

# Lower Manawatū Gravel Study

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REPORT

Tonkin+Taylor

# Lower Manawatū Gravel Study

## Gravel budgets

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## Executive summary

Two methods for estimating gravel budgets are presented in this report.

The first uses an end-over-area method to analyse cross-section survey data acquired using ground surveys in 2018 and 2022/23. The section of active riverbed in each cross-section is defined using cross-section offsets. Applying these offsets excludes components of the cross-section that are not active riverbed (i.e. banks or densely vegetated bars). Offsets were derived from interrogation of the most recently available aerial imagery. Offsets applied in the most recent prior Horizons Regional Council (HRC) study (Whale, 2019) were also used to make a comparison.

The second approach to deriving a gravel budget uses Geomorphic Change Detection (GCD), which uses repeat LiDAR survey to focus on the subaerial (dry) portion of the active riverbed (i.e. bare and lightly vegetated bars). GCD volumetric changes were assessed for two epochs, 2005 to 2016 and 2016 to 2022.

The key findings include:

**Spatial and Temporal Variability in Gravel Budgets:** There is significant spatial and temporal variability in the gravel budgets of the lower Manawatū River. This relates to the methods used, erosion events within the active river corridor, upstream sediment inputs, and possible effects of previous gravel extraction practices. Long-term, there is no clear trend either towards net gain or net loss in the lower Manawatū River. Previous work reviewed in this study has suggested the lower Manawatū River appeared to be in a degradation phase between 1997-2011. Reversal of this trend was identified between 2011-2018. The lower Manawatū River appears to have returned to a degradation trend for 2018-2023, with gravel extraction contributing to more than 30% of this reduction in gravel volume.

**Comparison of Analytical Approaches:** The two different methodologies, cross-sectional analysis, and GCD, yield differing results when estimating volume changes. Also, when the cross- section data was analysed using the HRC and the updated T+T offsets, they also produced different results. This offset difference was particularly evident in sections of the river where significant channel changes occurred during the study period.

**Uncertainty and Monitoring:** Given the high variability and therefore uncertainty of results, its recommended that careful, ongoing monitoring of the lower Manawatū River is considered. The efficacy of future management decisions will depend on having a comprehensive understanding of the river's sediment dynamics and additional monitoring would be required to improve our understanding. Future monitoring would need to mesh (spatially and temporally) both regular cross-sectional surveys and high-resolution, full-channel bathymetric surveys to capture changes in more detail.

# 1 Introduction

## 1.1 Purpose and scope

Tonkin & Taylor Ltd (T+T) was engaged by Horizons Regional Council (HRC) to complete an assessment of the current state of gravel resource of the lower Manawatū River, between the Manawatū Gorge and the sea.

This report is one of three being prepared to address gravel resource in the lower Manawatū River and provide an assessment of past river character and potential management scenarios. The collective suite of reports is referred to as the *Lower Manawatū Gravel Study.* The other reports cover:

- An assessment of the HRC 'Seven Bends',
- A natural character assessment and determination of management lines.

This report has been prepared in accordance with the agreement dated 17 November 2023 and counter-signed dated 21 December 2023.

A gravel budget of the Manawatū River has been assessed, using cross-section data and GCD tool for analyses. It identifies reaches between the Gorge and Ōpiki where gravel is deposited by the Manawatū River, and ascertains whether trends of channel incision, infilling, widening, or narrowing are evident in the silt reach downstream from Ōpiki.

## 1.2 Background

Understanding the character of a river and its recent trajectories of change is important to make geomorphologically informed management decisions. A high-level assessment of sediment processes and geomorphic trends in the lower Manawatū River was undertaken by T+T in 2019, to provide an overview of geomorphic processes in the catchment (Tonkin and Taylor, 2019). That report identified a series of river types used to define the contemporary character of the river channel in the lower Manawatū but did not quantify river planform change or gravel budget. HRC has previously carried out gravel studies in 2012 (Bell, 2012) and 2019 (Whale, 2019) to quantify gravel flux in the lower Manawatū River. Surveys of the lower Manawatū River have been undertaken at various times since 1992, with the most recent data collection undertaken in 2023. These previous studies undertook gravel budget analysis using survey data acquired along monumented cross-sections but have not utilised a long-term assessment of planform adjustment or assessed three-dimensional topographic change using available LiDAR data.

## 1.3 Site context

The Manawatū River is 235 km long and drains a catchment of 5,898 km$^2$ (LAWA, 2019). It drains from the eastern Ruahine Ranges, through the gap between the Ruahine and Tararua Ranges formed by the Manawatū Gorge, and across a large floodplain to the Tasman Sea at Foxton. The land use of the catchment is generally agricultural, with some indigenous forest and urban areas (Landcare Research, 2012). The lower Manawatū River runs slightly over 100 km from the mouth of the Manawatū Gorge to the Tasman Sea at Foxton Beach. It is generally a sinuous, passive meandering river with a sand bed in its lower reaches, while the gravel phase from the Gorge to Ōpiki has a more wandering planform. The Manawatū floodplain was once dominated by Kahikatea forest and swampland, however forest clearance and drainage has developed the floodplain for agriculture and urban use since the late 1800s.

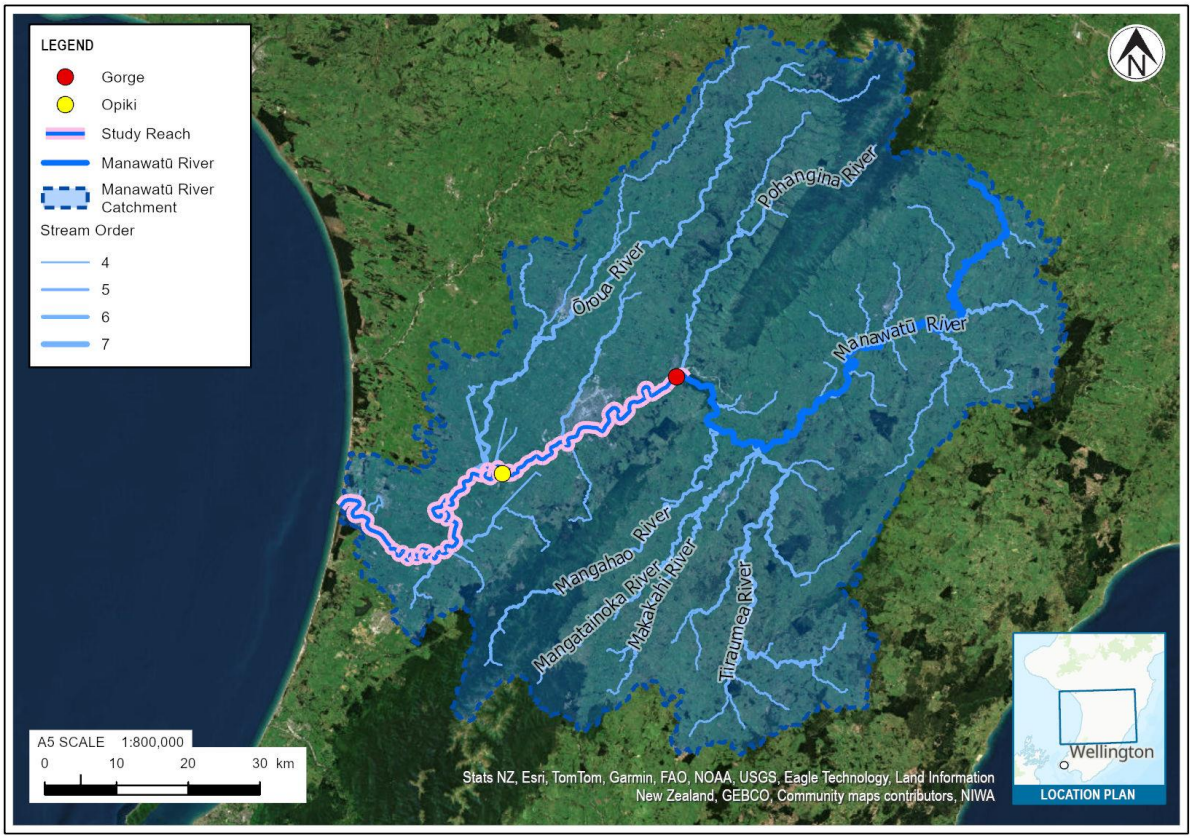



*Figure 1.1: Manawatū River catchment, with major tributaries labelled and lower Manawatū study reach highlighted.*

Figure 1.1 shows the study reach in the context of the Manawatū River catchment. Classification of the contemporary channel in the study reach by Tonkin and Taylor (2019) identified four key river types, which are described in Section 2.1 below. The geomorphic character of the study reach is informed by the 'sediment conveyor model' (Nicholas et al., 1995) where sediment is sourced from erosion in confined headwaters, transferred through partly confined valleys, and deposited in an accumulation zone within an alluvial valley. This is a conceptual model which, in reality, is often more complex. For the Manawatū River, a more complex geological setting (Figure 1.2), especially with the Manawatū Gorge mid-catchment, means that the process is not entirely linear. However, the lower Manawatū operates as both a transfer zone from the Gorge to Ōpiki and as an accumulation zone as a function of bed profile flattening in the vicinity of and downstream from Ōpiki (Figure 1.3).

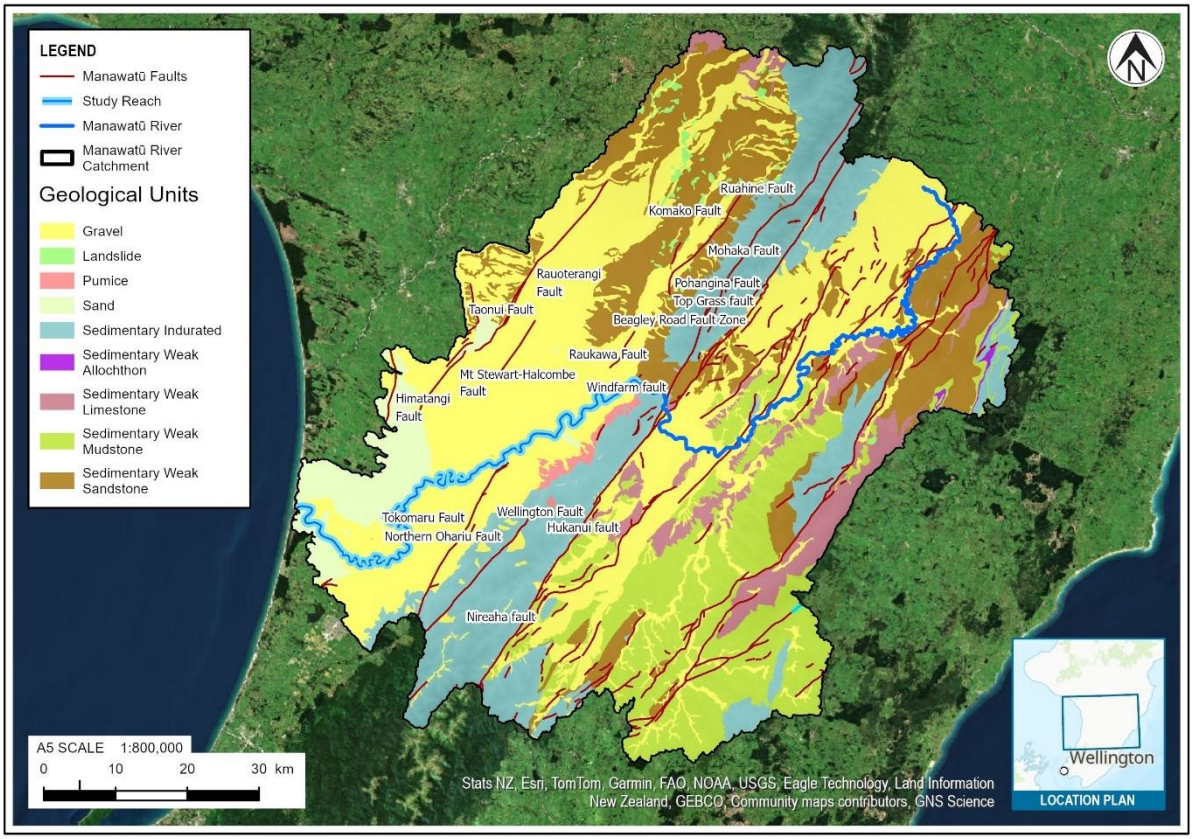



*Figure 1.2: Manawatū catchment geology. The study reach and length of the Manawatū river are shown. Major faults within the Manawatū catchment are shown, with key faults named.*

Figure 1.2 shows the geology of the Manawatū catchment. Gravels are principally sourced from indurated sedimentary greywacke in the catchment, as well as reworked terraced alluvium. The lower section of the river is tidal, with fine sediment exchange across the coastal margin.

The river has high cultural, economic, and ecological significance. Active meanders form the southern margin of the city of Palmerston North, which presents a challenge for management, particularly during storm events. Throughout the catchment, the February 2004 storm caused widespread erosion, changed the river's course, and caused over $300 million of damage (Vale, 2016). The Manawatū catchment is an important site for aquatic species, with 23 different fish species in the river (Manawatū River Leaders Accord, 2024). The Manawatū River is also an important feature for tangata whenua, with ancestors having a connection to the waterways for over seven hundred years.

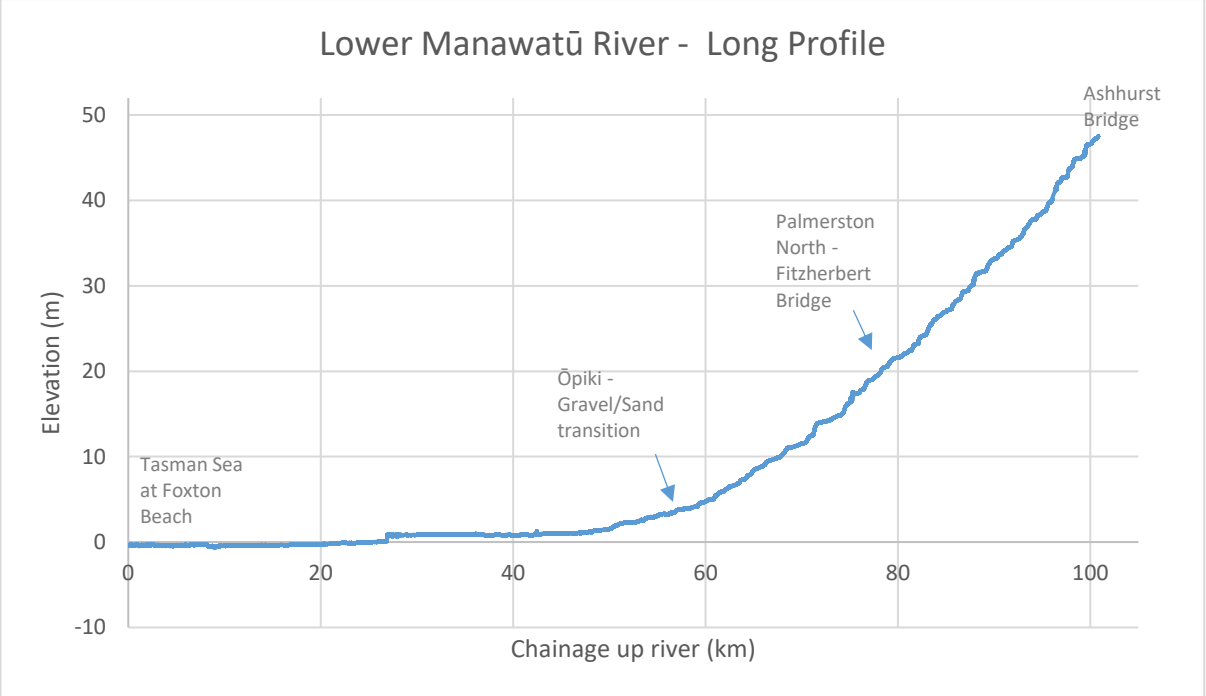



*Figure 1.3: Channel long profile from 2022 LiDAR along the centreline of the lower Manawatū River, with annotations.*

Downstream from the Gorge, where the river is confined and bedrock-lined, the lower Manawatū River becomes an unconfined, actively wandering to meandering river, up to the transition from gravel to sand bed at Ōpiki (Page & Heerdegen, 1985). Downstream of Ōpiki the river becomes a more passive meandering channel. This change is predominantly due to a change of energy from a slope transition (Figure 1.3).

In an alluvial river like the lower Manawatū, bank full flows perform the most geomorphic work. These flows correspond roughly to the 2-year Annual Recurrence Interval (ARI) flood event and are the dominant flows for transporting bedload (i.e. gravel), reworking sediment stored within the active channel, and initiating bank erosion. Suspended sediment is mainly transported at lower flows than the Mean Annual Flood (MAF) (Basher et al., 2012). This sediment may accumulate during lower flows, with larger floods being responsible for flushing this sediment and scouring the riverbed (Watson, 2008).

Changes in the river course throughout the river's history are evidenced by numerous palaeochannels across the floodplain (Lo Re et al., 2018). These palaeochannels form the wider active corridor which has, and will continue to be, reworked by the river through erosional and depositional processes. Some of these palaeochannels are demarcated by oxbow lakes and cutoffs. Changes in the active river channel can be seen throughout the temporal extent of aerial imagery, with new channels being occupied between the earliest full coverage of aerial imagery in 1941 and the most recent, in 2022 (see accompanying Natural Character Assessment (NCI) report). Throughout this time, changes in catchment land use, flood management (including the building of stop banks), erosion protection, and changes to the flood regime have all affected the river's geomorphic character. Stop banks have artificially confined the river, in places causing both rapid floodplain accretion and channel incision (Fuller et al., 2018).

## 1.4 Outline and approach

Having provided the purpose, background, and site context in Section 1, Section 2 of this report details the method used to complete the gravel budget assessment, including the archive aerial

photography, cross-section analysis, and the GCD tool. The results are presented in Section 3 and discussed in Section 4 including comparison of the two methods used herein, comparison with findings from the Whale and Bell assessments from previous epochs and a discussion of longer-term trends. Recommendations for future gravel budgeting strategies are outlined in Section 5.

Appendix A includes a map of the full length of the lower Manawatū River, showing cross section locations.

Appendix B includes a detailed methodology of the GCD workflow.

Appendix C includes the raw results from the cross-sectional analysis.

Appendix D includes the raw results from the GCD analysis.

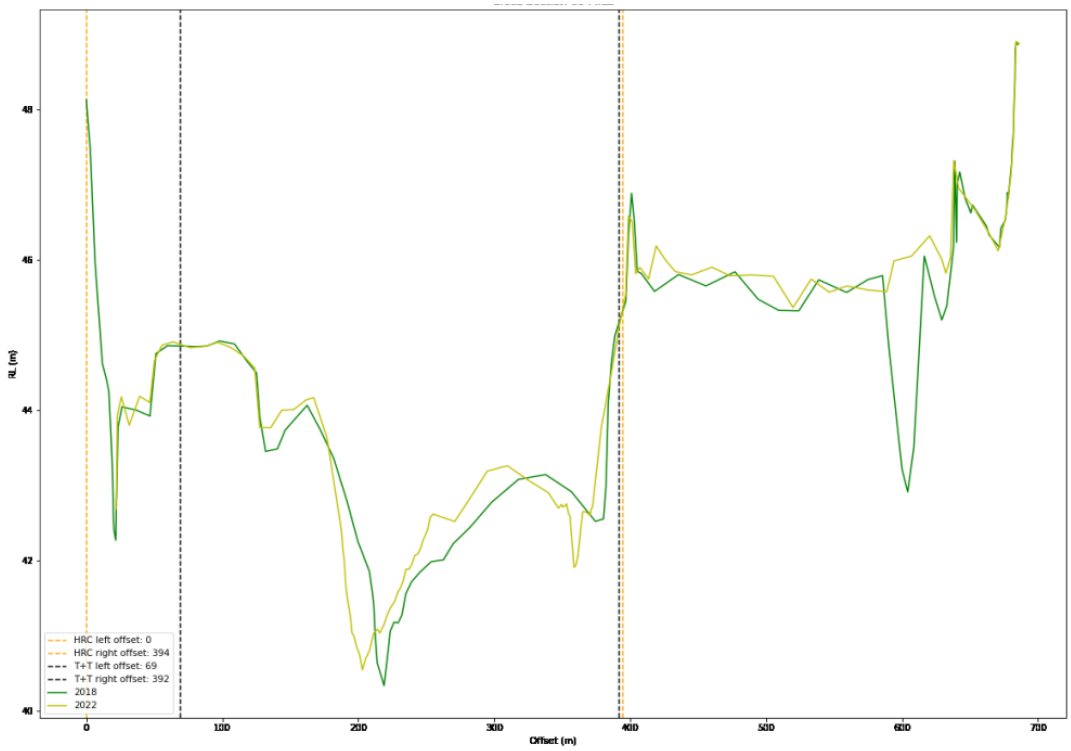
Appendix E includes a summary of selected morphological budget publications for background to the approaches adopted in this Report.

# 2 Methods

## 2.1 Channel cross-sections

HRC and its predecessors (Ministry of Works and Catchment Boards) have carried out cross section surveys at pre-determined locations along the Manawatū River, to enable monitoring of bed levels, from which to assess the gravel resource. The cross-section locations are shown in Appendix A. Survey data were collected over a period from October 2022 to October 2023 for this gravel assessment and in this study will be compared with the previous survey data collected in 2018. Elevations in all surveys were reported with reference to NZVD2016.

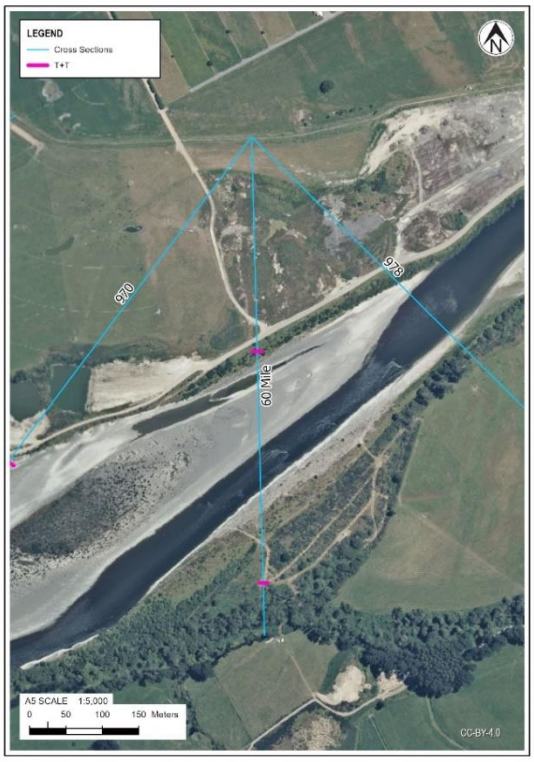
Analysis of the cross-section data was initiated by assigning "offsets". Offsets indicate the active channel boundary, which is the area of interest for the study, so survey data outside the offsets were excluded from analysis. Offsets used in previous studies (HRC offsets) were used, as well as revised offsets defined by T+T (T+T offsets). The T+T offsets have been defined to better reflect and capture the volume of gravel change associated with the active channel (Figure 2.1); this includes where the active channel has realigned outside the original HRC offset (Figure 2.2), and similarly will exclude any data beyond the current active channel that may have previously been included in the HRC offsets for a section. HRC offsets used in earlier analysis (Whale, 2019) were defined using 2016 aerial imagery and the use of more recent imagery in this assessment is a key reason for the offset changes. The HRC offsets have only been assigned for the gravel reach, from 63 to 37 Mile (Ashhurst to Ōpiki), whereas T+T offsets have been assigned from 63 Mile (Ashhurst) to BM 028 (Tasman Sea). The T+T offsets were defined using relevant aerial imagery (Manawatu – Whanganui Rural aerial photos 2021-2022), the cross sections and technical expertise. The analysis was undertaken twice, once with HRC offsets to allow continuity with previous studies and a second time, since the T+T offsets are more representative of the 2023 active channel and analyse the full length of the river downstream from Ashhurst Bridge (63 Mile). The change in gravel volume between 63 and 37 Mile was calculated to enable comparison of results between the two offsets. HRC has not provided offsets for the sand phase, since it does not contribute to the gravel resource, so the sand phase has only been analysed using the T+T offsets.




60 Mile cross-sections with both the HRC offsets in yellow and T+T offsets in black, as looking downstream. True Left is on the left of the graph. 2018 cross-section is in green; 2022/23 in yellow.



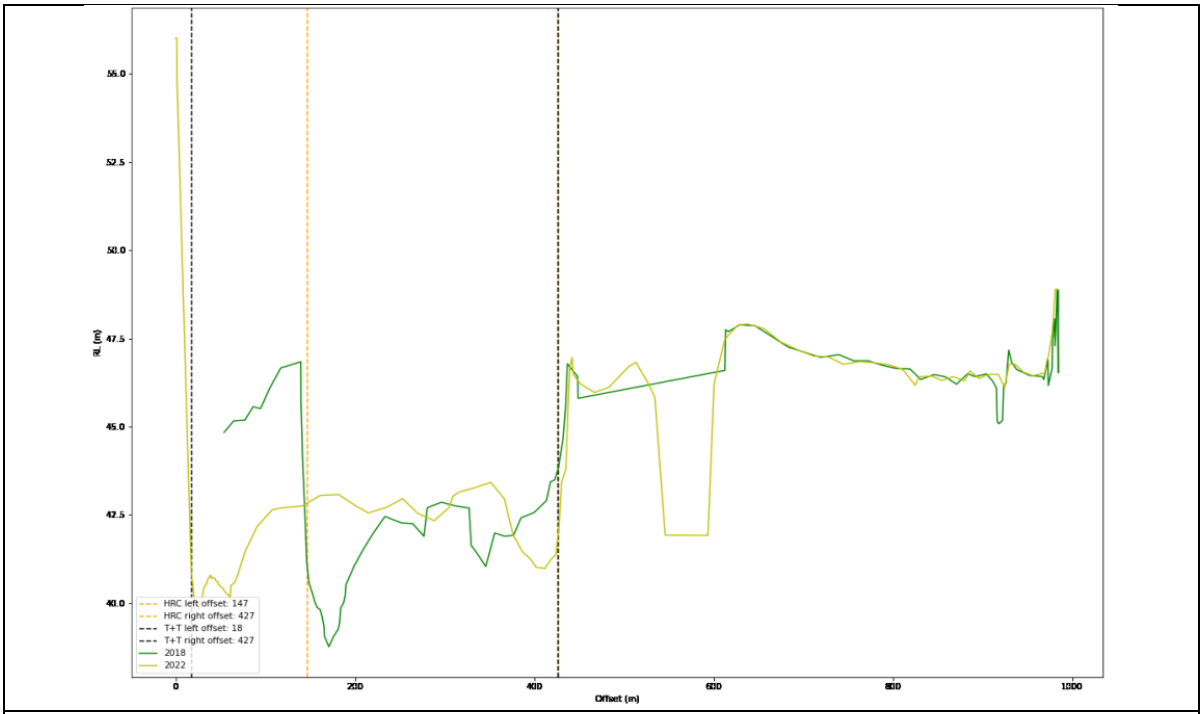

2016 aerial imagery of the Manawatū River channel at 60 Mile. The green lines indicate the HRC offsets.



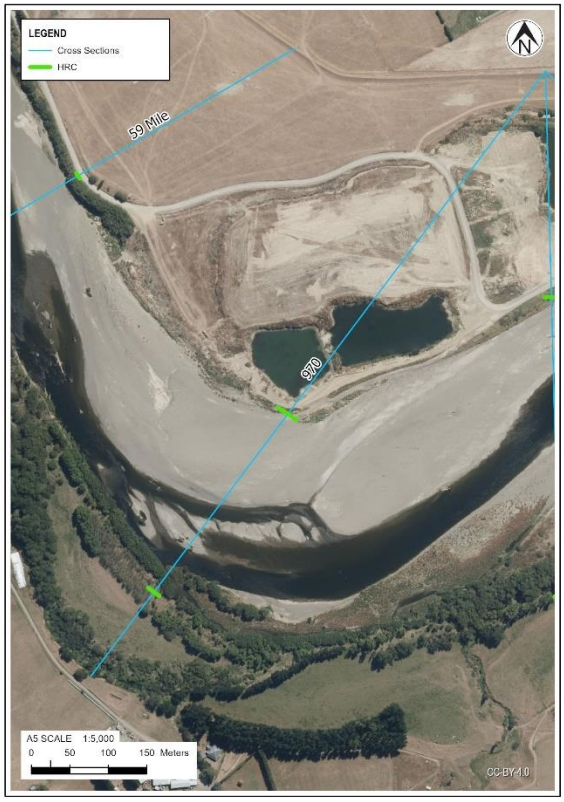

2022 aerial imagery of the Manawatū River channel at 60 Mile. The pink lines indicate the T+T offsets.

*Figure 2.1: Cross-sections and aerial imagery at 60 Mile cross-section, with the HRC and T+T offsets overlaid.*

At 60 Mile, the true right offset is consistent between HRC and T+T and reflects this margin of the active channel. However, the true left HRC offset incorporates a portion of heavily vegetated surface, which is inactive between 2016 and 2022. Changes apparent in the elevation of the surface at this location reflect different points surveyed along the section line between the two dates. Placement of the T+T offset towards the wetted channel (lower right image) better reflects the active surface between 2016 and 2022, though note that vegetation colonisation has occurred between these years, highlighting the need to regularly view offset locations prior to cross-section analyses.




BM 970 cross-sections with both the HRC offsets in yellow and T+T offsets in black. As looking downstream, True Left is on the left of the graph. 2018 cross-section is in green: 2022/23 in yellow. Note the rectangular trough indicates an excavated borrow pit that was wet in 2018 and omitted from the survey (note the straight line across this area).




2016 aerial imagery of the Manawatū River channel at BM 970. The green lines indicate the HRC offsets.




2016 aerial imagery of the Manawatū River channel at BM 970. The green lines indicate the HRC offsets.

*Figure 2.2: Cross-sections and aerial imagery of BM970, with the HRC and T+T offsets overlaid.*

At BM970 between 2016 and 2022 the wetted channel has migrated: deposition of gravel has occurred on the gravel point bar and erosion has occurred on the outside bend/true left bank (Figure 2.2). The true right offset remains an accurate delineation of that right margin, but the true left offset required adjustment to reflect the channel change at this location.

The change in volume was calculated by initially calculating the area between the offsets at each cross section for both the 2018 and 2023 survey. The end-over-area MBL (Environment Canterbury, n.d.) method was used to calculate the volume (Equation 1). Where the offsets did not intersect with a survey point, the RL was interpolated between survey points. In circumstances where the offsets were assigned to areas beyond the surveyed extent, the offset was "shifted" to the closest survey point for that year, and the area was calculated i.e., the survey data were not extrapolated to avoid introducing unwarranted error. An example of this approach is shown in Figure 2.3 with BM 970. The T+T left offset is beyond the 2018 survey data. The end area calculated for the 2018 survey is from 53 m to 427 m offset, whereas the end area for the 2022/23 data is calculated from the offset shown at 18 m to 427 m. With an RL of around 40 m, this can skew the analysis but is a result of the incomplete cross section data. The consequences of this missing information are discussed in the Seven Bends Report in connection with changes at Bend 1. In that report for this bend the 2016 LiDAR-derived elevation surface was used to reconstruct the missing information from 2018 (on the assumption that there was little or no geomorphic change along this elevated part of section BM 970). Retrospective adjustment of cross sections using LiDAR would help to improve the accuracy of the end-over-area method deployed by Horizons. Volumetric analysis was applied to the gravel reach, from 63 Mile to 37 Mile, and the sand reach from 37 Mile to benchmark (BM) 028. For the sand reach, a 10 m vertical offset was applied to all survey points to address the error arising from the bed level datum being below sea level. The 10 m offset has not been corrected for in this reach as doing so would result in a negative end area and therefore would result in a volume that is not representative of the trends in the sand reach. The findings of the analysis will be used to compare with previous years to gain an understanding of long-term trends. Refer to Appendix C for full dataset of cross-sections.

Equation 1: The end-over-area MBL equation:

$$Volume\ Available = V_x - V_{min} - V_{ex}$$

Where: $V_x = (D_2 - D_1) \times \left(\sqrt{(A_1 \times A_2)} + A_1 + A_2\right)/3$

$A_x = L_x \times W_x$

$D_x$ = river distance of cross-section $x$

$A_x$ = end area of cross-section $x$

$L_x$ = surveyed mean bed level at cross-section $x$

$W_x$ = fairway width at cross-section $x$

$V_{min}$ = volume between datum and minimum mean bed levels (using $L_{min}$ in place of $L_x$ in formula above)

$V_{ex}$ = volume known to have been excavated and removed since the survey (including reported returns and material yet to be reported)

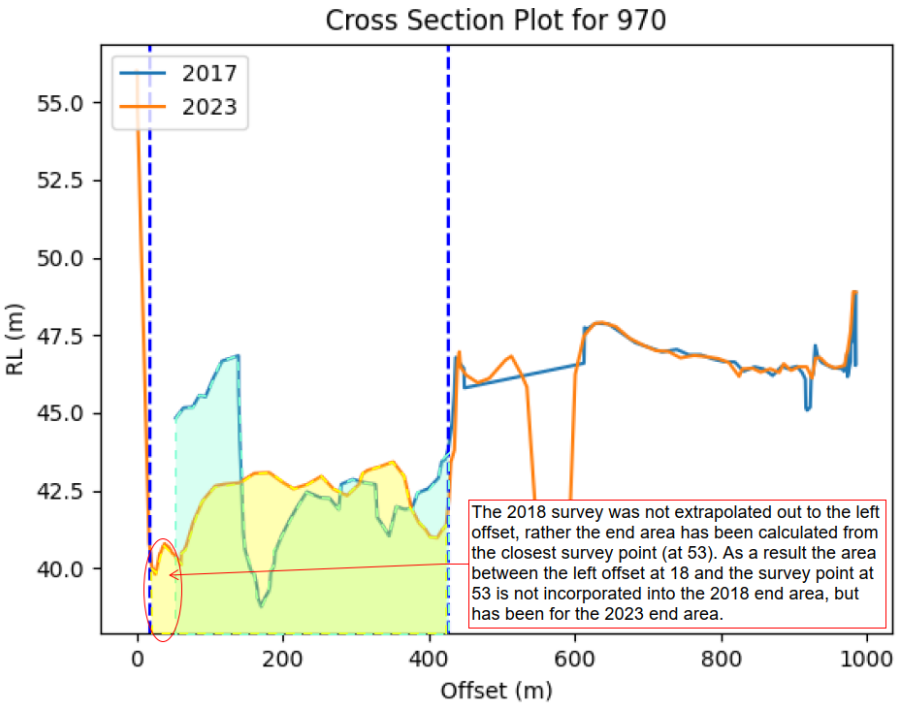



*Figure 2.3: Survey data at bend BM 970 showing the limitations of the methodology with incomplete survey data.*

## 2.2 Geomorphic Change Detection

Geomorphic Change Detection (GCD) was used to assess topographic change detection in the lower Manawatū River. The volumetric change in storage is calculated from the difference in surface elevations from Digital Elevation Models (DEMs) derived from repeat topographic surveys. GCD was run for two epochs: 2005-2016 and 2016-2022, based on LiDAR surveys supplied by HRC. Each of the surveys have been supplied with the following metadata (Table 2.1).

The vertical accuracy of LiDAR data points is given as 0.2 m (supplied). Change detection was given a threshold using a uniform value of 0.2 m, which means that elevation changes less than 0.2 m are excluded from analysis. Using this threshold reduces risk to volumes influenced by spurious changes that result from inaccuracies in the surfaces being compared. A threshold of 0.2 m provides a reasonable estimation of volumes and change detection.

**Table 2.1: HRC supplied DEM meta data used for DoD**

| DEM Name | Year | Coordinate system | Vertical Datum | Res |
|---|---|---|---|---|
| 2005_base8_NZVD16 | 2005 | NZGD_2000_Transverse_Mercator | NZGD2000 | 1 |
| 2016_base5_nzvd16 | 2016 | NZGD_2000_Transverse_Mercator | NZGD2000 | 1 |
| Manawatū_LMS_Corridor_DEM_20221229_NZVD16 | 2022 | NZGD_2000_Transverse_Mercator | NZGD2000 | 1 |

Detailed GCD methodology can be found in Appendix B.

# 3 Results

## 3.1 Channel cross-sections

The cross-section analysis takes into account both dry and wet gravel areas of the active channel. These areas are defined below.

- Dry gravel: Active gravel bars (exposed and lightly vegetated) in the river corridor that are not occupied by the wet channel.
- Wet gravel: Gravel underneath the wet channel in either or both survey years.

As outlined in this section, the cross-section plots were used to derive the gravel budget. See Appendix C for a detailed analysis for each cross-section. Figure 3.1 and Figure 3.2 show the change in gravel volume calculated at each cross-section site between 63 and 37 Mile using the offsets identified by HRC and T+T respectively. Figure 3.3 shows the change in the sand volume from 37 Mile to BM 028. Combined, Figure 3.1, Figure 3.2, and Figure 3.3 show the fluctuation of bed sediment storage (gravel and sand) along the lower Manawatū River.

Figure 3.1 (HRC offsets) shows a general decrease in gravel volume across the reach (from 63 Mile, just below Ashhurst Bridge to 37 Mile at Ōpiki), with large volumes of gravel degrading around BM 928 and 60 Mile and from Benchmark (BM) 923 to 43 Mile. The overall loss in gravel volume, from 63 Mile to 37 Mile was approximately 470,000 $m^3$.

Figure 3.2 (T+T offsets) show a general increase in gravel volume from 63 to 37 Mile, with an overall gravel volume increase of almost 540,000 $m^3$. The T+T offsets show the upper reach, from 63 Mile to BM 928 has increased in gravel volume (810,000 $m^3$) whereas the HRC showed a slight decrease in gravel volume (-1,000 $m^3$). Both T+T offsets and HRC offsets showed a decrease in gravel volume between BM 923 and 43 Mile, almost (-)360, 000 $m^3$ and (-)780,000 $m^3$ of gravel in the T+T and HRC offsets respectively. Downstream, from BM 681 to 37 Mile (Ōpiki bridge), T+T offsets estimated an increase in gravel volume of 90,000 $m^3$, and the HRC offsets estimated an increase in gravel volume of 310,000 $m^3$.

Figure 3.3 shows the cross-section analysis using the T+T offsets for the sand reach, from Ōpiki Bridge to the Tasman Sea. The graph shows an overall aggradation of sand, with the most aggradation occurring towards the river mouth, from BM 117 to BM 028.

Note: we were advised in correspondence dated 22 April 2024 that cross-section surveys collected in late 2022 (pre cyclone) were incomplete, comprising dry portions of the channel only. The wetted portion of these cross-sections was surveyed in mid-2023. This also means that the 2023 cross-section data are composite and do not represent the elevation of the bed at a single date. In turn this limits conclusions that can be drawn from these data since a significant flood event has occurred between collection of data from the dry and wetted portions of the channel.

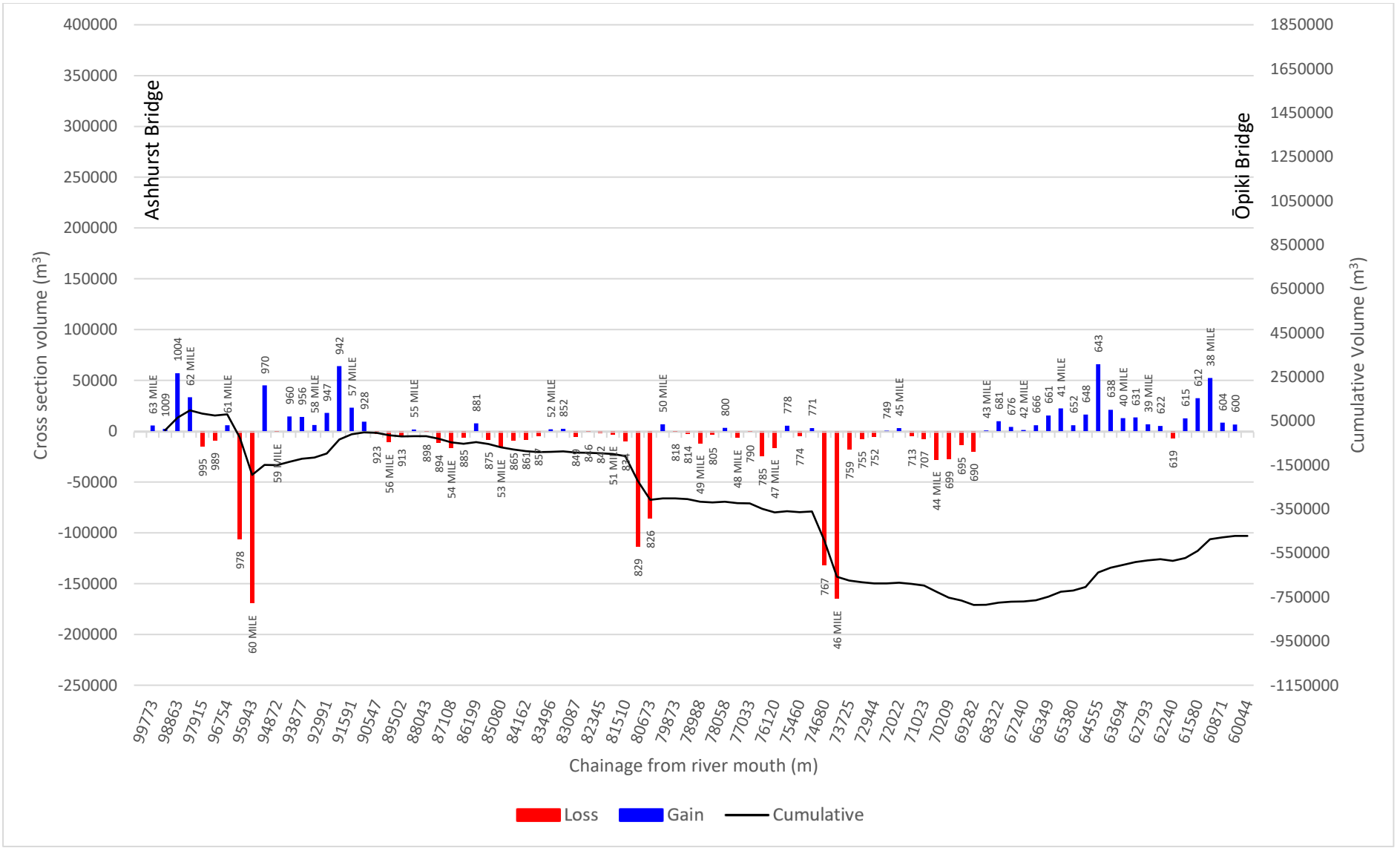



*Figure 3.1: Change in gravel volume 2018-2023 using the HRC offsets from below Ashhurst Bridge to Ōpiki.*

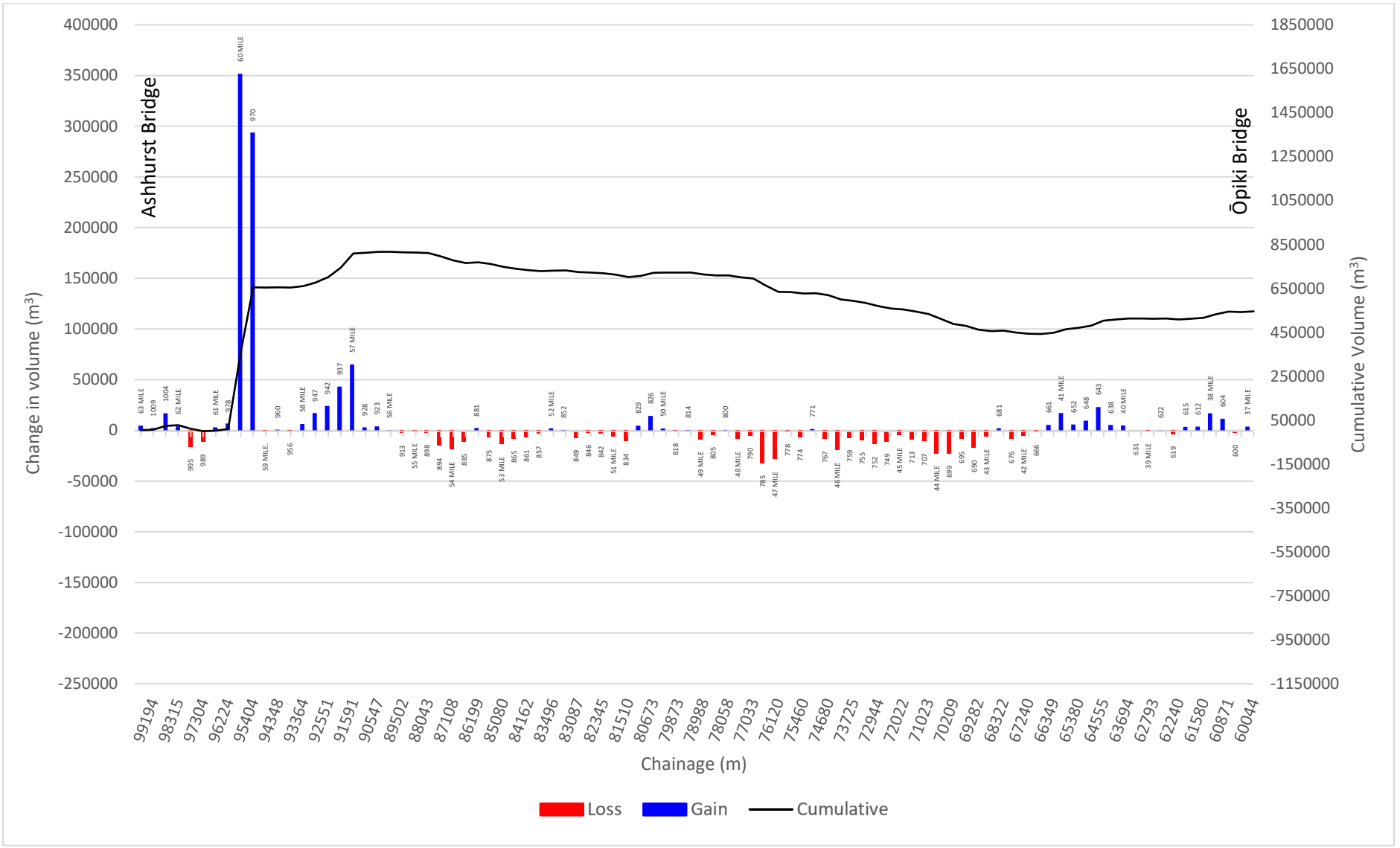



*Figure 3.2: Change in gravel volume 2018-2023 using offsets identified by T+T from below Ashhurst Bridge to Ōpiki.*

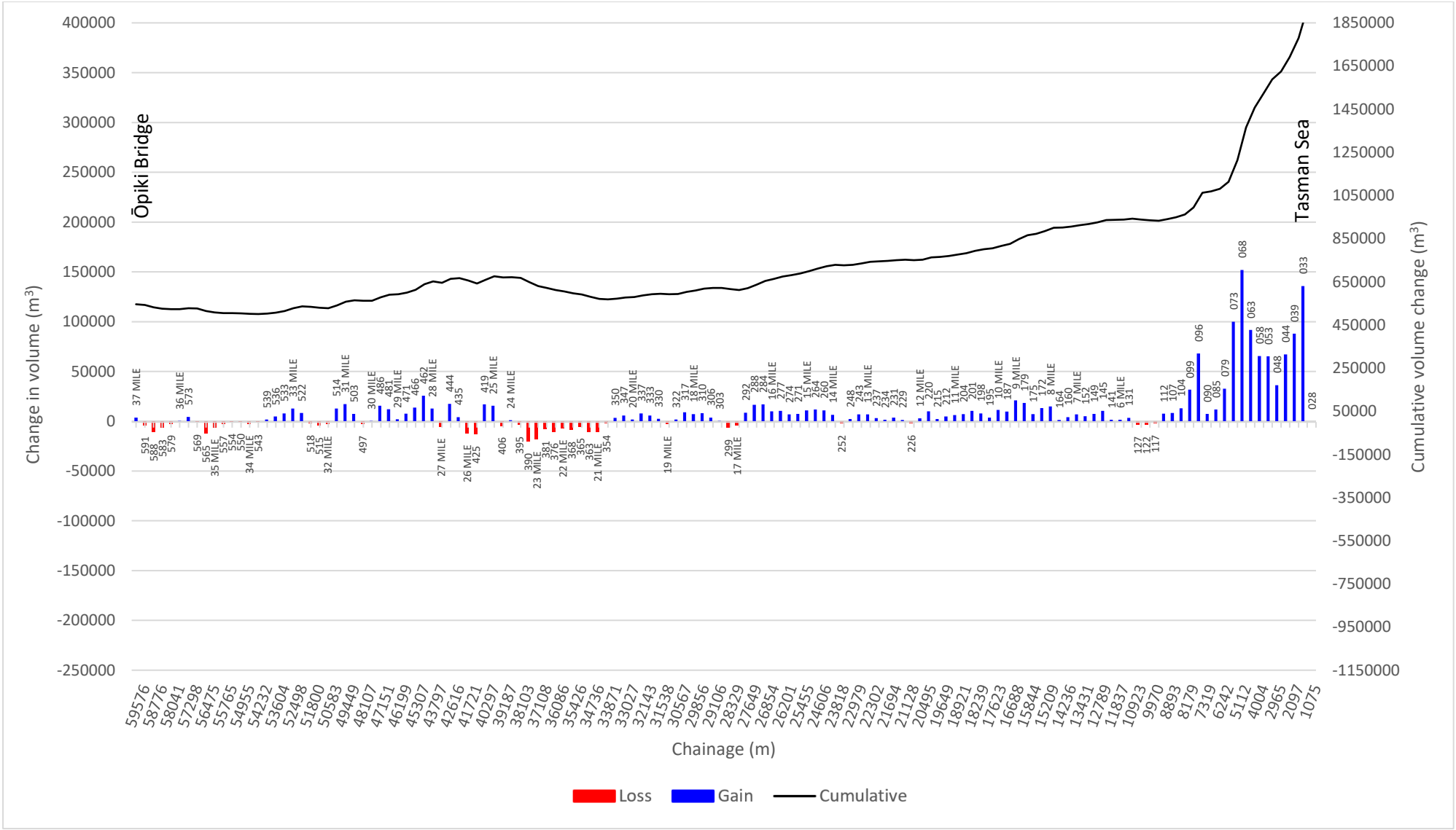



*Figure 3.3: Change in sand volume 2018-2023 using offsets identifed by T+T from Ōpiki Bridge to the Tasman Sea.*

## 3.2 Digital Elevation Models of difference (Geomorphic Change Detection)

Change detection utilised DEMs supplied by HRC for two time periods: 2005-2016 and 2016-2022 in the lower Manawatū. The 'whole of reach' morphological budget based on the GCD analysis are provided in Table 3.1 (2005-2016) and Table 3.2 (2016-2022). Morphological changes associated with this budget are presented in Appendix D which present the 'DEMS of difference' (DoDs) used in the GCD analysis, showing areas of deposition (blue) and erosion/degradation (red). Channel cross section locations are overlaid on these DoDs, providing a means of both spatial reference and comparison with the cross-section budget (Section 3.1). Longitudinal segmented morphological budgets for each cross-section sub-reach are given for 2005-2016 in Figure 3.4 and Figure 3.5 and for 2016-2022 in Figure 3.6 and Figure 3.7.

