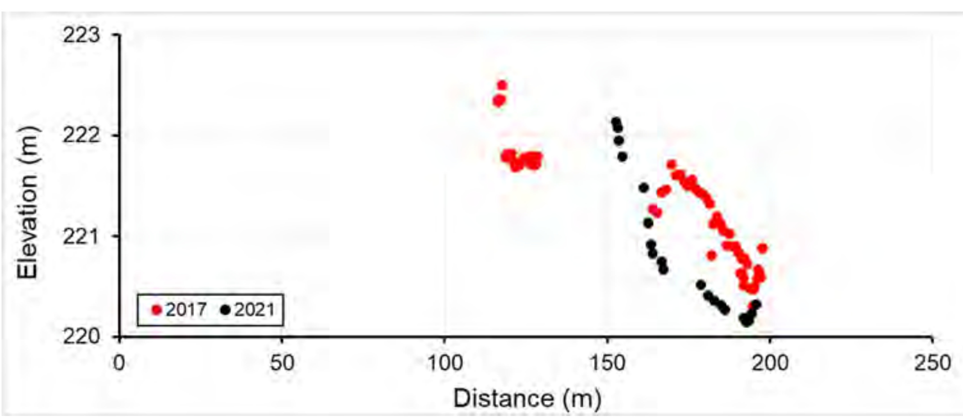

Figure 94 Lillooet River Middle Reach 50-metre transects – River Station 34+950. Section is plotted in a downstream viewed perspective.

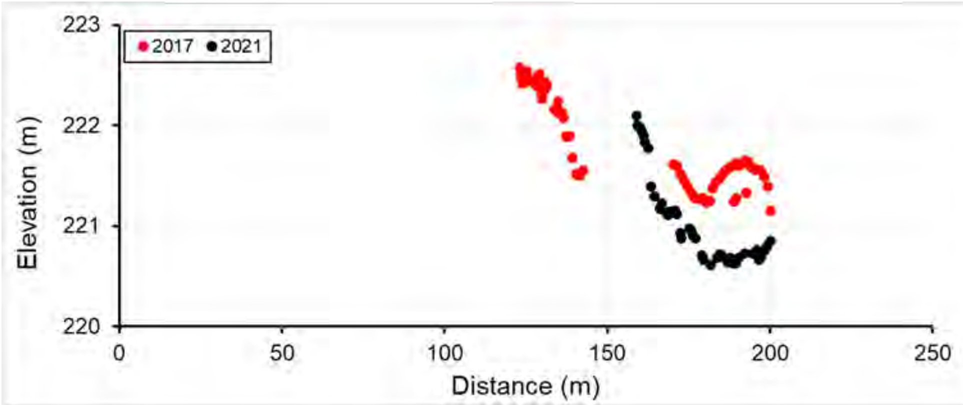

Figure 95 Lillooet River Middle Reach 50-metre transects – River Station 34+900. Section is plotted in a downstream viewed perspective.

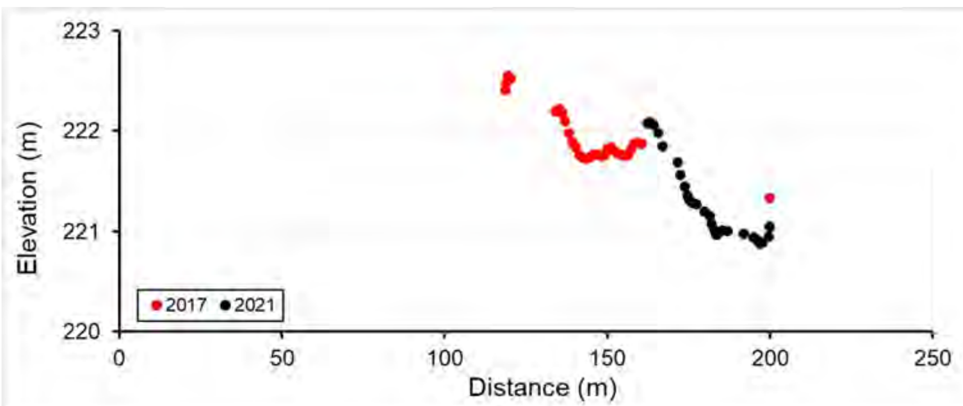

Figure 96 Lillooet River Middle Reach 50-metre transects – River Station 34+850. Section is plotted in a downstream viewed perspective.