**Table 3.1: 2005-2016 GCD Results**

| Attribute | RAW | THRESHOLDED | ERROR VOLUME |
|---|---|---|---|
| **AREAL** | | | |
| *Total Area of Surface Lowering ($m^2$)* | 683,668.00 | 506,945.00 | |
| *Total Area of Surface Raising ($m^2$)* | 1,027,086.00 | 824,678.00 | |
| *Total Area of Detectable Change ($m^2$)* | N/A | 1,331,623.00 | |
| **VOLUMETRIC** | | | |
| *Total Volume of Surface Lowering ($m^3$)* | 780,324.92 | 763,612.24 | ±101,389.00 |
| *Total Volume of Surface Raising ($m^3$)* | 712,796.99 | 692,569.70 | ±164,935.60 |
| *Total Volume of Difference ($m^3$)* | 1,493,121.91 | 1,456,181.93 | ±266,324.60 |
| *Total Net Volume of Difference ($m^3$)* | -67,527.93 | -71,042.54 | ±193,606.51 |
| **VERTICAL AVERAGES** | | | |
| *Average Depth of Surface Lowering (m)* | 1.14 | 1.51 | ±0.20 |
| *Average Depth of Surface Raising (m)* | 0.69 | 0.84 | ±0.20 |

**Table 3.2: 2016-2022 GCD Results**

| Attribute | RAW | THRESHOLDED | ERROR VOLUME |
|---|---|---|---|
| **AREAL** | | | |
| *Total Area of Surface Lowering ($m^2$)* | 1,296,568.00 | 1,074,145.00 | |
| *Total Area of Surface Raising ($m^2$)* | 770,843.00 | 590,054.00 | |
| *Total Area of Detectable Change ($m^2$)* | N/A | 1,664,199.00 | |
| **VOLUMETRIC** | | | |
| *Total Volume of Surface Lowering ($m^3$)* | 822,821.43 | 800,261.15 | ±214,829.00 |
| *Total Volume of Surface Raising ($m^3$)* | 521,948.63 | 504,793.39 | ±118,010,80 |
| *Total Volume of Difference ($m^3$)* | 1,344,770.07 | 1,305,054.54 | ±332,839.80 |
| *Total Net Volume of Difference ($m^3$)* | -300,872.80 | -295,467.76 | ±245,108.24 |
| **VERTICAL AVERAGES** | | | |
| *Average Depth of Surface Lowering (m)* | 0.63 | 0.75 | ±0.20 |
| *Average Depth of Surface Raising (m)* | 0.68 | 0.86 | ±0.20 |

Appendix D highlights spatial variability in detectable morphological changes along sub-aerial surfaces in the lower Manawatū River from the Manawatū Gorge to the Tasman Sea. Generally, the lower reaches below Ōpiki (cross-section 37) show minimal change due to the nature of sediment in those reaches (sand) where the river lacks the capacity to store and rework sediment (few sub aerial surfaces). As a result of the lack of detected change, the DoD shows no volumes on the maps downstream from Ōpiki. Above Ōpiki (map series A-F), variable changes in gravel storage patterns are evident. This variability occurs during both epochs, with minimal erosion or aggradation highlighted in the GCD on exposed gravel bar surfaces. Trends upstream and downstream of Ōpiki are discussed in more detail in Section 4.2.

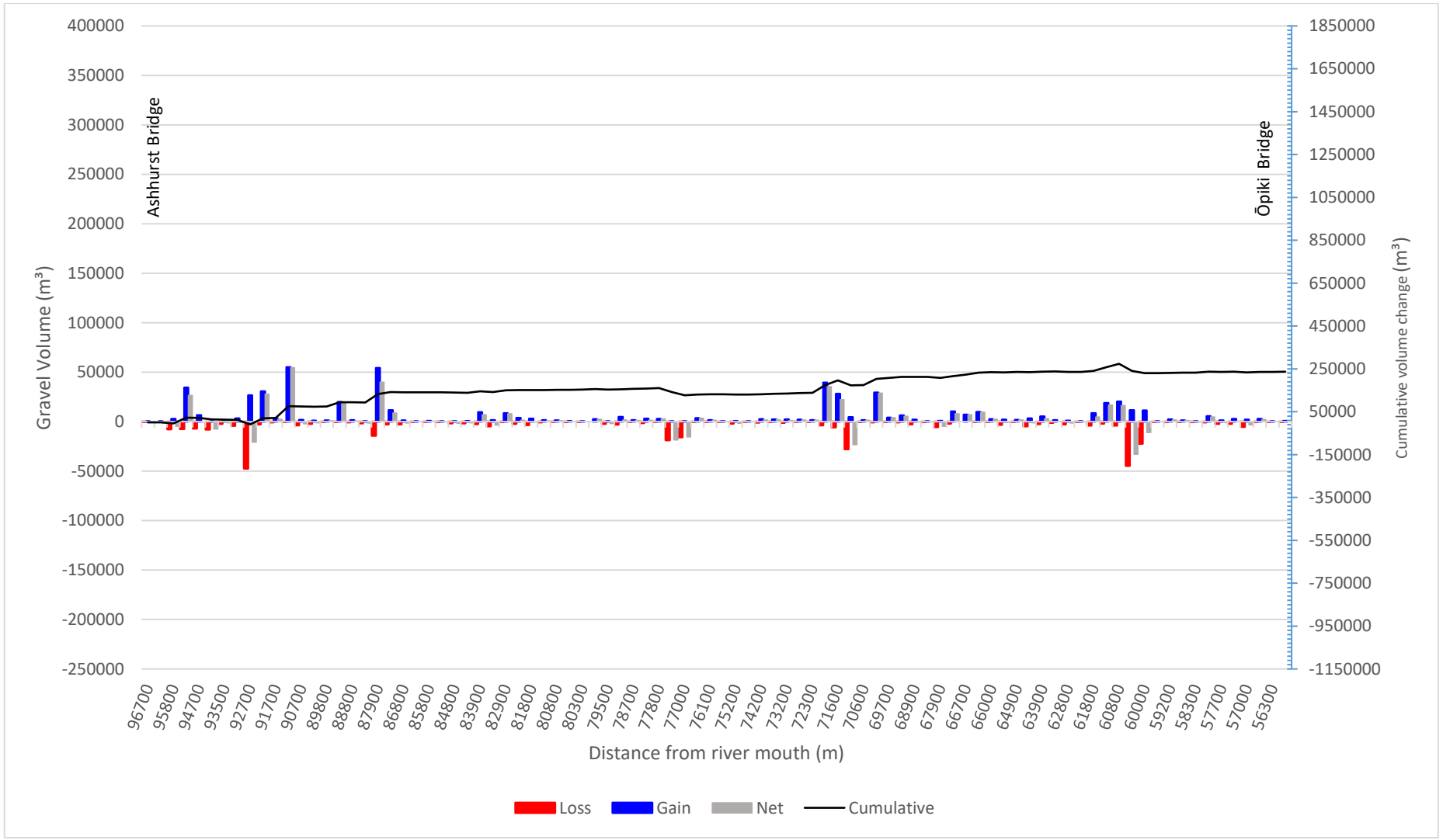



*Figure 3.4: Change in gravel volume Ashhurst Bridge to Ōpiki Bridge from 2005-2016 using GCD analysis scaled for cross-section comparison (Figure Appendix D.1, Figure Appendix D.2, Figure Appendix D.3, and Figure Appendix D.4), detailed graphs in Appendix D. Note: GCD is only feasible from consecutively dry surfaces from 2005-2016.*

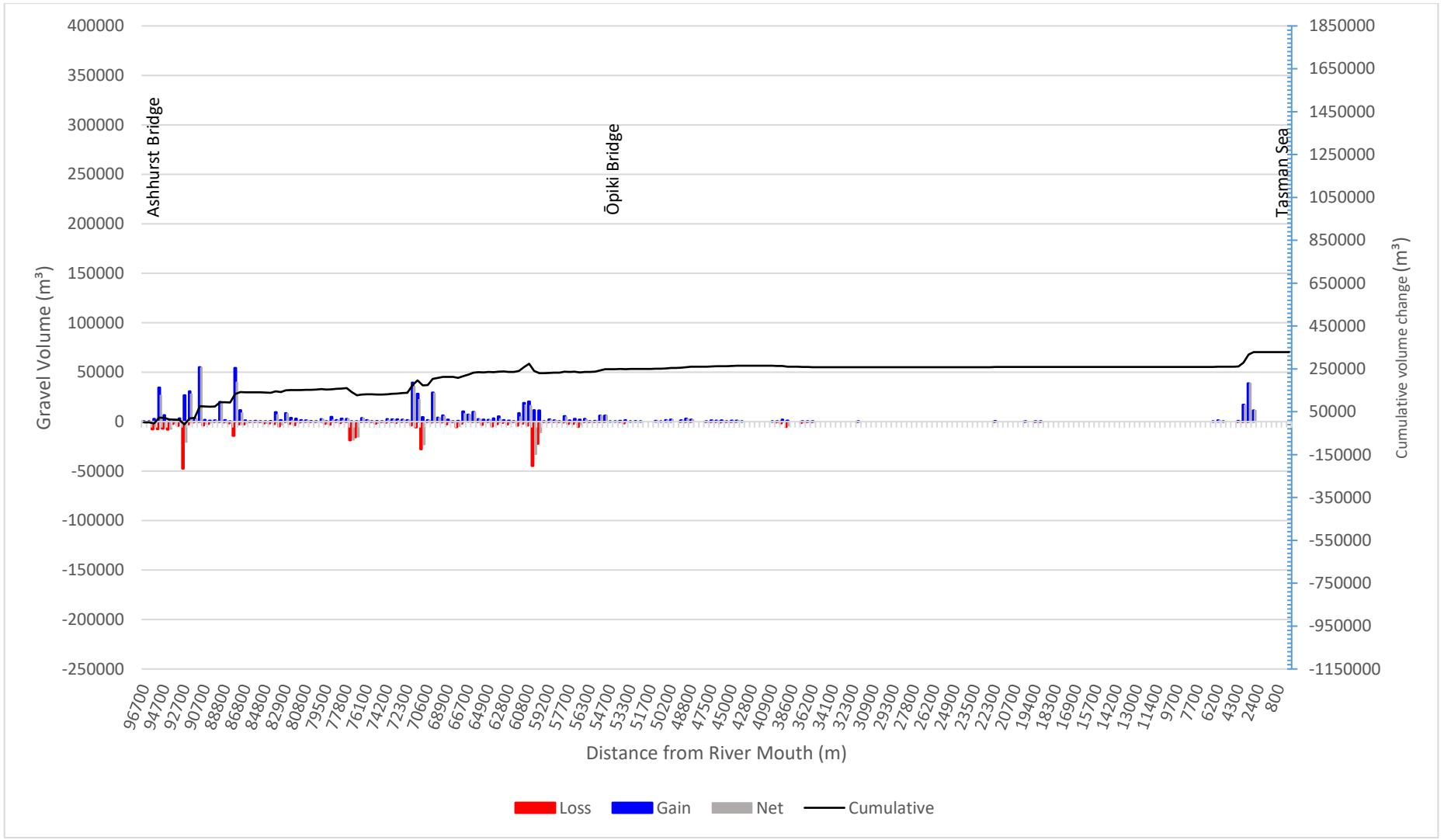



*Figure 3.5: Change in sediment volume Ashhurst Bridge to Tasman Sea from 2005-2016 using GCD analysis scaled for cross-section comparison (Figure Appendix D.1, Figure Appendix D.2, Figure Appendix D.3, and Figure Appendix D.4), detailed graphs in Appendix D. Note: GCD is only feasible from consecutively dry surfaces from 2005-2016.*

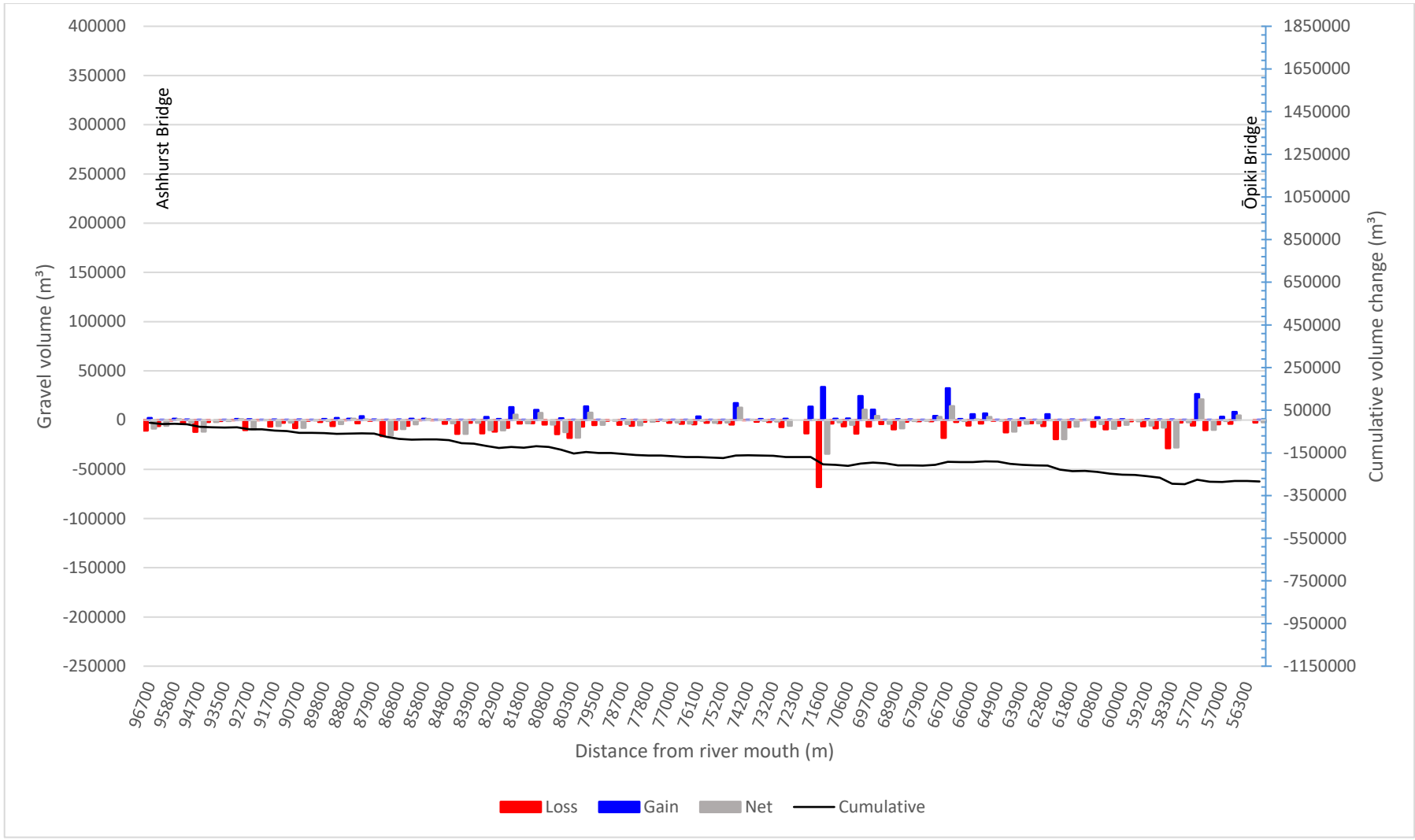



*Figure 3.6: Change in gravel volume Ashhurst Bridge to Ōpiki Bridge from 2016-2022 using GCD analysis scaled for cross-section comparison (Figure Appendix D.1, Figure Appendix D.2, Figure Appendix D.3, and Figure Appendix D.4), detailed graphs in Appendix D. Note: GCD is only feasible from consecutively dry surfaces from 2016-2022.*

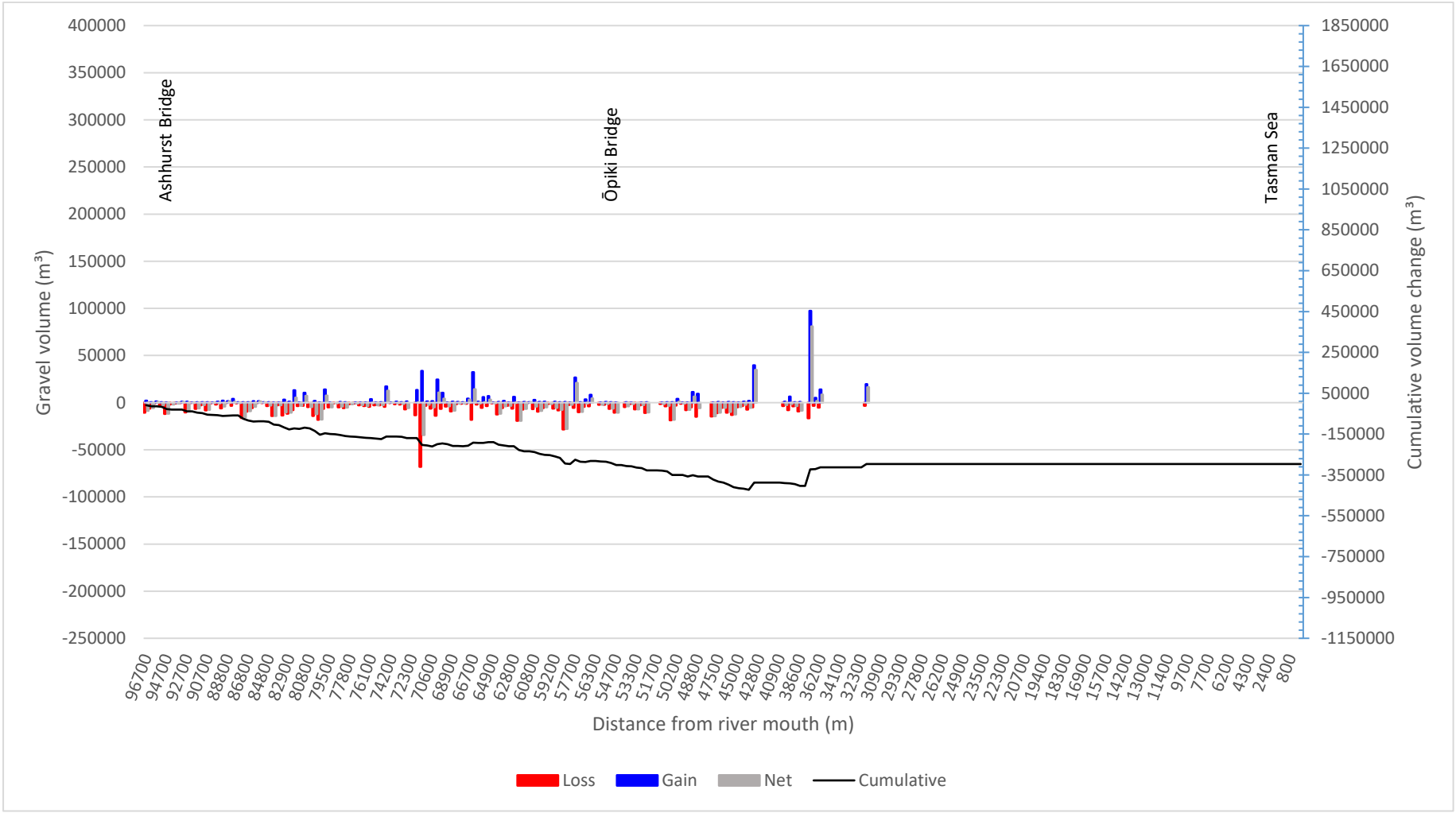



*Figure 3.7: Change in sediment volume Ashhurst Bridge to Tasman Sea from 2016-2022 using GCD analysis scaled for cross-section comparison (Figure Appendix D.1, Figure Appendix D.2, Figure Appendix D.3, and Figure Appendix D.4), detailed graphs in Appendix D. Note: GCD is only feasible from consecutively dry surfaces between 2016-2022.*

# 4 Discussion

Comparisons with the Whale (2019) gravel budget, T+T cross-sectional budget and GCD have been assessed, where downstream from Ōpiki is referenced as the 'sand phase' and upstream of Ōpiki as the 'gravel phase' within this report. The gravel-sand transition in the lower Manawatū is taken as Ōpiki (after Page and Heerdegen, 1984), at cross-section 37. Detailed assessment of the gravel budget above Ōpiki at discrete bends has been provided as part of the 'Seven Bends' Report.

## 4.1 Cross-section: Horizons Regional Council and Tonkin & Taylor Ltd offsets

Implementing a morphological budget using cross-sectional analysis comes with certain constraints, which include:

- An assumption that the averaged sediment output of two cross sections is uniformly applicable to the section of river between the cross sections does not account for any local bed level variations between surveyed cross-sections. This is a significant assumption since erosion and deposition of bedload in gravelly rivers is rarely spread evenly across a riverbed or bar surface due to the nature of fluvial processes responsible for erosion, transport and deposition of bed material.
- The time it takes to complete a surveying campaign. Some cross-sections were composite – the true left and right bank were surveyed at different times from the wetted channel. Although all survey data were gathered between October 2022 to October 2023, this incorporated a significant flood attributed to Cyclone Gabrielle in February 2023.
- The RL has not been extrapolated beyond survey points in cross sections where the offsets are beyond the survey line. As a result, the change in volume calculated at these sections may not be a true representation of the change in gravel volume since morphological changes that occurred beyond the extent of a cross-section have not been included in the morphological budget.

In the gravel phase, the approximate net change in gravel volume using the HRC offsets for 2018-2023 was a decrease of almost (-)470,000 $m^3$, while using T+T offsets indicated a net gain of almost 540,000 $m^3$. Both HRC and T+T offset analysis show three distinct sections in the gravel phase, as outlined in Table 4.1, where bed levels are either exhibiting degradation or aggradation.

In the sand phase, downstream of 37 Mile/Ōpiki Bridge the total approximate change in sediment volume using T+T offsets was an increase of almost 1,370,000 $m^3$.

A summary of the change in volume in the gravel and sand phases is presented in Table 4.1.

**Table 4.1: Summary of HRC and T+T offsets**

| Phase (river marker) | HRC offsets | | T+T offsets | |
|---|---|---|---|---|
| | Gravel volume change ($m^3$) (2018-2023) | Aerial and cross section observations and comments | Gravel volume change ($m^3$) (2018-2023) | Aerial and cross-section observations and comments |
| Gravel phase (63 Mile to BM 928) | -1,000 | Mean bed level is typically degrading. This includes almost 170,000 $m^3$ of gravel eroded from 60 Mile, from the realignment of the channel. | 810,000 | Mean bed level is typically aggrading.<br>The combined increase in gravel at 60 Mile and BM 970 is due to the incomplete 2018 survey data at bend 970. As a result, the calculated volume for the 2023 survey is much larger than the 2018 data.<br>The net gain from these two cross sections is almost 650,000 $m^3$. This gain is skewing the results for this phase. |
| Gravel phase (BM 928 to 43 Mile) | -780,000 | Mean bed level is degrading.<br>The greatest loss of gravel volume was around 46 Mile where a point bar has eroded and there is evidence of bank erosion directly downstream of 46 Mile.<br>There are pockets where the gravel volume did increase likely because of lateral or point bar development or development of riffles.<br>The increases in gravel volume approximated are small (around 39,000 $m^3$ cumulatively) compared to the loss in gravel volume (more than 820,000 $m^3$) in this section. | -360,000 | Mean bed level is degrading.<br>There was a loss in gravel volume at Mile 46, but a much smaller magnitude compared with what was captured in the HRC offsets.<br>The loss in gravel volume through this section was relatively consistent at each cross-section site.<br>There are pockets where the gravel volume did increase likely because of lateral or point bar development or development of riffles.<br>The increase in gravel volume approximated is small (approximately 45,000 $m^3$ cumulatively) compared with the loss in gravel volume (more than 400,000 $m^3$) in this section. |
| Gravel phase (43 Mile to 37 Mile) | 310,000 | Mean bed level of the active channel is aggrading.<br>BM 619, the only area recording a loss of gravel volume in this section, is likely due to erosion of the point bar. | 90,000 | Mean bed level of the active channel is aggrading.<br>Gravel volume decreased at cross sections BM 676 to 42 Mile and BM 619, likely due to erosion of point bars. |
| Silt Phase | Not analysed | Not analysed | 1,370,000 | Channel is generally aggrading. However, from |

| | | | | |
|---|---|---|---|---|
| **(37 Mile to BM 028)** | | | | BM 591 – BM 543, and BM 406 – BM 354 the channel appears to be narrowing and incising, with lowering mean bed levels in these reaches. |

In the upper section of the gravel phase (63 Mile to BM 928), the HRC offsets suggest the Manawatū River is almost in equilibrium, with a slight net gravel volume loss. Whereas the T+T offsets show that the Manawatū River is aggrading. However, this is likely a misrepresentation as not all the erosion from the 60 Mile and BM 970 cross-sections has been captured due to the incomplete survey data at BM 970 (Figure 2.3: Survey data at bend BM 970 showing the limitations of the methodology with incomplete survey data.). As a result, almost 650,000 $m^3$ of gravel has been estimated to have been deposited across the two cross sections, skewing the results to an aggradation trend when the survey data and aerial imagery indicate that there is significant erosion at BM 970. However, this does overlook the potentially significant volume of sediment introduced into the river as a consequence of bank erosion as the bend at BM 970 migrated. Therefore, although there has been significant migration of the bend, the bed of the wetted channel along BM 970 is actually higher in 2023 than in 2018 (Figure 2.2), hence the aggradation identified in the area under assessed between the offsets by the MBL end-over-area method. The full extent of the erosion at this bend is not captured because the 2023 wetted channel is outside of the offsets. The channel adjustment and volumetric change at this location (Bend One) is discussed in more detail in the Seven Bends Report. It is notable that extrapolating the BM 970 section using the 2016 LiDAR results in a net loss at this location, which reflects the significant bank erosion, generating an overall lower bed level, but in terms of the gravel budget this bank erosion would actually represent a gain (input) of sediment into the channel system. A limitation of cross-section analysis using MBL is that bank erosion is counted as loss (lowering of the surface) rather than gain. The localised aggradation at 60 Mile and BM 790 is probably a better (if imprecise) reflection of sediment trends in the river as whole. In the middle section (BM 923 to 43 Mile), both analyses show a net loss in gravel volume, and in the lower section (43 to 37 Mile), both analyses show an increase in gravel volume. These results highlight the sensitivity of mean bed level analyses, which are significantly influenced by offset location, as well as channel migration.

The results from the two analyses are quite different in trend in the upper section and magnitude in the middle and lower sections. This is likely because the T+T offsets were reviewed and updated to the active channel boundary that was relevant for the 2018–2023 period. Thus, gravel bars that have been incorporated into the floodplain pre-2018 have not been accounted for in HRC offsets, and vertical changes here may reflect a significant accumulation of fines deposited on the vegetated surface, rather than gravel aggradation. Similarly, a straight application of HRC offsets may miss loss of material (gravel and fines) where the river is now eroding a floodplain. It should be noted that where bank erosion has occurred, volumetric losses cannot solely be attributed to gravel because banks in the lower Manawatū are composite, comprising basal gravels overlain by a top layer of sands and silts. The thicknesses of these deposits and their relative contribution to the budget presented in this cross-section analysis is unknown and has not been quantified. Nevertheless, by refining and reducing the area of the active channel (as done by applying the T+T offsets) this has reduced the change in gravel volume captured in the T+T offset results and has resulted in smaller volumes than those captured by applying the HRC offset analysis. The updated offset likely provides a better representation of changes in gravel storage, albeit likely overestimating gravel losses due to incorporation of an unknown volume of bank top fines where the floodplain has been eroded.

Offsets for the sand phase were not provided from previous HRC analysis so could not be undertaken or compared to the T+T analysis.

## 4.2 Cross-section and Geomorphic Change Detection compared

The GCD and cross section analyses both assess the gravel and sand volume changes throughout the lower Manawatū River. The following limitations apply when comparing the results:

1 GCD measures net change in gravel volume for dry areas, while the cross-section analysis assessed the net change in gravel volume for dry and wet areas.

2 The GCD analysis has large levels of uncertainty. For example, for the whole river between 2005 and 2016, the net volume change is -71,000 $m^3$, but the inherent LiDAR source error associated with it is ±193,600 $m^3$ (see Section 2.2 for GCD error calculation rationalisation).

3 The two gravel volume methods were assessed over different time periods. GCD was assessed over two epochs: 2005-2016 and 2016-2022, while cross-sections were assessed from 2018-2023.

Table 4.2 presents a summary of gravel volume change in the gravel phase determined by both the cross section and GCD analyses from 2005 to 2022/23.

The change in gravel volume calculated by the GCD from the 2005–2016 epoch is quite different to the cross-sectional analysis undertaken by Whale from 2011–2018. The GCD calculated a loss of 186,000 $m^3$ and Whale (2019) reported an increase in gravel volume by more than 1,020,000 $m^3$. The end over area MBL equation that was applied to analyse the 2018-2023 analysis, was applied to the cross-section data from 2011-2018, and calculated a volume increase in gravel of 860,000 $m^3$, which is broadly consistent with Whale's (2019) volumes. The significant disparity between GCD and the cross-section derived volumes is likely a product of both the GCD omitting the wetted channel, as cross-sections show the bed level was aggrading, and that the GCD analysis included surface changes from 2005, not 2011.

The cross-section analysis using HRC offsets calculated a decrease in gravel volume by over 470,000 $m^3$ from 2018 to 2023 between 63 and 37 Mile. Contrastingly, the T+T offsets estimated an increase of almost 550,000 $m^3$, although if 60 Mile and BM 970 are removed from the analysis due to the incomplete survey data, a loss in gravel of almost (-)100,000 $m^3$ is estimated. The GCD results also indicate a net decrease in gravel volume, an estimate of 186,000 $m^3$, with an error volume of ±217,000 $m^3$. These results suggest that the epoch may reflect active channel narrowing as point and lateral bars are incorporated into floodplains, and that the active channel is otherwise incising.

**Table 4.2: Summary of net change in volumes gravel phase**

| Year period | Cross section analysis – Total net volume of difference (excludes silt) | | GCD | |
|---|---|---|---|---|
| | HRC offsets ($m^3$) | T+T offsets ($m^3$) | Threshold ($m^3$) | Error volume ($m^3$) |
| 1997-2011 | Quasi Equilibrium | - | - | - |
| 2005–2016 | Not calculated | - | -163,657 | ±166,848 |
| 2011–2018 | ~1,024,000*<br>~876,030**<br>(864,750***) | - | - | - |
| 2016–2022 | - | - | -185,979 | ±217,358 |
| 2018–2023 | -472,057 | 546,078 (-99,397.7 if 60 Mile and BM 970 are omitted) | - | - |

* Reported as net gravel volume (which is total volume and extraction volume summed) in Whale (2019). **Total volume change from cross-section analysis reported in Whale (2019). ***Total volume change from 2011-2018 cross-sections calculated using end-area MBL methodology applied for the 2018-2023 analysis – a relatively small discrepancy can be attributed to slight differences in the HILLTOP approach used in Whale (2019) and the end-over-area approach. HILLTOP analysis has not been assessed.

Table 4.3 presents a summary of the sediment volume change in the sand phase determined by both the cross section and GCD analyses from 2005 to 2023. Both the GCD and cross section analysis identified an increase in sediment deposition from the 2005/11-2016/18 epochs suggesting narrowing of the channel. For the 2016/18 – 2022/23 epoch, the cross-section analysis using T+T offsets indicate over 1,000,000 $m^3$ of sediment has aggraded. The GCD identified that there was a reduction of over 100,000 $m^3$ of sediment in the sand phase. As the cross-section analysis accounts for the wetted areas and the GCD only the dry areas, this epoch could reflect that some channel widening has occurred, but more likely reflects infilling of the wetted channel.

**Table 4.3: Summary of net change in volumes in the sand phase**

| Year period | Cross-section analysis – Total net volume of difference (excludes silt) | | GCD | |
|---|---|---|---|---|
| | HRC offsets ($m^3$) | T+T offsets ($m^3$) | Threshold ($m^3$) | Error volume ($m^3$) |
| 1997-2011 | Not reported | | | |
| 2005-2016 | - | - | 92,614 | ±29,688 |
| 2011-2018 | 94,387* | Not calculated** | - | - |
| 2016-2022 | - | - | -109,491 | ±29,460 |
| 2018-2023 | Not provided | 1,369,113 | - | - |

*Reported in Whale (2019) for upper reach (Ōpiki to Oroua 37-32 Mile) only, remainder of reach assessed over different epochs – see 4.3 for detail), **not within scope given the gravel focus.

## 4.3 Previous studies

Previous studies of the change in gravel volume have been undertaken by Bell (2012) from the 1997-2011 epoch and Whale (2019) from the 2011-2018 epoch. Both studies used the HILLTOP software for the cross-section analysis. HILLTOP software calculates the cross-sectional area of the active channel at each cross-section location, the user then integrates the cross-sectional areas between adjacent cross sections to obtain a volume. The volumes between surveys are then compared, to

calculate a change in volume. This process is comparable to the end over area Mean Bed Level equation used for the analysis of the 2018-2023 epoch data.

Between 1997-2012 Bell (2012) documented a net loss of ~1,000,000 $m^3$ of gravel between 63 and 47 Mile, which approximates the 1,064,832 $m^3$ of gravel extracted in this period. A similar volume of aggradation (1,000,000 $m^3$) was documented between 47 and 37 Mile (Bell, 2012). Without extraction, the volume of gravel between 63 and 37 Mile would have been in equilibrium and Bell (2012) states that moving the gravel extraction from the degrading to the aggrading section was necessary. However, Bell (2012) notes that bed lowering after the halting of the gravel extraction in the degrading section ended and suggested that nevertheless there may have been an underlying natural process causing the riverbed lowering. Bell did not look at the sand phase.

In contrast, Whale's (2019) assessment of the following epoch (2011-2018) concluded that there was a shift from the gravel phase being in quasi equilibrium to aggrading. Over these seven years, 890,000 $m^3$ (148,000 $m^3$ pa) of gravel was deposited in the gravel phase (Ashhurst to Ōpiki). Whale observed that between 63 and 47 Mile, the river was recovering from the degradation documented by Bell (2012). These changes could be in part due to the tighter management on gravel extraction as less than 150,000 $m^3$ (147,471 $m^3$) was extracted over this timeframe. In the sand phase of the lower Manawatū (downstream of Ōpiki) Whale (2019) reported that there was net aggradation in the upper reaches: - 37 to 32 Mile: ~95,000 $m^3$ between 2011-2018 and 32-24 Mile: ~162,000 $m^3$ between 1993-2018. Annualised volumes for these periods suggest 15,700 $m^3$ aggraded per annum for 37 to 23 Mile and ~6,700 $m^3$ for 32 to 24 Mile. Downstream, narrowing and deepening of the channel was associated with net losses of sediment annualised at ~4,500 $m^3$ from 24 Mile to 19 Mile (1994-2018), ~43,500 $m^3$ from 19 Mile to BM 127 and ~54,000 $m^3$ from BM 127 to BM 25. Losses in these lower reaches could reflect a variety of variables, including tidal influences in the lower river. However these degrading sites are located downstream from the Moutoa Floodway, which could effectively siphon quantities of sediment away from the lower river when operational.

Direct comparison between the cross-section analysis here with previous work is challenging as a consequence of significant channel changes and uncertainties involved in cross-section analysis (cf. 4.1). Offset definitions have been demonstrated to substantially alter the results of analysis in this study. Appropriate offsets need to be carefully defined to reduce some of this uncertainty. It should be noted that application of the end-over-area approach to the 2011-2018 cross-section data generated a volume consistent with that reported by Whale (2019) (Table 4.2). Application of the same HRC offsets to the 2018-2023 cross section data generated an overall volumetric loss for the gravel phase of the lower Manawatū (Ashhurst to Ōpiki) of ~472,000 $m^3$, which would reverse the aggradation reported for the preceding epoch (2011-2018) by Whale (2019). However, to account for channel change, applying updated (T+T) offsets, overall volumetric change in this reach reverts to aggradation with a net volume of ~546,000 $m^3$. This significant volume of aggradation may however be masking an otherwise degrading state of much of the gravel phase in the lower Manawatū (Figure 3.2) because these gains reflect localised changes in cross sections at 60 Mile and BM 970 (Bend One of the Seven Bends) in response to significant channel change. If these sections are excluded, the overall volumetric change becomes negative, with a loss of ~99,000 $m^3$ from the gravel phase of the lower Manawatū (Table 4.2). GCD-derived volumes from the dry surfaces (only) for an equivalent period (2016-2022) also indicate a net loss (186,000 $m^3$, Table 4.2). Some of these losses could be attributed to gravel extraction, reported as 58,225 $m^3$ in the 2018-2023 period (HRC personal communication, refer Appendix F), but this volume only accounts for around a third of total degradation measured in this study, suggesting an underlying natural trend to this degradation.

The sand phase in the lower Manawatū River continued to aggrade overall from 2018-2023, increasing in 1,040,000 $m^3$ (260,000 $m^3$ pa) as a whole, with notable aggradation evident in the lower reaches in contrast to the degradation observed in the lower river by Whale (2019).

## 4.4 Long-term trends

Cross-section derived gravel budgets show considerable spatial and temporal variability. Long-term, there is no clear trend either towards net gain or net loss in the lower Manawatu River. Changes are likely cyclic, reflecting pulsed sediment supply from erosion events both within the active river corridor, and from upstream sediment inputs. Furthermore, some cross-section data are composite and do not represent the elevation of the bed at a single date. In turn this limits conclusions that can be drawn from these data since a significant flood event during Cyclone Gabrielle (February 2023) has occurred between collection of data from the dry and wetted portions of the channel along these composite sections. However, the lower Manawatū River does appear to display an extended period of degradation for the epochs 1997-2011. This degradation trend is particularly unexpected in this part of the system and potentially reflects over-extraction of gravel resource. Reversal of this trend from 2011 to 2018 may reflect the reduced gravel extraction in this period. However, the lower Manawatū River appears to have returned to a degradation trend for the 2018 – 2023 epoch, with gravel extraction contributing to over 30% of this decrease in gravel volume. This suggest the lower Manawatū River is sensitive to extraction, and gravel supply and river effects should be carefully monitored.

As determined in the Lower Manawatū Sediment Study (T+T, 2019; Watson, 2008) the lower Manawatū has exhibited a degradational trend since the 1800s. However, it is also vital to consider future potential trends under climate change. The predicted changes in rainfall associated with the various atmospheric $C0_2$ concentration (RCP2.6, 6.0, and 8.5)[1] are not spatially or seasonally consistent. As mentioned in the Lower Manawatū Sediment Study (T+T, 2019) the upper Manawatū Catchment is predicted to have a 2% increase in rainfall annually for the RCP2.6 and 6.0, predicted to result in warmer wetter summers which may increase plant growth, and limit any predicted increases in sediment generated above the gorge. T+T (2019) also mention that under RCP 2.6, gravel sediment loads do not show a noticeable change, however there is a predicted increase in fine grained material by 50%. As such, this is likely to continue to promote an aggradation response in the lower sand-phase reaches. Sediment pulses are often driven by episodic climatic events, resulting in large sediment volumes moving through a river system. As such, there are likely to be short term aggradation in some reaches, which will need to be monitored. However, as these pulses are episodic, it is important to look at the longer term degradational trends to get an indication of the overall sediment regime of the lower Manawatū.

[1] MfE (2016) provided updated predictions on climate change based on the predicted changes in atmospheric CO2 and these are known as Representative Concentration Pathways (RCP's). Three scenarios have been identified for assessment as part of the MfE report:

- RCP2.6 requires the removal of some of the atmospheric CO2 and shows the lowest change in climate.
- RCP6.0 is if atmospheric CO2 concentrations stabilise, and they show moderate levels of climate change.
- RCP8.5 is for a continuing increase in atmospheric CO2 which will result in larger changes in climate.

# 5 Recommendations

Our assessment of the current state of gravel resource in the lower Manawatū River indicate ongoing degradation, notwithstanding potentially significant localised sediment inputs associated with bend migration in the vicinity of BM 970 (see Seven Bends Report), which are in need of further investigation. Whale (2019) suggests in earlier reports that gravel resource is manageable at the current extraction rates. However, the trend switch from aggradation to degradation in the lower Manawatū reported here suggest this is no longer the case. It is possible that apparently significant local aggradation attributed to changes at 60 Mile and BM 970 could begin to work its way downstream to offset the degradation trends observed in these lower reaches of the gravel phase in the lower Manawatū. Gravel supply and transport is typically pulsed, and longer-term monitoring will be required to establish whether this 'wave' is genuine and the extent to which it may be dispersed. In addition, it is also likely that pulsed sediment supply from the Pohangina River, which was significantly disturbed by Cyclone Gabrielle in February 2023, could begin to enter the lower Manawatū in the near future. Monitoring of both the lower Manawatū and the Pohangina are recommended to understand this longitudinal gravel connectivity.

Morphological budgeting using GCD suggests that subaerial surfaces are lowering. This is consistent with continuing degradation (e.g. a net -160,000 to -180,000 $m^3$) between 2005-2016 and 2016-2022 in the upper reaches. In addition, the GCD suggests there has been a shift from aggradation to degradation in the lower sand phase below Ōpiki, but subaerial features are limited in this section of the lower Manawatū River. The cross-section analysis, which captures the subaqueous morphology, suggests significant sediment accumulation in the sand-phase. As suggested in the 'Seven Bends' Report, the lower Manawatū may be exhibiting an overall channel narrowing, however, this is likely a combination of a decrease in gravel supply and management practices (largely bank protection intended to prevent widening, narrow the channels, promote incision and increase sediment transport through the reaches).

The Manawatū River is dynamic and changes in morphology are not always captured through static surveying techniques (cross-section and LiDAR). Survey data between offsets was often incomplete and was therefore excluded from analysis. As such, resolution is lost from the less frequently surveyed cross-sections. Disparities in the analysis arose with the offsets. Due to the migration of the Manawatū River, offsets set by Whale (2019) were not necessarily applicable to capture the change in gravel volume from the 2018-2023 period. Therefore, new, refined offsets which were relevant to the 2018-2023 active channel were also analysed. Generating a gravel budget with cross sections using the end-over-area MBL method captures the sediment trends at that time. Inconsistencies are introduced when the survey is not completed over a short time period - the survey of cross sections was done over a period from 2022 (dry channel) and 2023 (wet channel). Increasing the spatial coverage of the data set, to include the floodplains of the wider Manawatū River catchment, and inclusion of topographic information for the in-channel build-up of sediment would help for future analysis.

As mentioned in Section 3.2, LiDAR does not penetrate the water column and as such does not pick up subaqueous changes in gravel column. Bathymetric LiDAR would enable a whole channel assessment and pick up bars beneath the water surface. While airborne bathymetric LiDAR can provide more reliable spatially continuous, three-dimensional outputs, data processing using appropriate software and clear documentation of the workflow for all data collected (e.g. from LiDAR or drone images) should follow a consistent process so that all data are collected and processed the same way each time. Data processing is an important step in analysis, as the addition of a water mask for example may result in high interpolation between data points and hides vital geomorphic information if the in-stream geomorphic units. Consistency across all datasets allows for direct comparisons to be made in analysis and interpretation.

As highlighted in Section 4.4 long term climate trends are likely to trigger pulses of coarse-grained sediment and an overall increase in fine grained sediment input. As such, there is a need for having a monitoring system in place specifically for understanding geomorphic processes at a catchment scale. This includes identifying the sources of sediment from the wider Manawatū catchment to understand pulsed sediment inputs to the lower Manawatū River from contributing sub-catchments.

Careful monitoring of the Manawatū gravel budget is required in light of spatiotemporal variability indicated by previous cross-section budgets, the cumulative losses indicated in the GCD analysis, and the net losses reported in the current cross-section analysis. A conservative approach to allocation of gravel volumes is recommended.