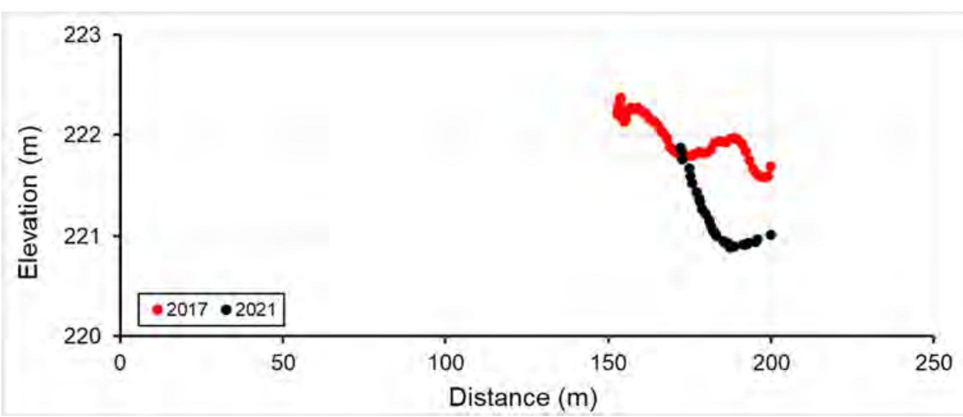

Figure 97 Lillooet River Middle Reach 50-metre transects – River Station 34+800. Section is plotted in a downstream viewed perspective.

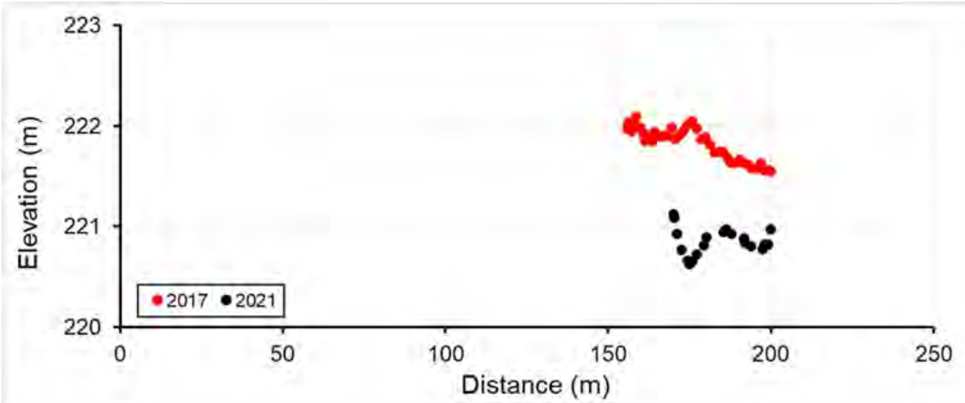

Figure 98 **Lillooet River Middle Reach 50-metre transects – River Station 34+750. Section is plotted in a downstream viewed perspective.**

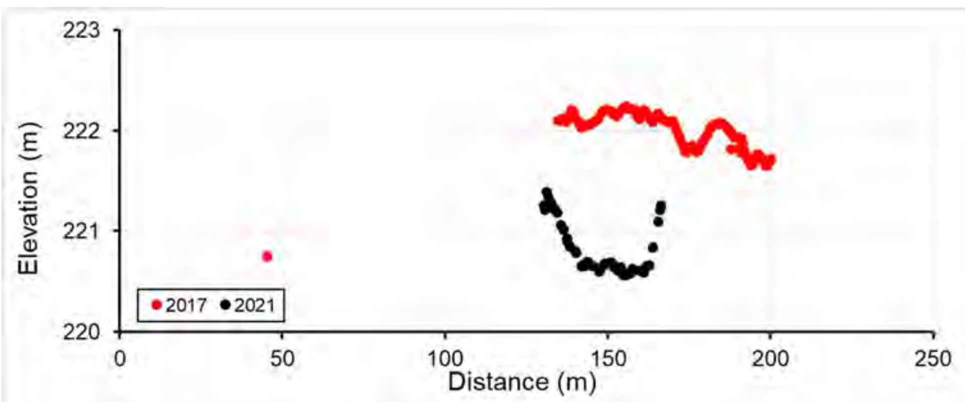

Figure 99 **Lillooet River Middle Reach 50-metre transects – River Station 34+700. Section is plotted in a downstream viewed perspective.**

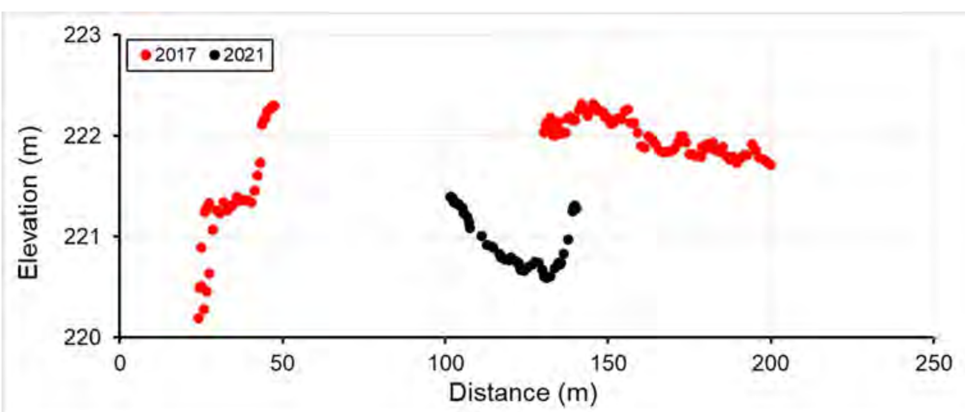

Figure 100 **Lillooet River Middle Reach 50-metre transects – River Station 34+650. Section is plotted in a downstream viewed perspective.**

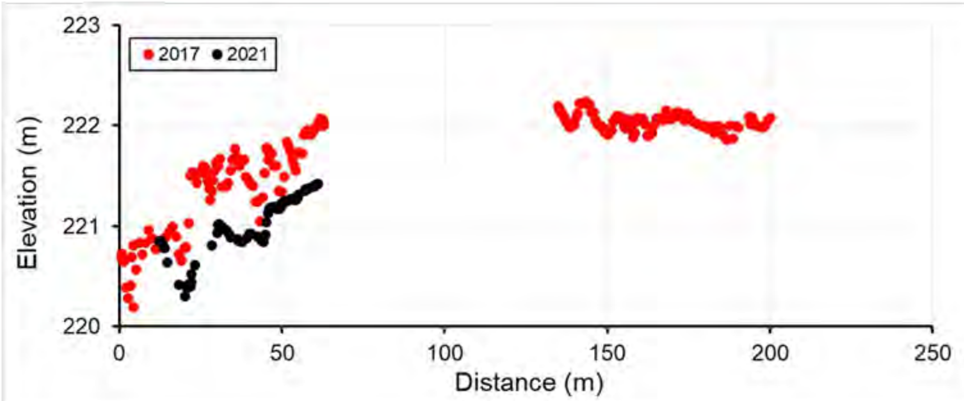

Figure 101 **Lillooet River Middle Reach 50-metre transects – River Station 34+600. Section is plotted in a downstream viewed perspective.**