Further analysis should assess gravel budgets alongside flow records to link changes in channel morphology and gravel budgets to flood timing and magnitude. The impact of an event like Cyclone Gabrielle cannot be determined by temporally composite cross-section surveys that straddle such an event. These linkages would be best assessed using annualised budgets and targeting critical sub-reaches (e.g. Seven Bends) at finer time intervals.

Future monitoring should use bathymetric LiDAR for three-dimensional acquisition of both dry and wet channel morphologies, simultaneously, from which GCD can be assessed. Surveys could be executed within the course of a week, which provides a more temporally consistent assessment of bed morphologies, from which changes in sediment (gravel) storage can be assessed with a higher degree of confidence than either GCD of subaerial surfaces, or cross-sections surveyed over a period encompassing several bed-changing events. Repeat surveys every ~5 years would likely be of sufficient resolution to identify key trends in sufficient time to action any necessary river management protocol (e.g. revised limits on allocable gravel extraction volumes).

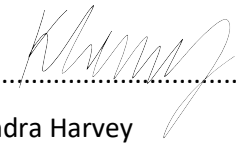
Channel boundary composition would be worth exploring to elucidate the extent to which morphological changes observed in both GCD, and cross-section analyses actually reflect change in gravel storage (and therefore gravel resource). It is likely that thick drapes of finer-grained deposits, not viable as a source of aggregate, are responsible for some of the changes detected in morphological budgeting reported here. Monitoring of bed textures in the active channel can be achieved remotely via high-resolution LiDAR acquisition, with ground-truthing at key locations. Furthermore, there would be value in partitioning gravel budgets into bed and bank components. Bank erosion actually represents a positive sediment input to a river (albeit not necessarily pure gravel).

# 6 Applicability

This report has been prepared for the exclusive use of our client Horizons Regional Council, with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose, or by any person other than our client, without our prior written agreement.

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# 7 References


Basher, L., Payne, J. and Watson, B. (2012). *Suspended sediment yields in the Manawatū catchment: analysis of data collected by Horizons Regional Council.* Report prepared for AgResearch and Horizons Regional Council.

Bell, J., (2012). *Lower Manawatū Scheme Gravel Resource Study.* Horizons Regional Council, Report No. 2012/EXT/1222.

Brasington, J., Rumsby, B. and McVey, R., (2000). Monitoring and modelling morphological change in a braided gravel-bed river using high resolution GPS-based survey. *Earth Surface Processes and Landforms*, 25: 973–990.

Brasington, J., Vericat, D. and Rychkov, I. (2012). Modeling River Bed Morphology, Roughness, and Surface Sedimentology Using High Resolution Terrestrial Laser Scanning. *Water Resources Research*, 48, W11519. https://doi.org/10.1029/2012wr012223

Brewer, P., and Passmore, D., (2002). Sediment budgeting techniques in gravel bed rivers. In Jones, S., Frostick, L. (Eds), *Sediment Flux to Basins: Causes, Controls and Consequences* (pp. 97–113). London: Special Publication 191. Geological Society

Brierley, G., and Fryirs, K., (2005). *Geomorphology and River Management*. Blackwell Publishing.

Carson, M. and Griffiths, G., (1989). Gravel transport in the braided Waimakariri River: Mechanisms, measurements and predictions. *Journal of Hydrology*, 109: 3–4, pp.201-220. doi.org/10.1016/0022-1694(89)90016-4.

Christensen, K., (2013). *Te Kāuru Upper Ruamāhanga Floodplain Management Plan.* Greater Wellington Regional Council Report.

Church, M., (2006). Bed material transport and the morphology of alluvial river channels. *Annual Review of Earth Planetary Sciences*, 34: 325–354.

Conn, S. and Groom, J. (2019). *Lower Manawatū Sediment Study*. Report prepared for Horizons Regional Council.

Environment Canterbury. (no date). *Appendix B: Environment Canterbury Available volume calculation procedure*. PDF file.

ESRI (2021). Online: Advantages of using lidar in GIS—ArcMap | Documentation (arcgis.com). Accessed 28/03/2024.

Fuller, I., Passmore, D., Heritage, G., Large, A., Milan, D., Brewer, P. (2002). Annual sediment budgets in an unstable gravel bed river: the River Coquet, Northern England. In Jones S. and Frostick, L. (Eds), Sediment Flux to Basins: Causes, Controls and Consequences, (pp. 115–131). London: Special Publication 191. Geological Society.

Fuller, I., Large, A., Charlton, M., Heritage, G. and Milan, D., (2003). Reach-scale sediment transfers: an evaluation of two morphological budgeting approaches. *Earth Surface Processes & Landforms,* 28: 889-903.

Fuller, I. C., & Vale, S. S. (2009). Morphological budgeting in the Motueka River: an analysis of technique.

Fuller, I.C., Macklin, M.G., Toonen, W. and Holt, K. (2018). Storm-generated Holocene and historical palaeofloods in the Manawatu River, New Zealand. *Geomorphology*, 310, 102-124.

Land Air Water Aotearoa (LAWA). (2019). *Manawatū-Wanganui region.* https://www.lawa.org.nz/explore-data/manawatu-wanganui-region/.

Manawatū River Leaders Accord (2024) https://www.manawaturiver.co.nz/science/aquatic-life/

Ministry for the Environment (MfE) (2016) Climate Change Projections for New Zealand: Atmosphere Projections Based on Simulations from the IPCC Fifth Assessment. Wellington: Ministry for the Environment.

Tunnicliffe, J., and Baucke, D., (2021). *Bedload Transport and Gravel Supply in the Waiapu Catchment*. Gisborne District Council.

Vale, S., Fuller, I., Procter, J., Basher, L., and Smith, I. (2016). Characterization and quantification of suspended sediment sources to the Manawatū River, New Zealand. *Science of the Total Environment*, 543: 171 – 186.

Watson, M. (2008). Lower Manawatū river cross-sections: Ōroua river confluence to Ashhurst bridge 1907 to 2005. Analysis of river cross-section surveys using tools available in Hilltop Software's reach module. Report prepared for Horizons Regional Council.

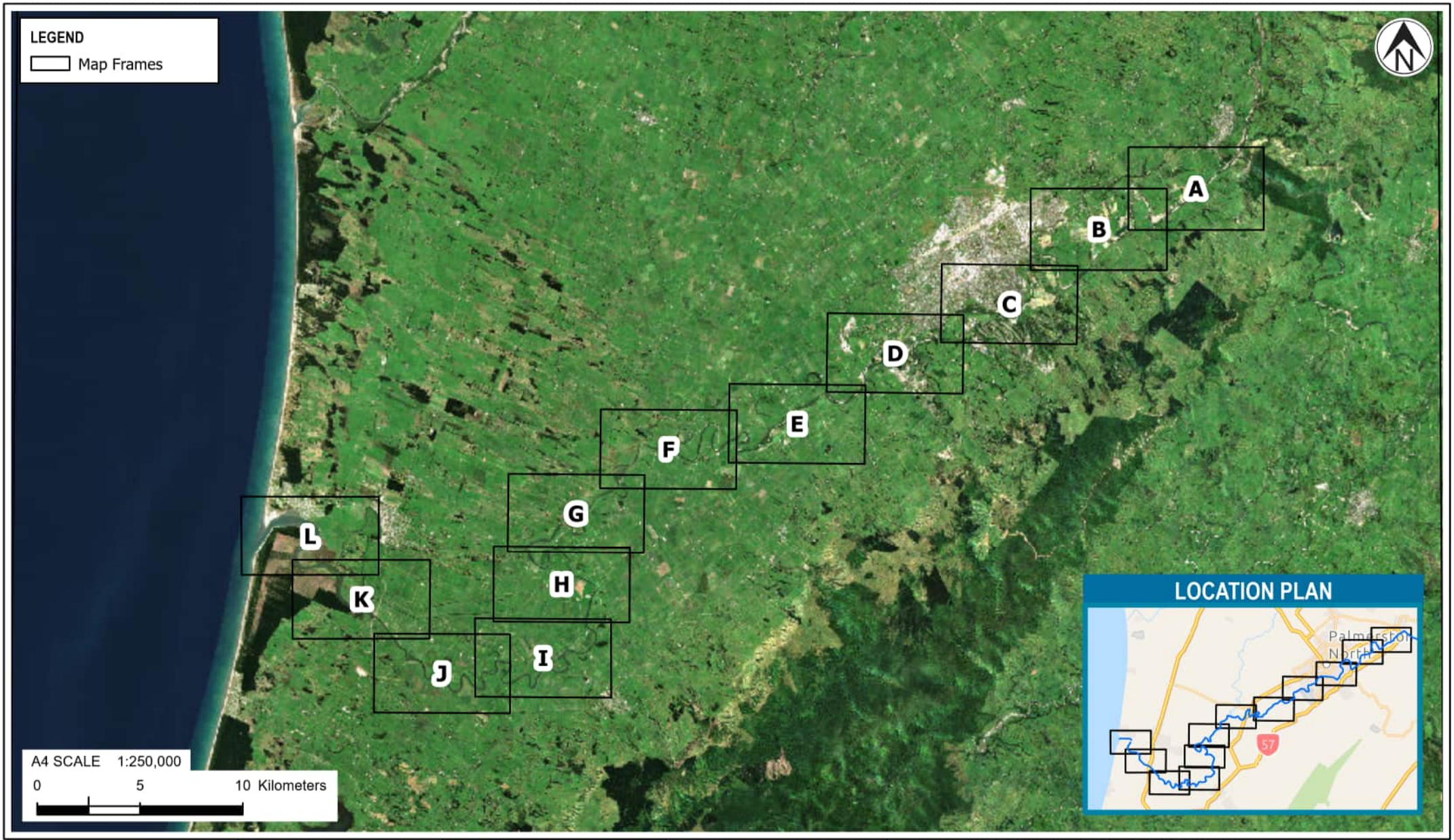
Whale, E., (2019). *Lower Manawatū Gravel Resource Study.* Horizons Regional Council, Report mo. 2019/EXT/1635.

Wheaton, J., Brasington, J., Darby, S. & Sear, D. (2009). Accounting for uncertainty in DEMs from repeat topographic surveys: Improved sediment budgets. *Earth Surface Processes and Landforms*. 35. 136 - 156. 10.1002/esp.1886.

# Appendix A Cross-section plan, Manawatū River

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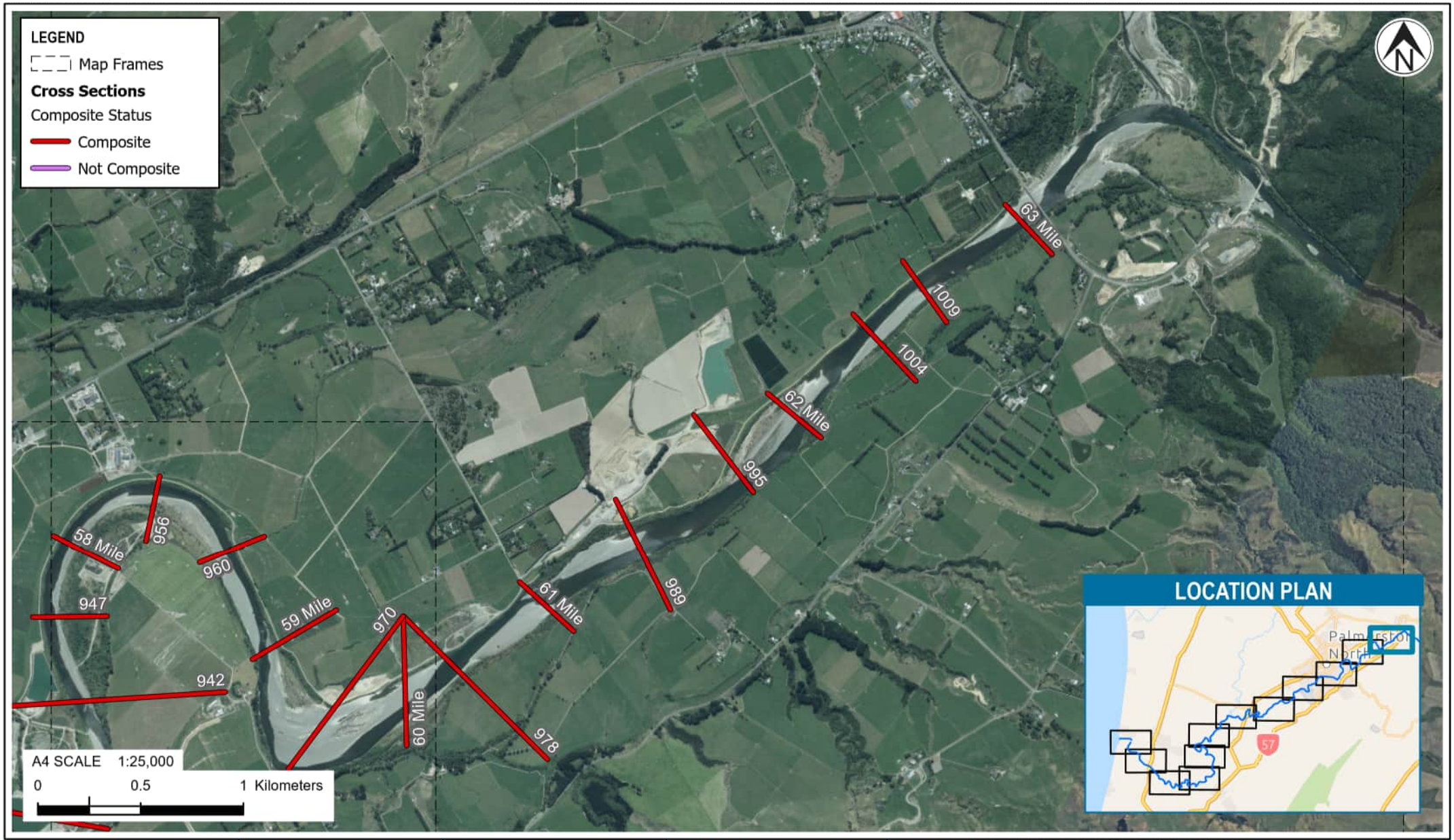
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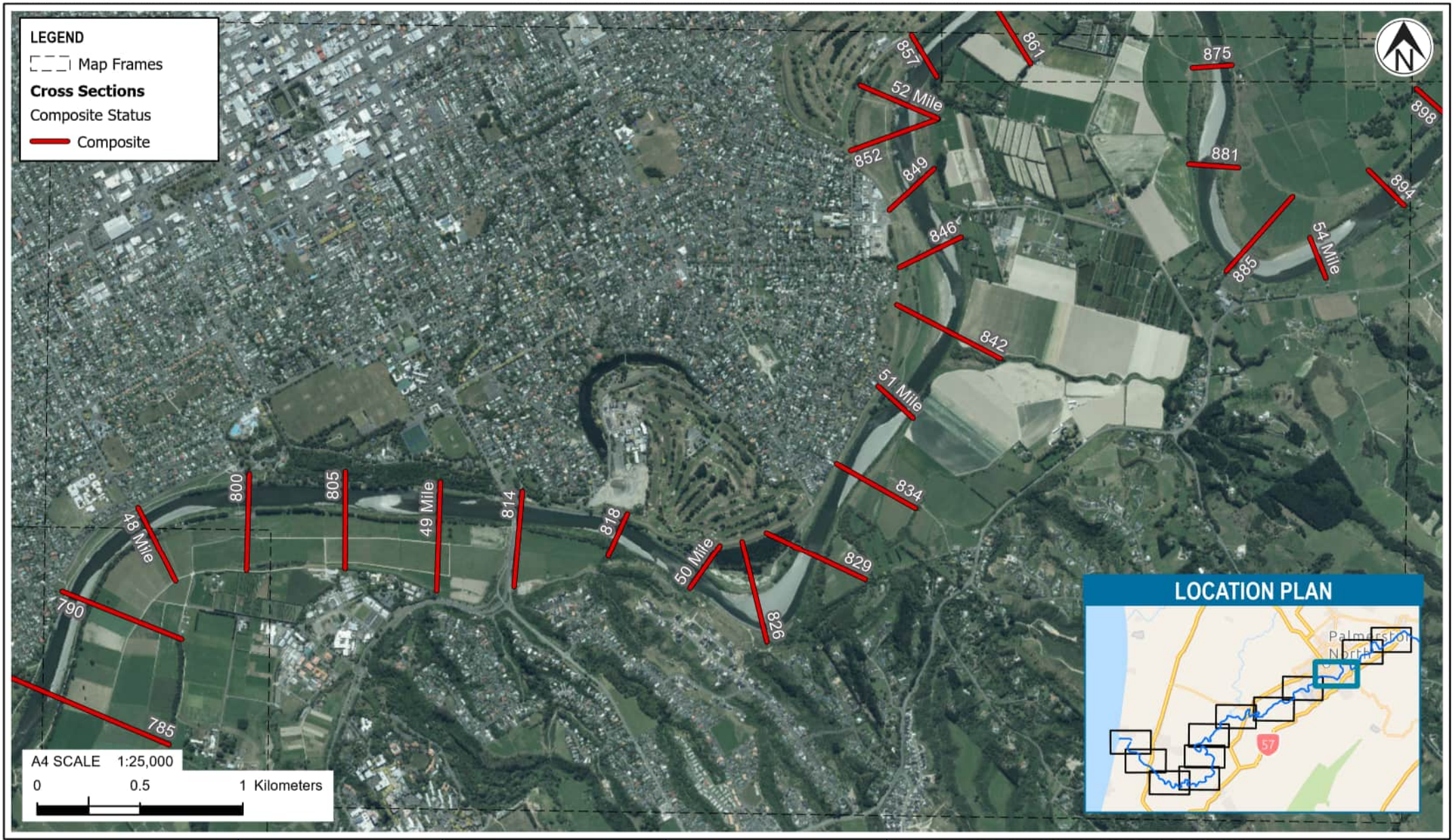
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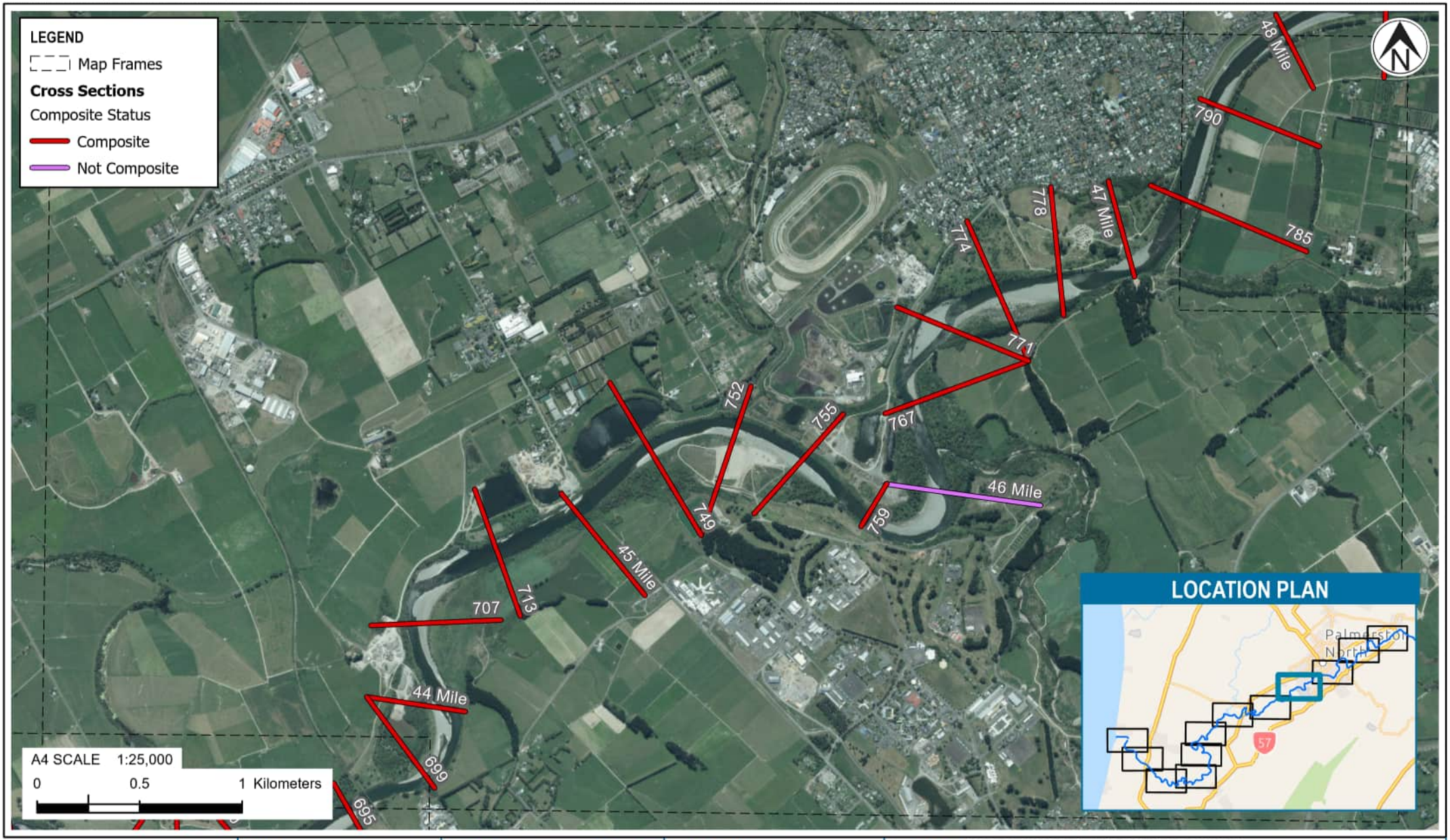
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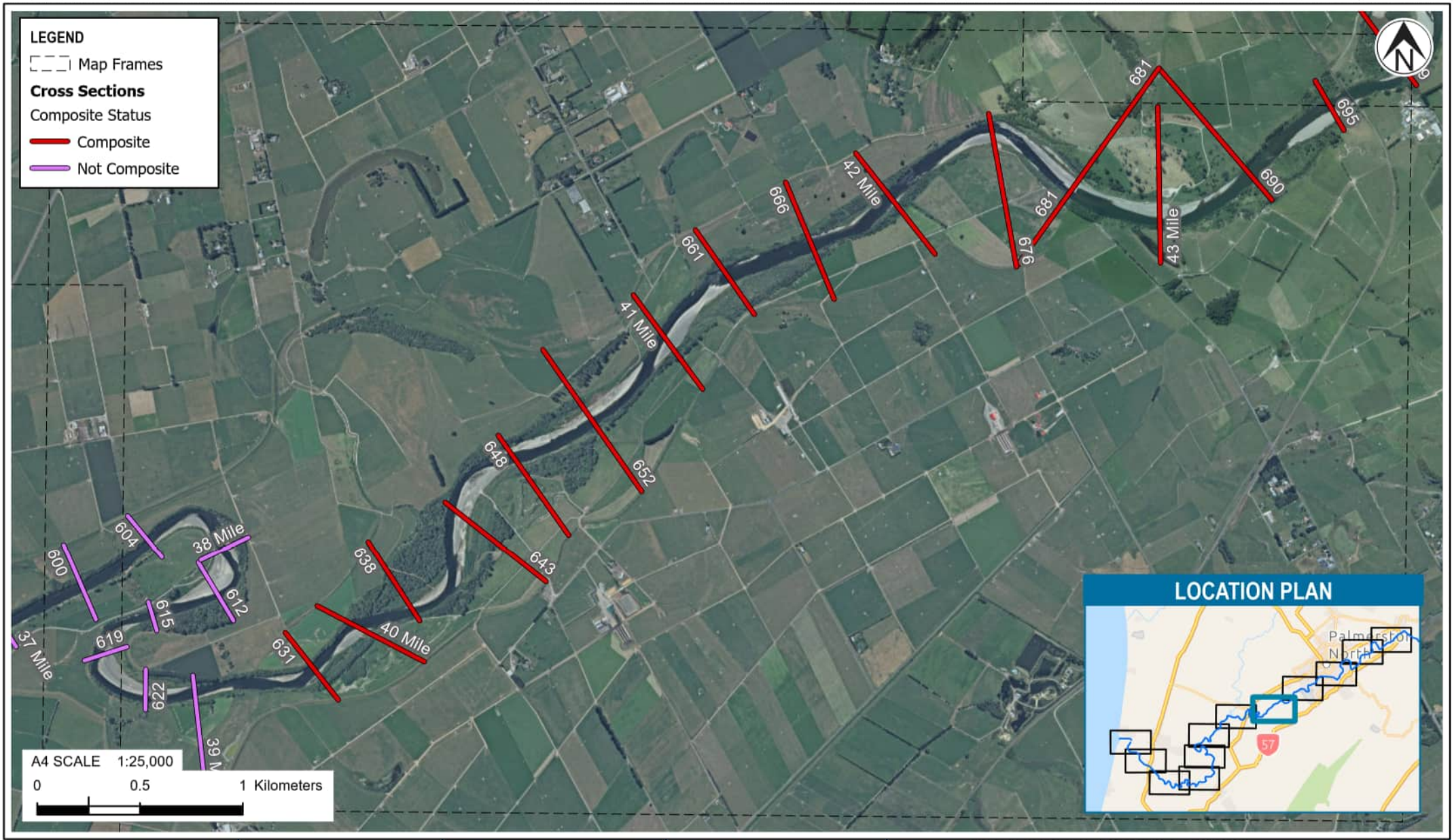
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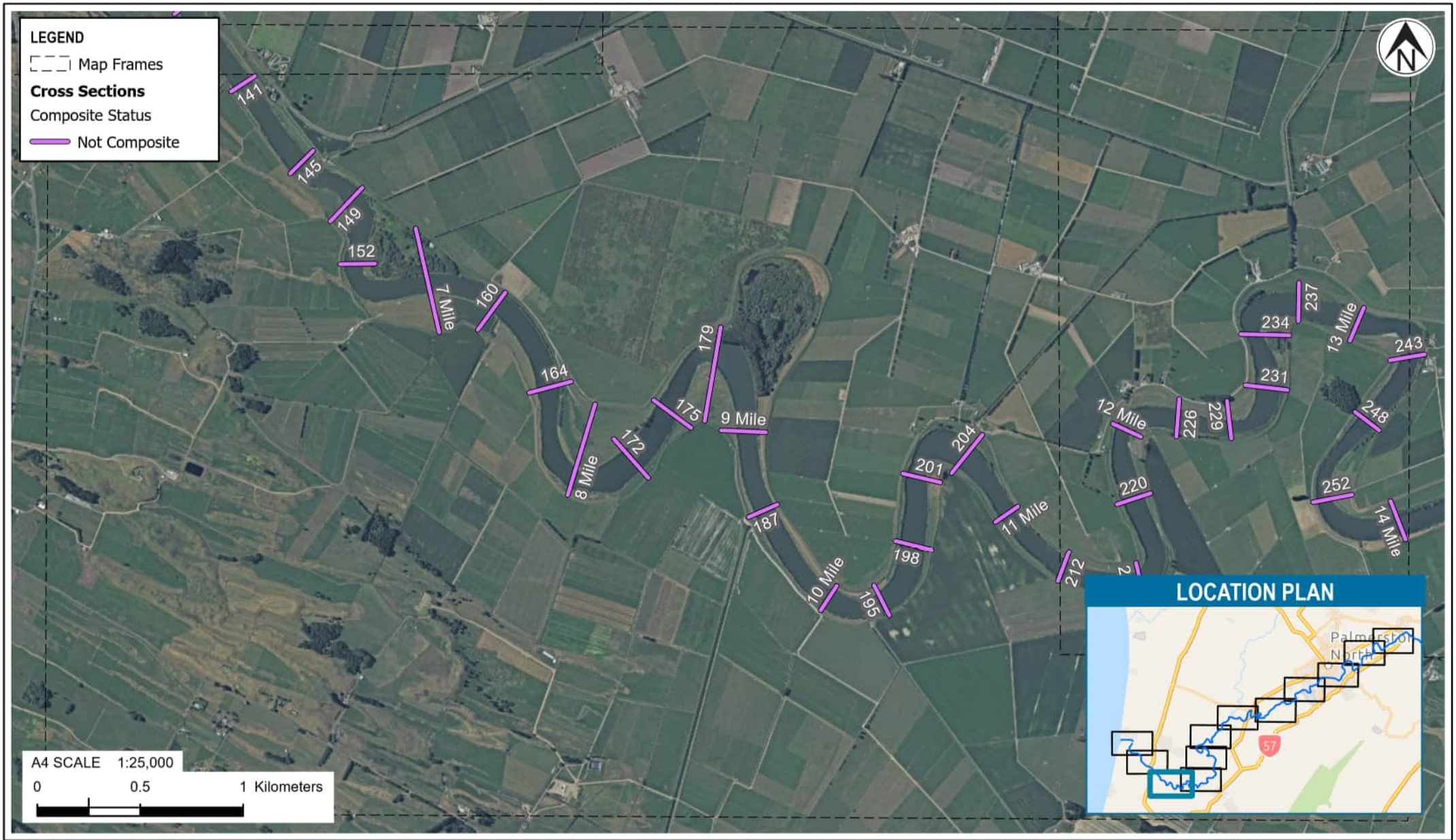
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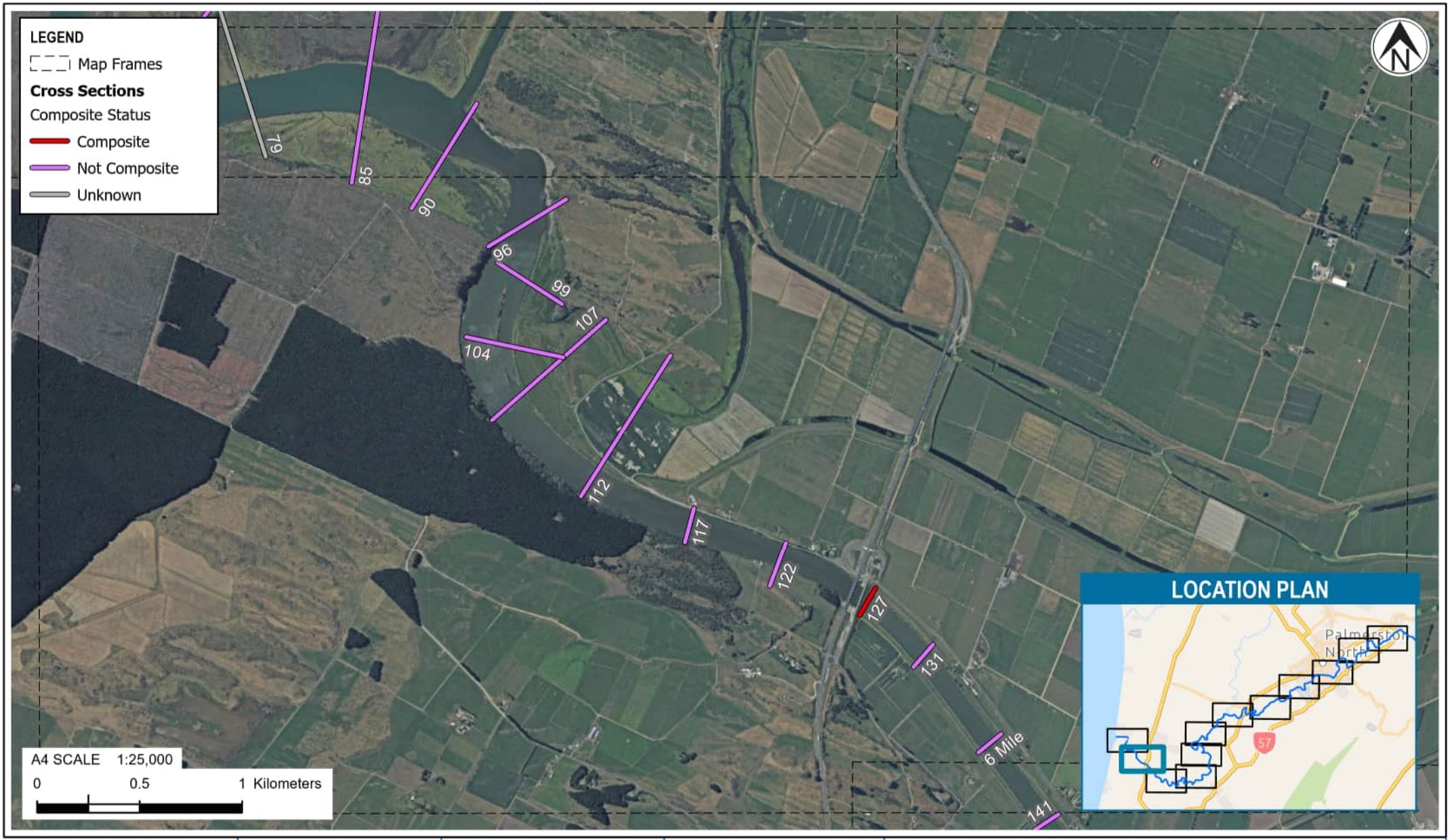
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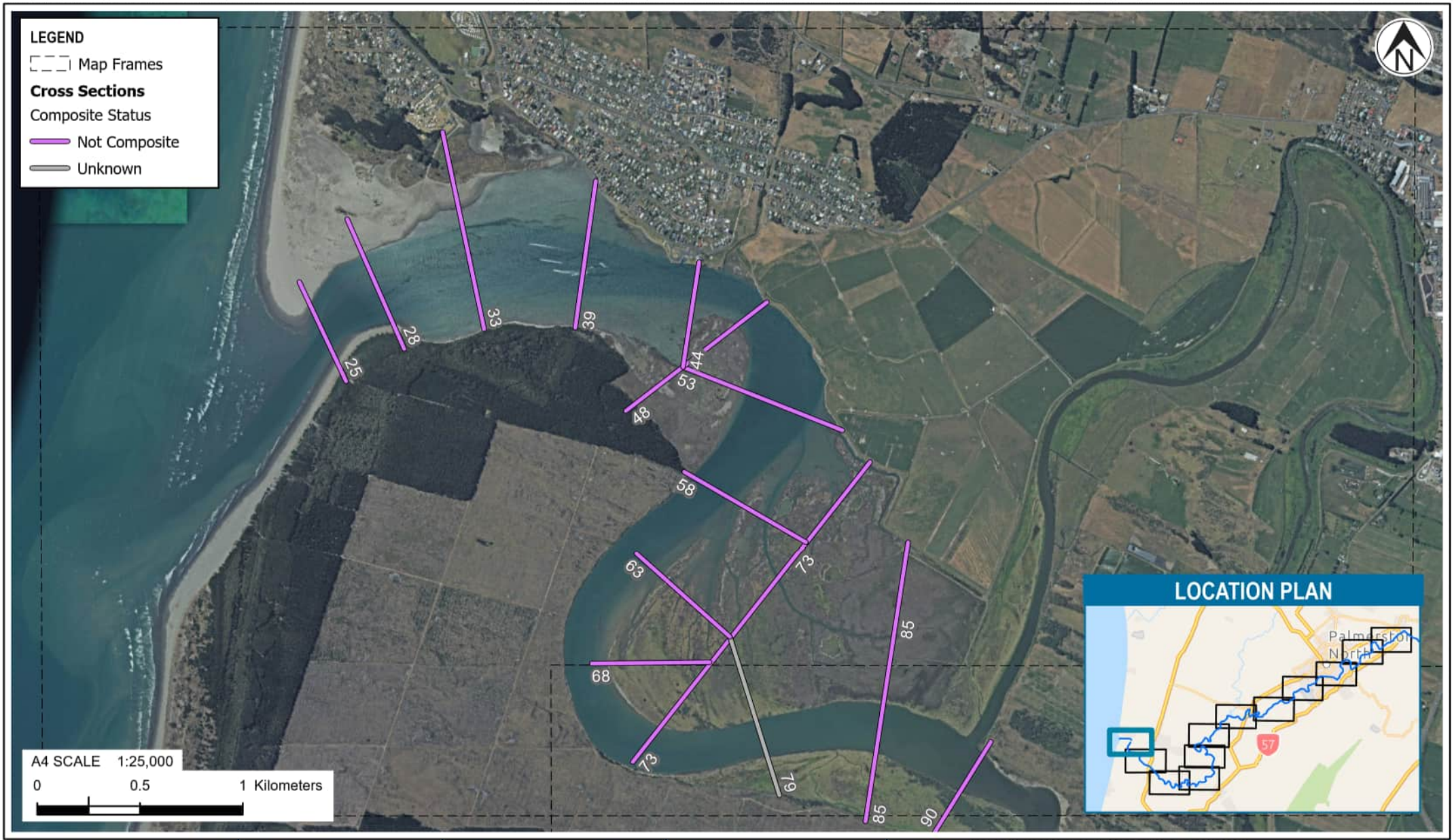
PROJECT **LOWER MANAWATŪ GRAVEL STUDY**

TITLE CROSS SECTION LOCATIONS

SCALE (A4) 1:25,000 FIG No. APPENDIX A, FIGURE 1K REV 1

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\\ttgroup.local\corporate\Tauranga\Projects\1092594\WorkingMaterial\GIS\Map Documents\Lower_Manawatu_GCD\Lower Manawatu GCD\Lower Manawatu GCD - Figures.aprx Layout: Full River Cross Section Map Series 2024-Jul-01 5:24 pm Drawn by CHSA




Tonkin+Taylor

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*Exceptional thinking together*

**NOTES:**

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| REVISIONS | NO. | BY |
|---|---|---|
| First version (01/07/24) | 1 | CHSA |

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| PROJECT No. | 1092594 | |
| DESIGNED | CHSA | JUL.24 |
| DRAWN | CHSA | JUL.24 |
| CHECKED | DSMI | JUL.24 |
| APPROVED | 16/7/24 | DATE |

CLIENT **HORIZONS REGIONAL COUNCIL**

PROJECT **LOWER MANAWATŪ GRAVEL STUDY**

TITLE CROSS SECTION LOCATIONS

SCALE (A4) 1:25,000 FIG No. APPENDIX A, FIGURE 1L REV 1

# Appendix B Geomorphic Change Detection methodology

**GCD overview**

Conventional LiDAR does not reliably or consistently penetrate the water column, to ensure consistency in analysis the wetted portions of the active channel in the lower Manawatū were clipped out from the DEM surface used in the GCD analysis. This means GCD is from dry surface to dry surface only. This restriction to dry surface change detection cuts out a potentially significant portion of the gravel budget because subaqueous changes are not considered, this means erosional changes associated with shift in the 2022 wetted channel and deposition infilling the 2022 wetted channel are not identified, because the bed cannot be reliably detected. As such, GCD outputs using these clipped DEMs represents an uncertain estimation of change in gravel storage in the lower Manawatū, and an underestimation of the sum of gravel flux and storage.

To ensure consistency between surfaces and meaningful comparison with the cross-section gravel budget, the following preprocessing steps were carried out. Cross checking the DEM input files, to ensure they are all of the same resolution and grid size ensures the GCD will be running and calculating differencing from the exact same points. In some instances, if the DEM sizes are different (e.g. 2022 was larger than 2016 and 2005) they need to be clipped to the extent of the smallest DEM.

Masking is the method the GCD uses to segment surfaces to analyse discrete budgets for a given area. For the entire channel from the Manawatū Gorge to the mouth, masks were created of the gravel bars between every cross section. Corresponding upstream and downstream identifiers were assigned to each segment, leaving a series of polygons outlining the gravel bars with unique cross-sectional IDs for each year (see Appendix A) for detailed methodology of the segmentation process).

The following steps were carried out within the GCD software:

- Assigning the *Area of Interest (AOI)* which includes the gravel bars.
- Running the GCD for the 2005-2016 and 2016-2022 epochs with the 2016 and 2022 *AOI* – include a minimum detection threshold of 200 mm.
- Load the *regular masks* into the GCD.
- Run a budget segregation for each DoD using the assigned gravel bars regular mask.

Error analysis calculated by GCD Error volumes are very conservatively estimated with error propagation on a cell-by-cell basis. For every change detection that is done based on error surfaces in the inputs, a raster error layer is calculated. The error propagation is carried out on a cell-by-cell basis to get an estimation of propagated vertical error. Error volume is estimated like the change detection values are estimated, by multiplying vertical value (in this case propagated DEM error instead of elevation change) by the cell area, which is the square of the cell resolution. A 0.2 m error surface was applied to all GCD runs. Due to the varying nature of the cross-section feature geometry and the meandering nature of the river, the assigning of cross section IDs is complex and has therefore been undertaken through a FME workbench. Cross section line features are split by the river channel polygon to create several segments.

The cross-sections are run through a series of test filters to extract the line segments that intersect the generalised river polygon in the appropriate locations. The remaining cross-section segments are used to split the generalised river channel polygon to create a river zones polygon layer. Using a spatial relator, it is identified where the cross sections polygons overlap with the river zones

polygons, The IDs of the cross-sections are assigned to the zoning polygons. The gravel bar polygon layer is split by the cross-sections. The centre point of each gravel bar polygon is determined. The centre points are run through a neighbour finder with the river zones polygon. The cross-section IDs attributed to the zoning polygons are assigned to each gravel bar centre point based on the nearest distance. The newly obtained ID is assigned back to the individual gravel polygons and the gravel bar polygons are dissolved by their cross-section ID, resulting in 1 multipart polygon per cross-section ID.

**Detailed breakdown of the FME workbench.**

Creating cross-section polygons:

- River channel polygon is buffered (bufferer).
- Buffered river polygon is intersected with the cross-sections (line on area overlayer).
- The lines are extracted from the intersected output. The lines are put through a test filter to extract only the line segments that intersect the river polygon (test filter).
- The length of each line segment is calculated (length calculator).
- For each cross-section, the segment lengths are compared and the segment with the largest length value is selected (statistics calculator plus testfilter).
- The largest segment of each cross-section is buffered to create a polygon feature (bufferer).

Creating river segments:

- Centreline is generated from the river channel polygon (centreline replacer).
- River centreline is buffered to create an even polygon around the river (bufferer).
- Holes in the polygons are removed (donut hole extractor).
- Cross-sections are extended in length on both sides (line extender).
- The river polygon is used to clip the extended cross-section lines (clipper).
- The cross-section segments are split into single part features (deaggreator).
- The length of each line segment is calculated (length calculator).
- For each cross-section, the segment lengths are compared and the segment with the largest length value is selected (statistics calculator plus test filter).
- The 'tidied' cross-section lines are used to clip the even river polygon (polygon cutter).

Assigning cross-section ids to the river segments:

- A spatial relator is used to identify where the polygon cross-sections overlap with the segmented river polygon. Each segmented river polygon is assigned the cross-section ID from the overlapping cross-sections.

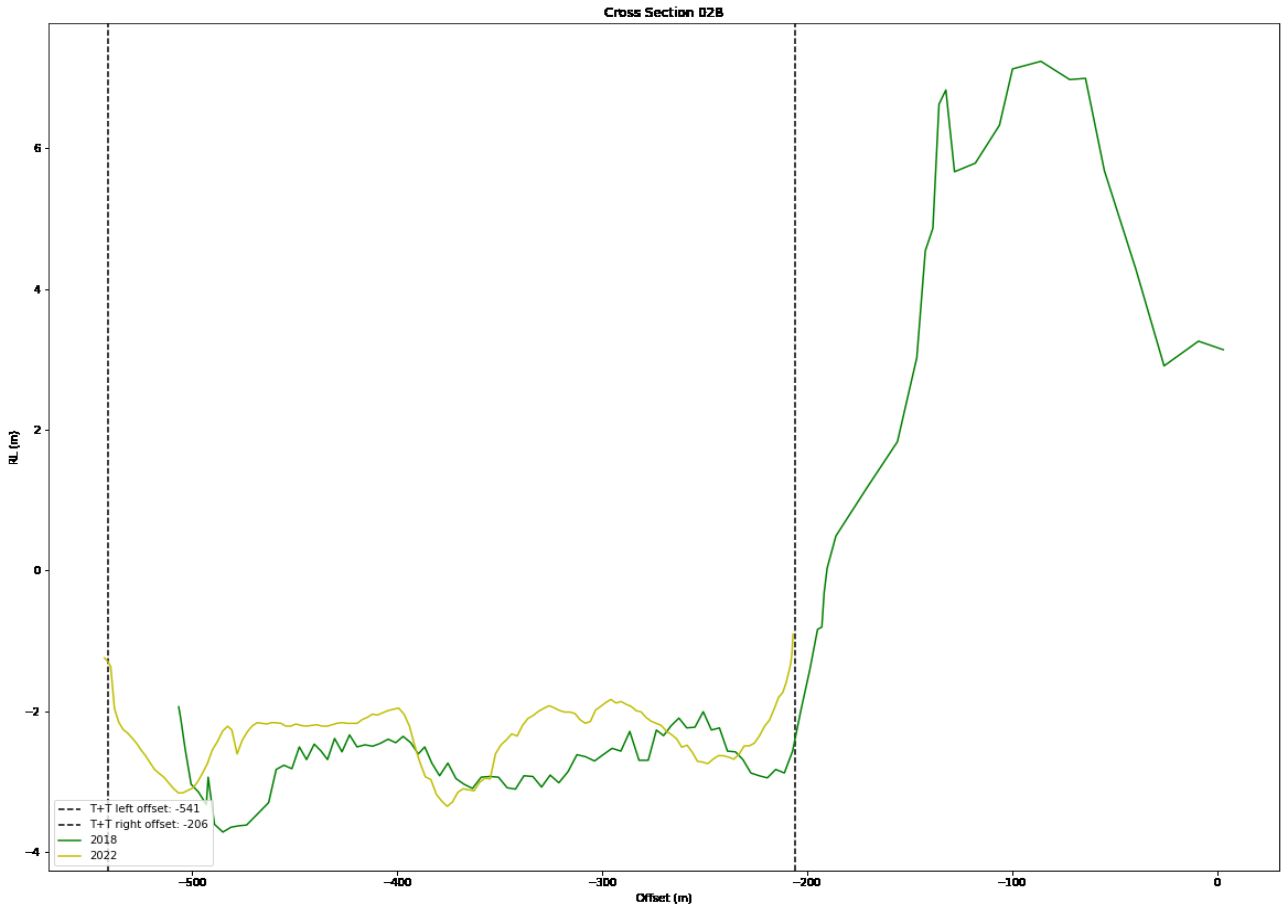
Cross-section IDs are assigned to each gravel bar:

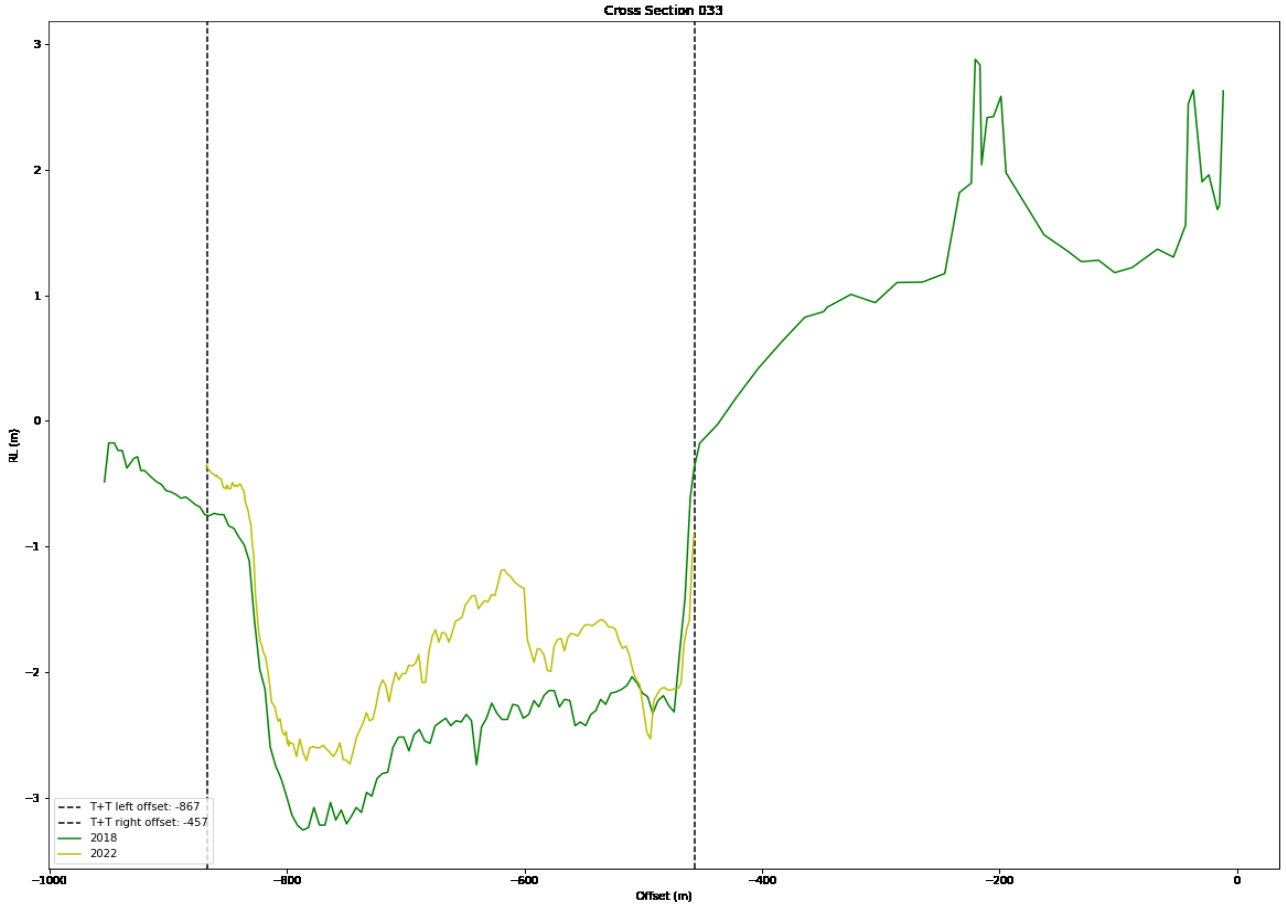
- Gravel bar polygons are split by cross-sections (polygon cutter plus clipper).
- The split gravel bar polygons are assigned unique IDs (counter).
- A point feature is generated for the centre point of each gravel bar polygon (centre point replacer).
- The IDs of the segmented river polygons that is the nearest to the gravel bar centre point is assigned to the points (neighbour finder).
- The newly obtained ID is assigned back to the individual gravel polygons (feature merger).

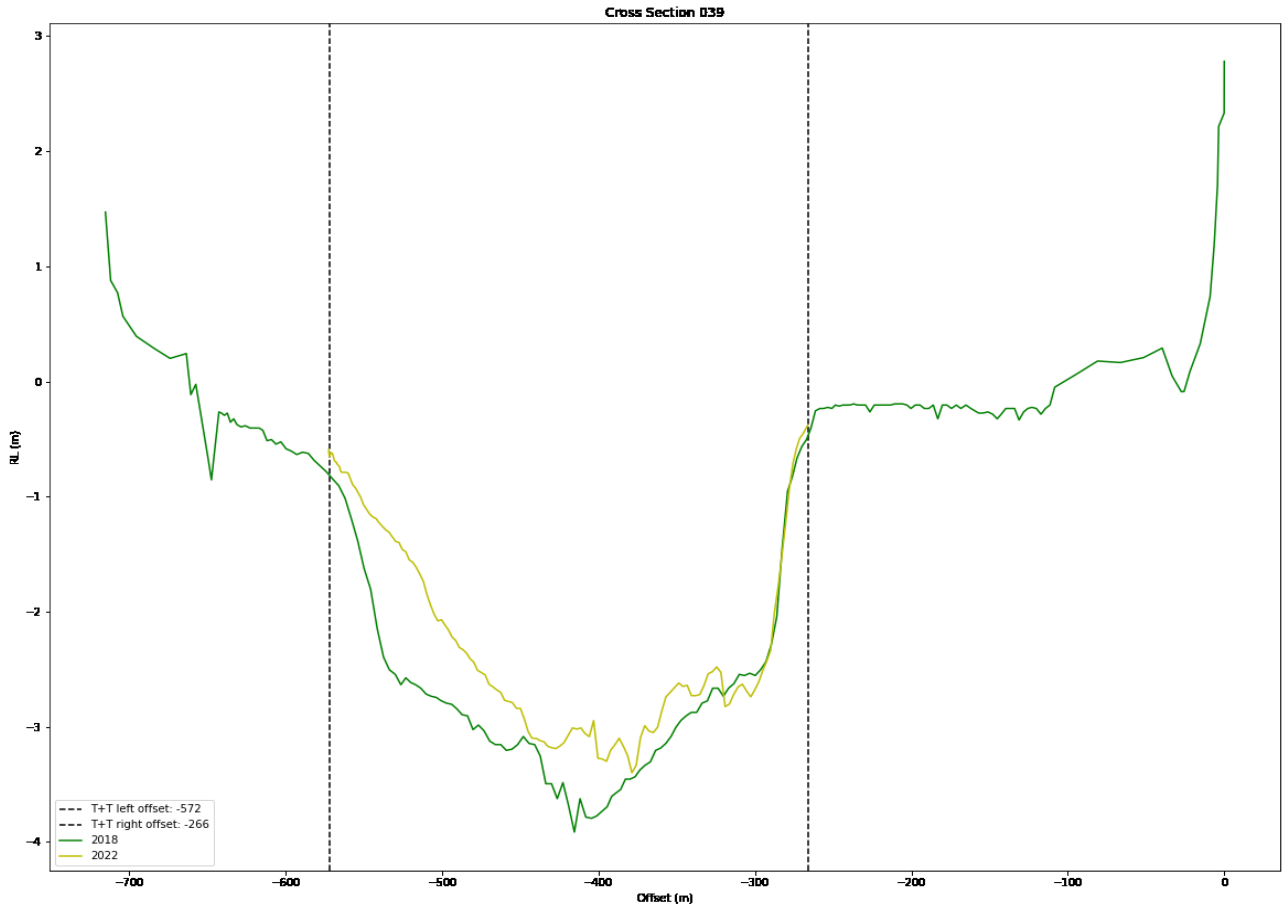
The gravel bar polygons are dissolved by their cross-section ID, resulting in one multipart polygon per cross-section id.

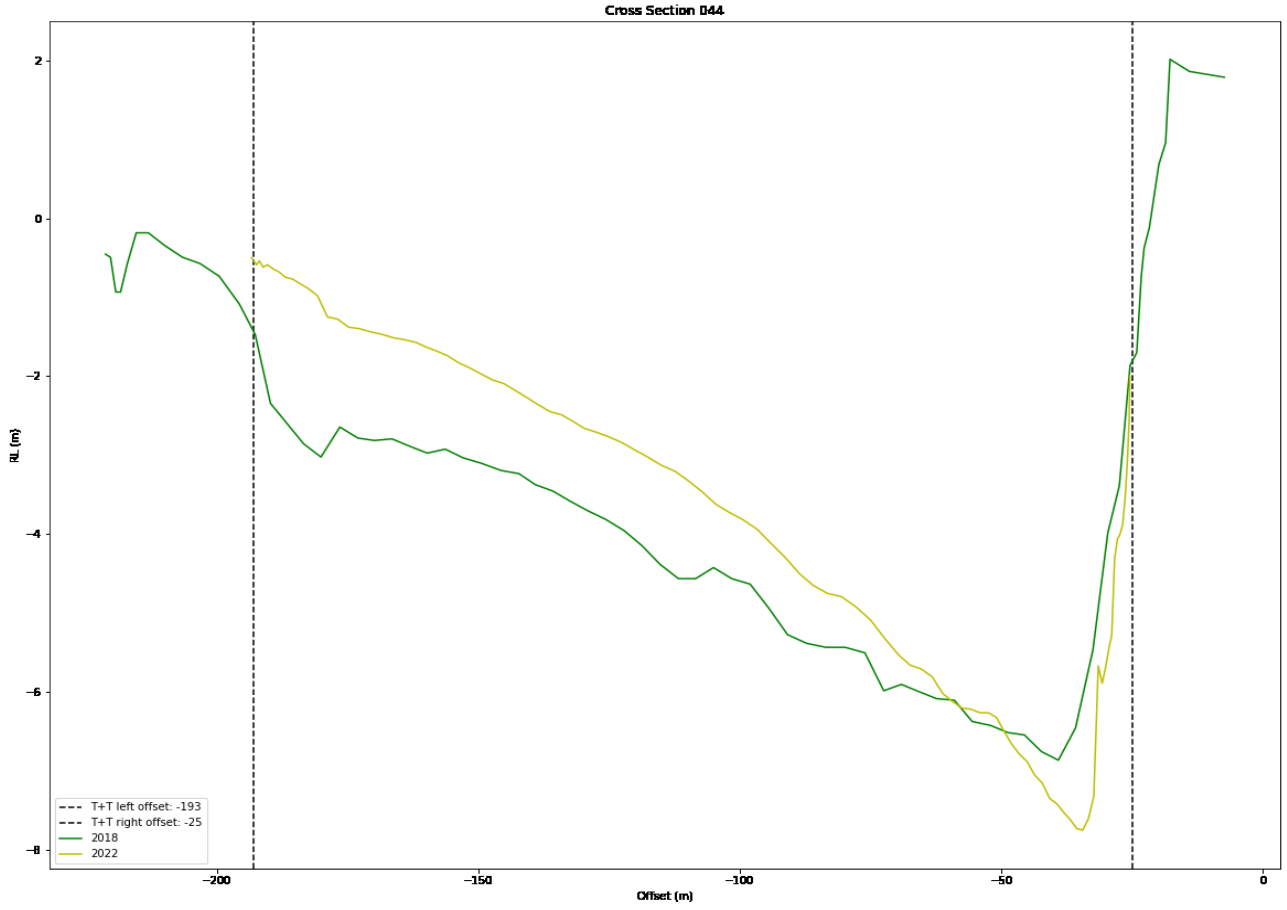
# Appendix C Cross-section analysis raw results

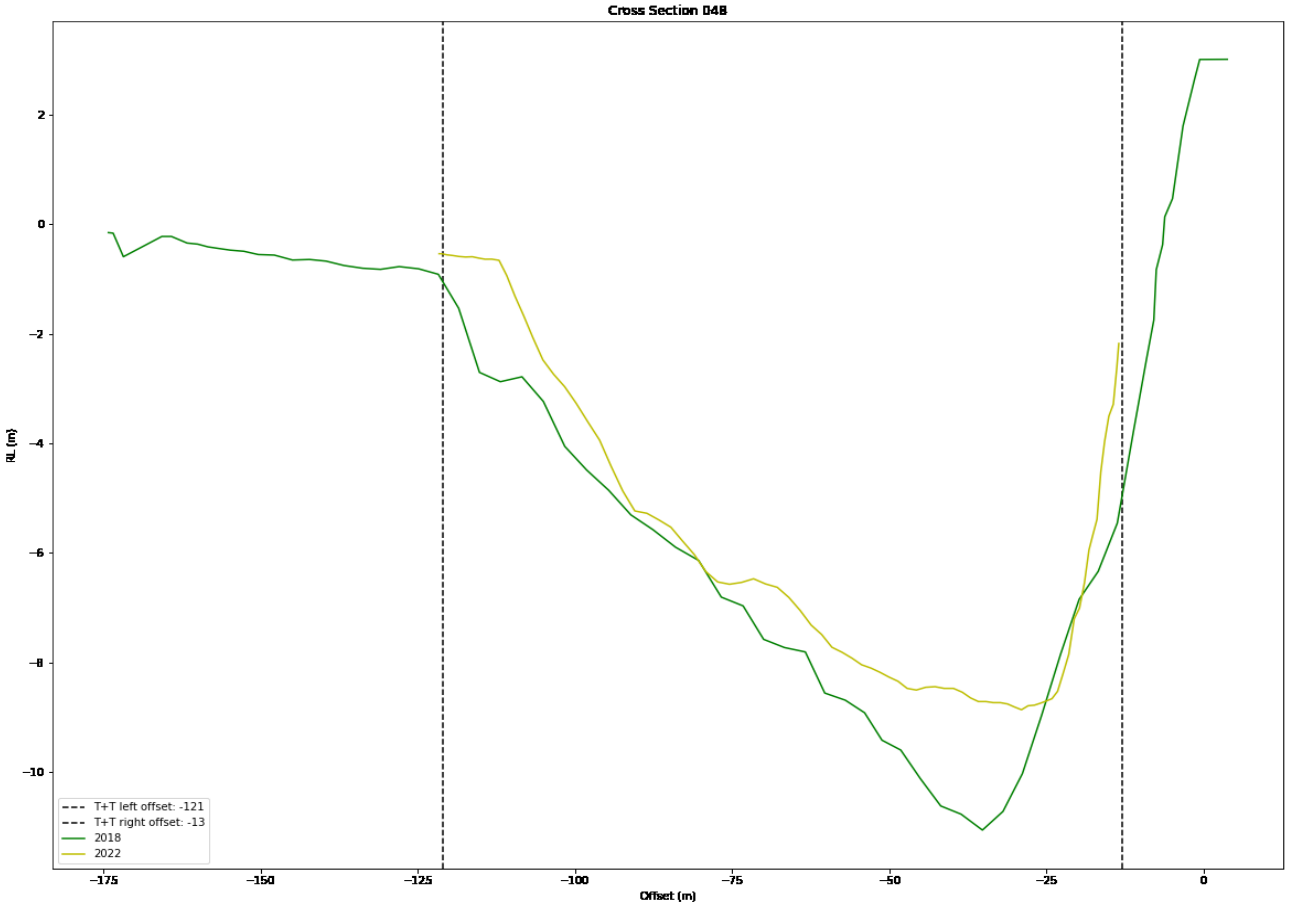
- **Cross-sections from 63 to BM 028 - Horizons offsets and T+T offsets**

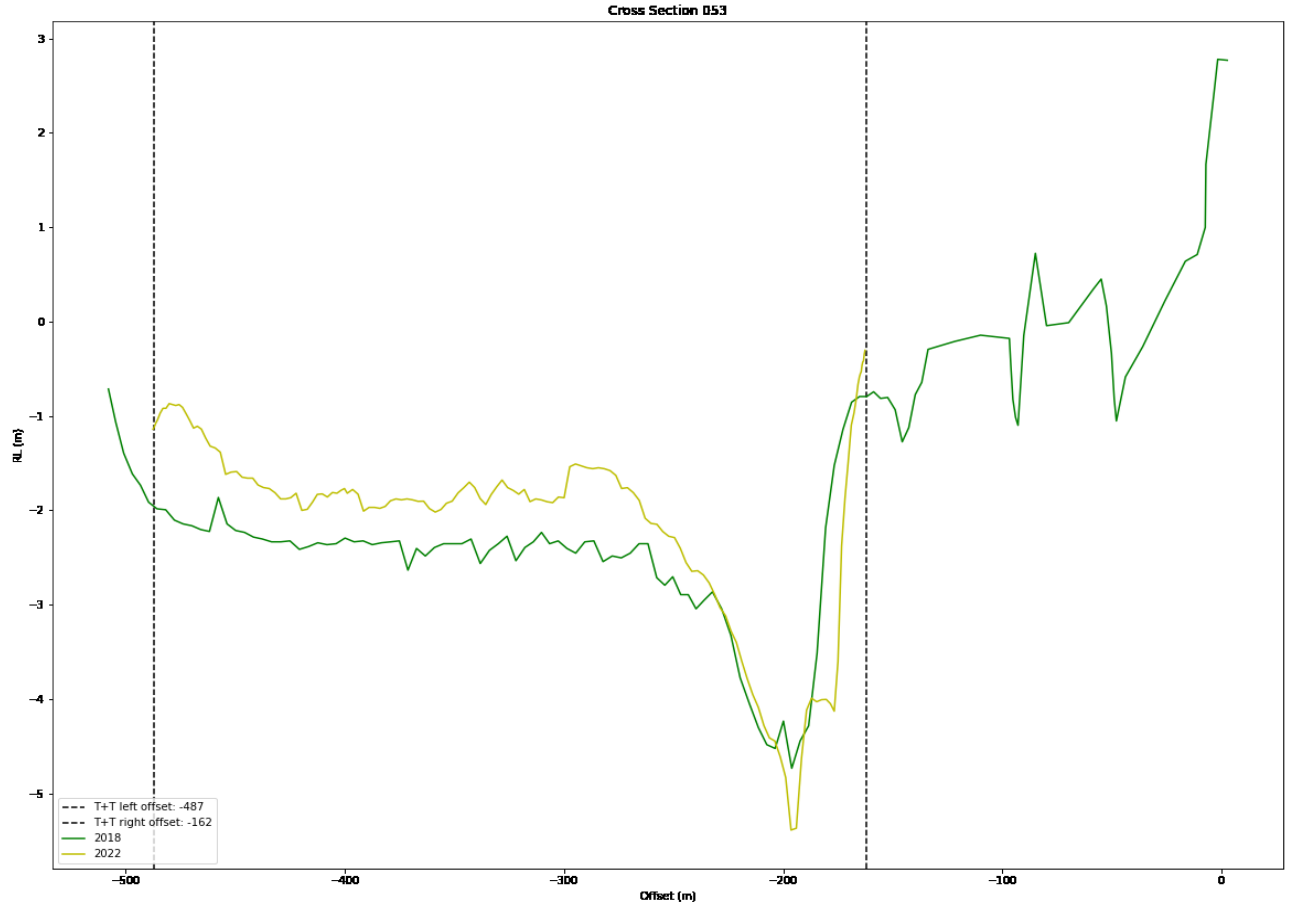

Cross Section 028
RL (m)
Offset (m)
T+T left offset: -541
T+T right offset: -206
2018
2022

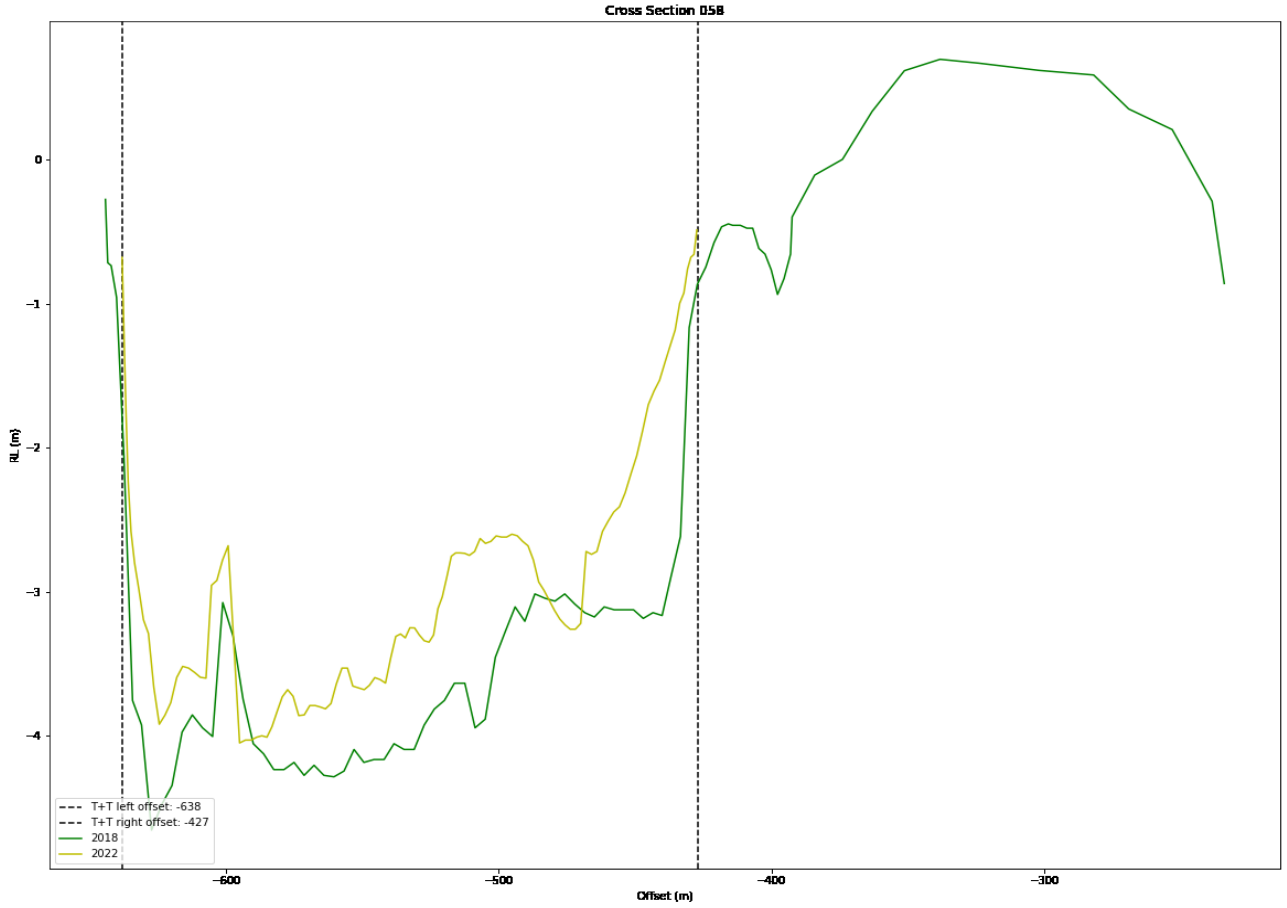

Cross Section 033
RL (m)
Offset (m)
T+T left offset: -867
T+T right offset: -457
2018
2022

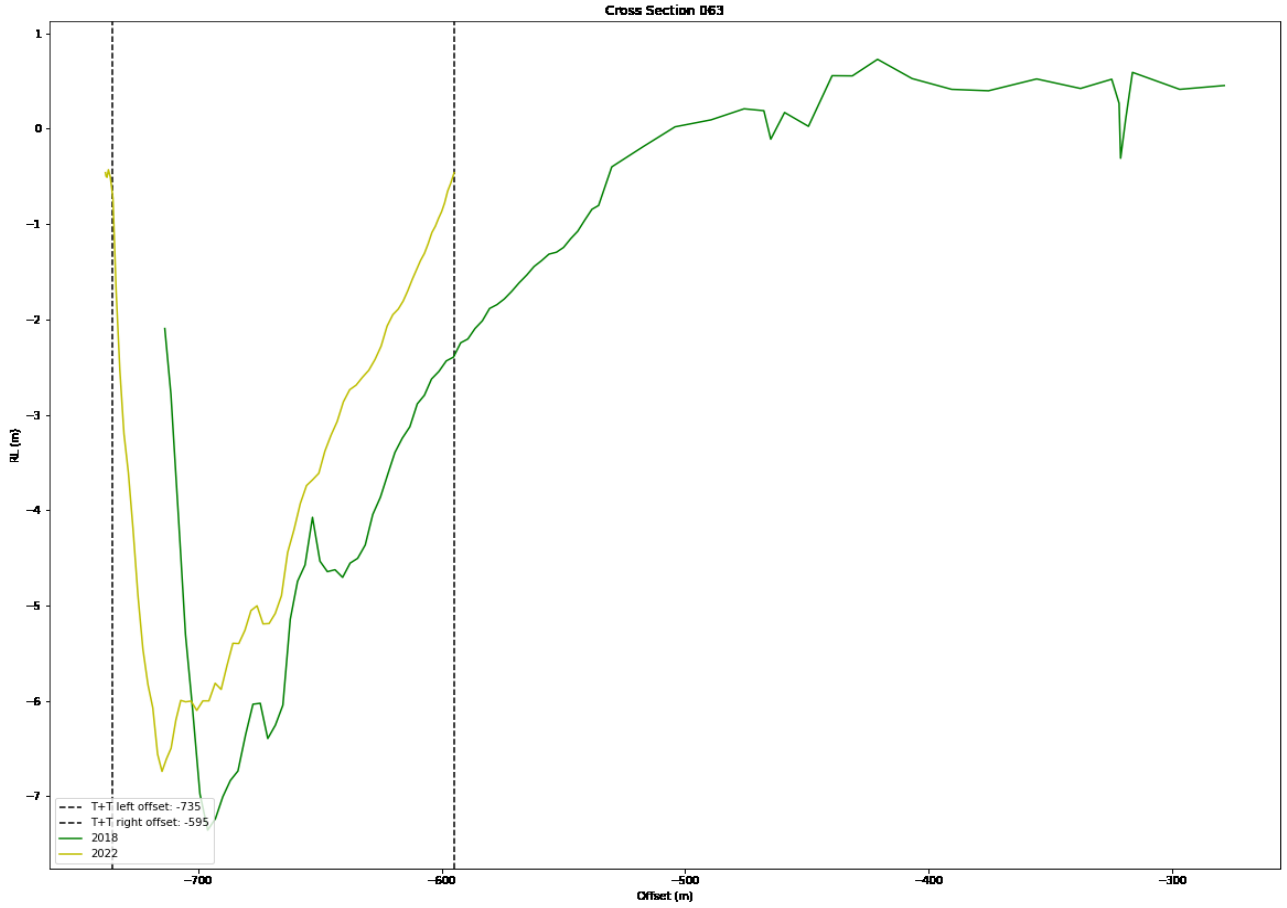

Cross Section 039
RL (m)
Offset (m)
T+T left offset: -572
T+T right offset: -266
2018
2022

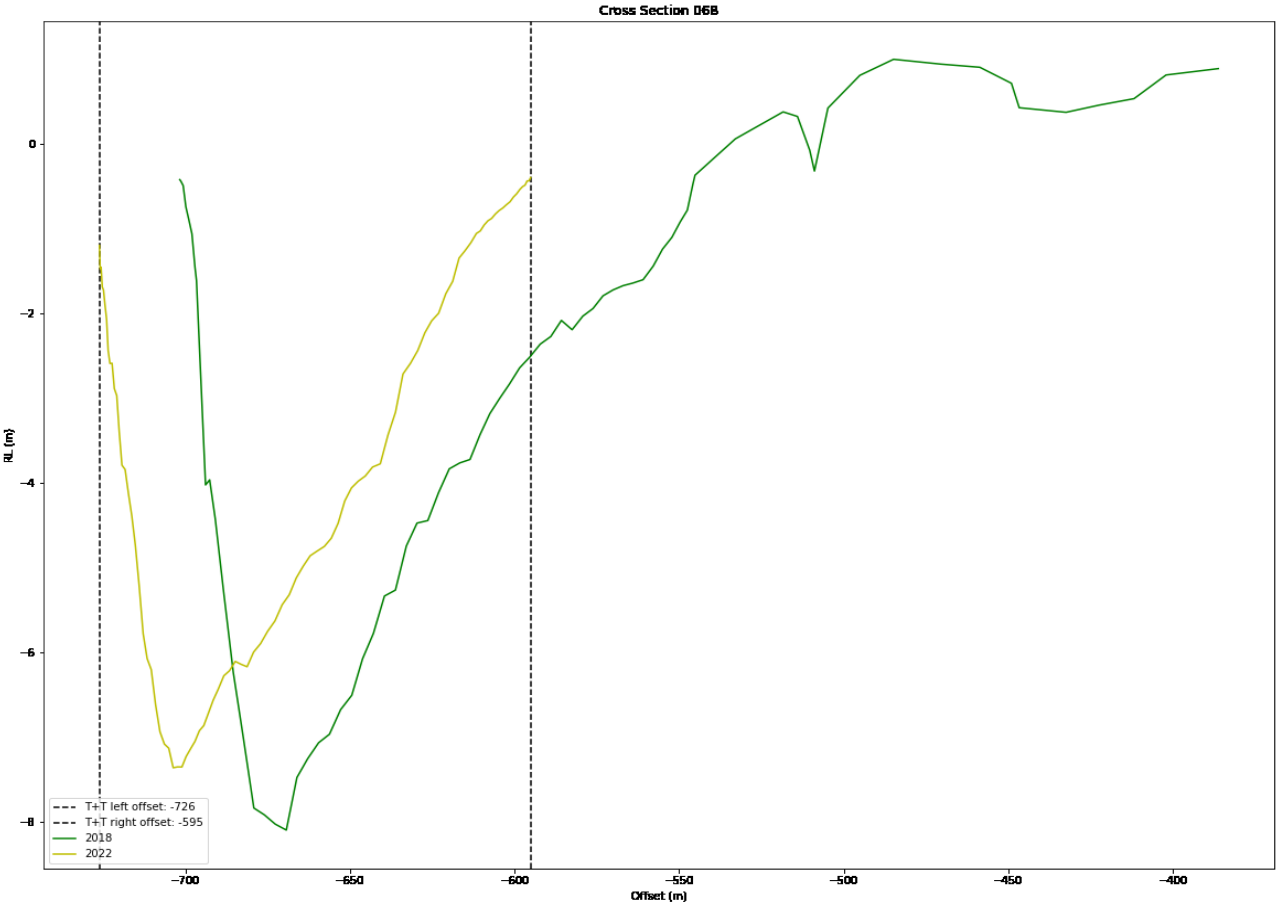

Cross Section 044
RL (m)
Offset (m)
T+T left offset: -193
T+T right offset: -25
2018
2022

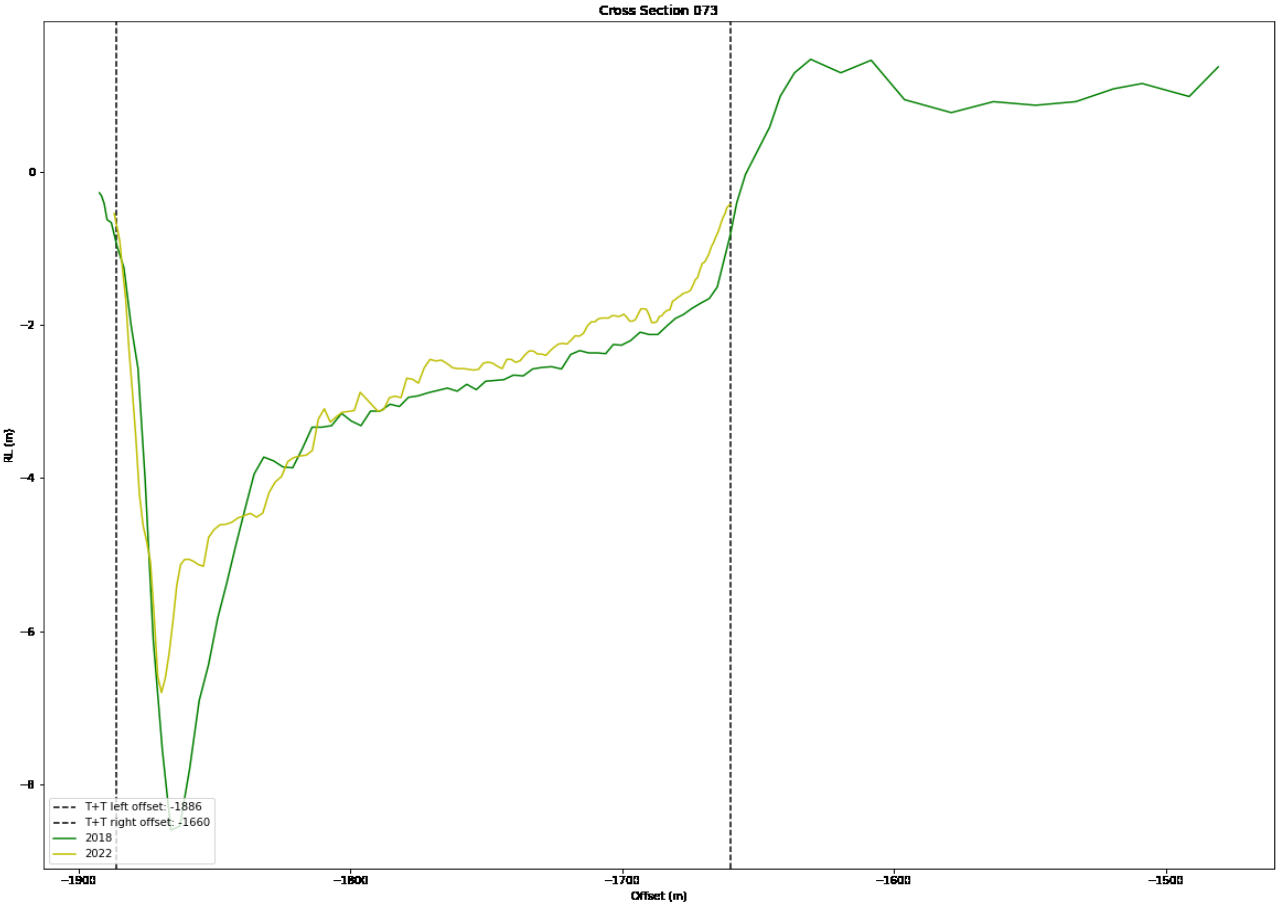

Cross Section 048
RL (m)
Offset (m)
T+T left offset: -121
T+T right offset: -13
2018
2022

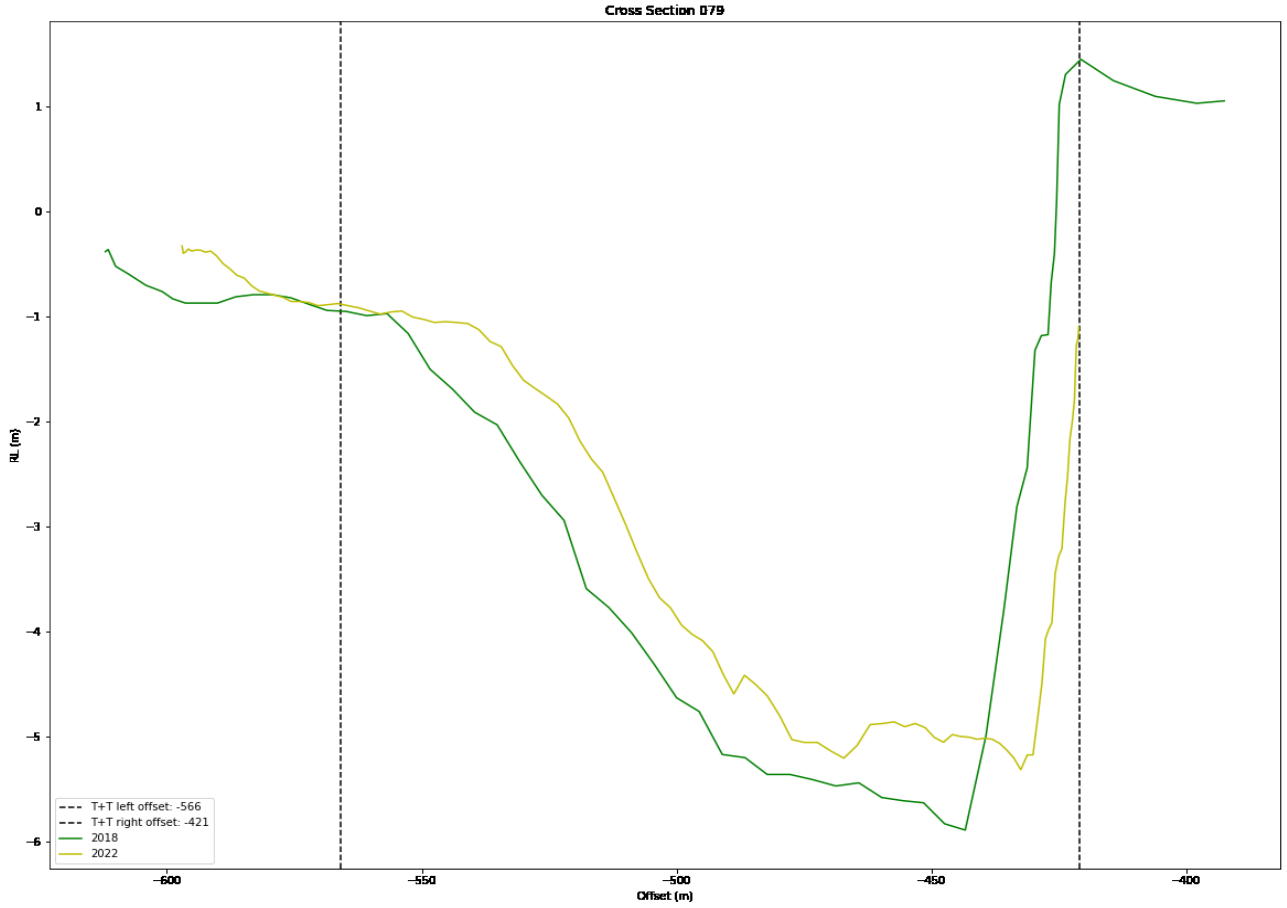

Cross Section 053
RL (m)
Offset (m)
T+T left offset: -487
T+T right offset: -162
2018
2022

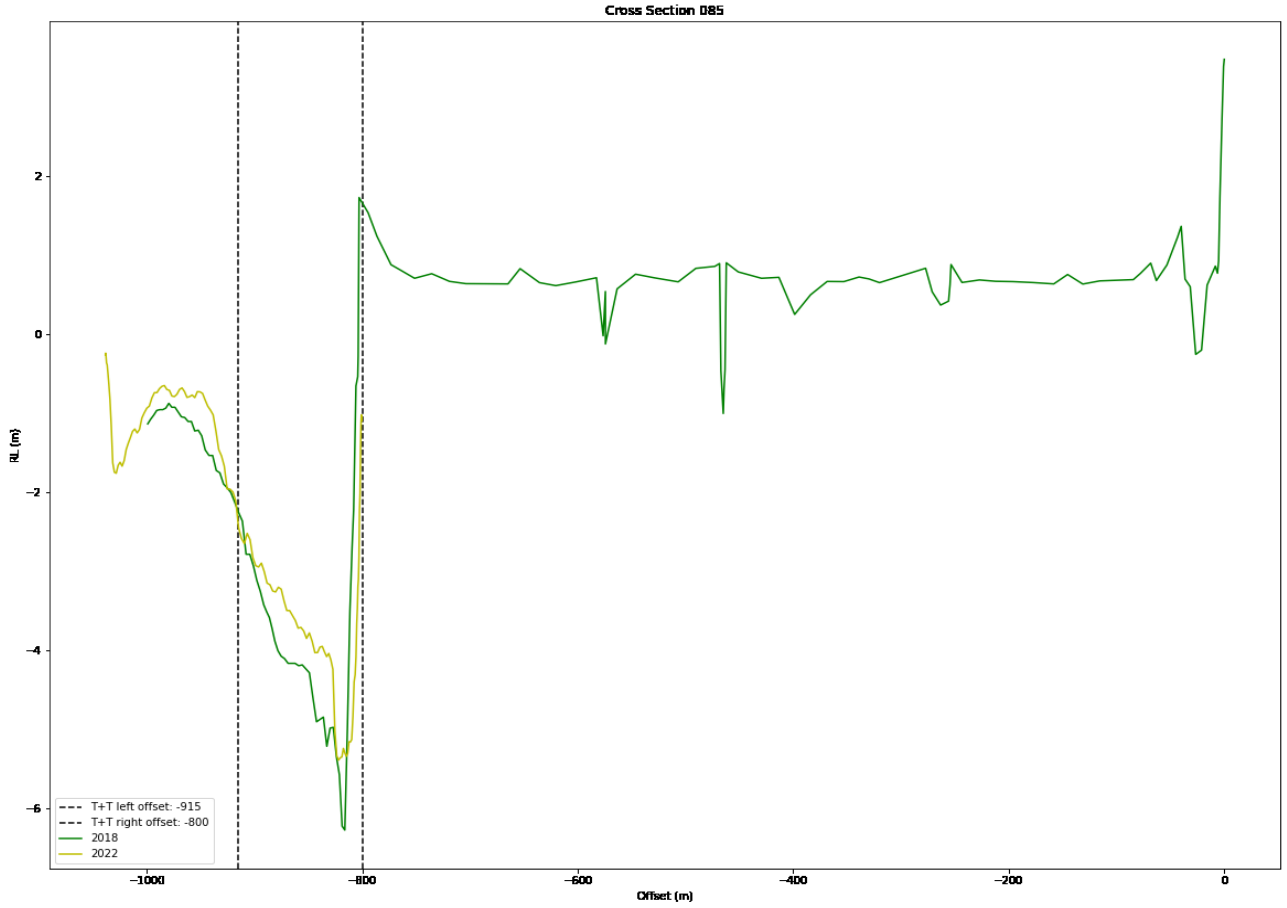

Cross Section 058
RL (m)
Offset (m)
T+T left offset: -638
T+T right offset: -427
2018
2022

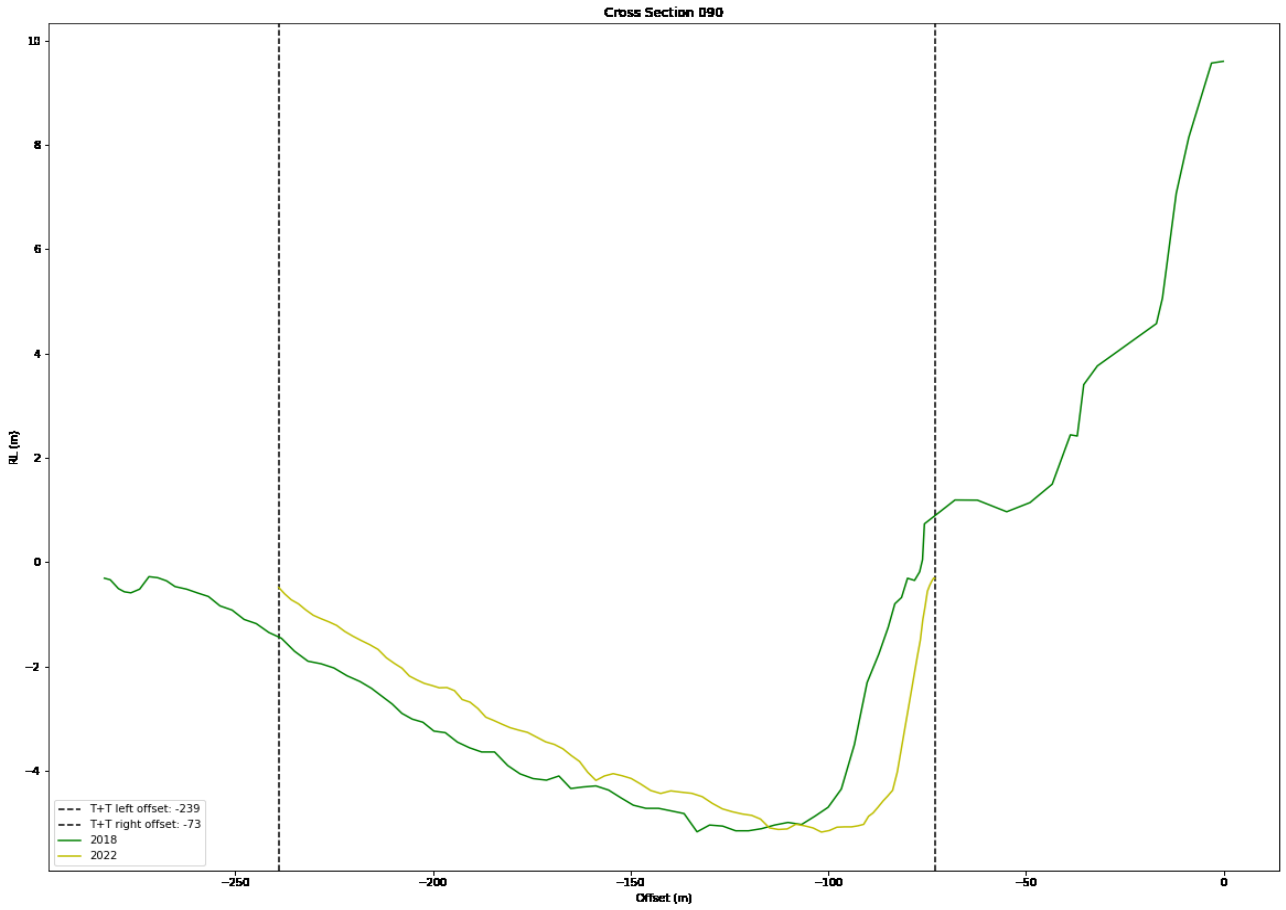

Cross Section 063
RL (m)
Offset (m)
T+T left offset: -735
T+T right offset: -595
2018
2022

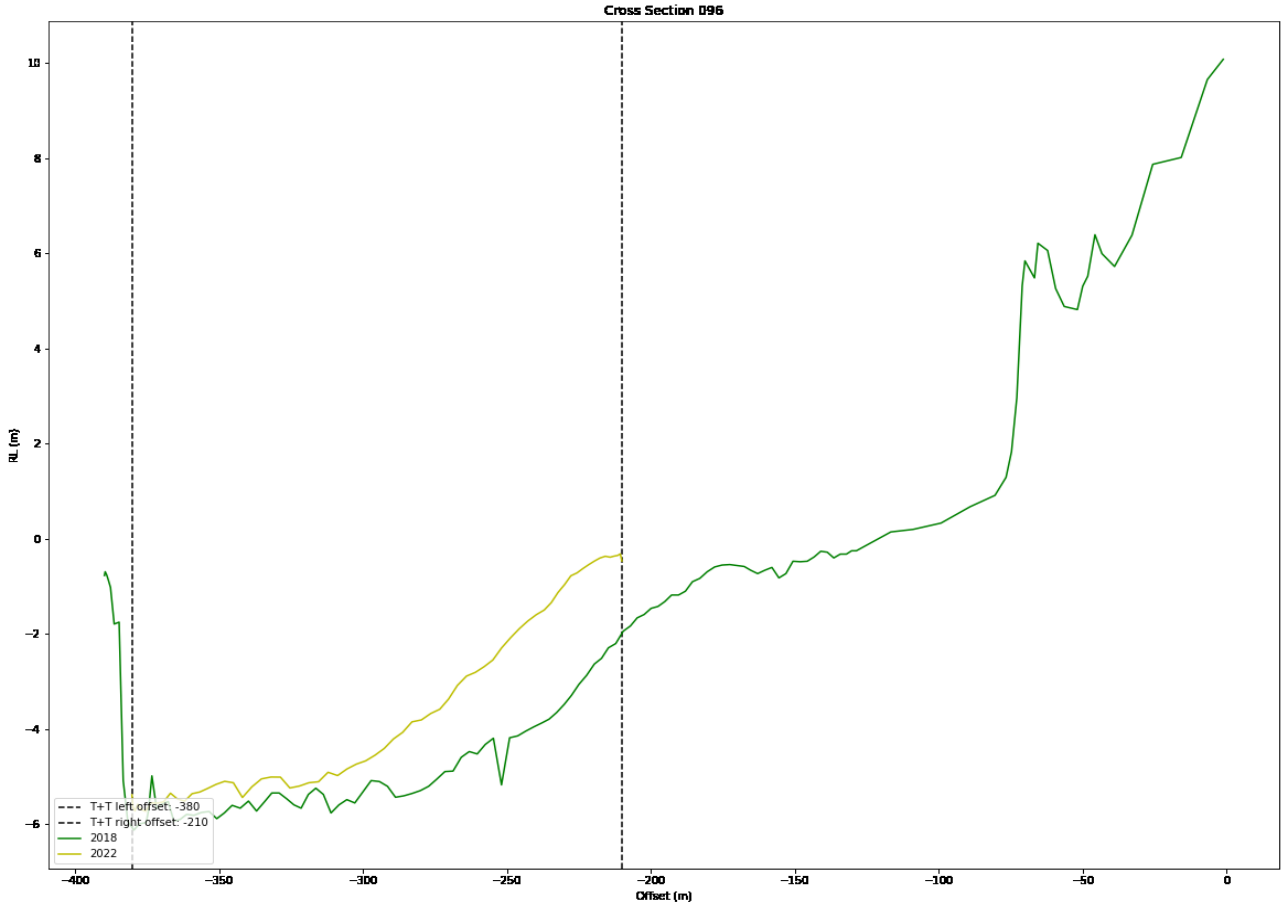

Cross Section 068
RL (m)
Offset (m)
T+T left offset: -726
T+T right offset: -595
2018
2022