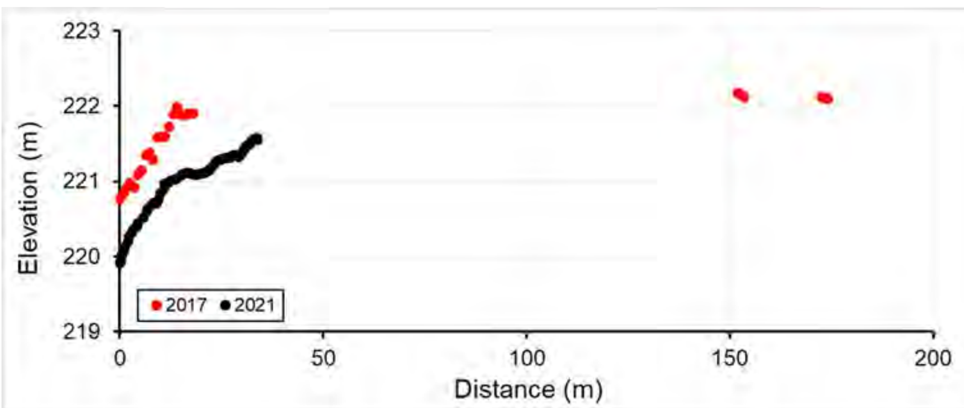

Figure 102 **Lillooet River Middle Reach 50-metre transects – River Station 34+550. Section is plotted in a downstream viewed perspective.**

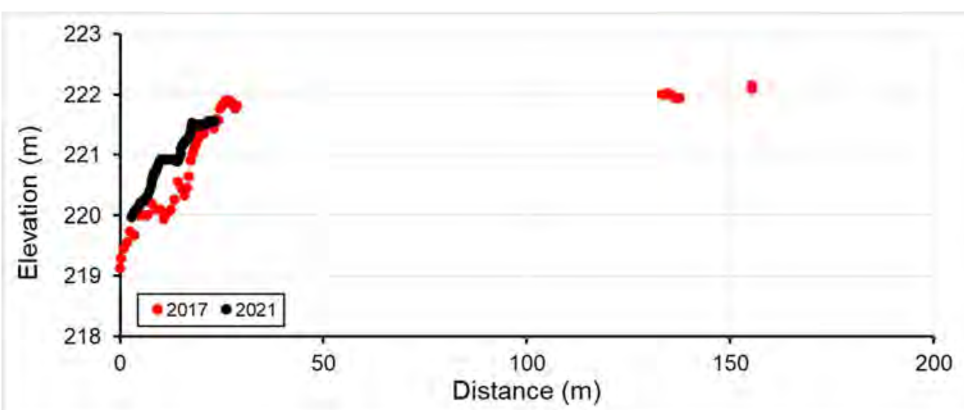

Figure 103 **Lillooet River Middle Reach 50-metre transects – River Station 34+500. Section is plotted in a downstream viewed perspective.**

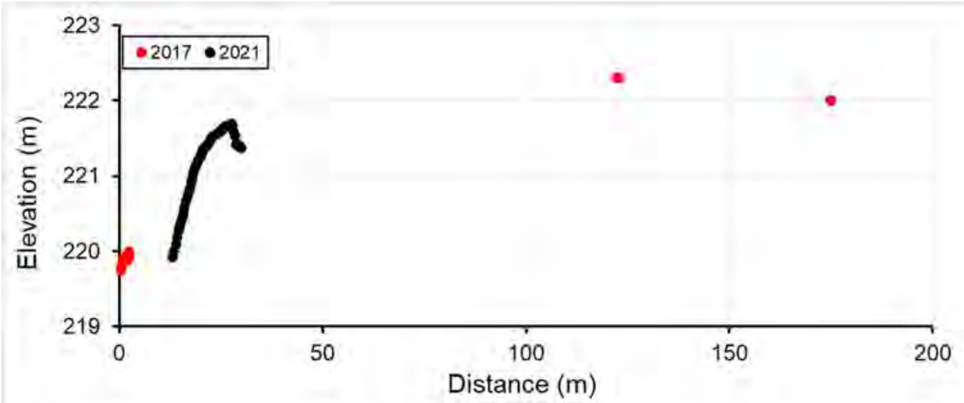

Figure 104 Lillooet River Middle Reach 50-metre transects – River Station 34+450. Section is plotted in a downstream viewed perspective.