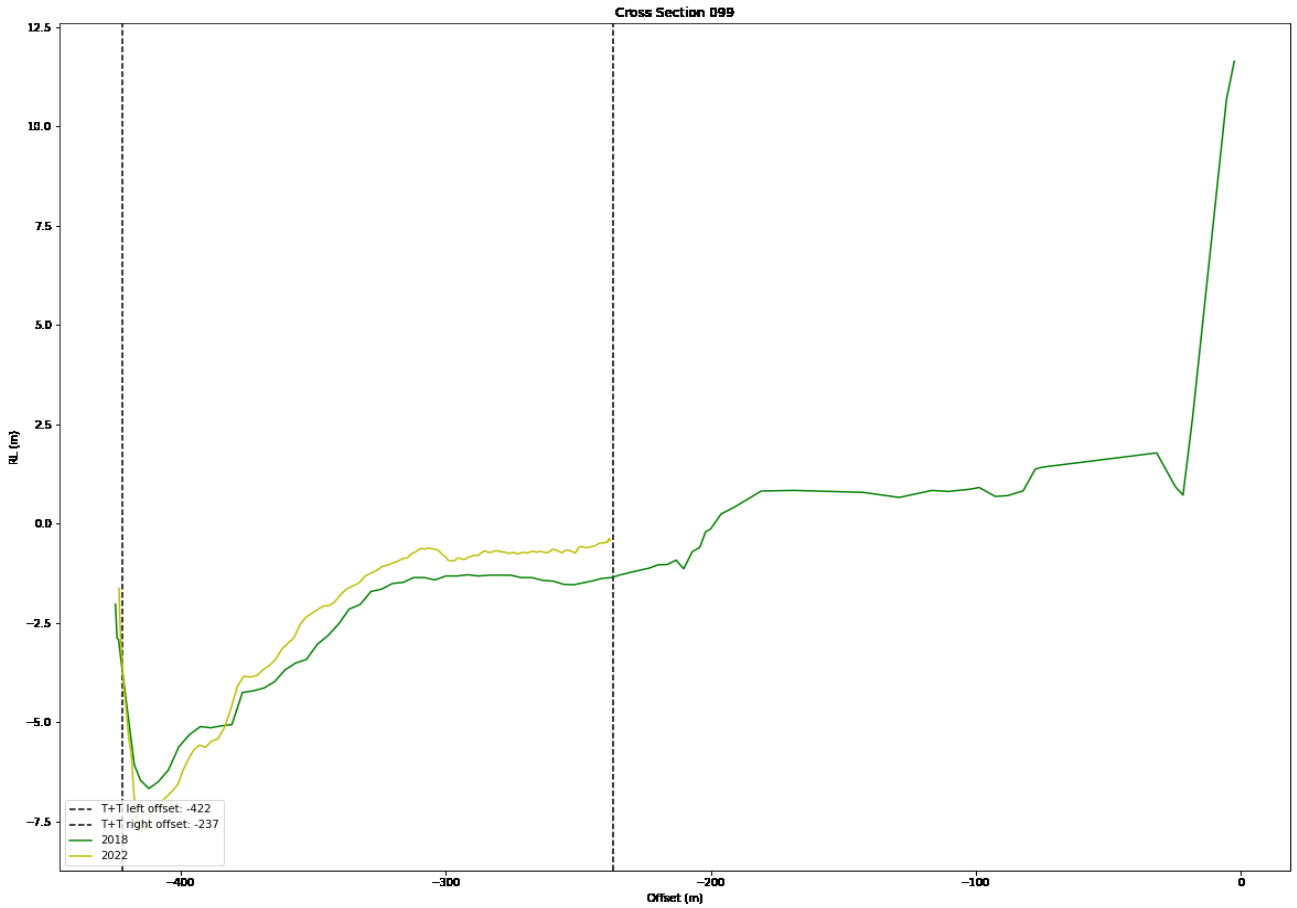

Cross Section 073
RL (m)
Offset (m)
T+T left offset: -1886
T+T right offset: -1660
2018
2022

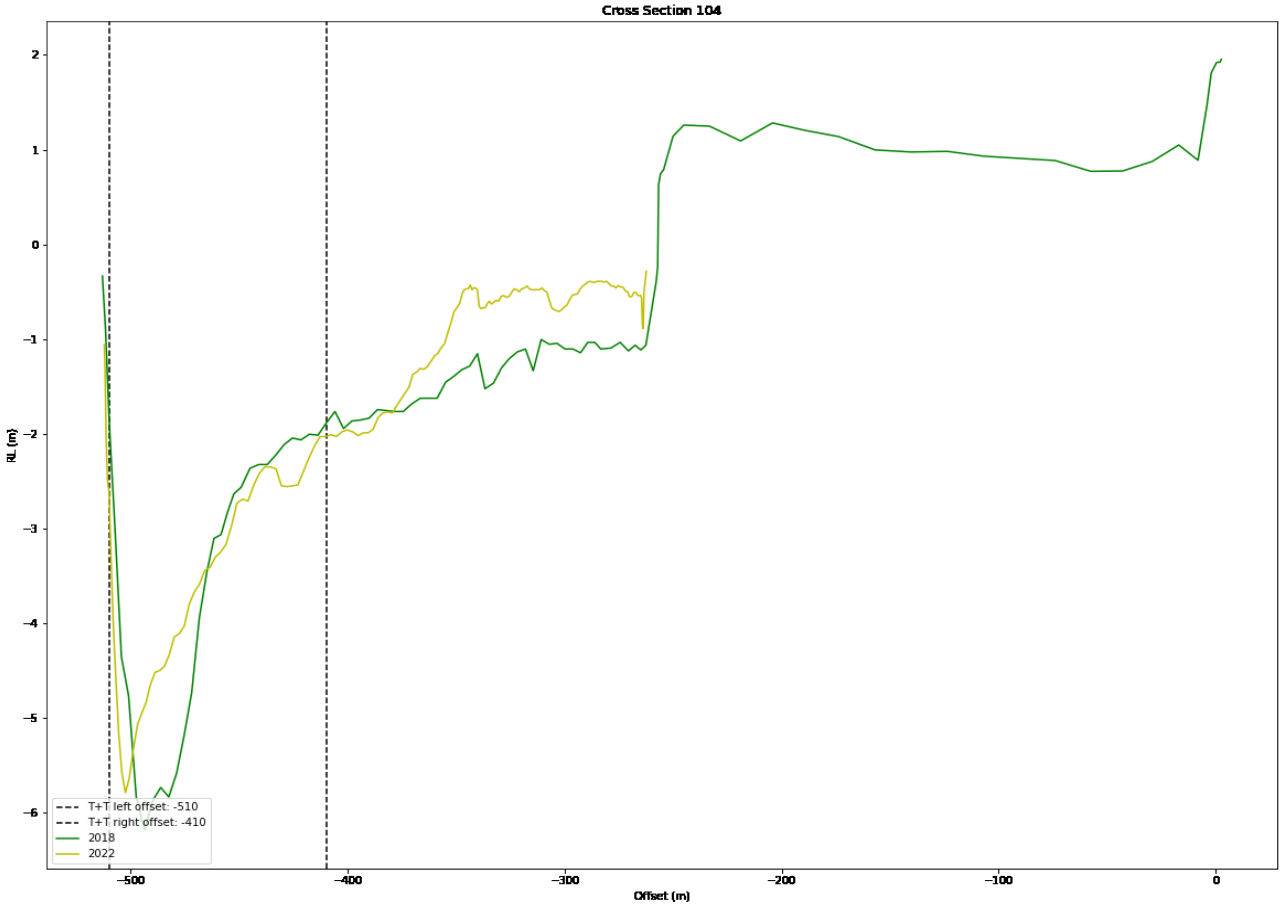

Cross Section 079
RL (m)
Offset (m)
T+T left offset: -566
T+T right offset: -421
2018
2022

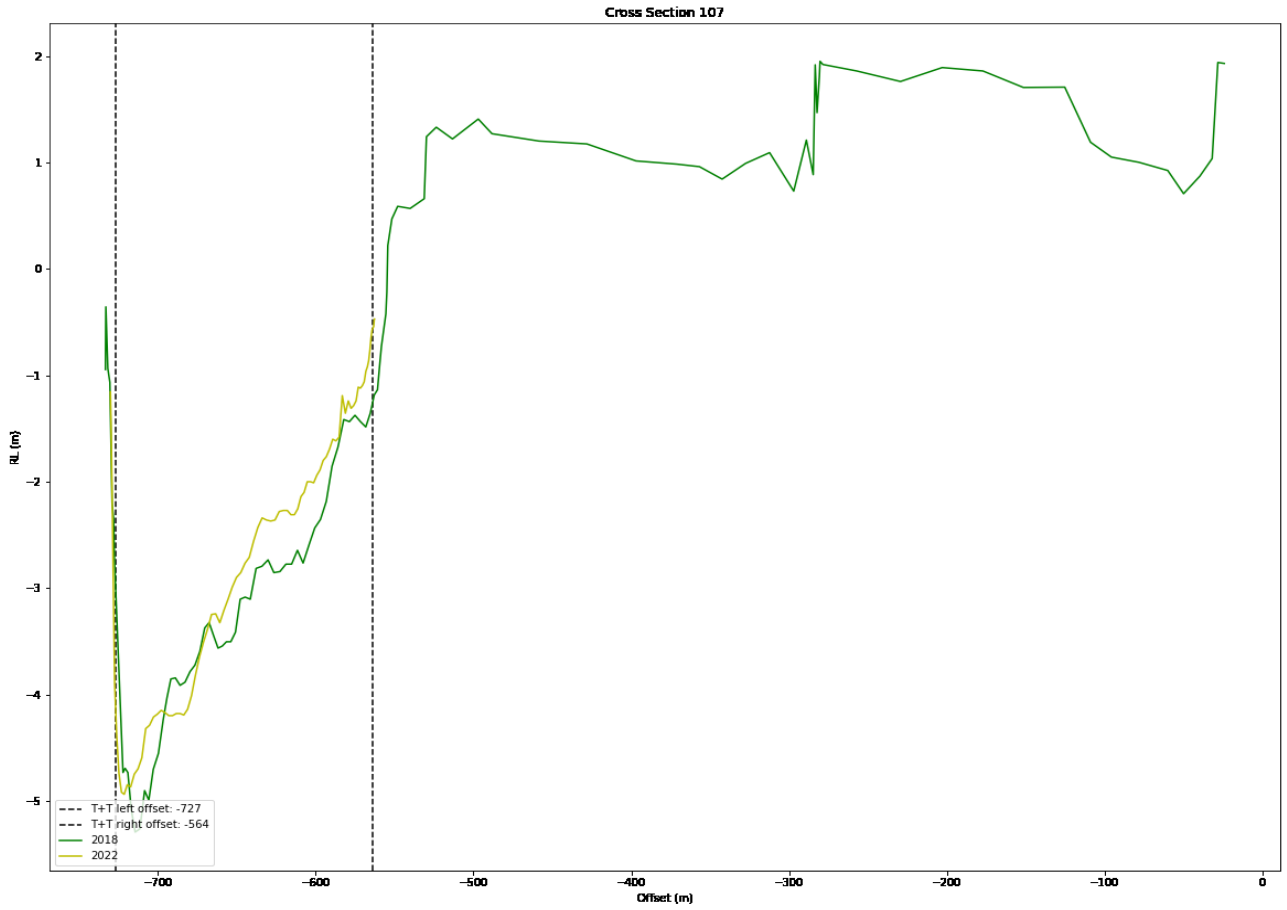

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RL (m)
Offset (m)
T+T left offset: -915
T+T right offset: -800
2018
2022

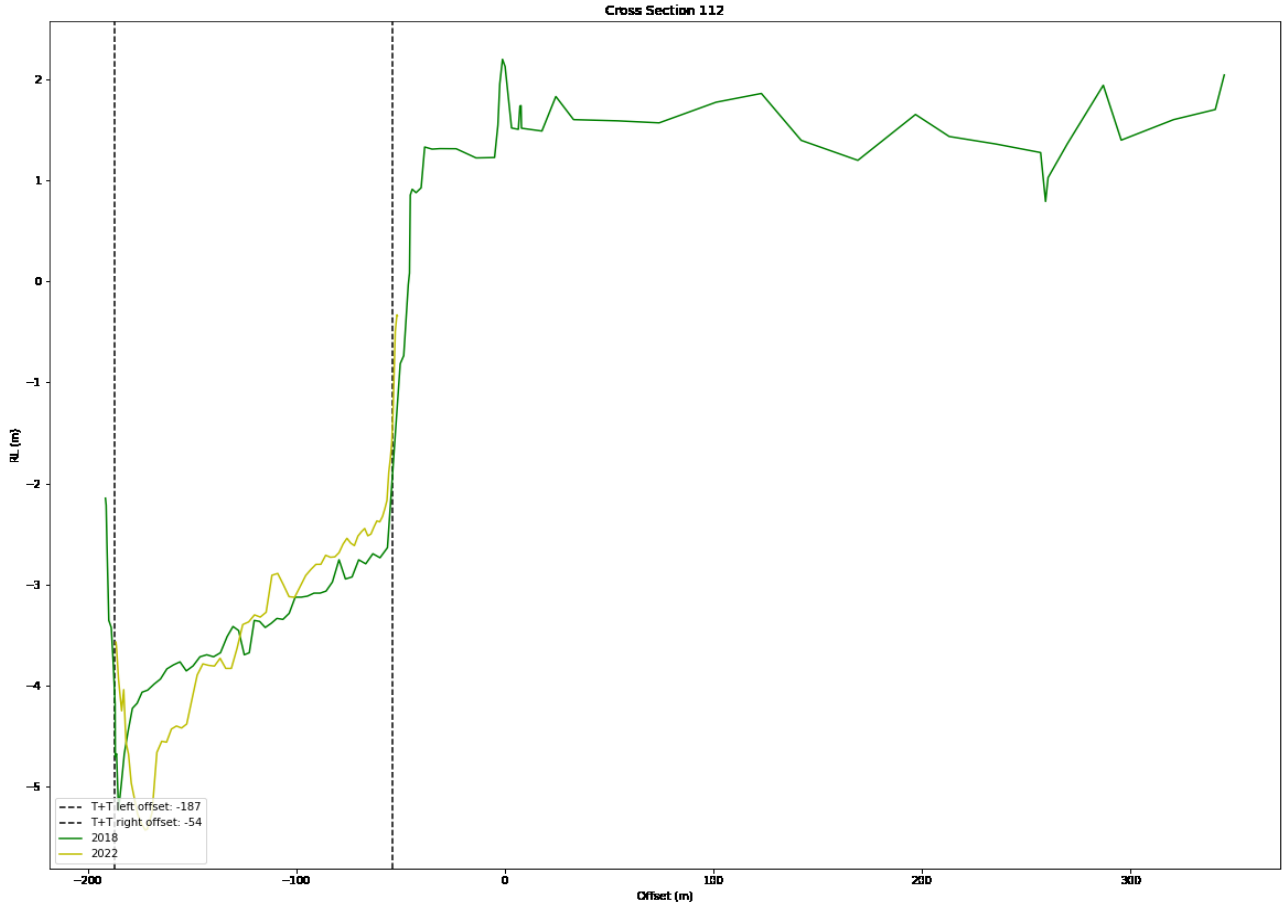

Cross Section 090
RL (m)
Offset (m)
T+T left offset: -239
T+T right offset: -73
2018
2022

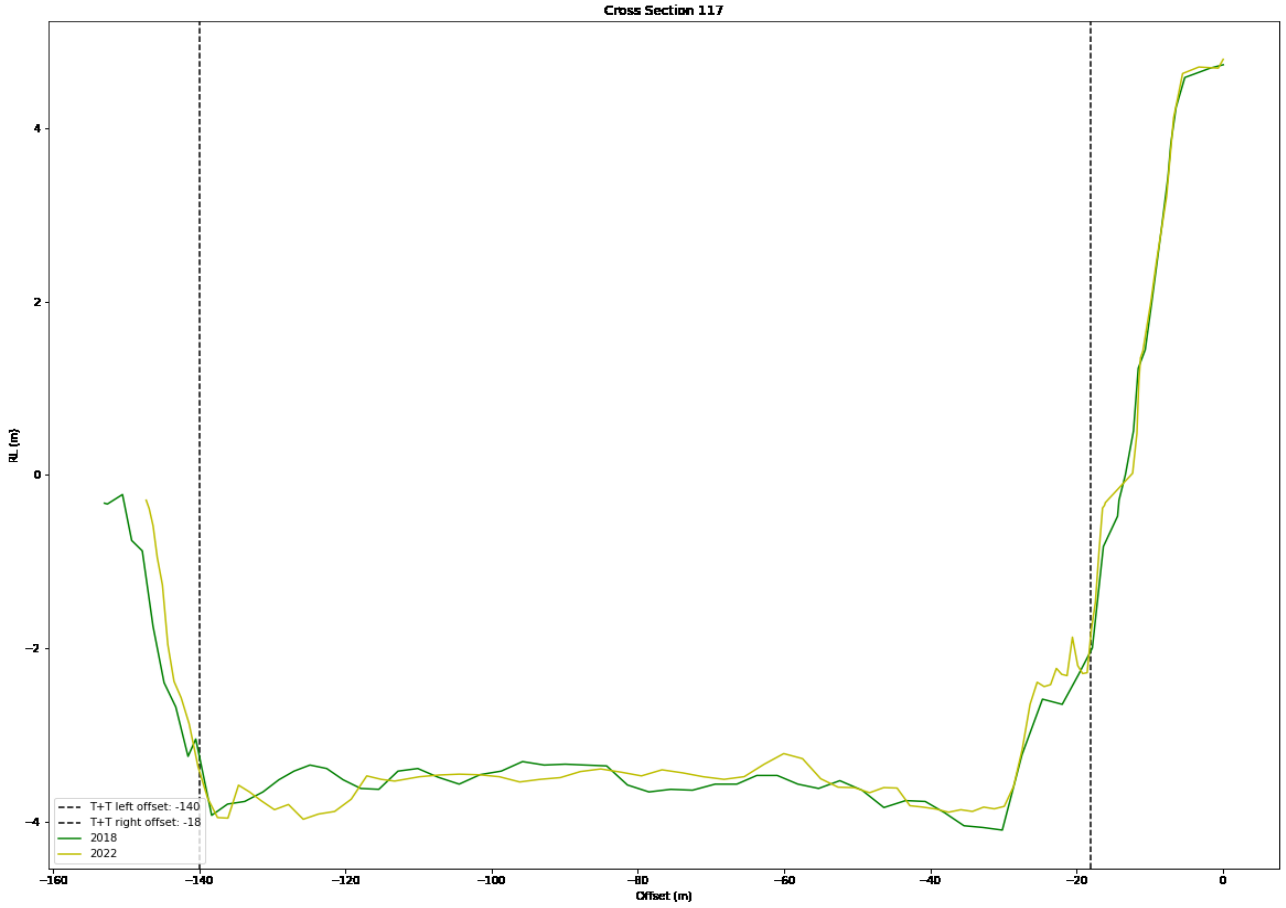

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RL (m)
Offset (m)
T+T left offset: -380
T+T right offset: -210
2018
2022

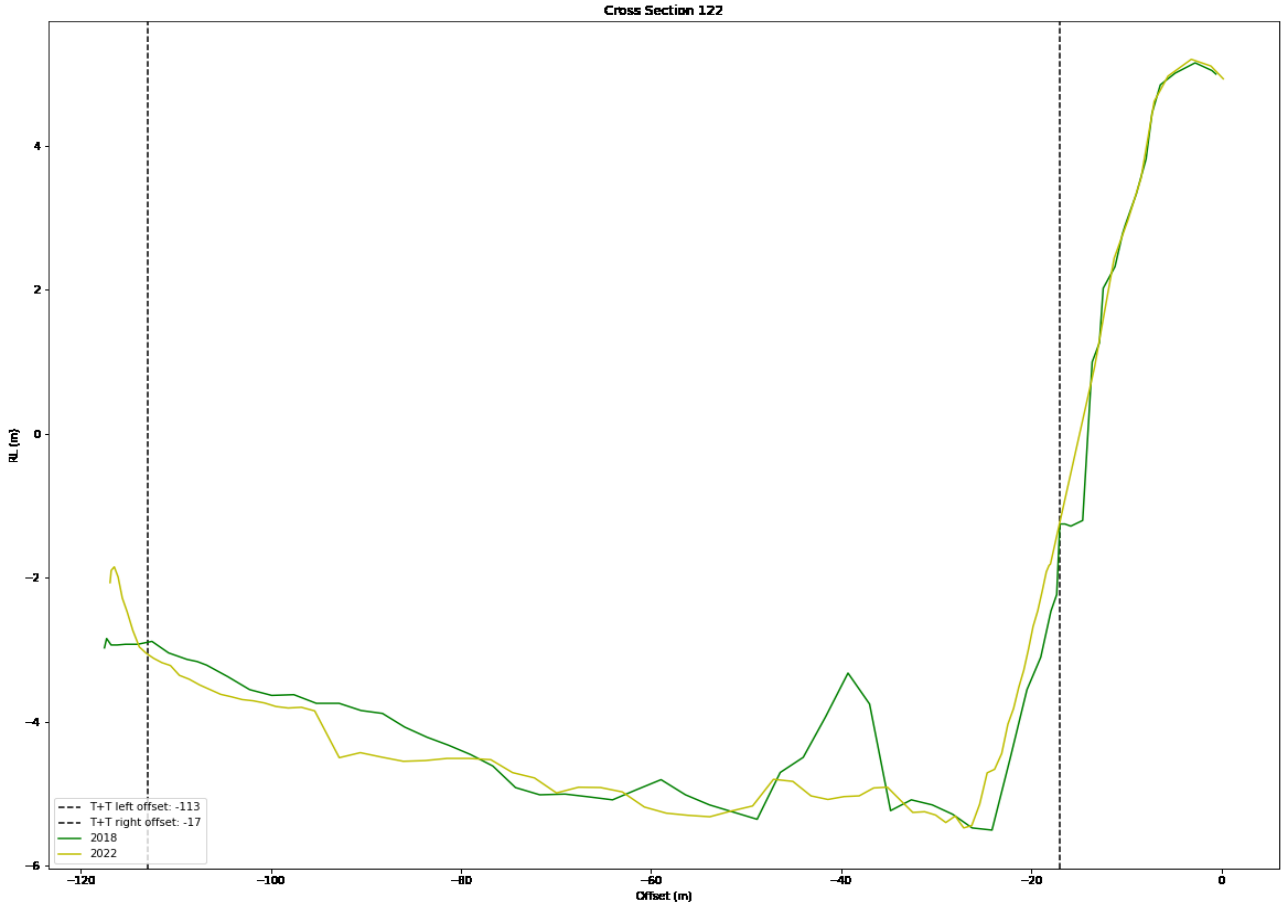

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Offset (m)
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T+T right offset: -237
2018
2022

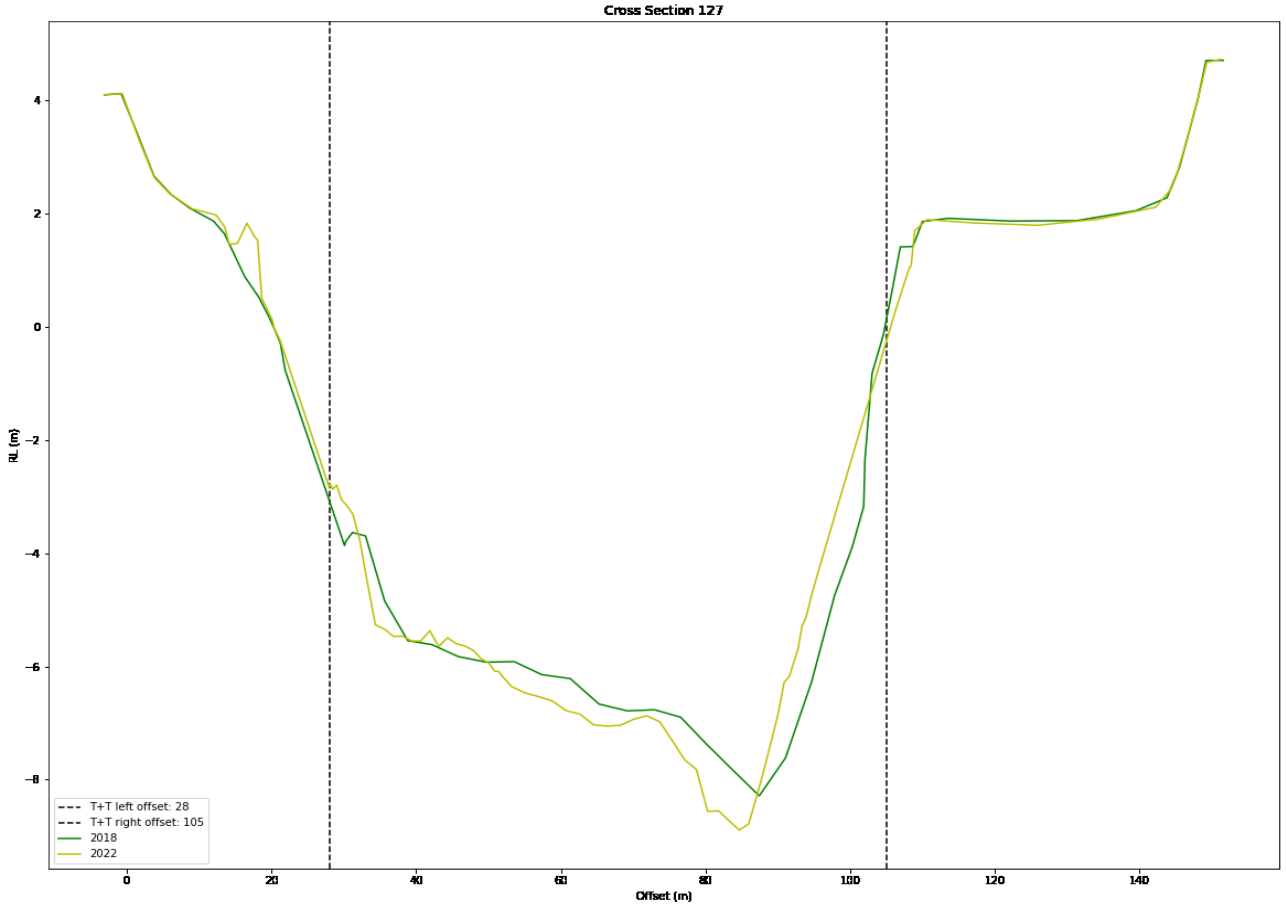

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Offset (m)
T+T left offset: -510
T+T right offset: -410
2018
2022

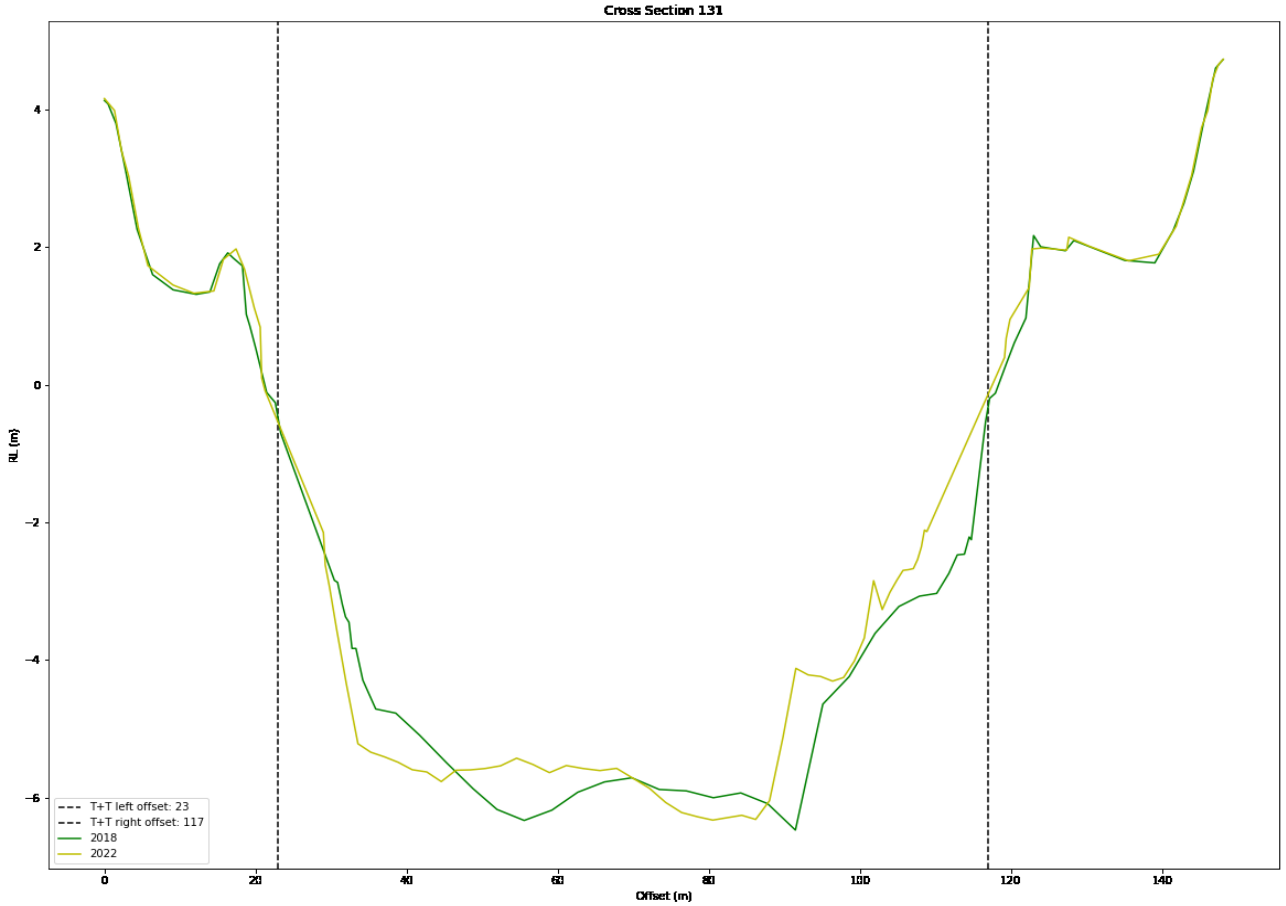

Cross Section 107
RL (m)
Offset (m)
T+T left offset: -727
T+T right offset: -564
2018
2022

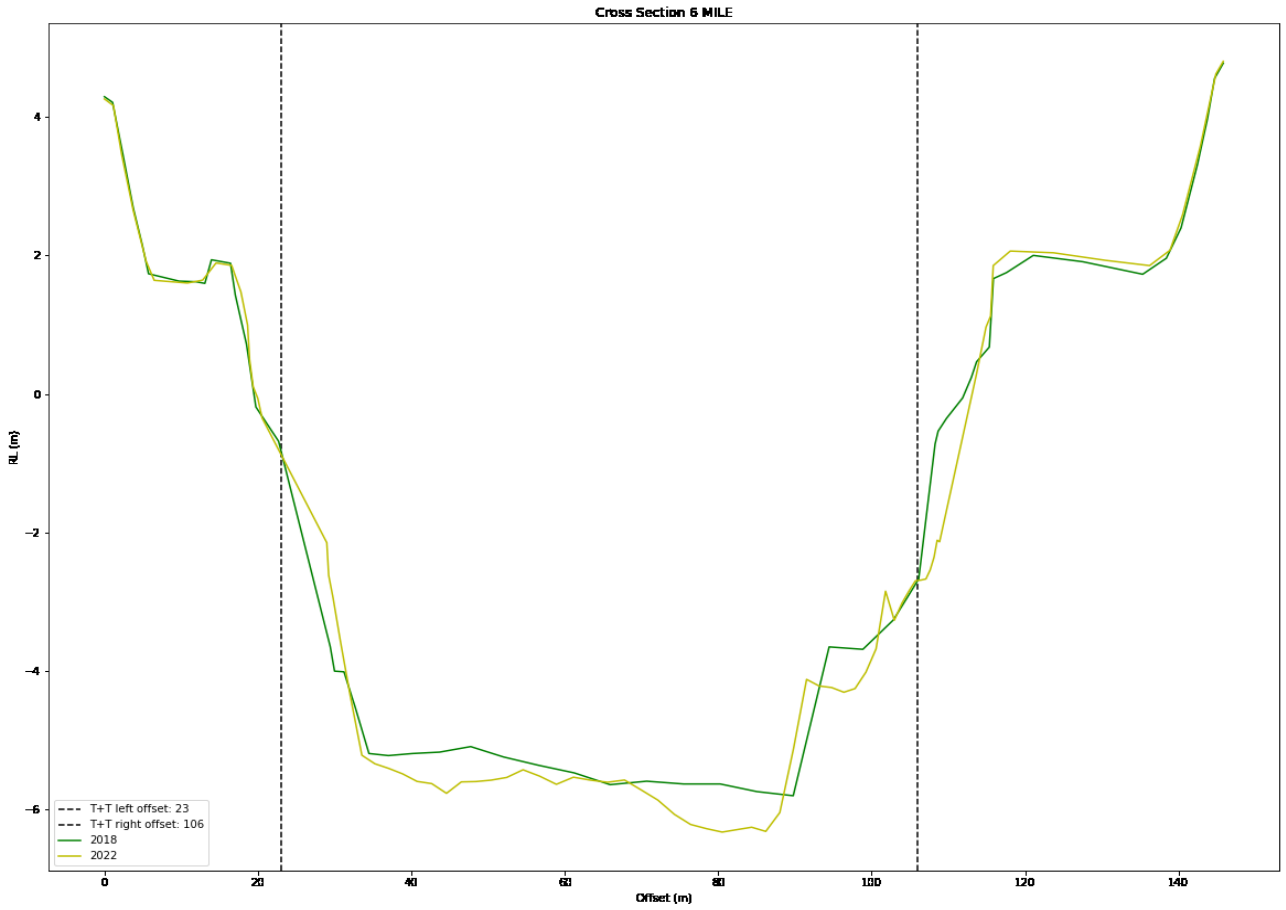

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T+T left offset: -187
T+T right offset: -54
2018
2022

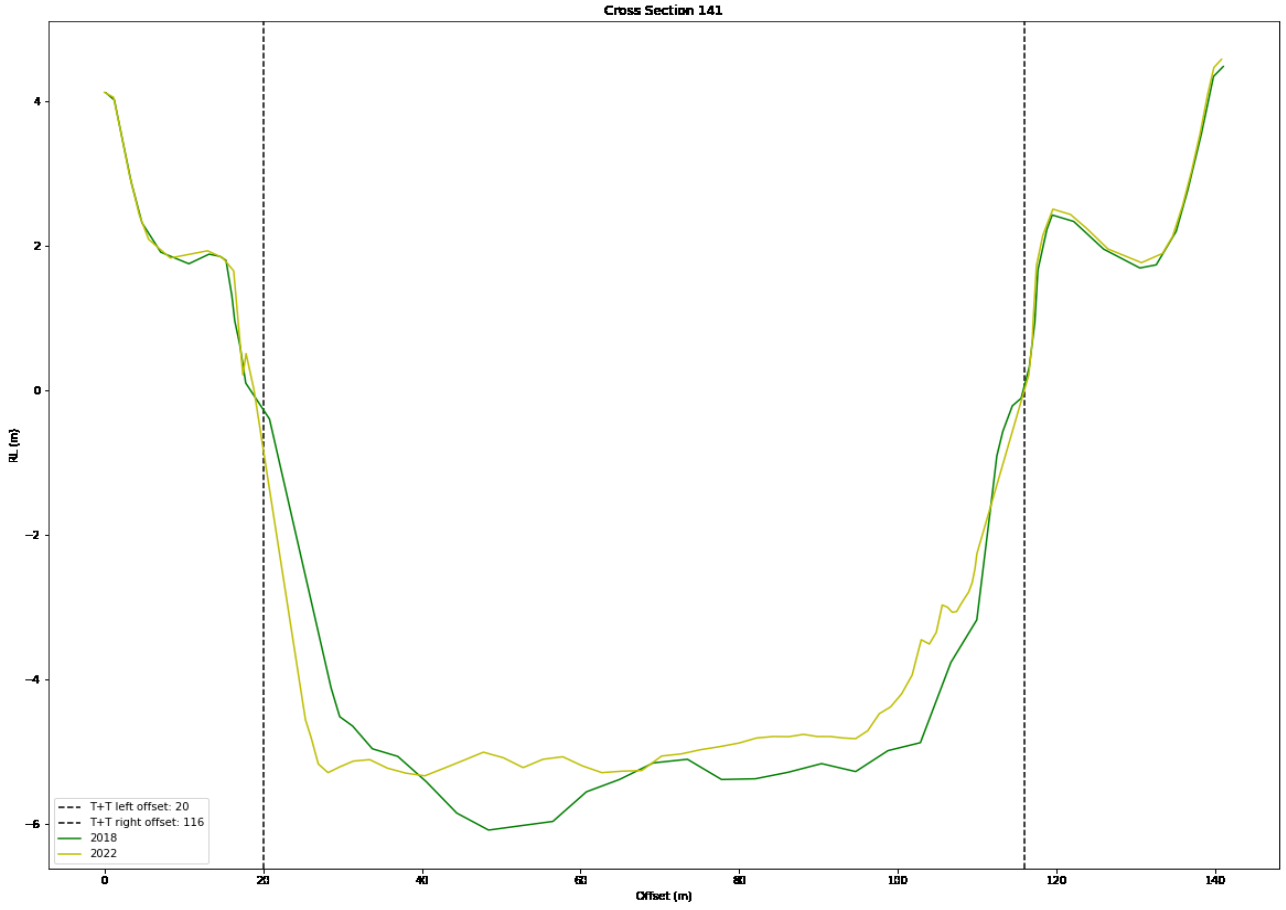

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Offset (m)
T+T left offset: -140
T+T right offset: -18
2018
2022

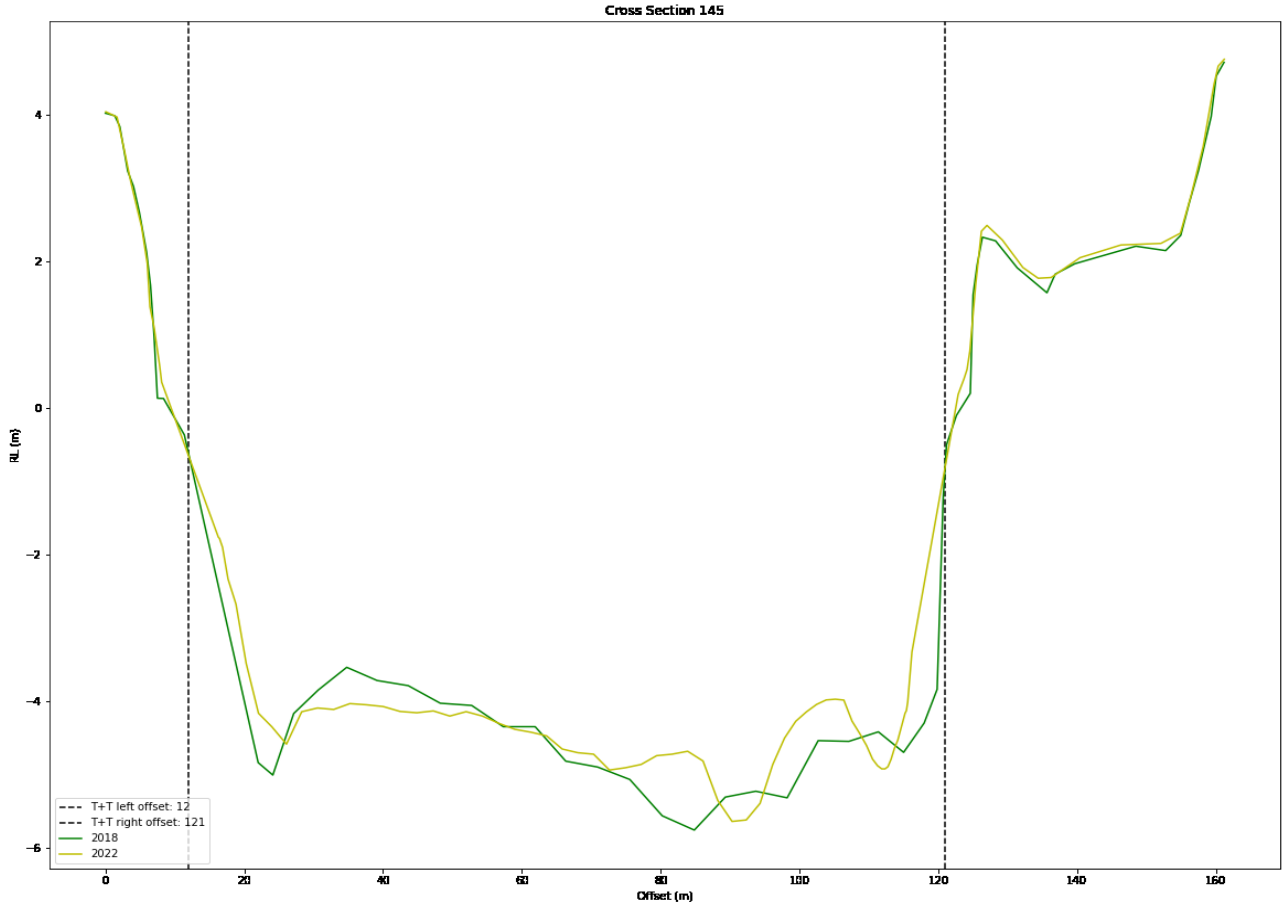

Cross Section 122
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Offset (m)
T+T left offset: -113
T+T right offset: -17
2018
2022

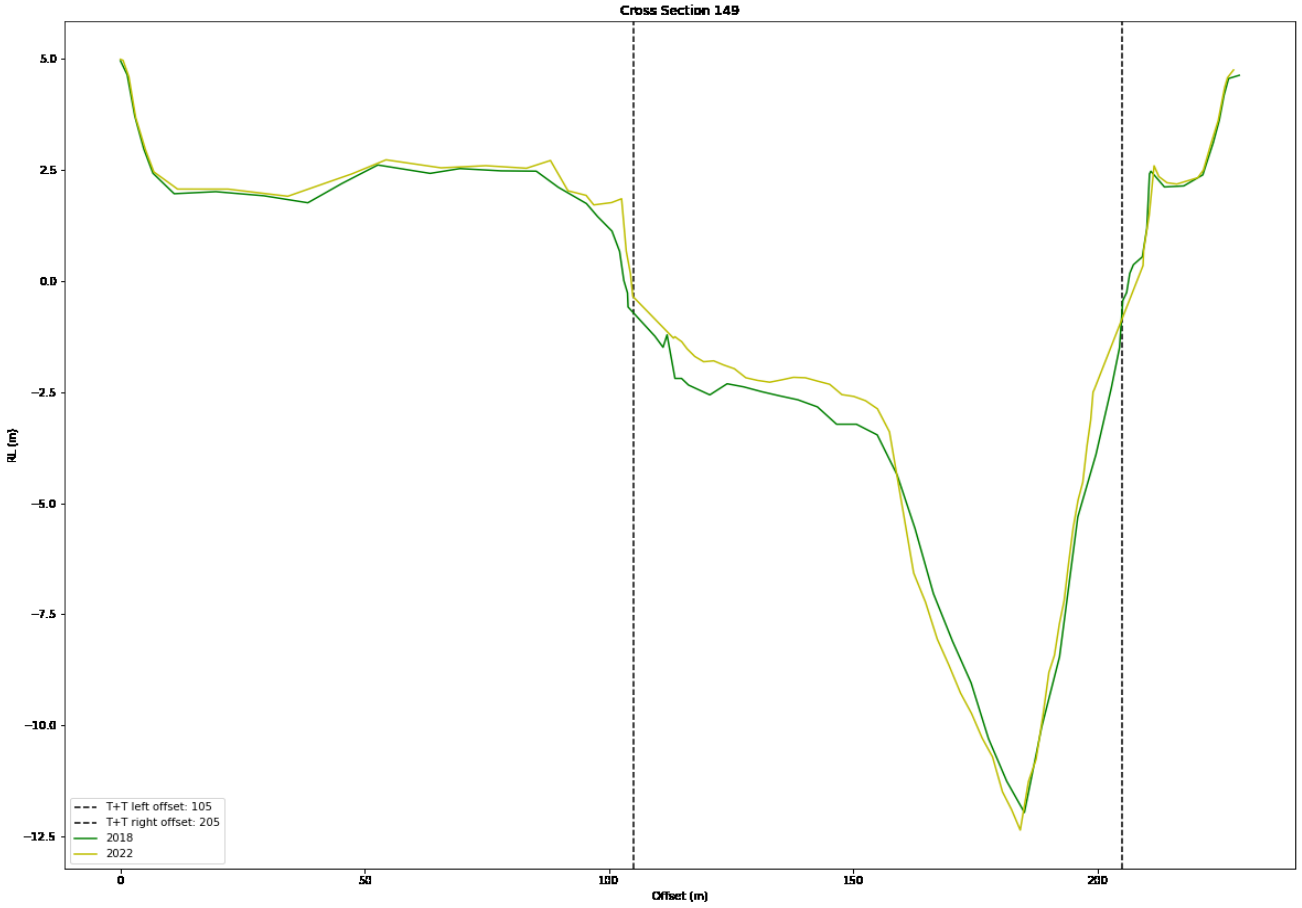

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Offset (m)
T+T left offset: 28
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2018
2022

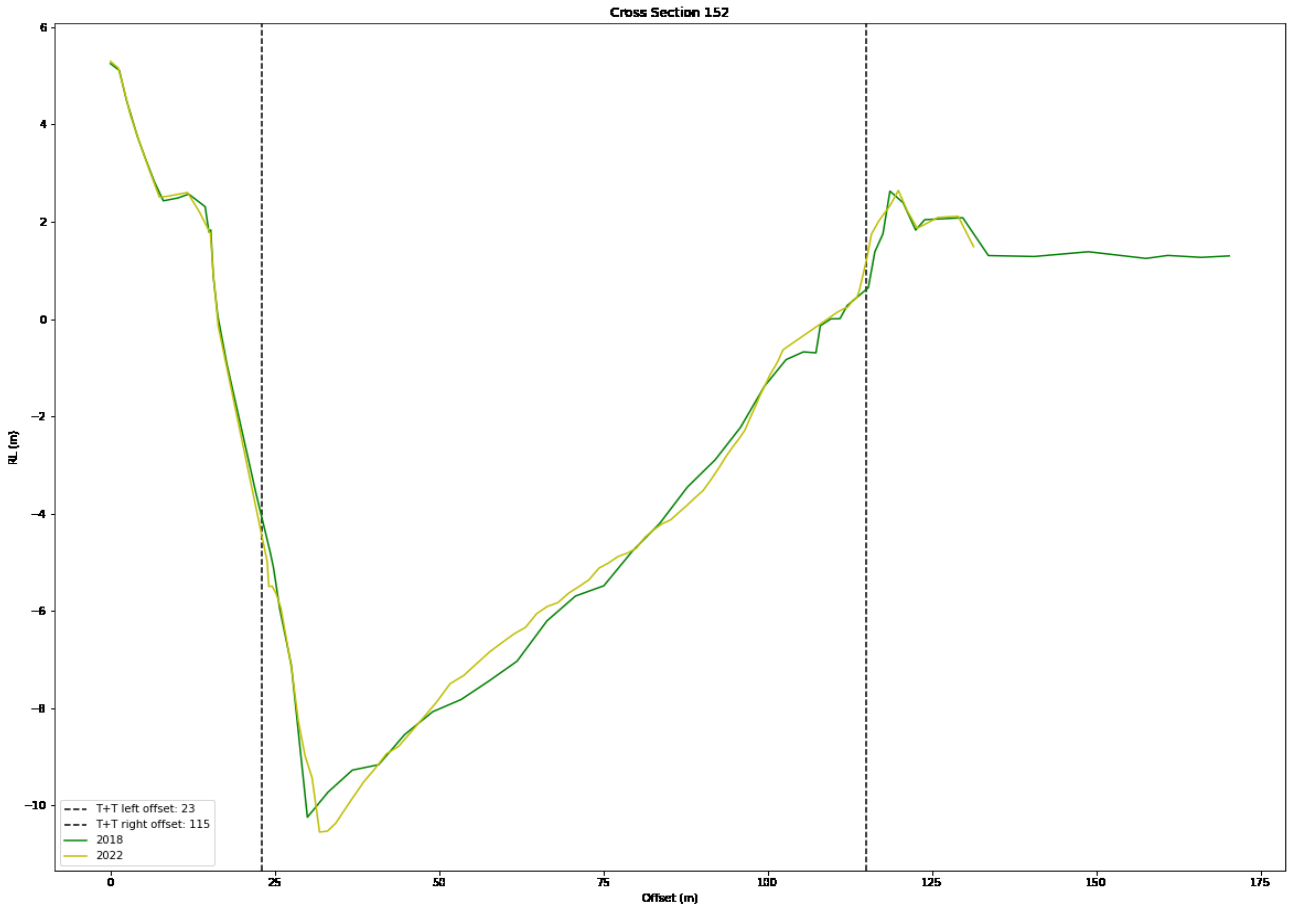

Cross Section 131
RL (m)
Offset (m)
T+T left offset: 23
T+T right offset: 117
2018
2022

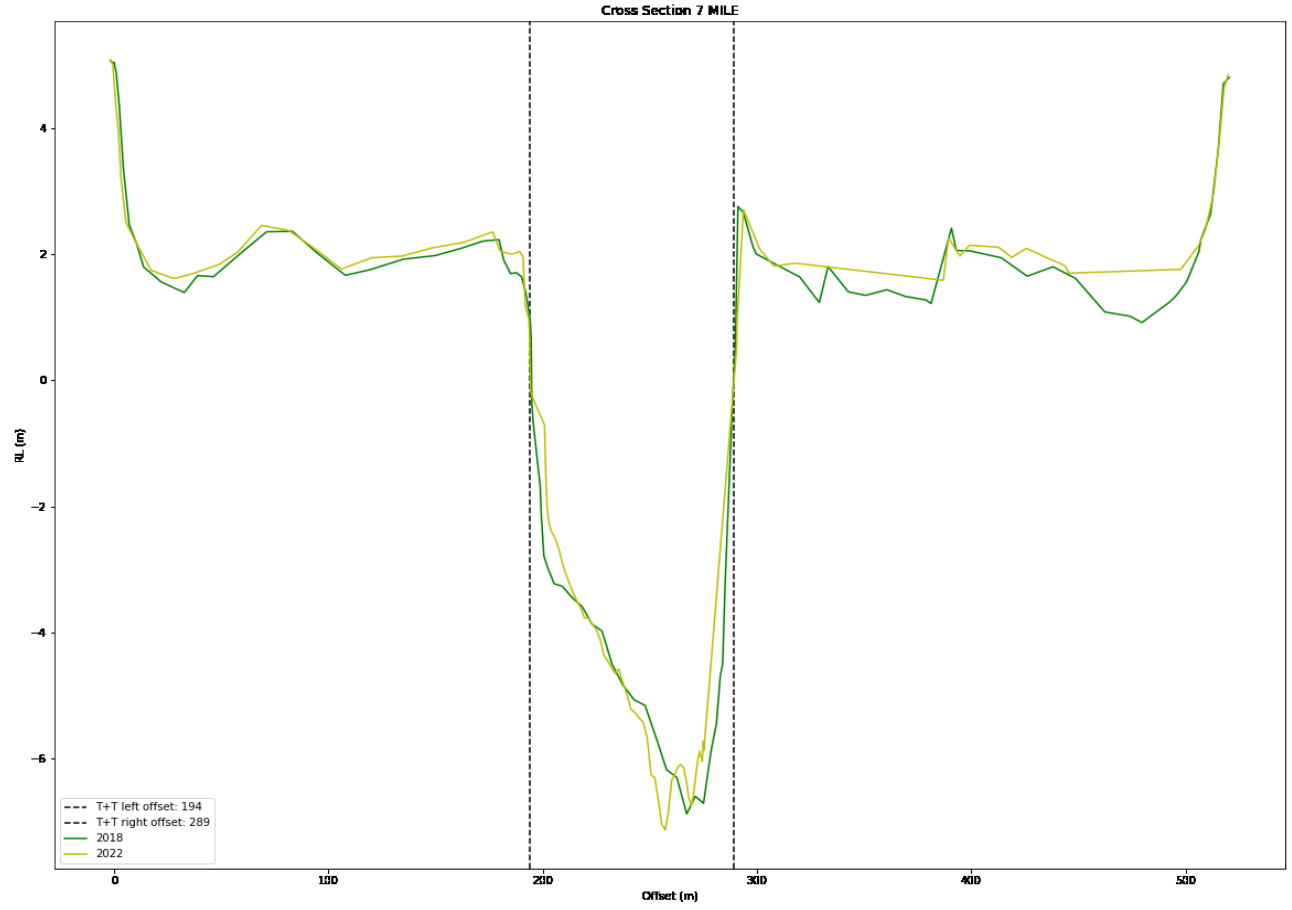

Cross Section 6 MILE
RL (m)
Offset (m)
T+T left offset: 23
T+T right offset: 106
2018
2022

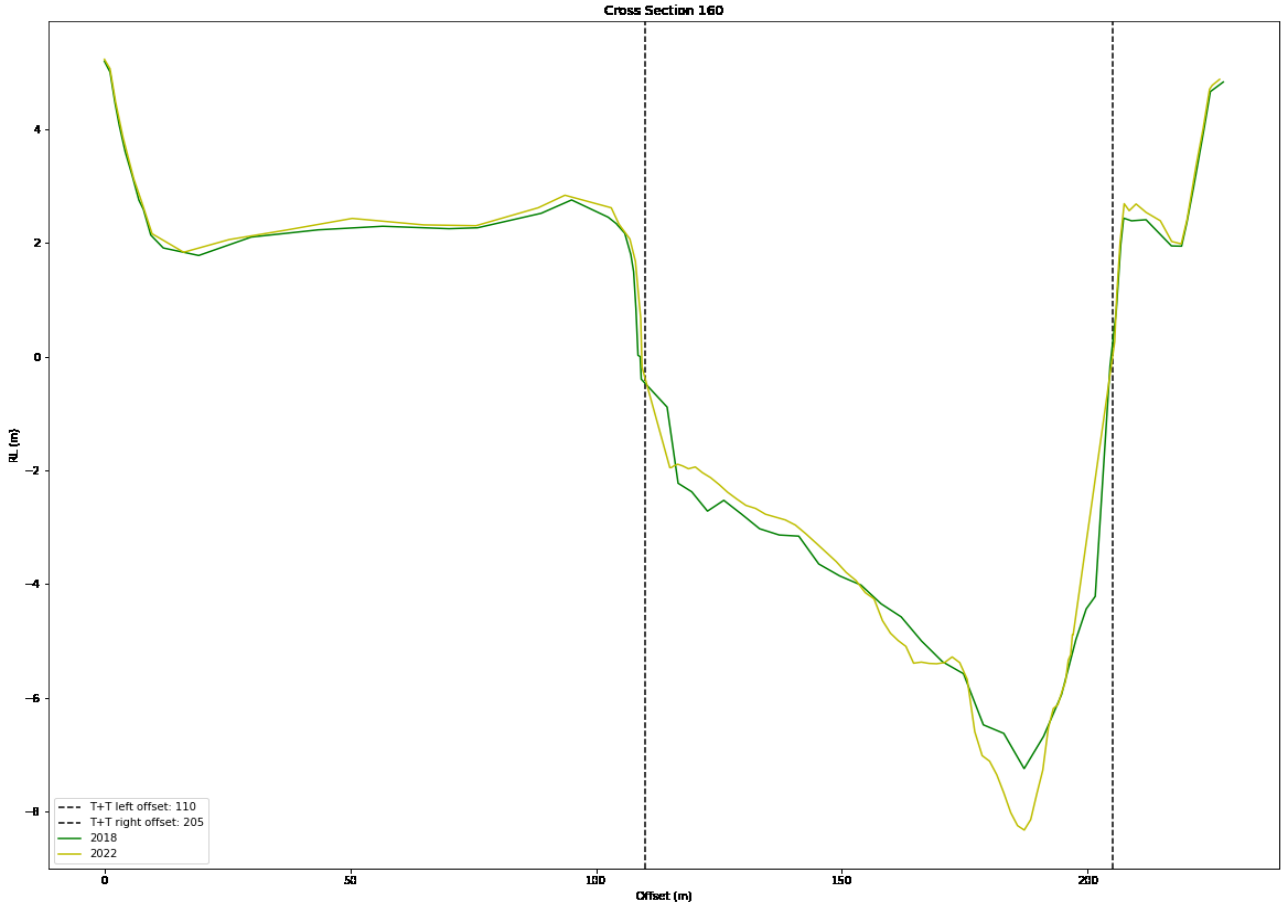

Cross Section 141
RL (m)
Offset (m)
T+T left offset: 20
T+T right offset: 116
2018
2022

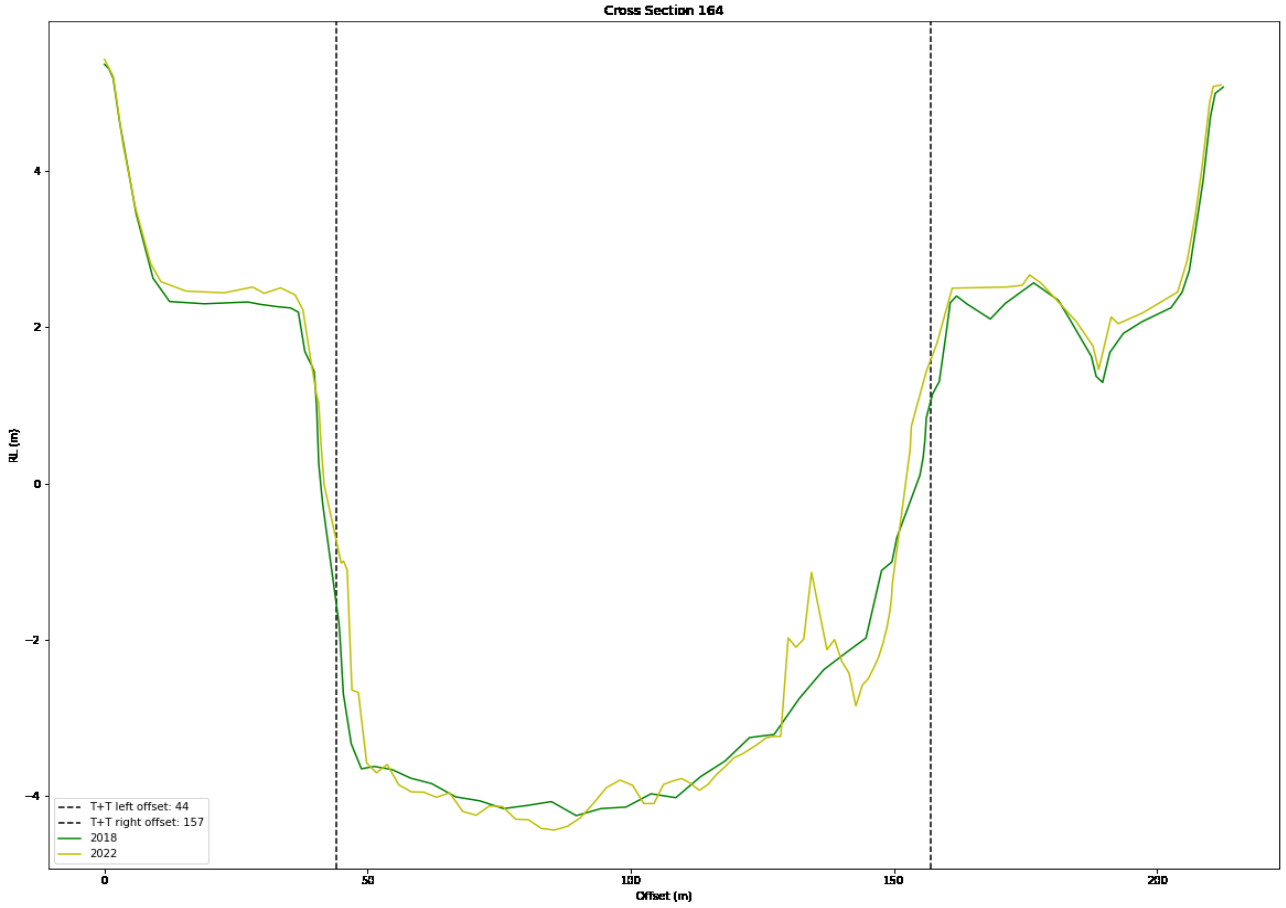

Cross Section 145
RL (m)
Offset (m)
T+T left offset: 12
T+T right offset: 121
2018
2022

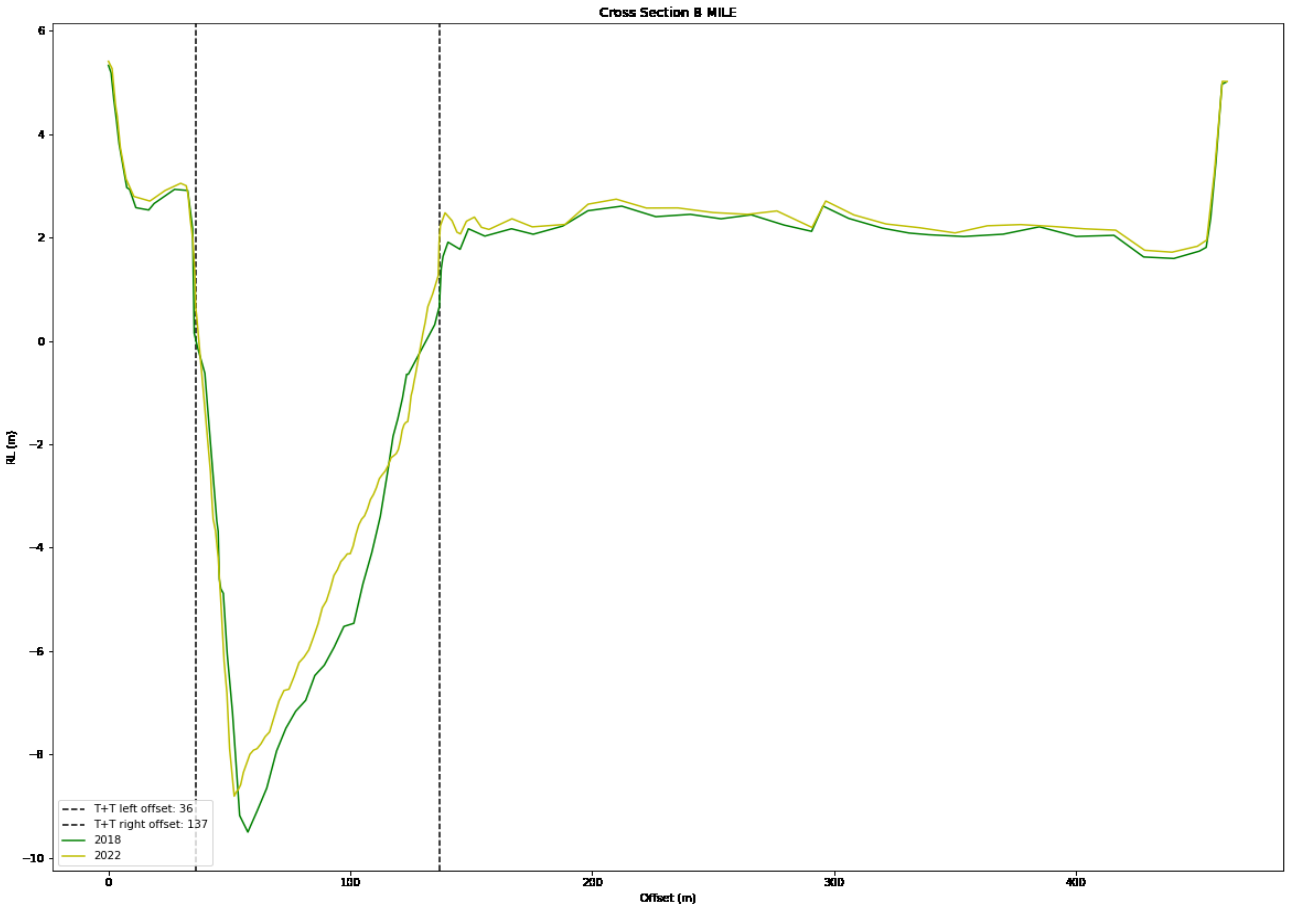

Cross Section 149
RL (m)
Offset (m)
T+T left offset: 105
T+T right offset: 205
2018
2022

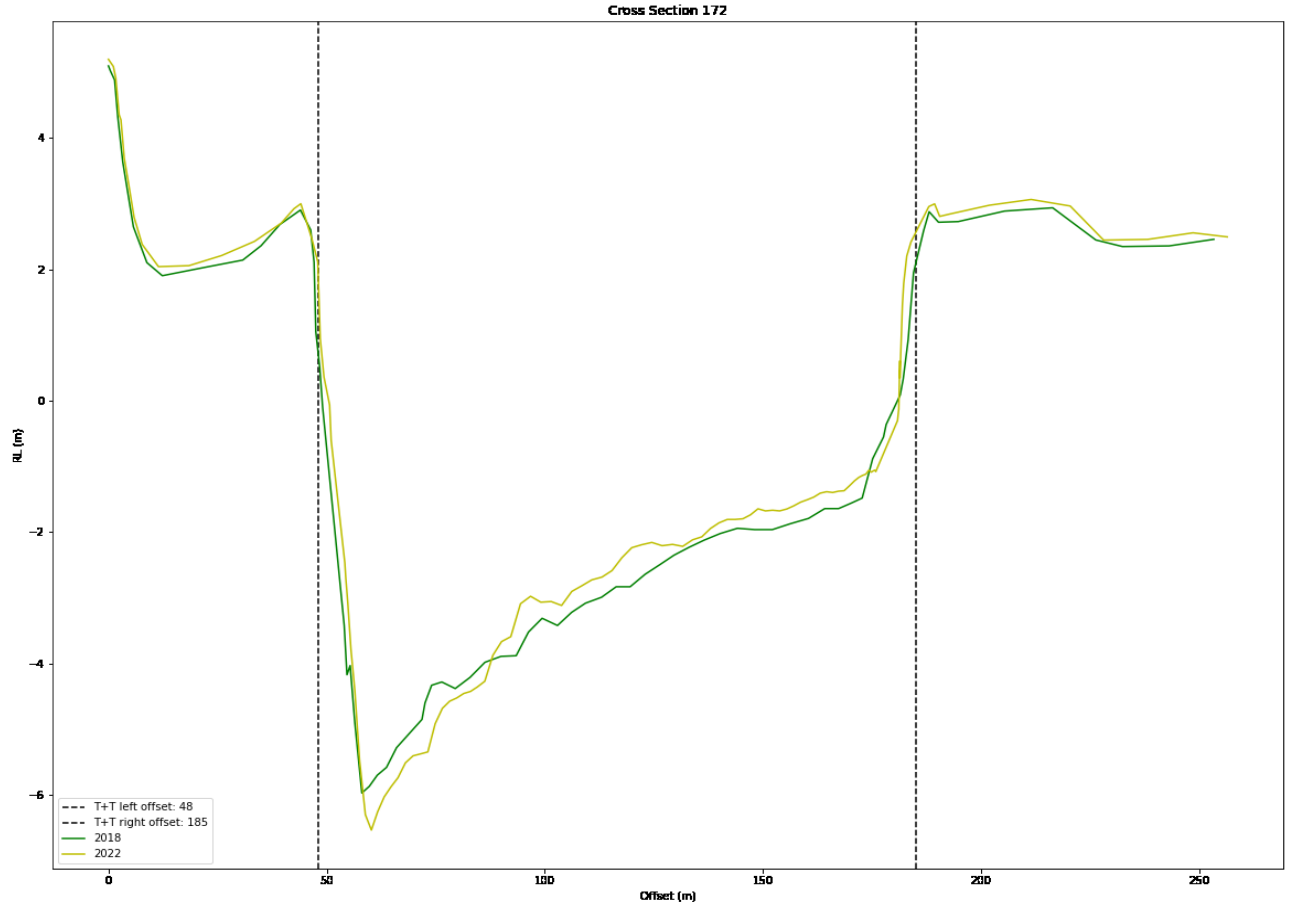

Cross Section 152
RL (m)
Offset (m)
T+T left offset: 23
T+T right offset: 115
2018
2022

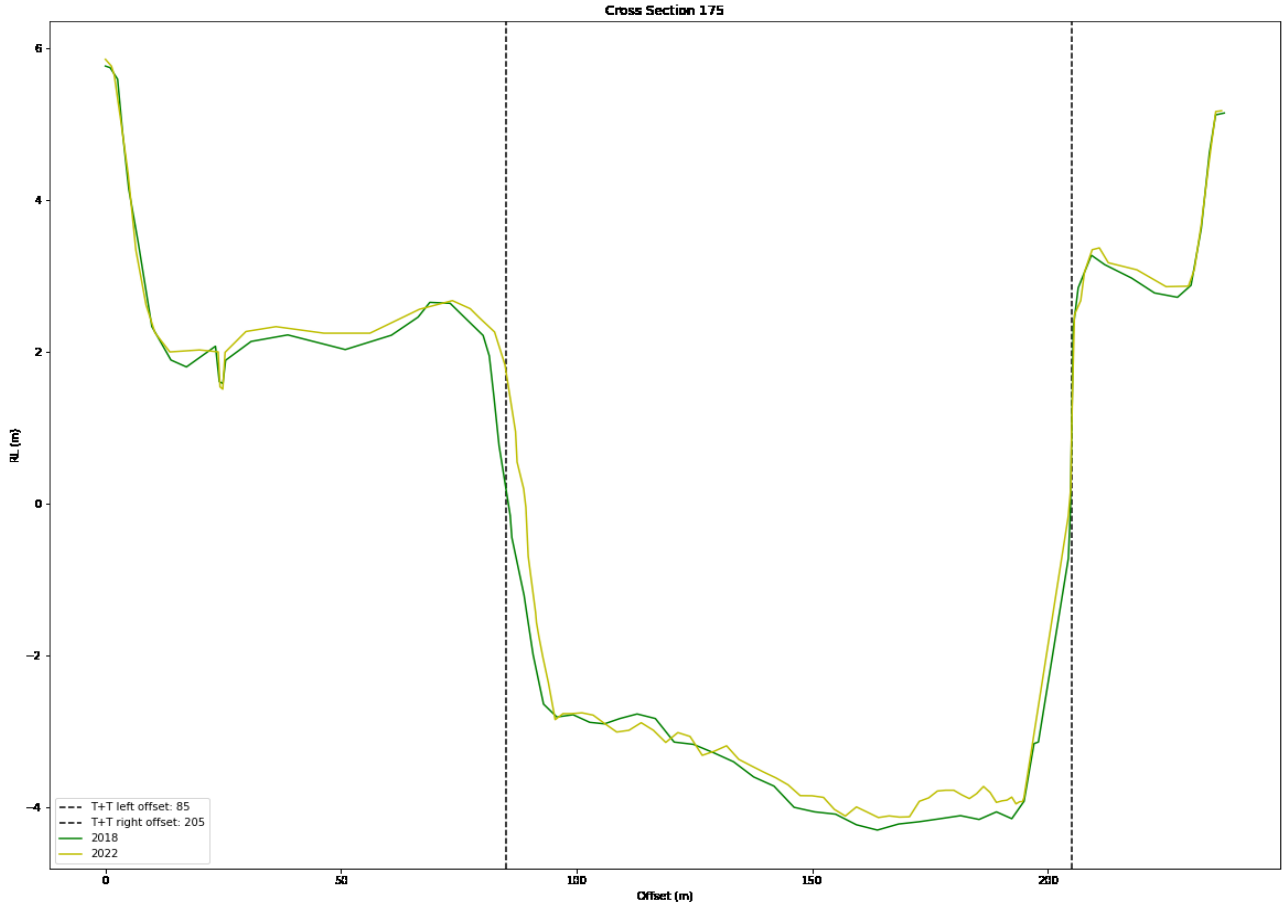

Cross Section 7 MILE
RL (m)
Offset (m)
T+T left offset: 194
T+T right offset: 289
2018
2022

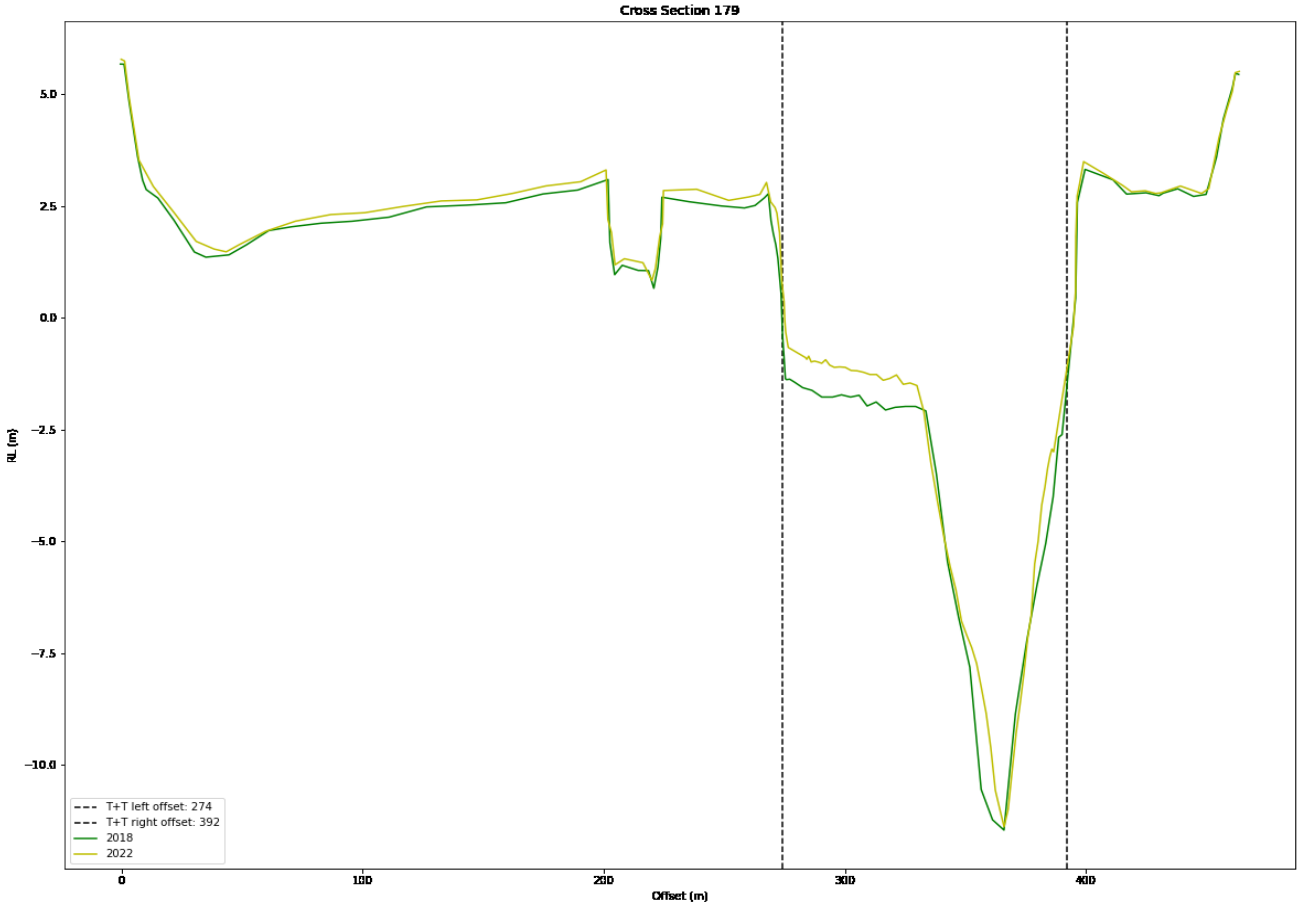

Cross Section 160
RL (m)
Offset (m)
T+T left offset: 110
T+T right offset: 205
2018
2022

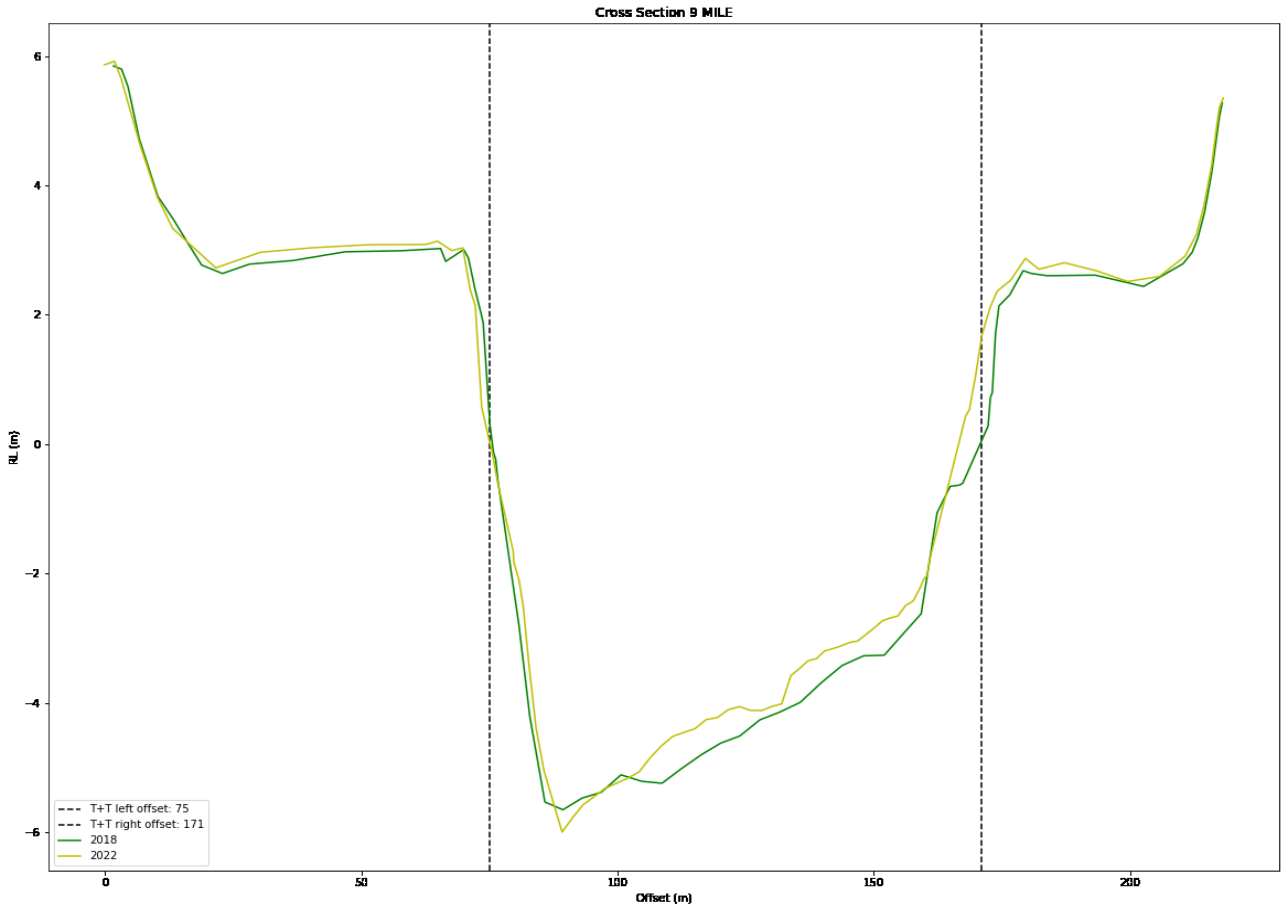

Cross Section 164
RL (m)
Offset (m)
T+T left offset: 44
T+T right offset: 157
2018
2022

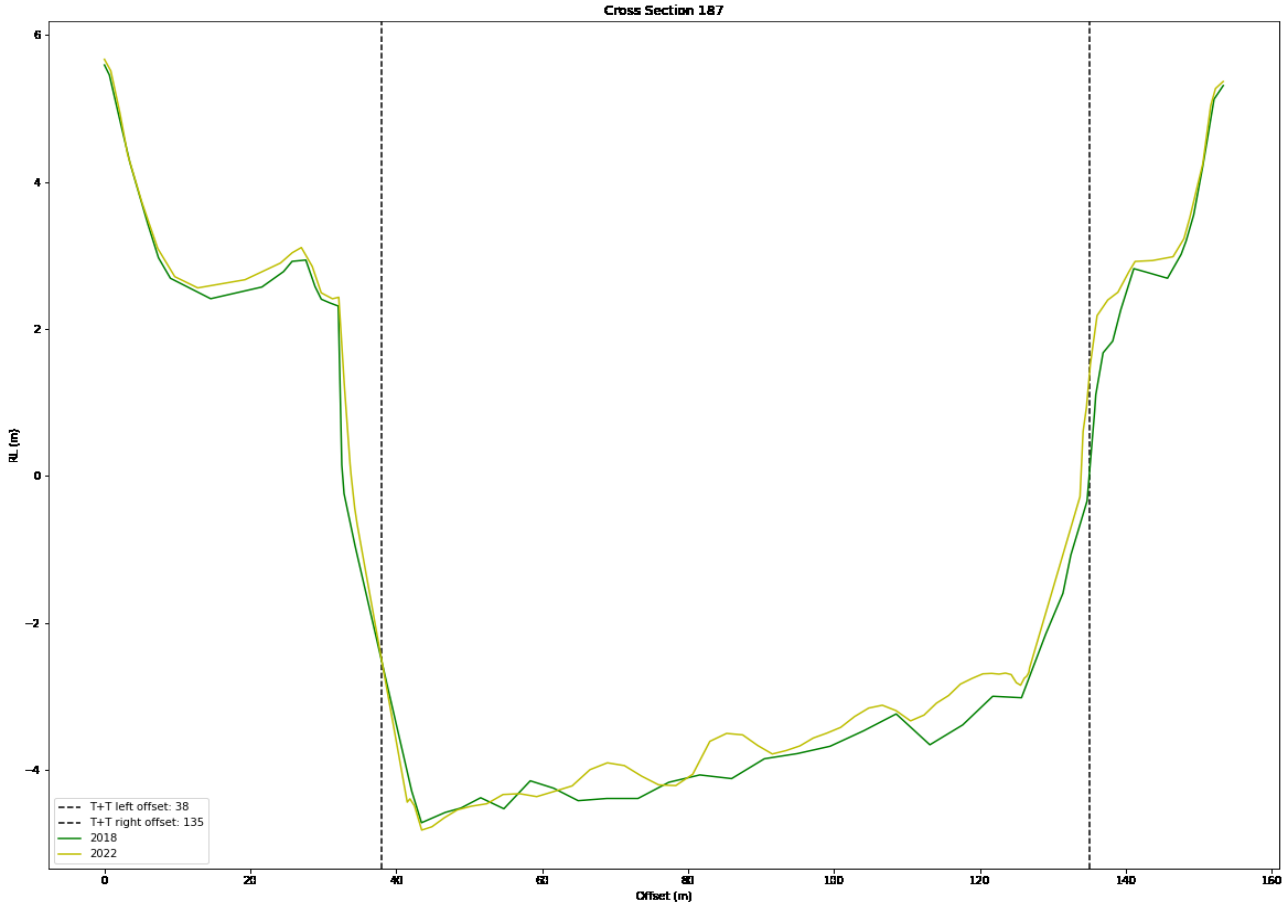

Cross Section B MILE
RL (m)
Offset (m)
T+T left offset: 36
T+T right offset: 137
2018
2022

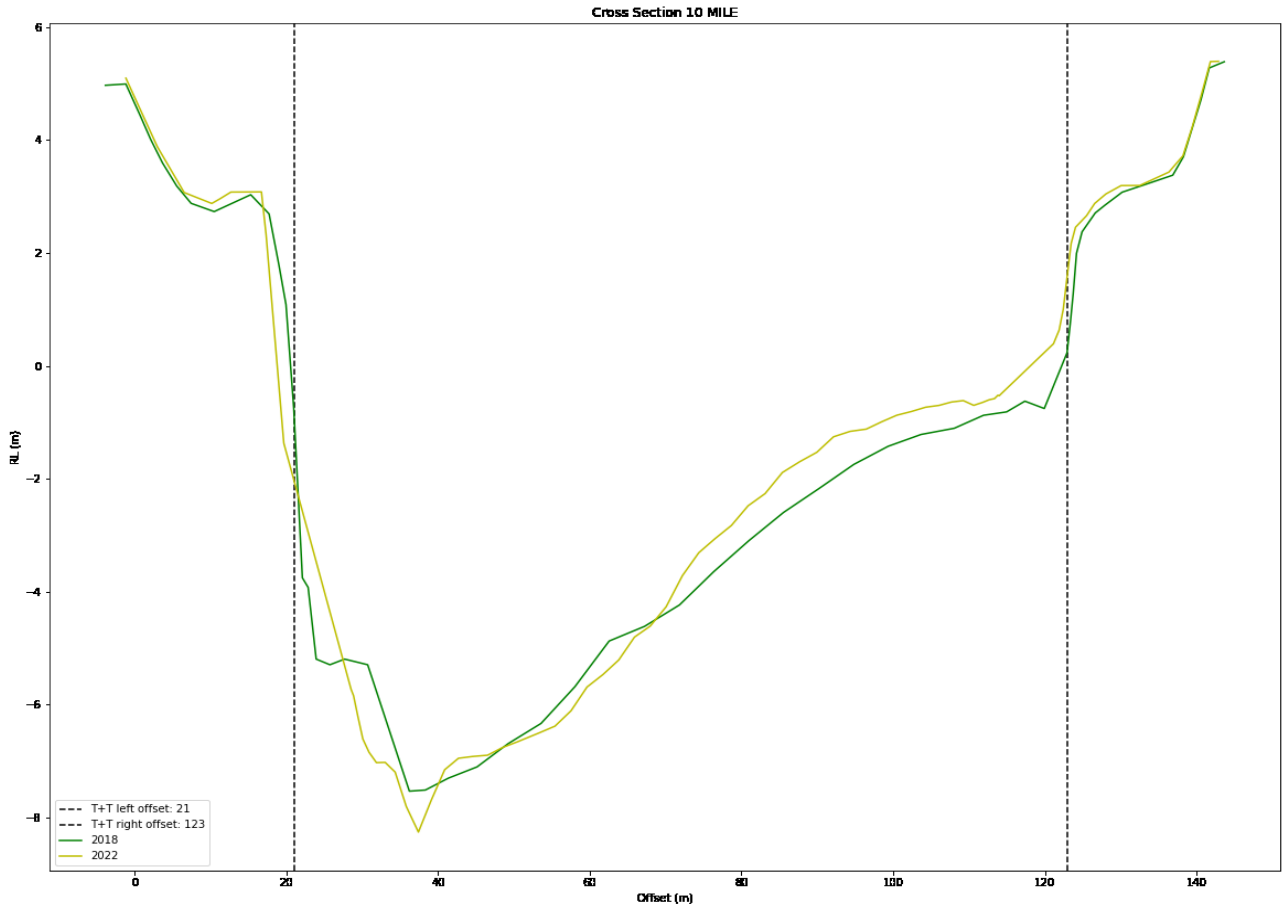

Cross Section 172
RL (m)
Offset (m)
T+T left offset: 48
T+T right offset: 185
2018
2022

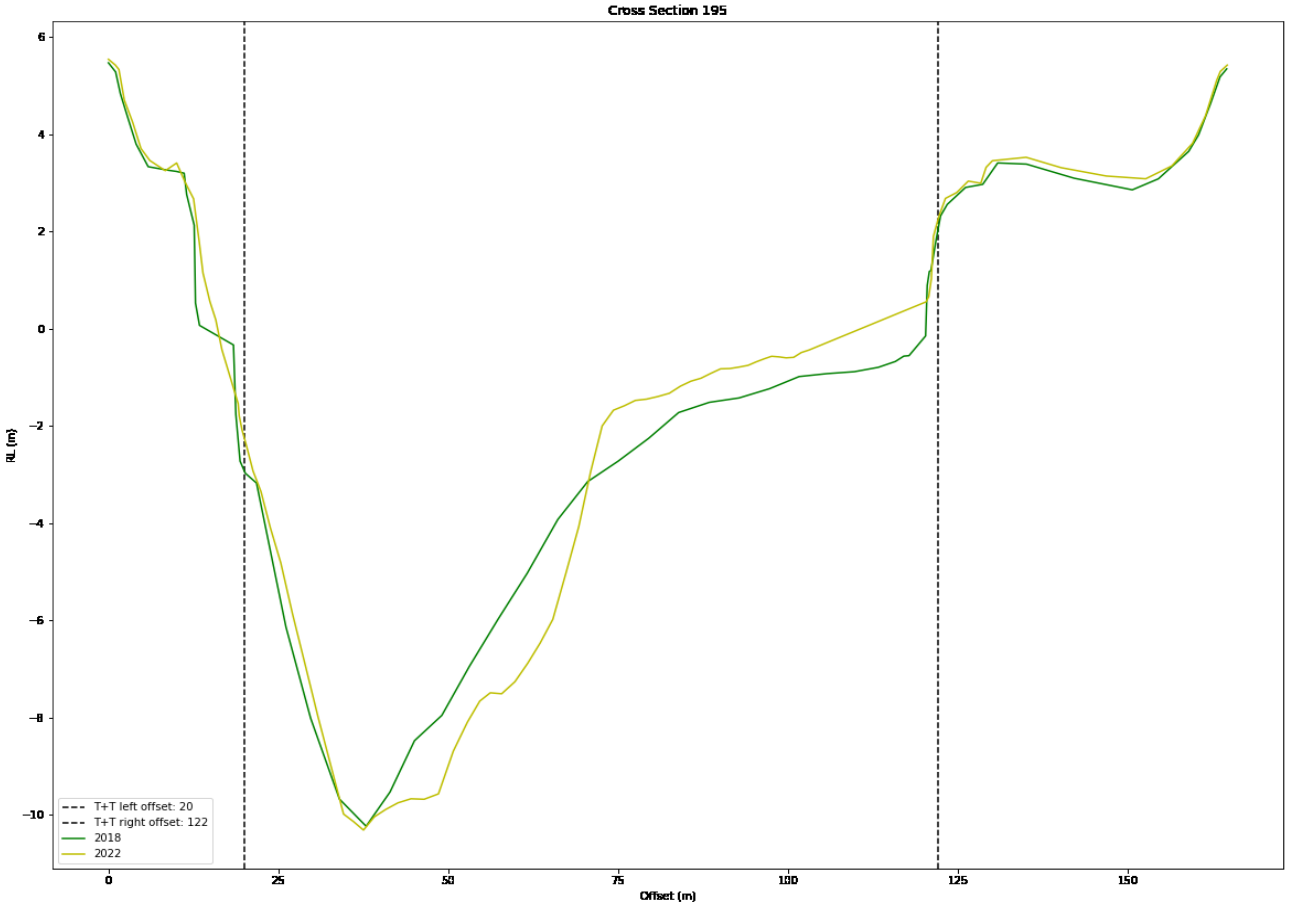

Cross Section 175
RL (m)
Offset (m)
T+T left offset: 85
T+T right offset: 205
2018
2022

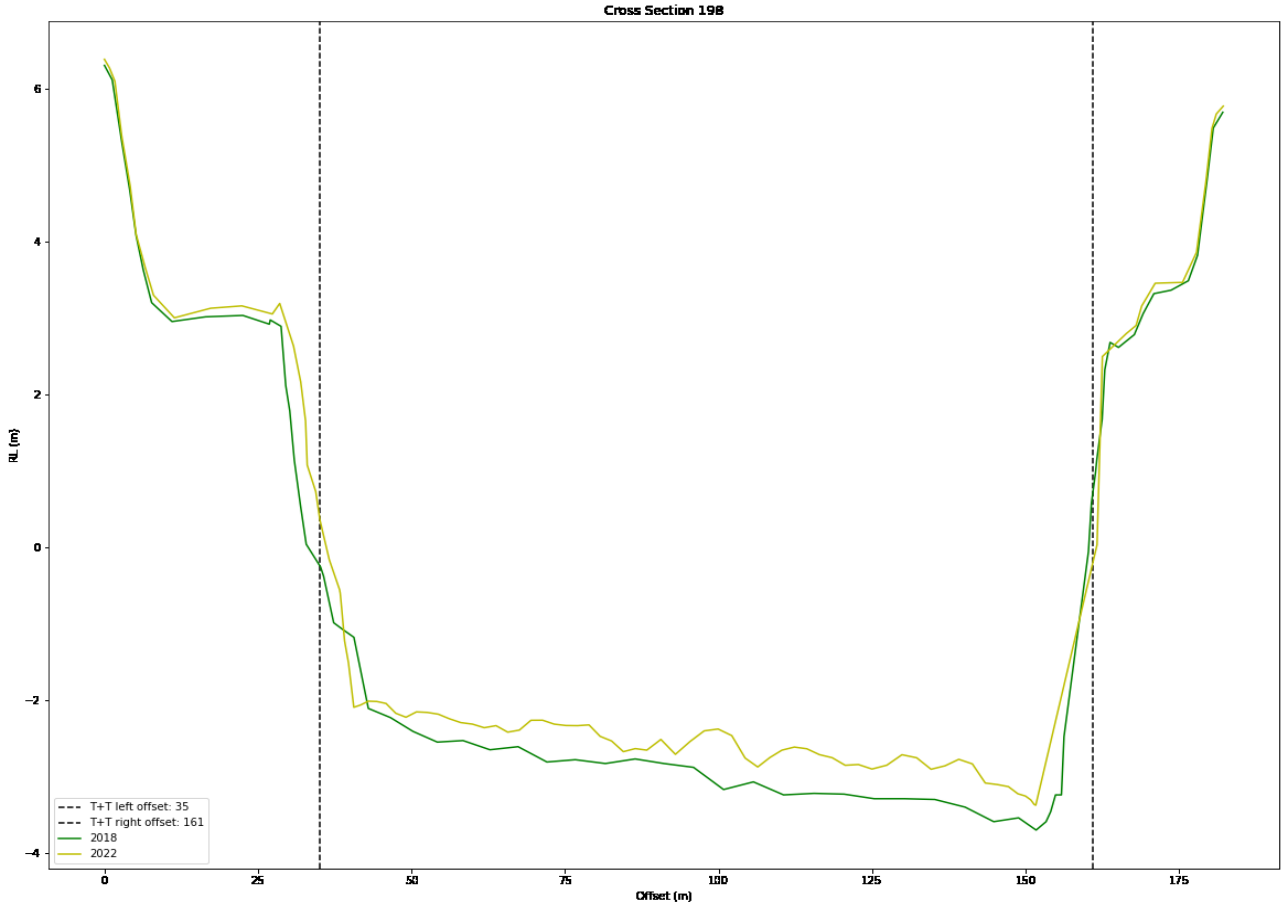

Cross Section 179
RL (m)
Offset (m)
T+T left offset: 274
T+T right offset: 392
2018
2022