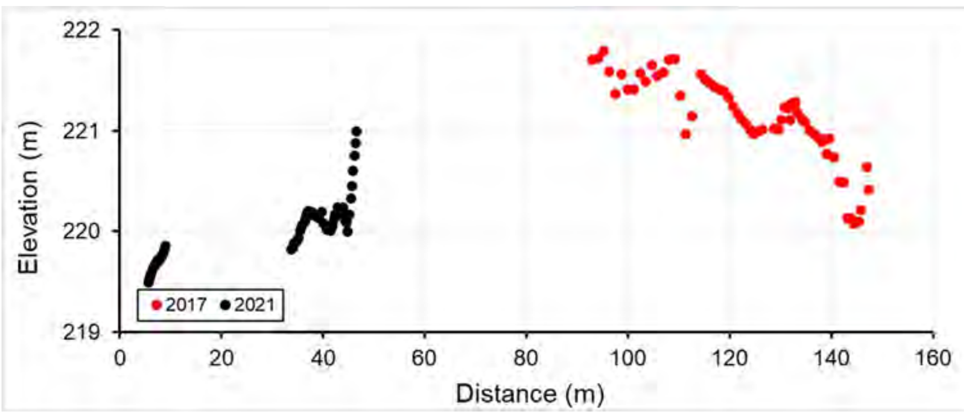

Figure 105 Lillooet River Middle Reach 50-metre transects – River Station 34+400. Section is plotted in a downstream viewed perspective.

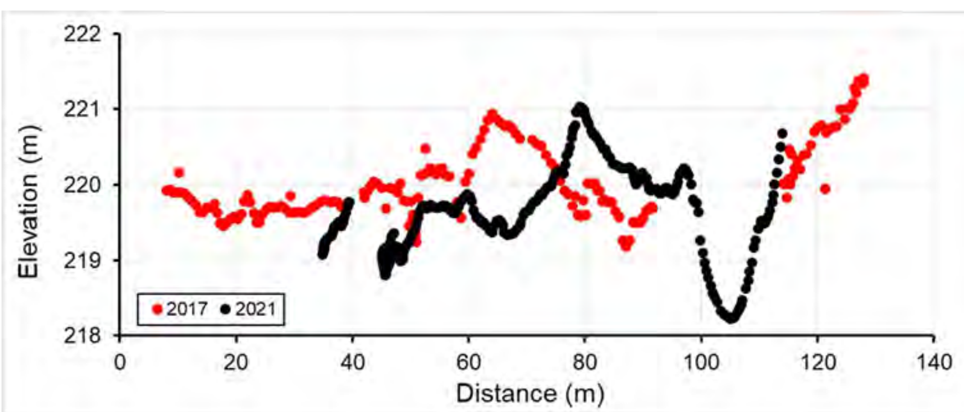

Figure 106 Lillooet River Middle Reach 50-metre transects – River Station 34+350. Section is plotted in a downstream viewed perspective.

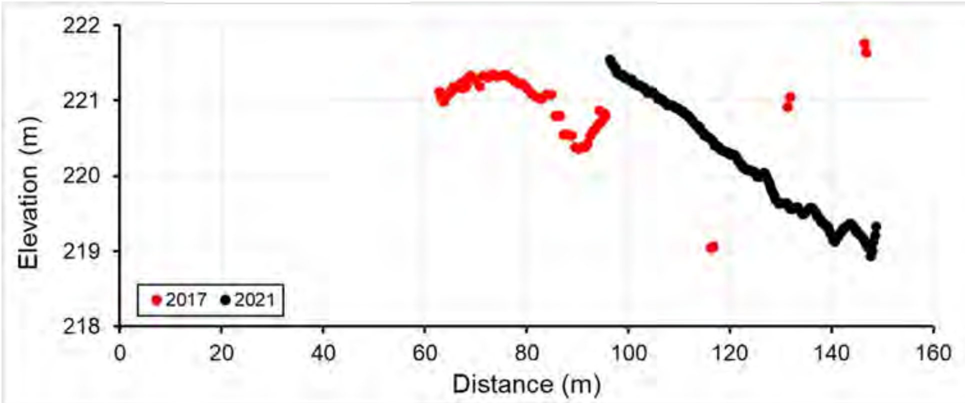

Figure 107 **Lillooet River Middle Reach 50-metre transects – River Station 34+300. Section is plotted in a downstream viewed perspective.**