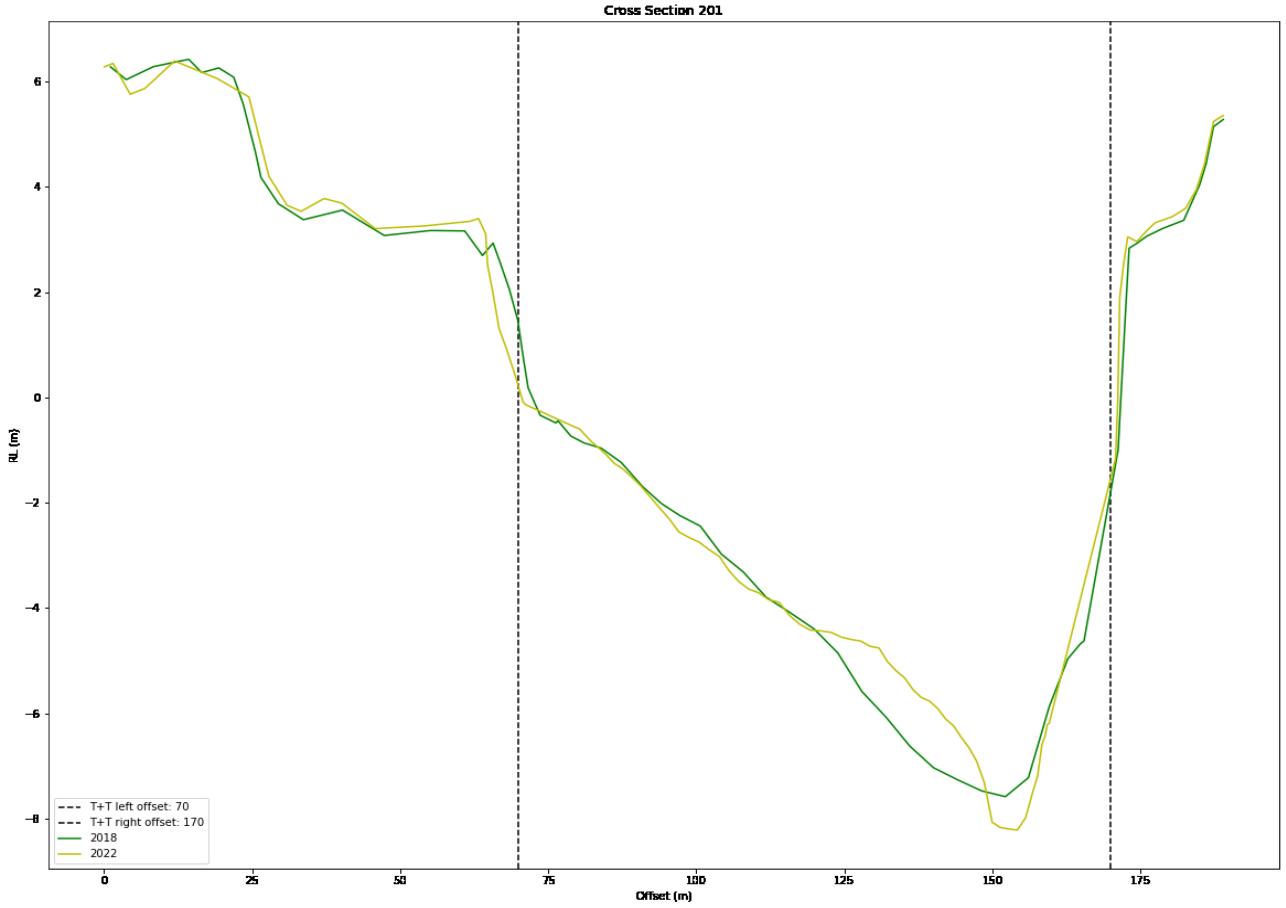

Cross Section 9 MILE
RL (m)
Offset (m)
T+T left offset: 75
T+T right offset: 171
2018
2022

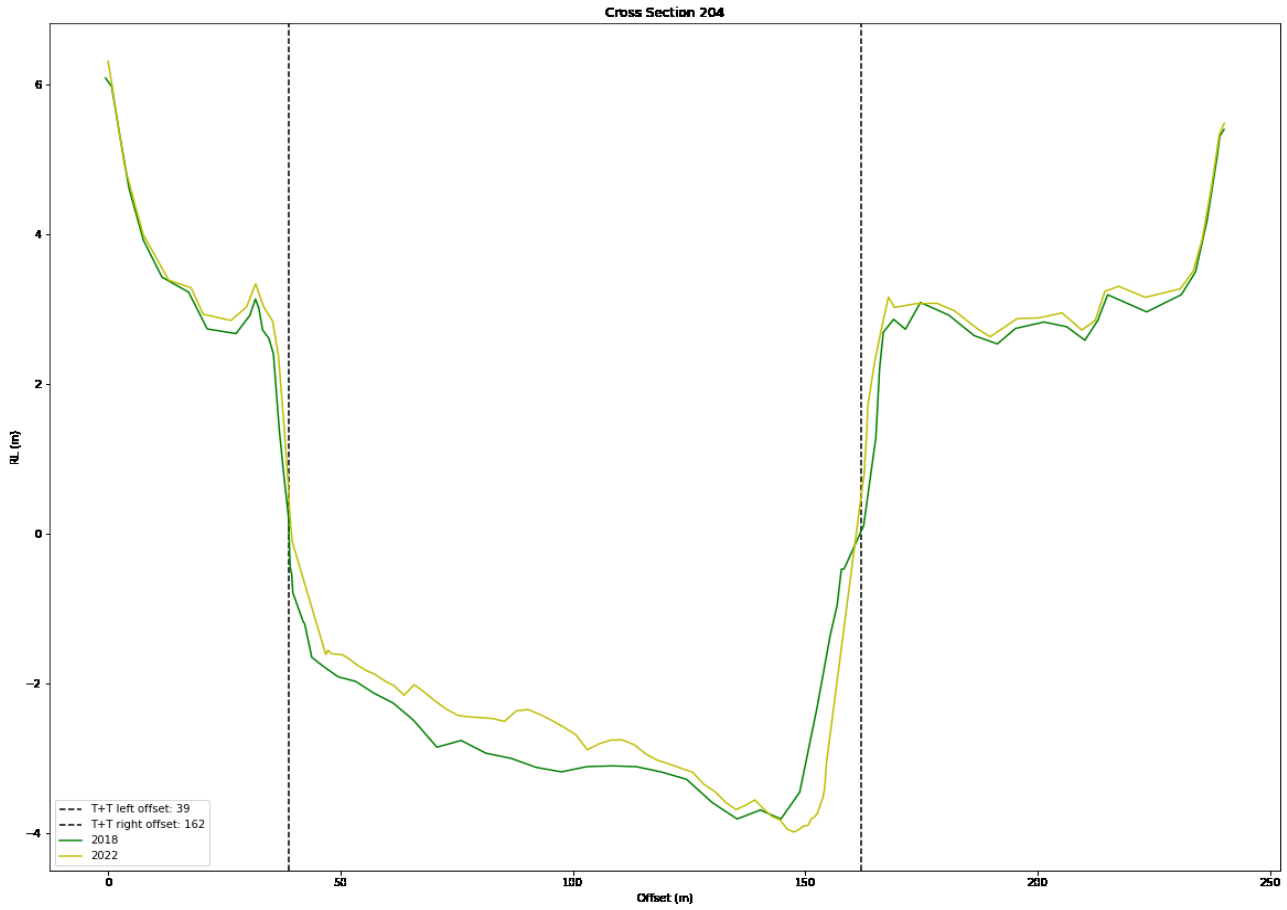

Cross Section 187
RL (m)
Offset (m)
T+T left offset: 38
T+T right offset: 135
2018
2022

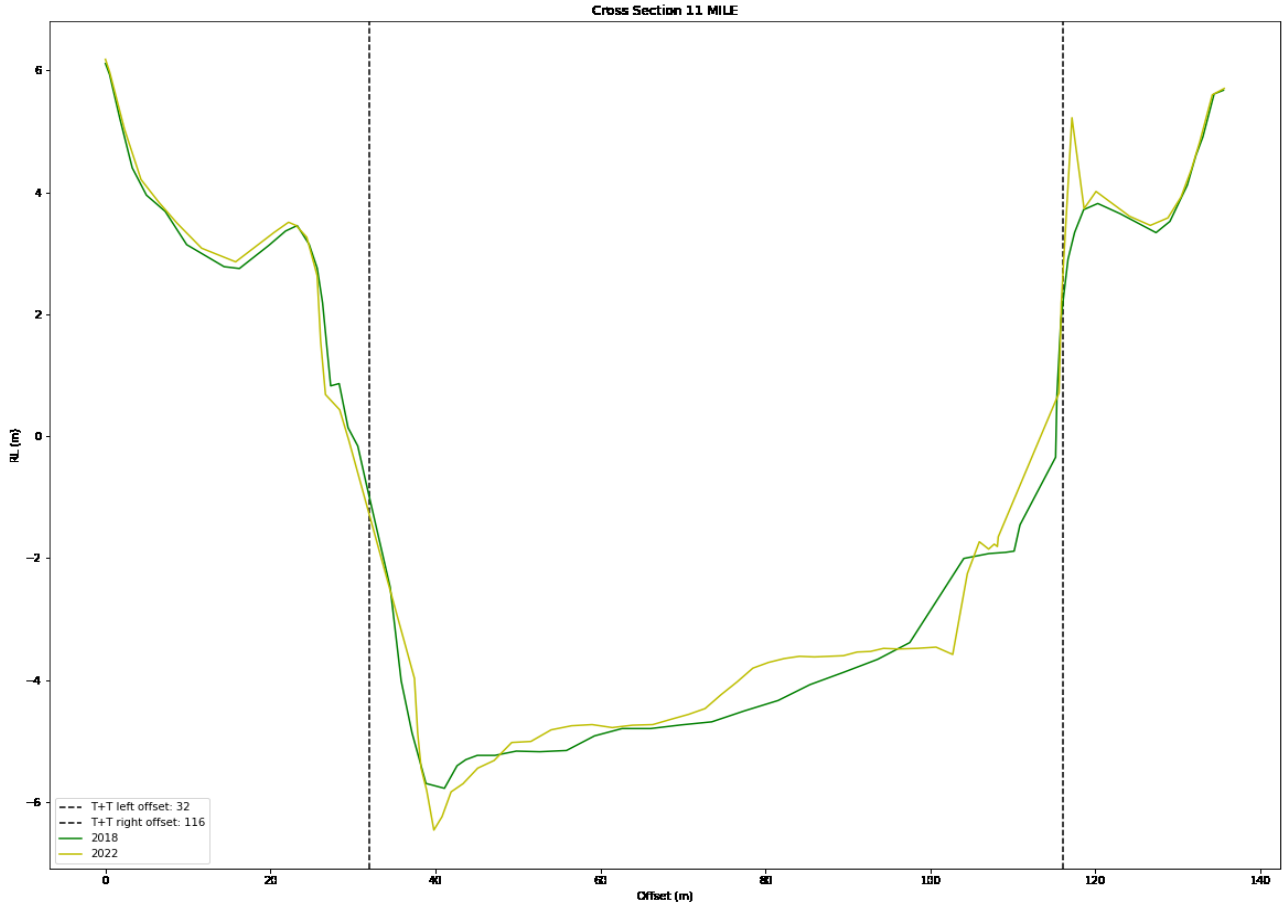

Cross Section 10 MILE
RL (m)
Offset (m)
T+T left offset: 21
T+T right offset: 123
2018
2022

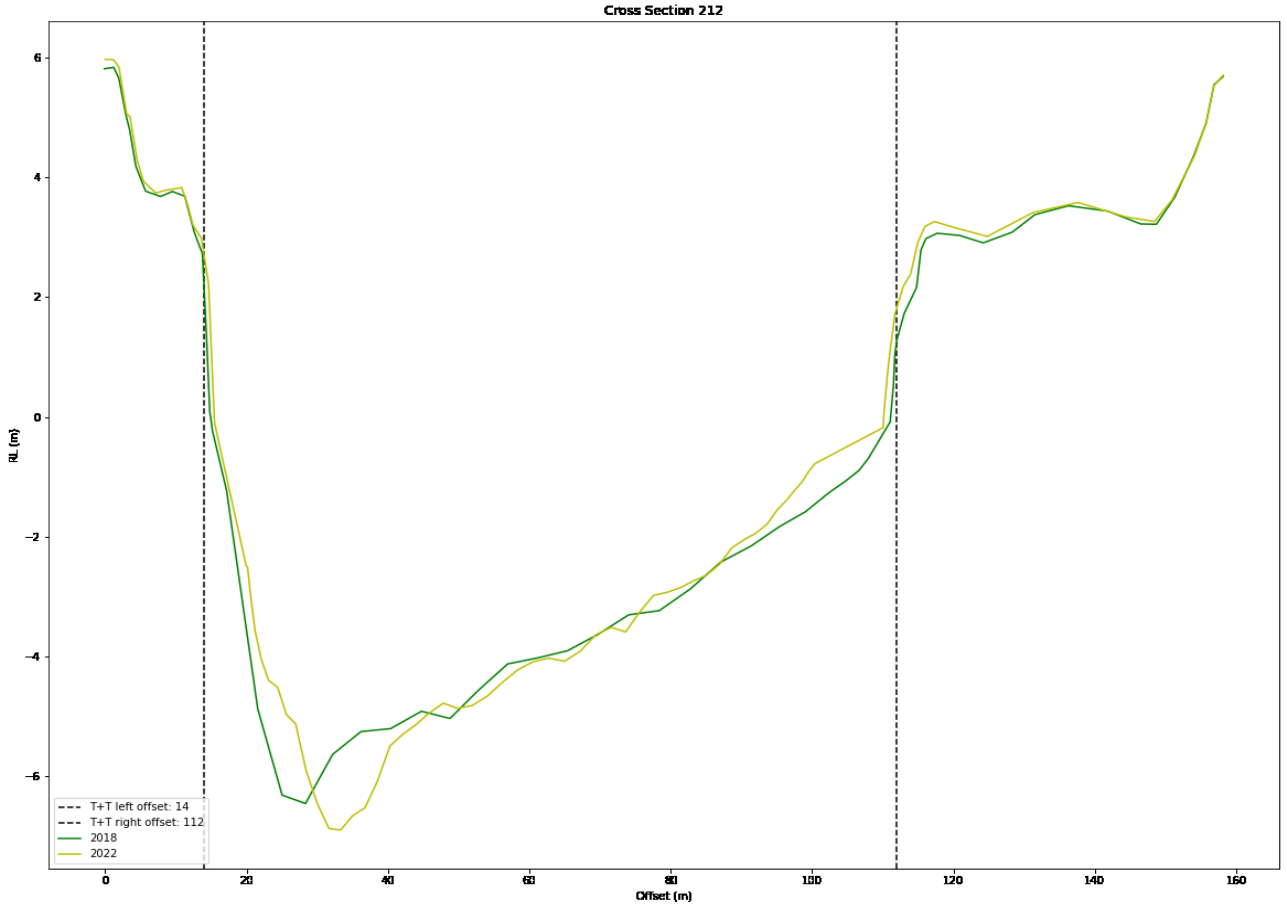

Cross Section 195
RL (m)
Offset (m)
T+T left offset: 20
T+T right offset: 122
2018
2022

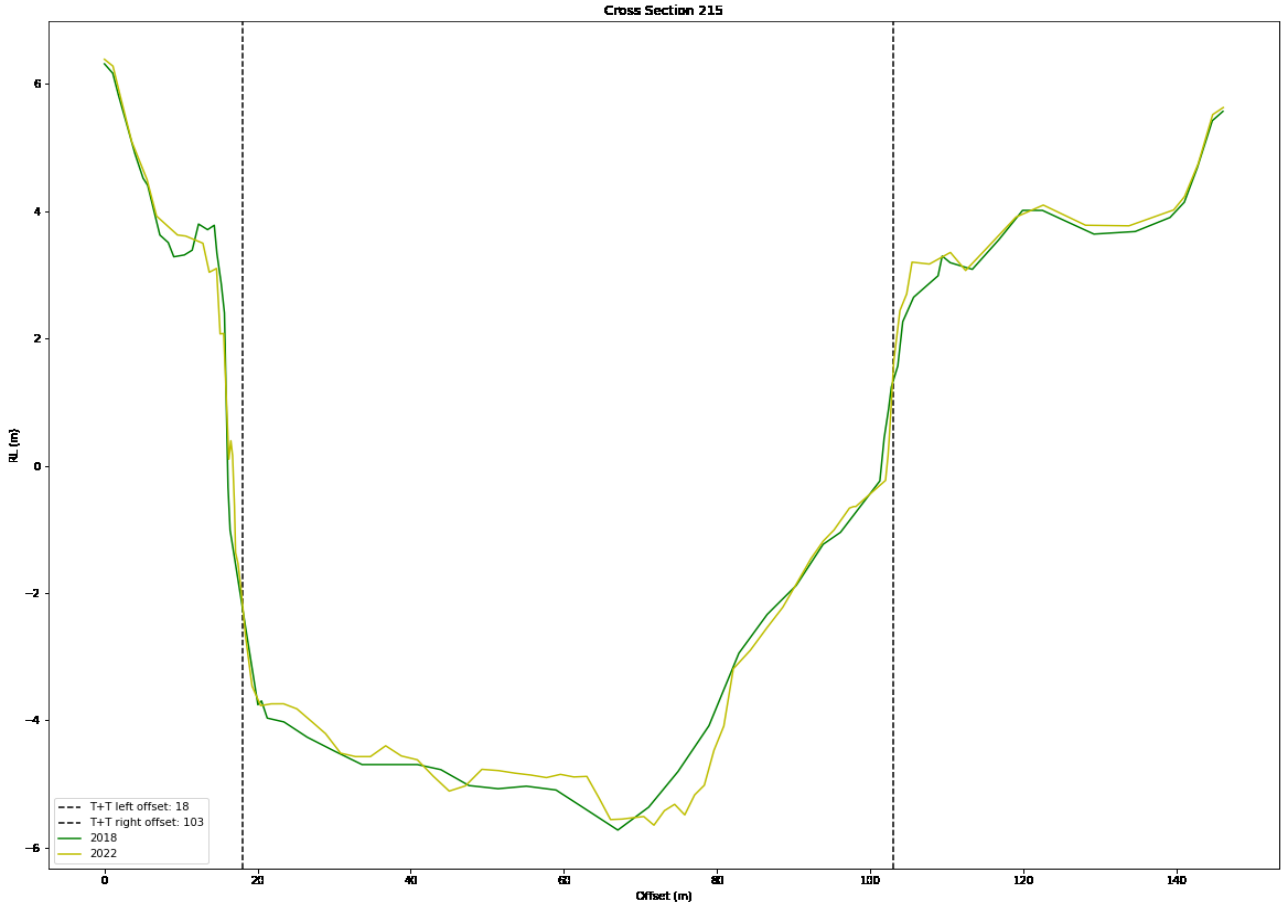

Cross Section 198
RL (m)
Offset (m)
T+T left offset: 35
T+T right offset: 161
2018
2022

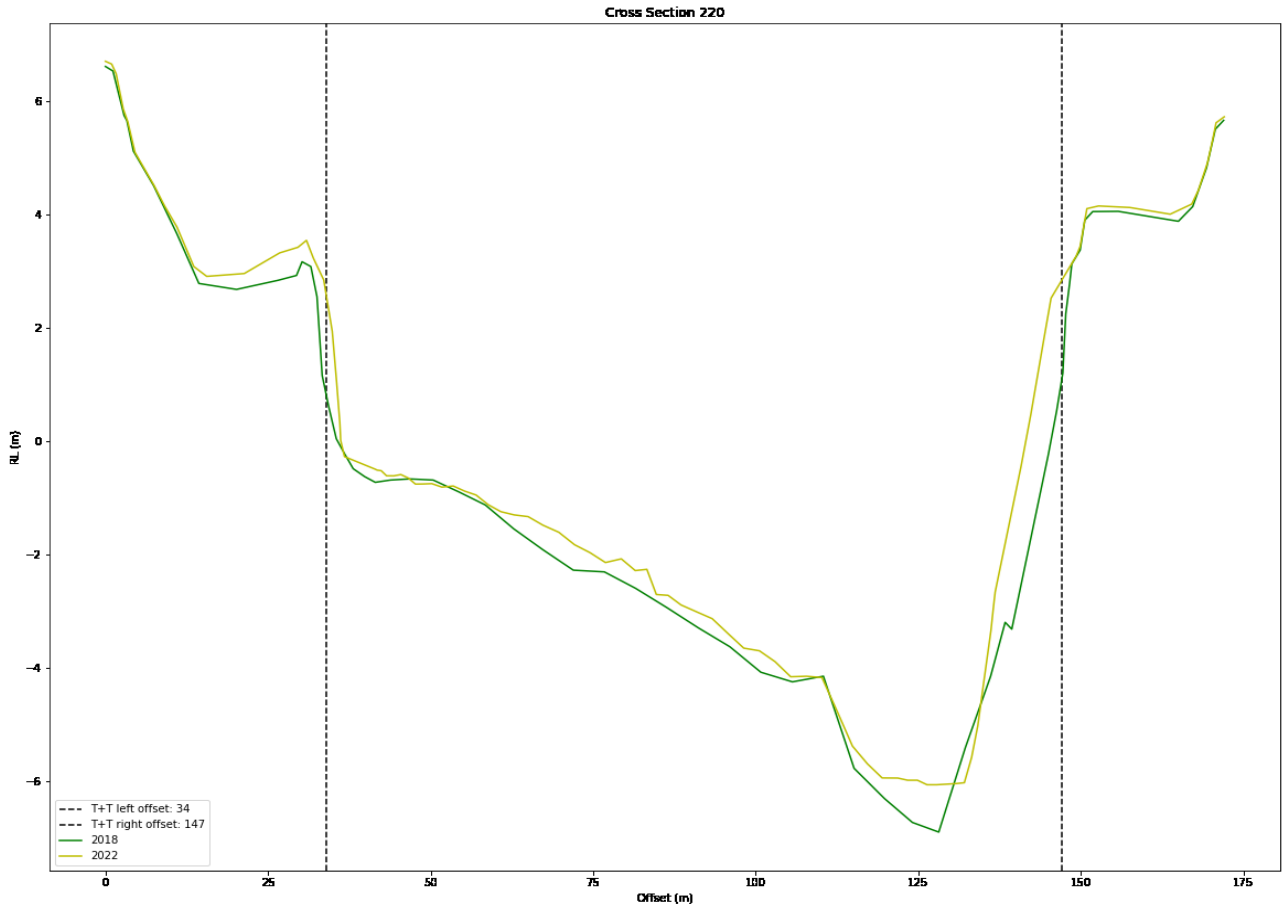

Cross Section 201
RL (m)
Offset (m)
T+T left offset: 70
T+T right offset: 170
2018
2022

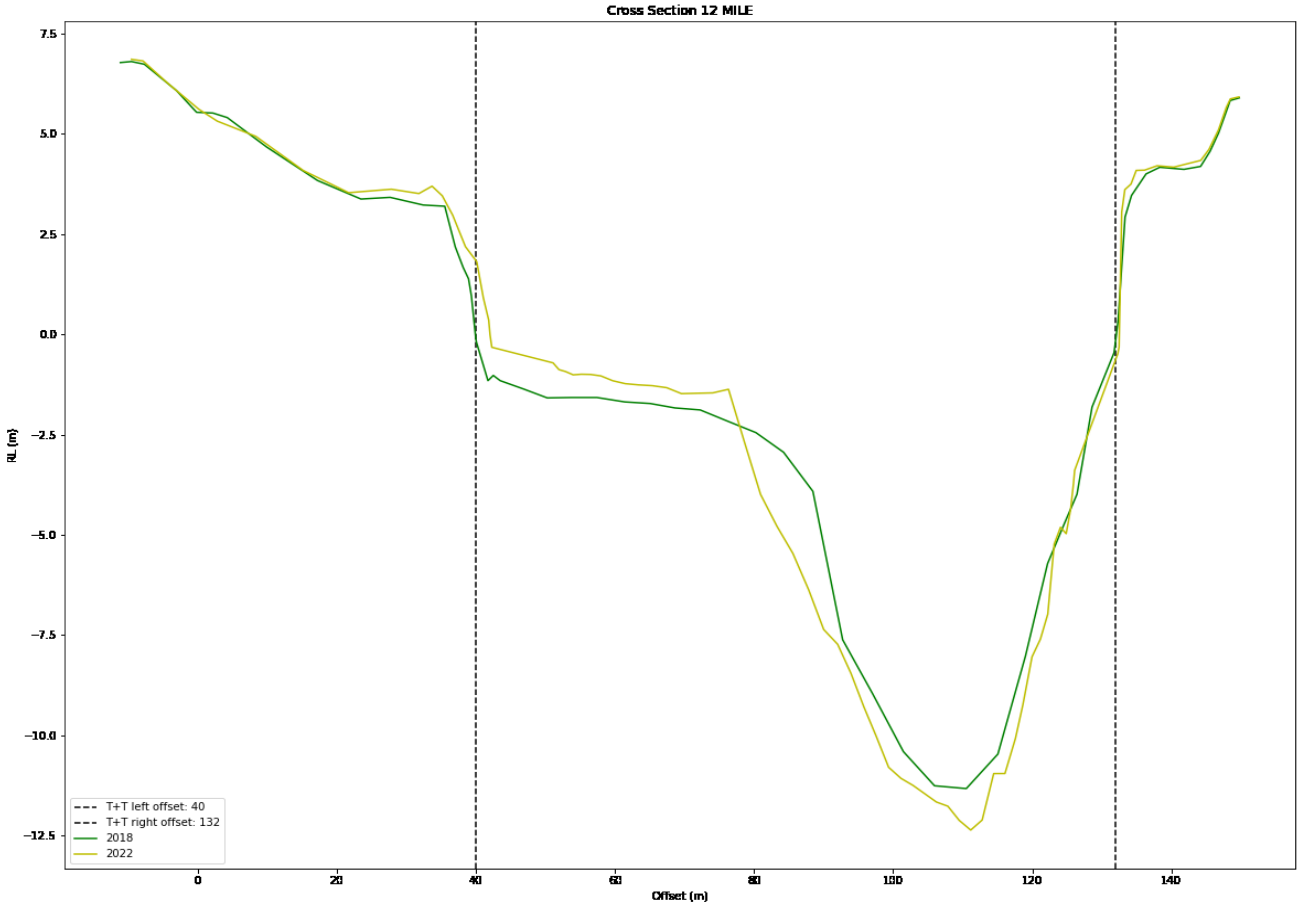

Cross Section 204
RL (m)
Offset (m)
T+T left offset: 39
T+T right offset: 162
2018
2022

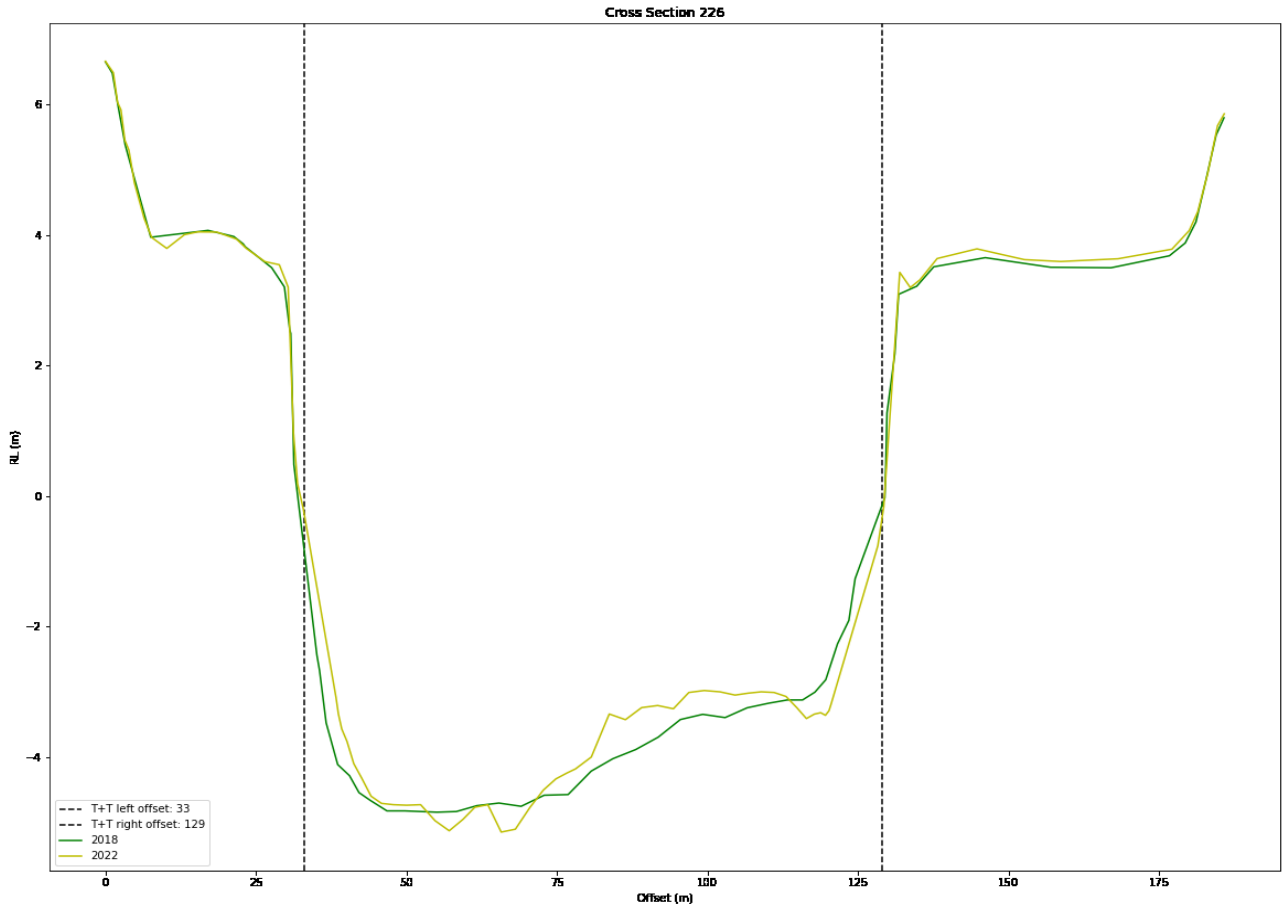

Cross Section 11 MILE
RL (m)
Offset (m)
T+T left offset: 32
T+T right offset: 116
2018
2022

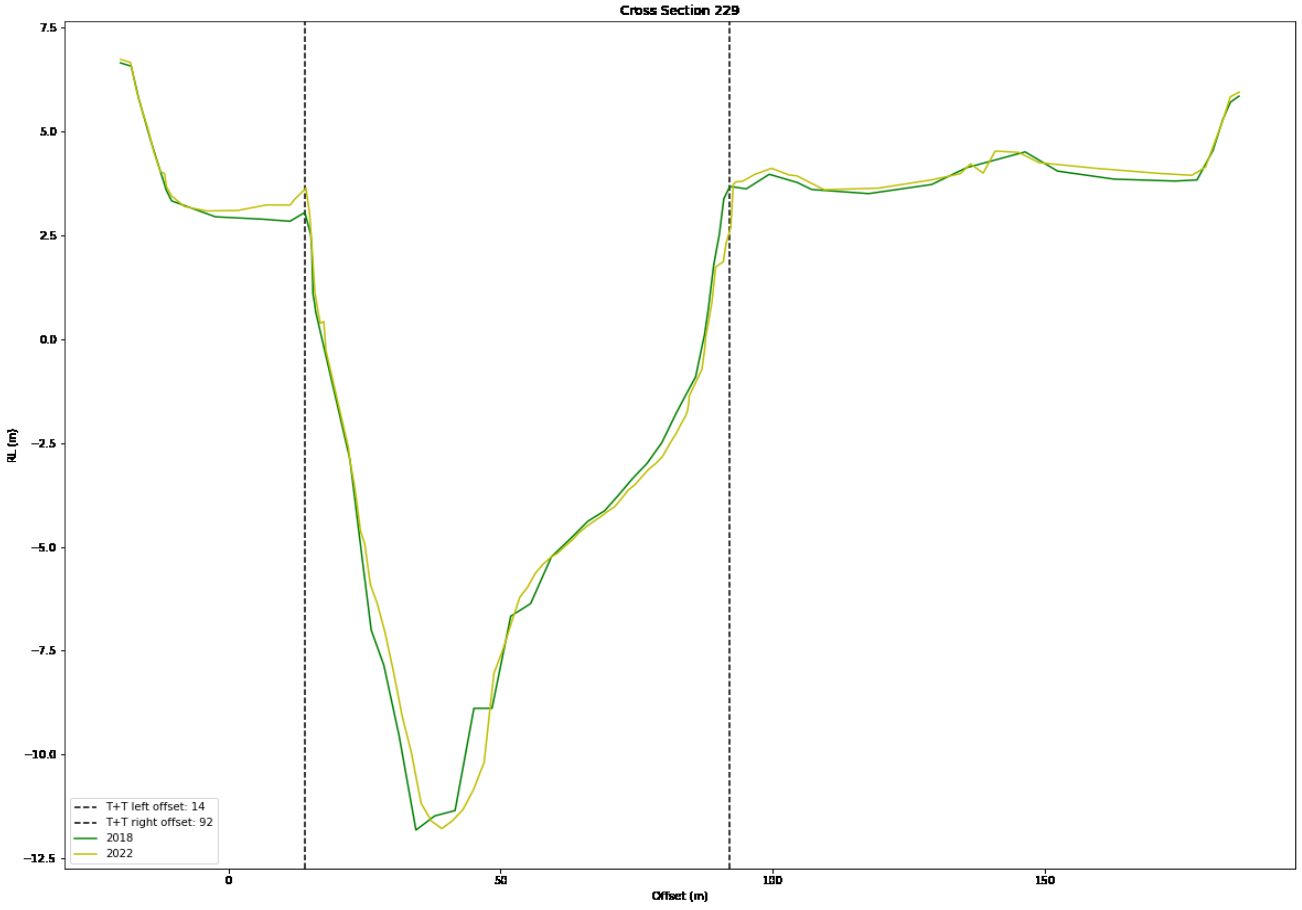

Cross Section 212
RL (m)
Offset (m)
T+T left offset: 14
T+T right offset: 112
2018
2022

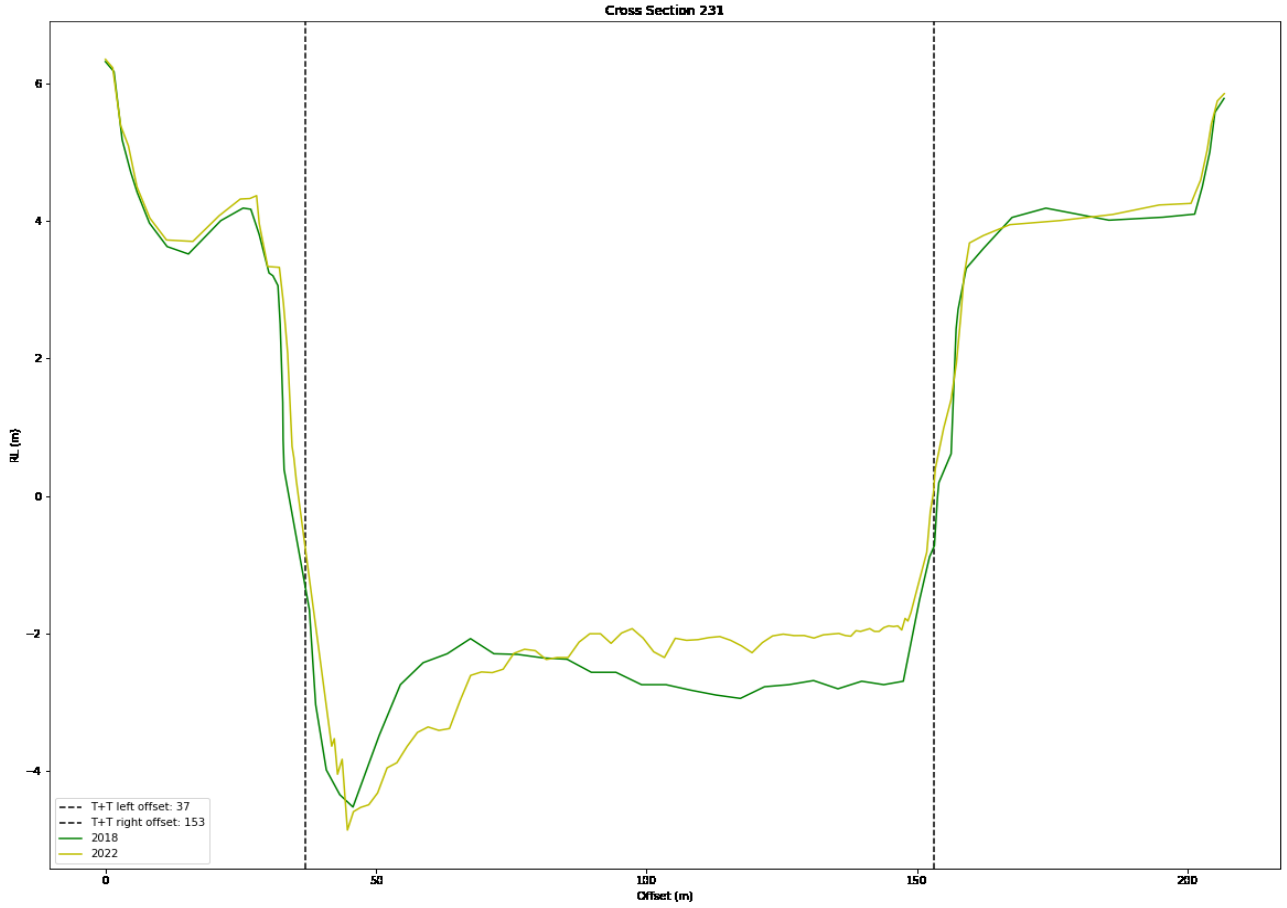

Cross Section 215
RL (m)
Offset (m)
T+T left offset: 18
T+T right offset: 103
2018
2022

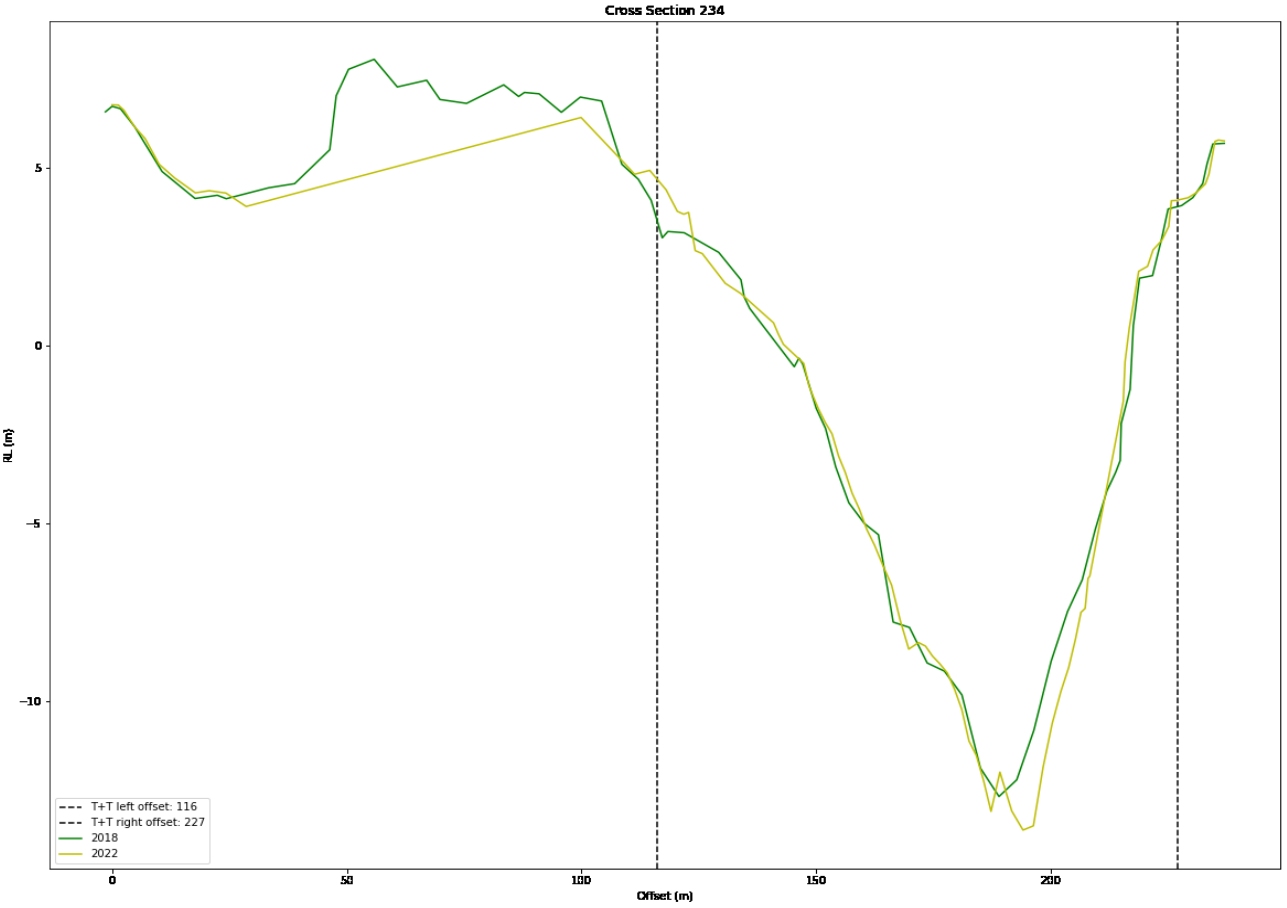

Cross Section 220
RL (m)
Offset (m)
T+T left offset: 34
T+T right offset: 147
2018
2022

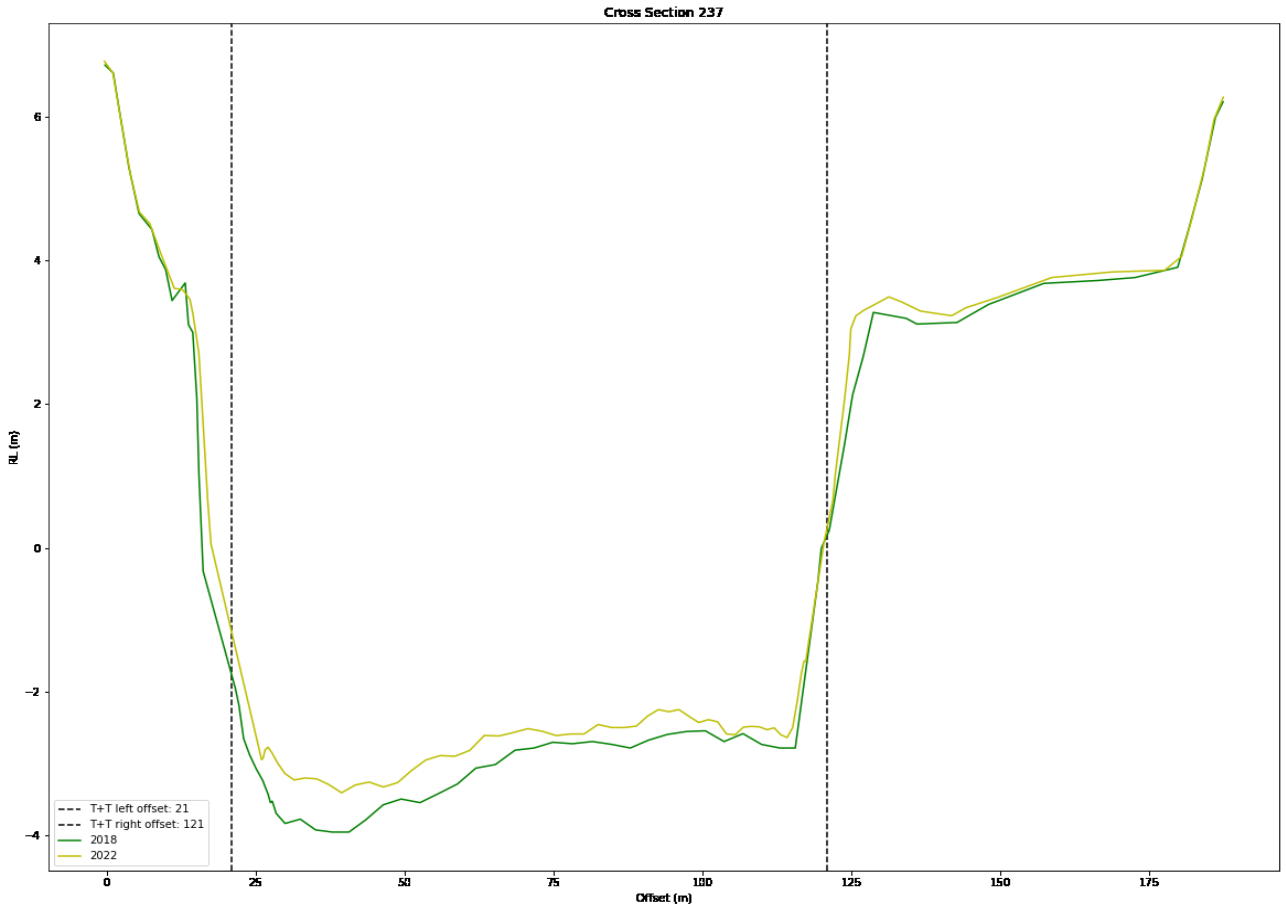

Cross Section 12 MILE
RL (m)
Offset (m)
T+T left offset: 40
T+T right offset: 132
2018
2022