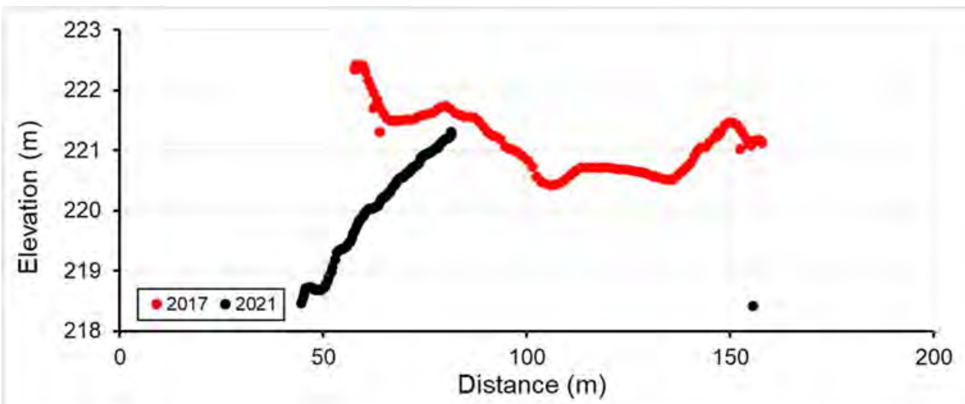

Figure 108 **Lillooet River Middle Reach 50-metre transects – River Station 34+250. Section is plotted in a downstream viewed perspective.**

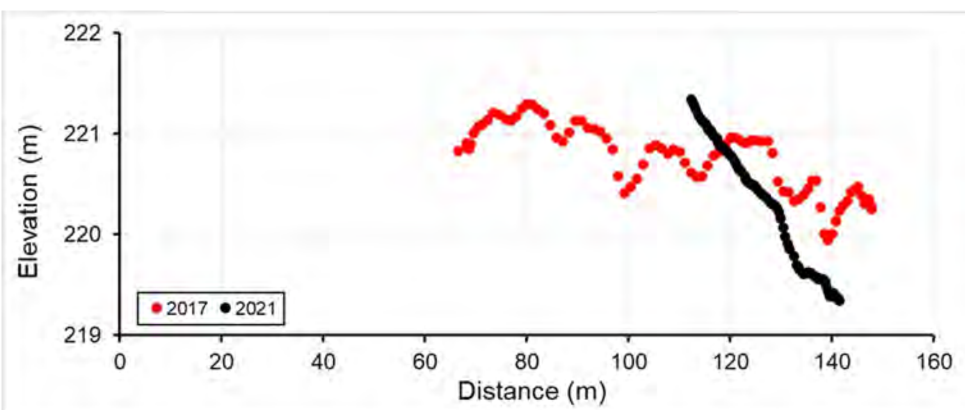

Figure 109 **Lillooet River Middle Reach 50-metre transects – River Station 34+200. Section is plotted in a downstream viewed perspective.**

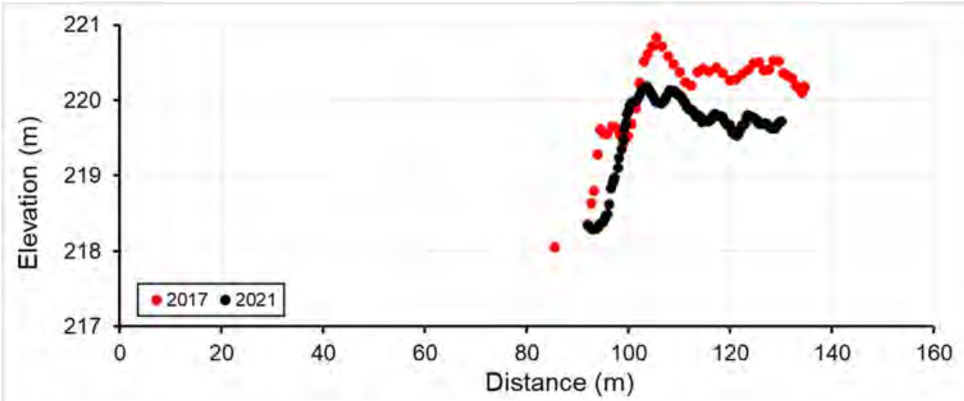

Figure 110 Lillooet River Middle Reach 50-metre transects – River Station 34+150. Section is plotted in a downstream viewed perspective.