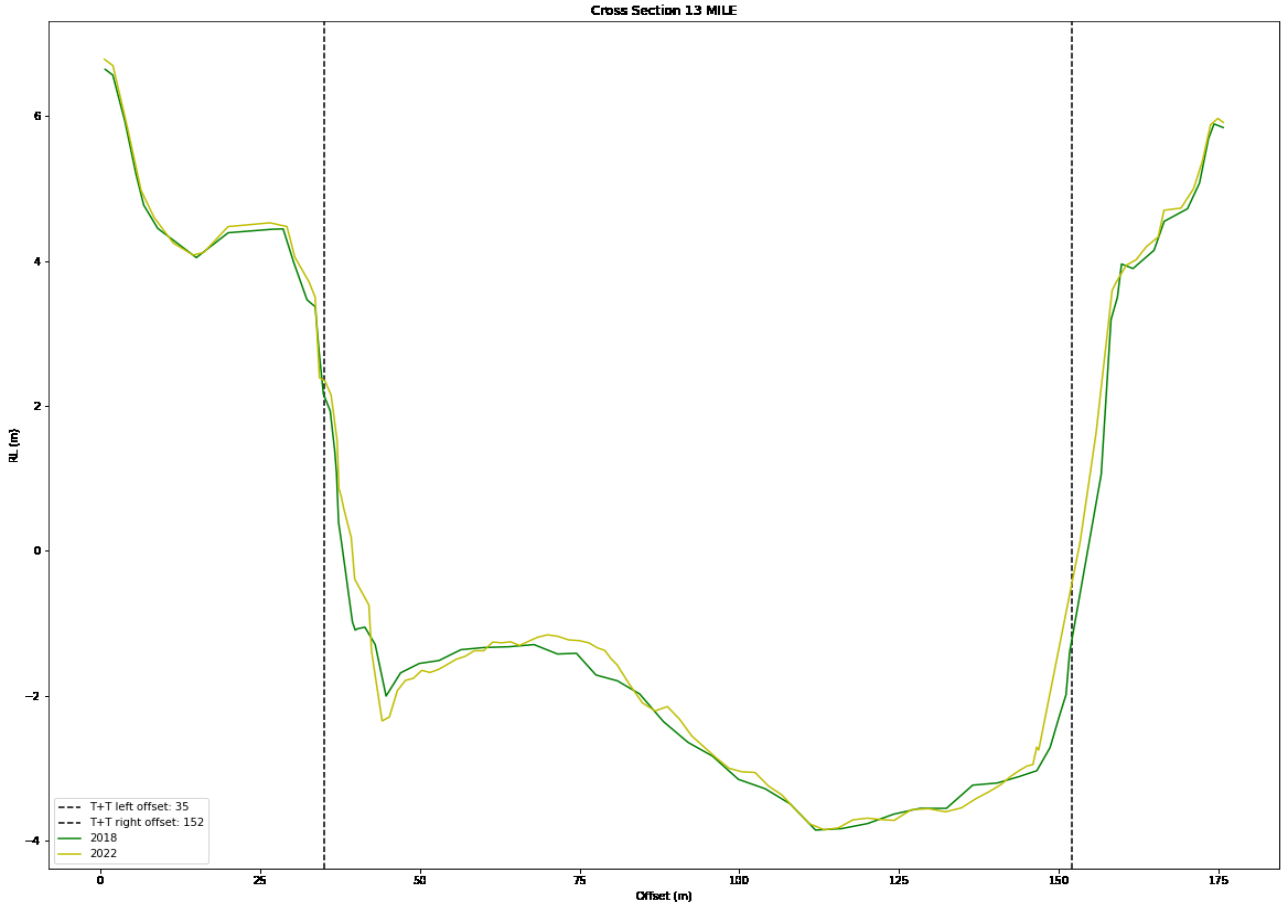

Cross Section 226
RL (m)
Offset (m)
T+T left offset: 33
T+T right offset: 129
2018
2022

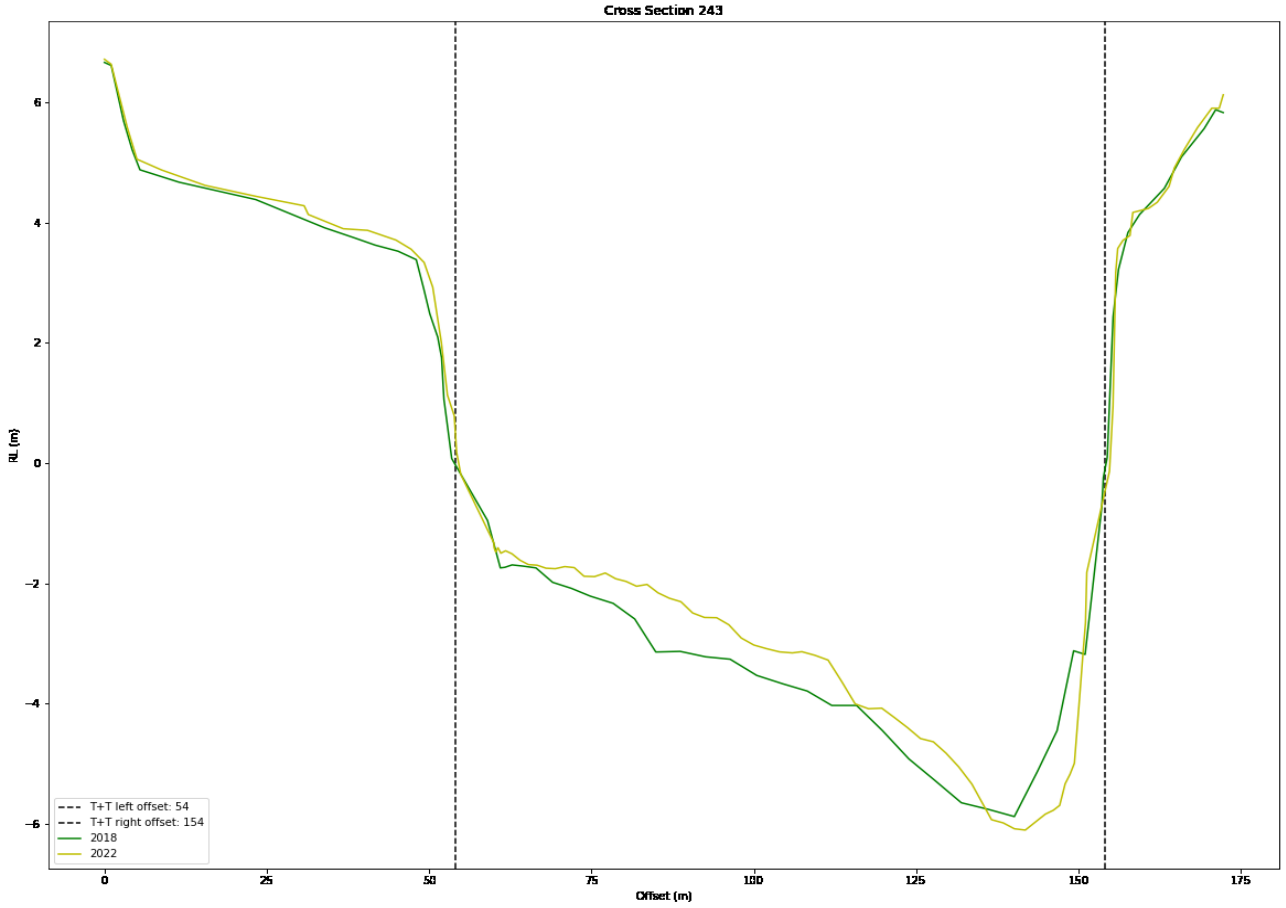

Cross Section 229
RL (m)
Offset (m)
T+T left offset: 14
T+T right offset: 92
2018
2022

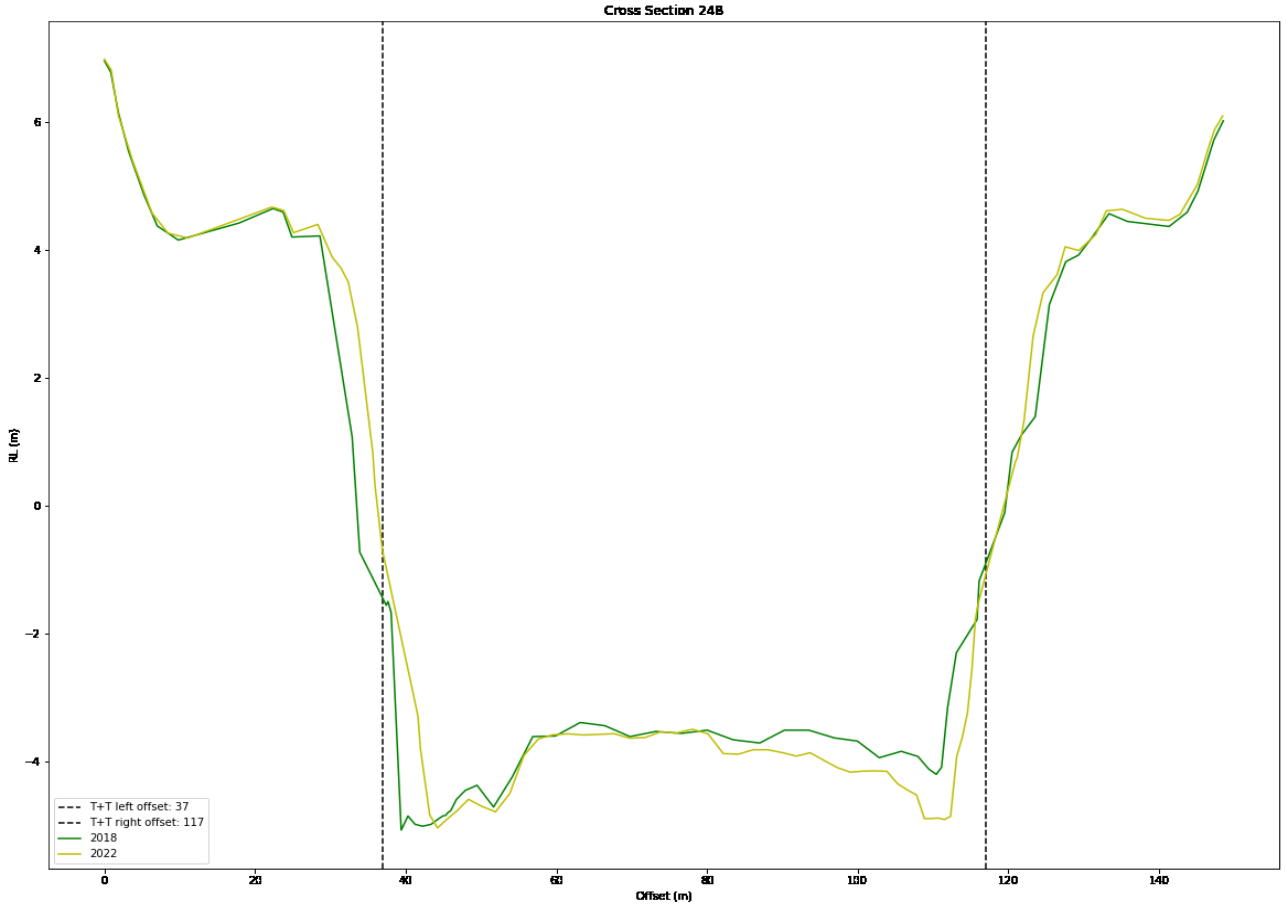

Cross Section 231
RL (m)
Offset (m)
T+T left offset: 37
T+T right offset: 153
2018
2022

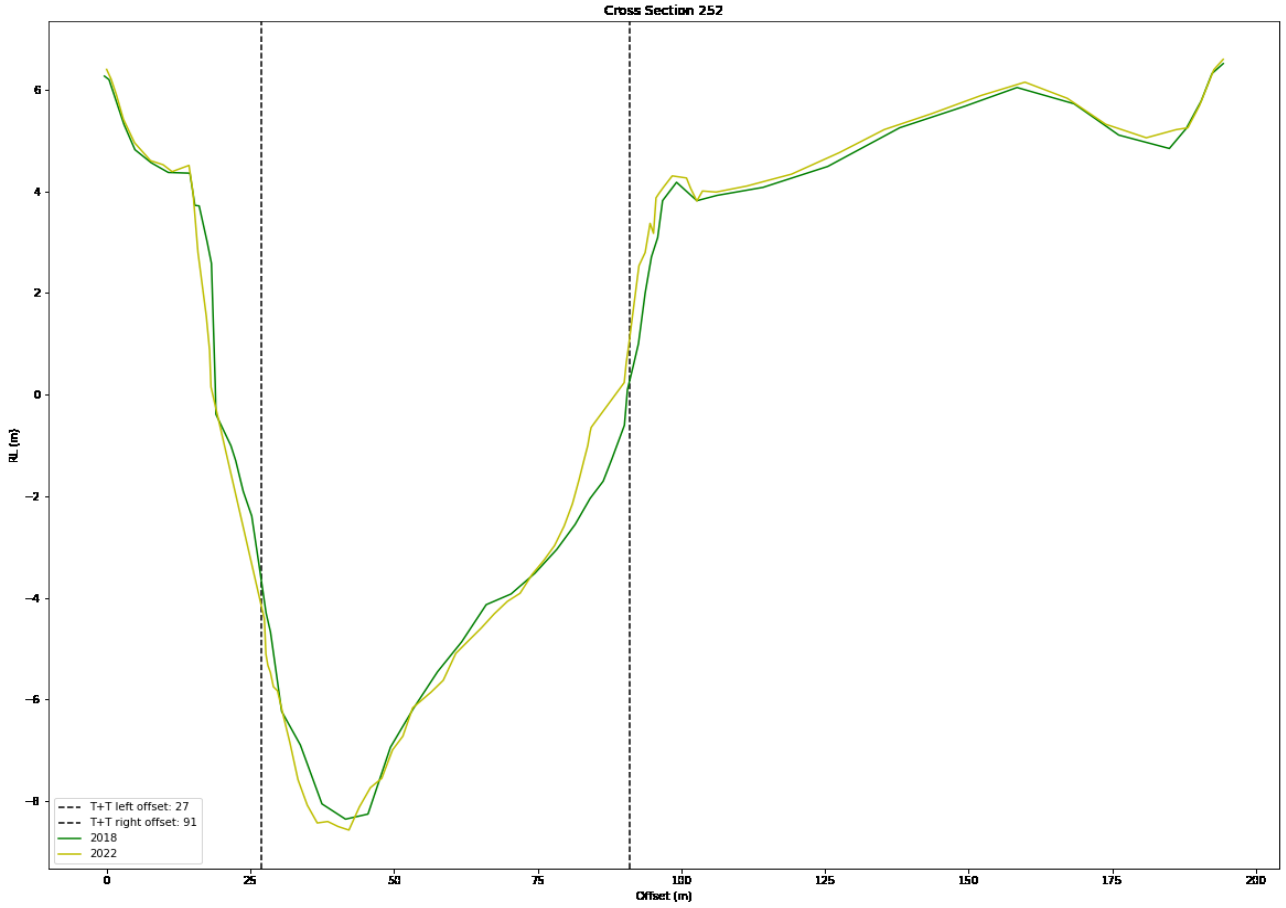

Cross Section 234
RL (m)
Offset (m)
T+T left offset: 116
T+T right offset: 227
2018
2022

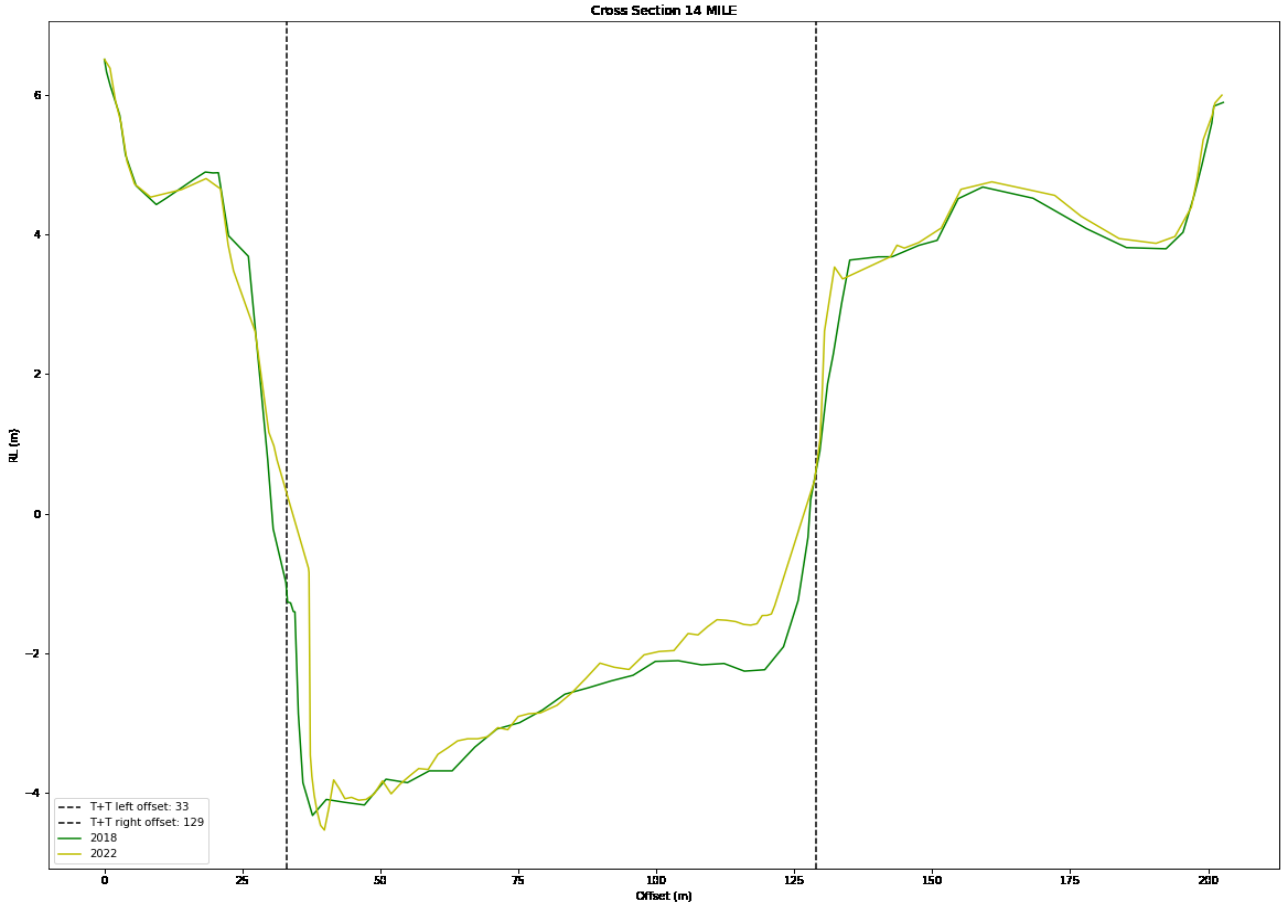

Cross Section 237
RL (m)
Offset (m)
T+T left offset: 21
T+T right offset: 121
2018
2022

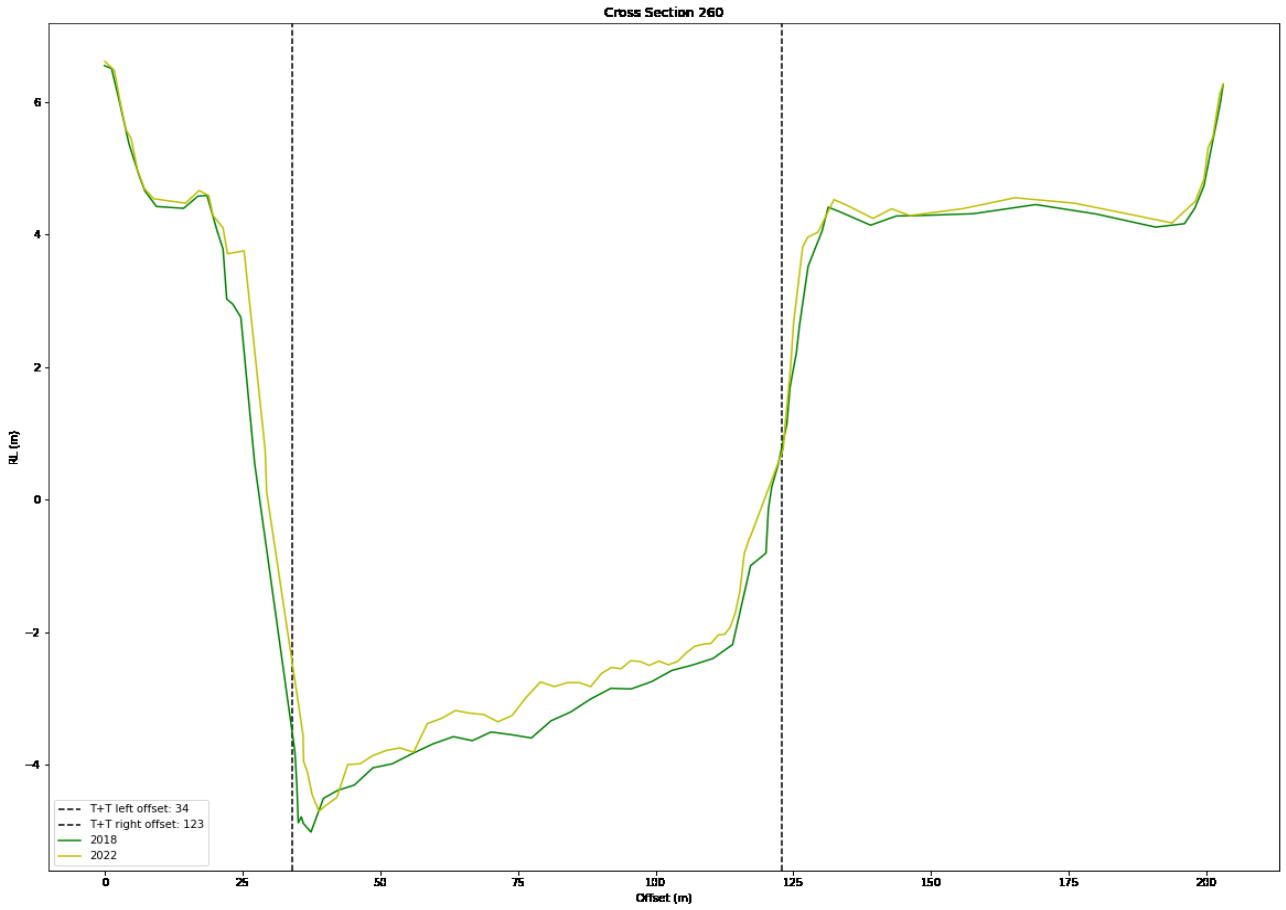

Cross Section 13 MILE
RL (m)
Offset (m)
T+T left offset: 35
T+T right offset: 152
2018
2022

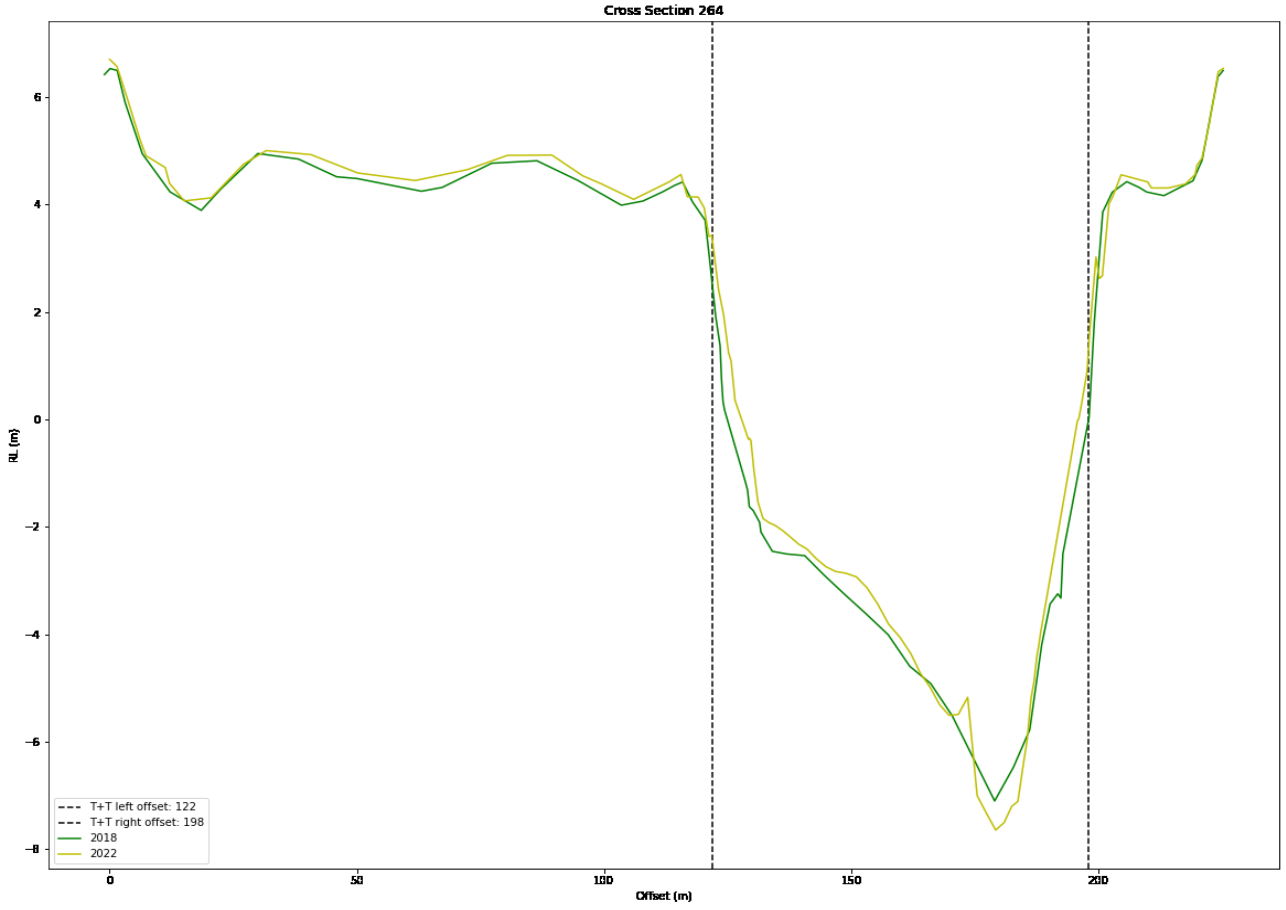

Cross Section 243
RL (m)
Offset (m)
T+T left offset: 54
T+T right offset: 154
2018
2022

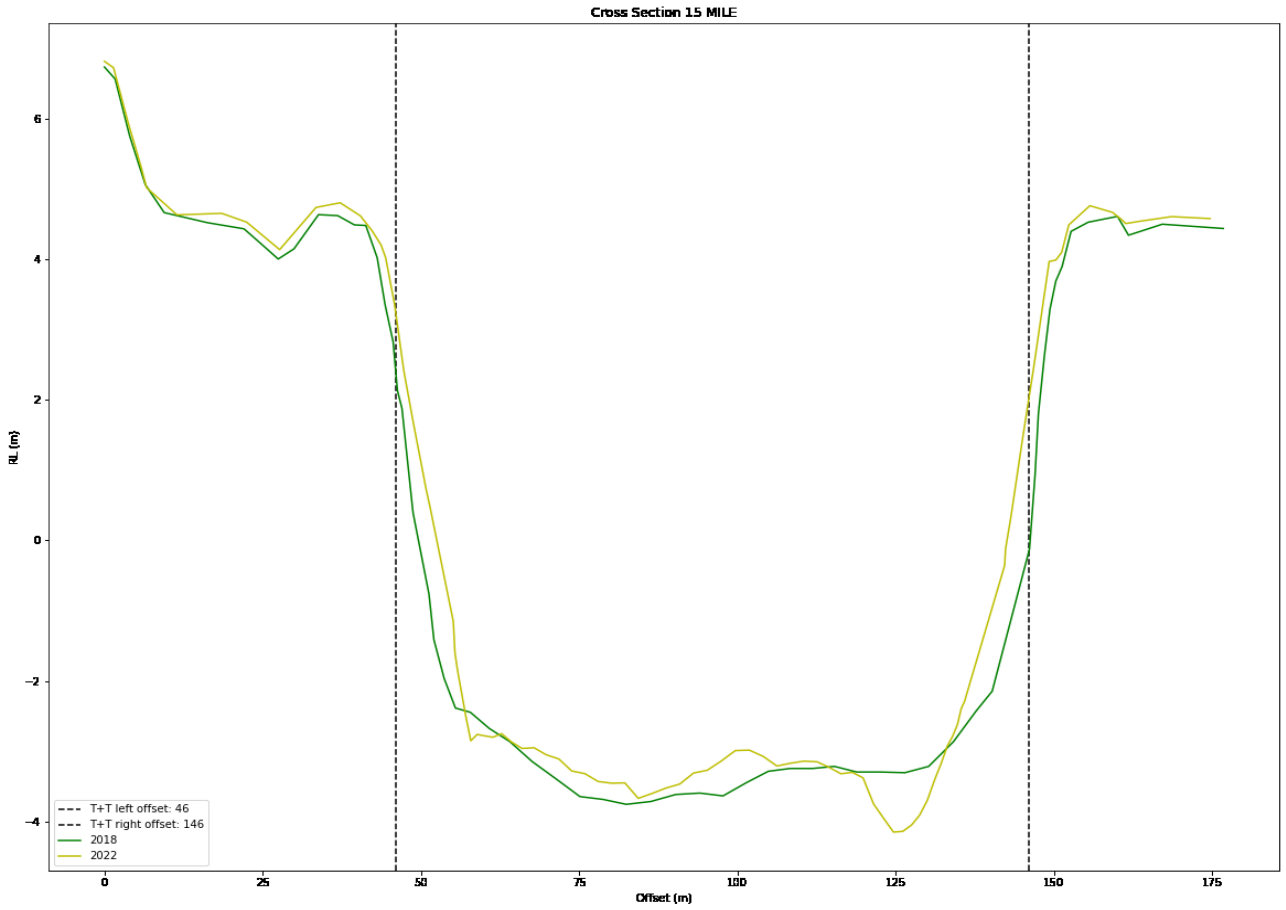

Cross Section 248
RL (m)
Offset (m)
T+T left offset: 37
T+T right offset: 117
2018
2022

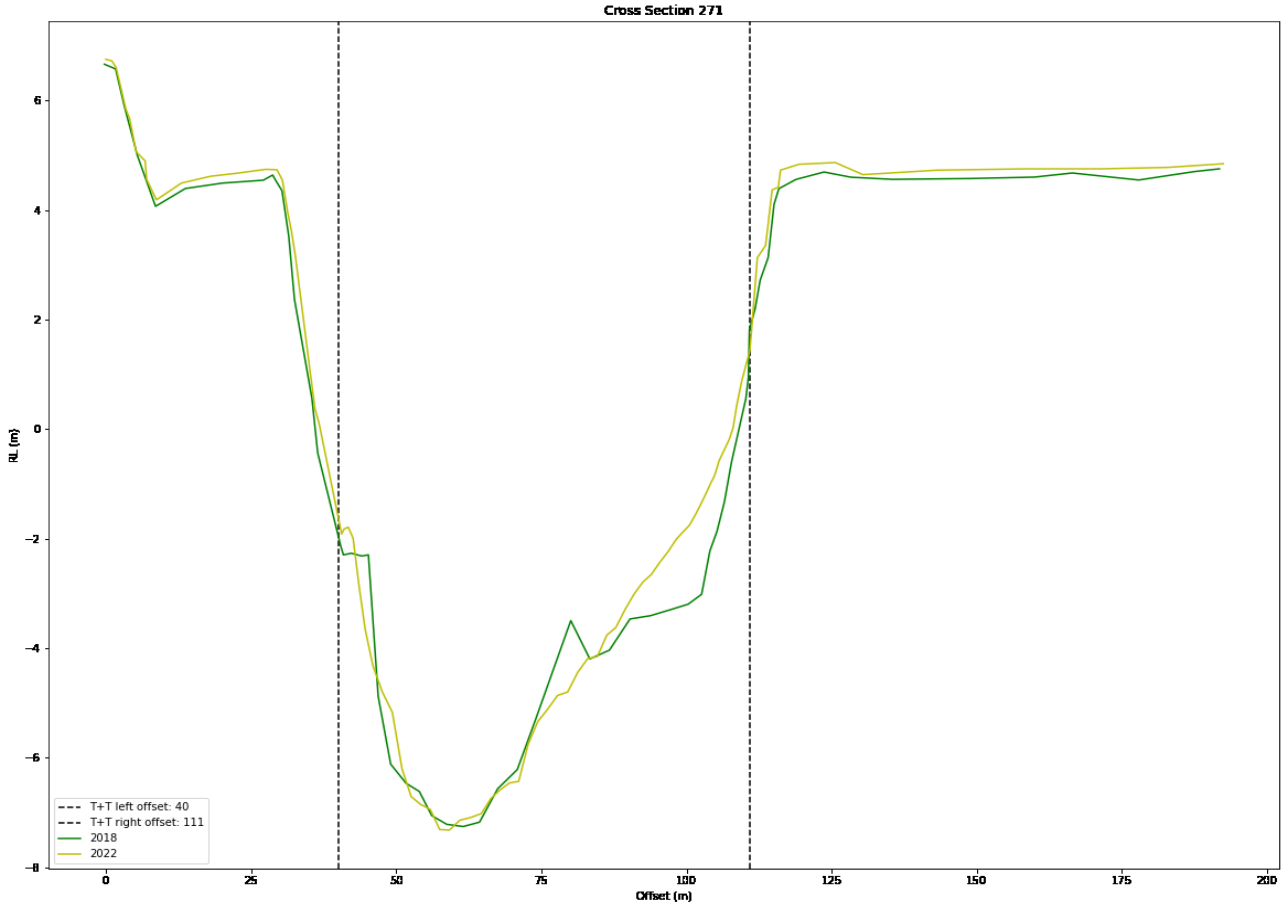

Cross Section 252
RL (m)
Offset (m)
T+T left offset: 27
T+T right offset: 91
2018
2022

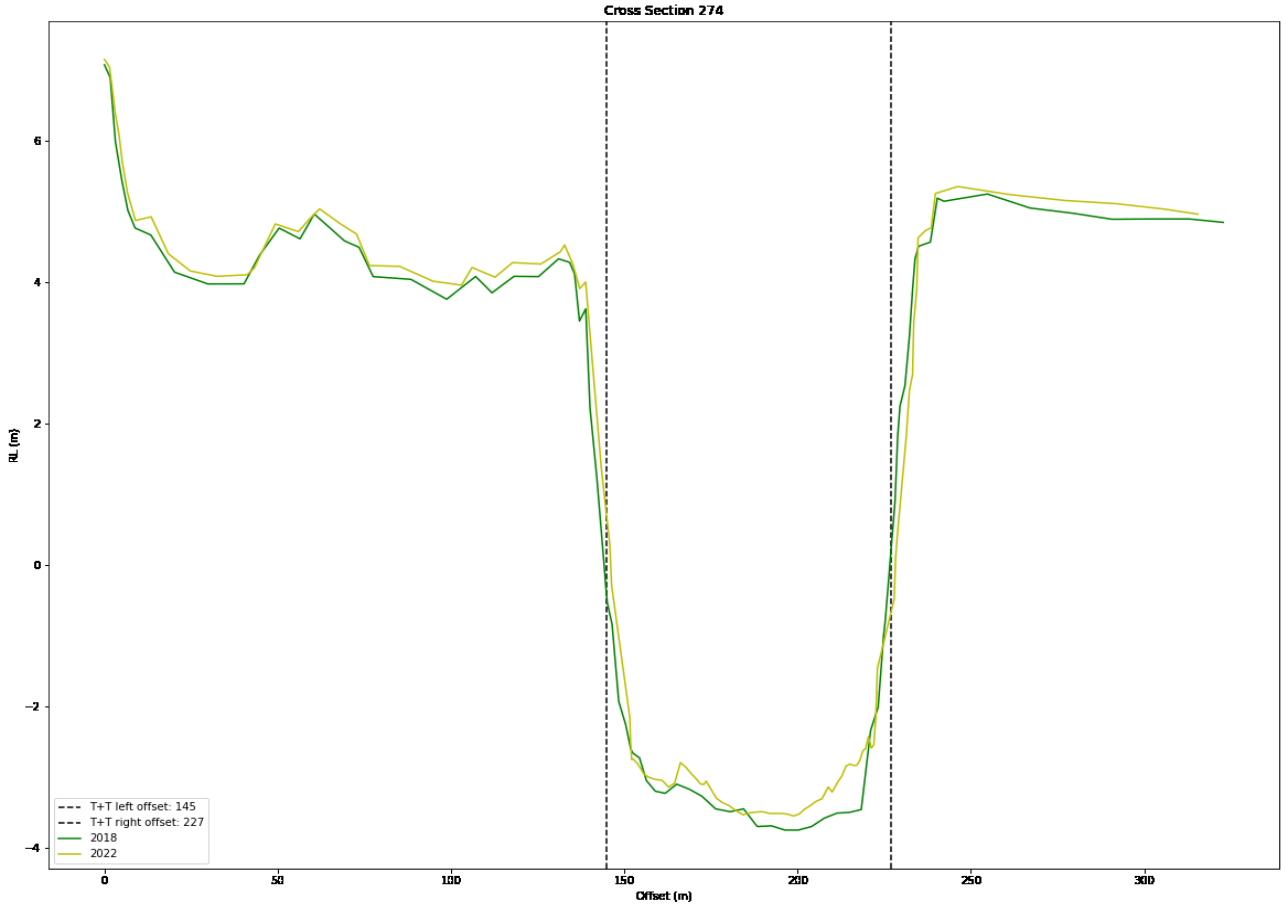

Cross Section 14 MILE
RL (m)
Offset (m)
T+T left offset: 33
T+T right offset: 129
2018
2022

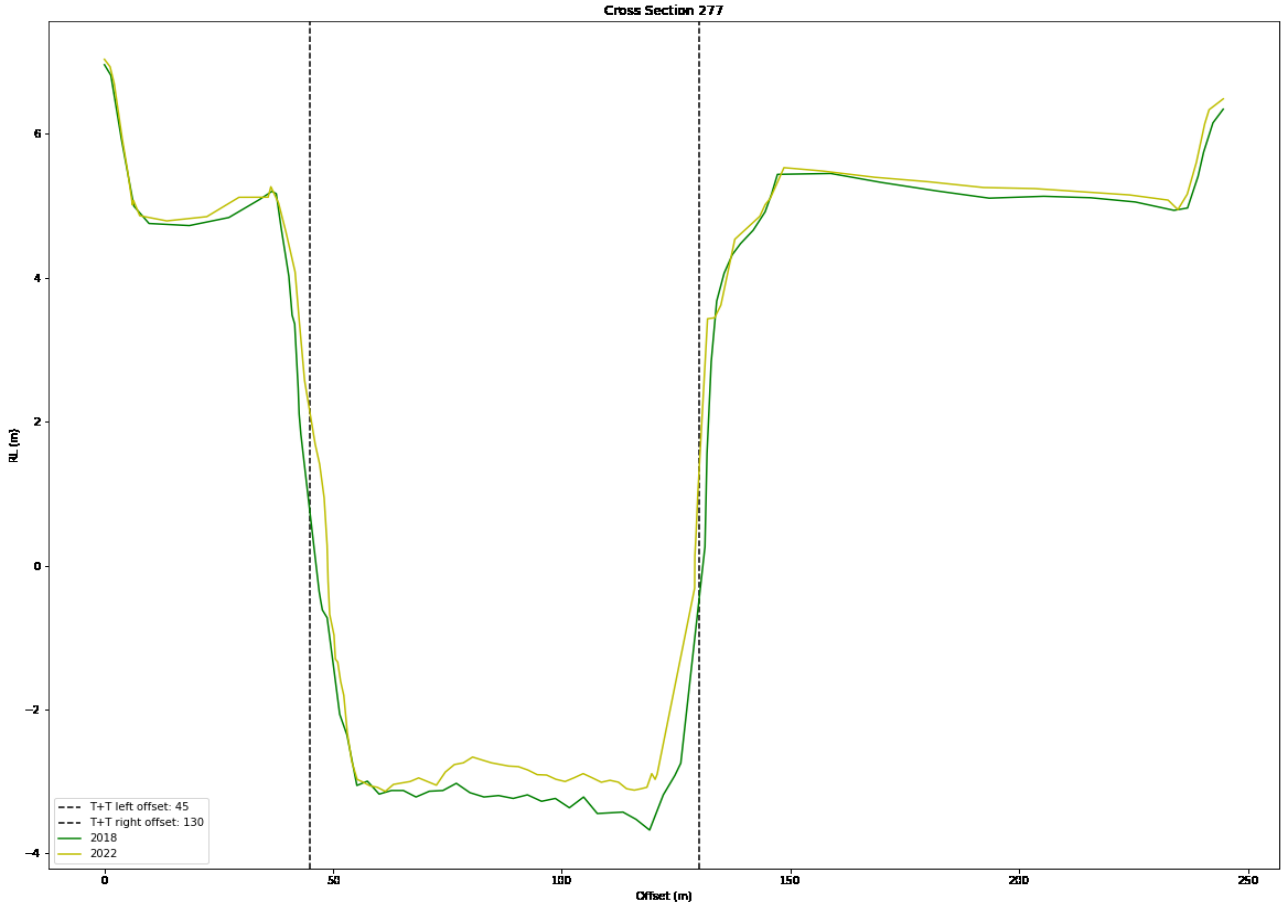

Cross Section 260
RL (m)
Offset (m)
T+T left offset: 34
T+T right offset: 123
2018
2022

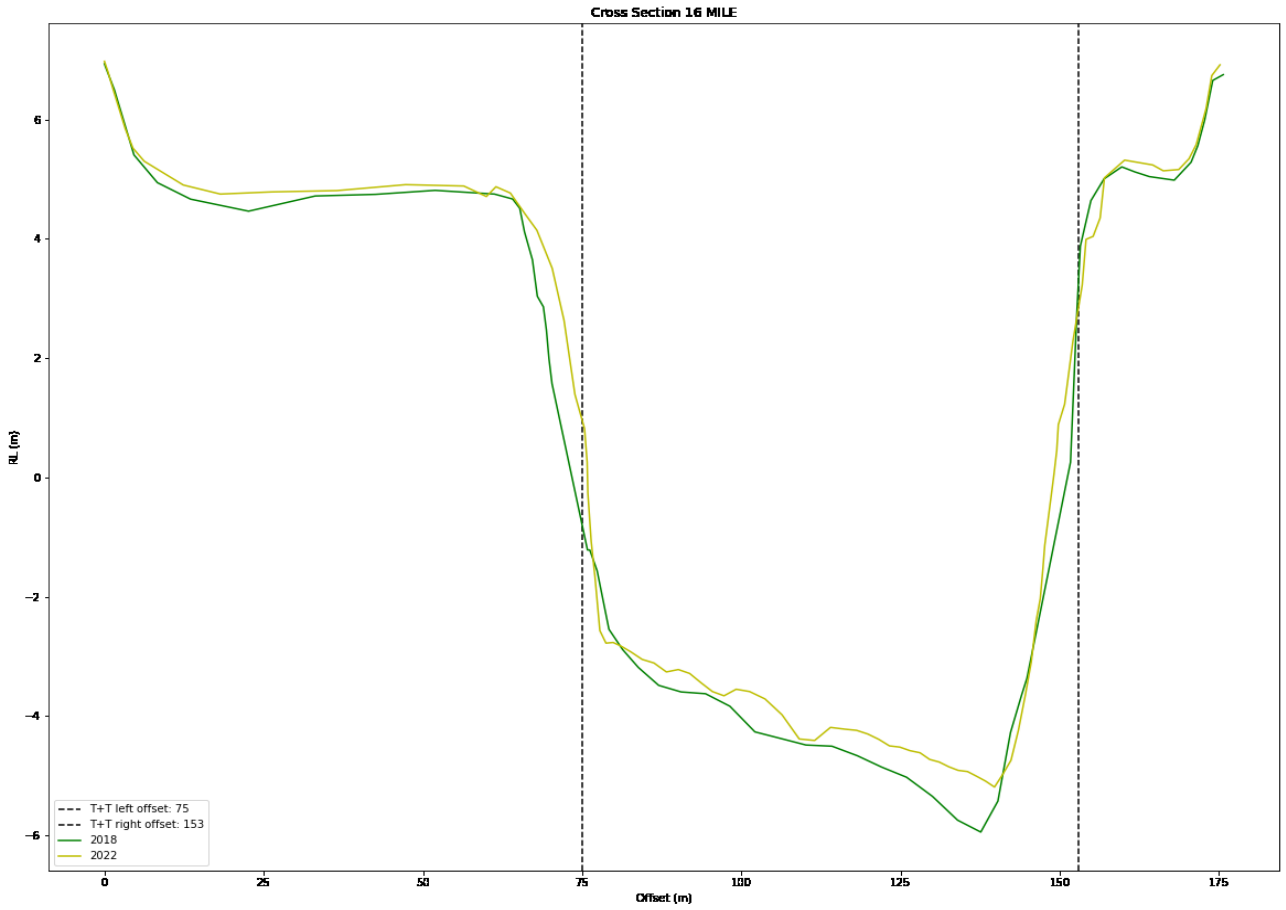

Cross Section 264
RL (m)
Offset (m)
T+T left offset: 122
T+T right offset: 198
2018
2022

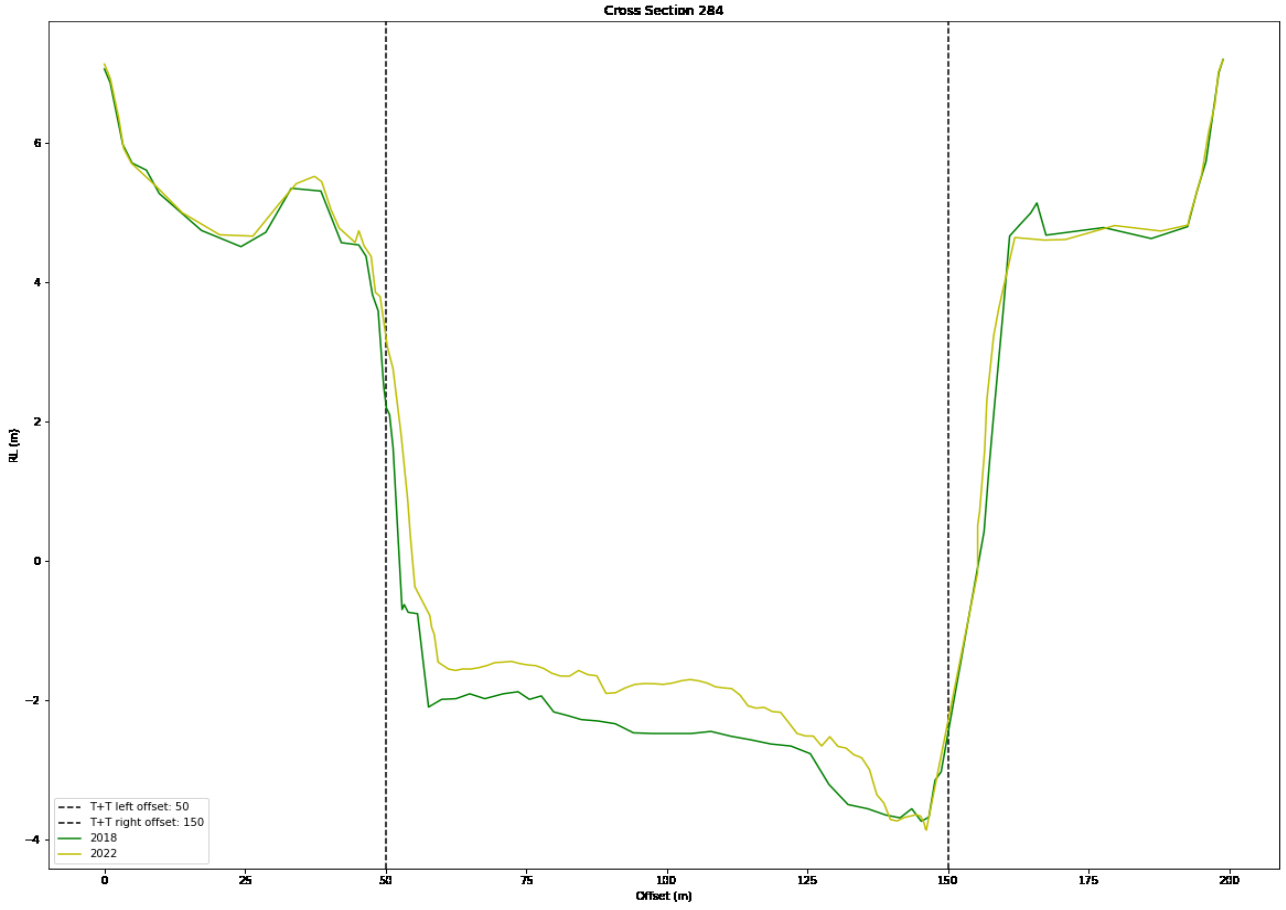

Cross Section 15 MILE
RL (m)
Offset (m)
T+T left offset: 46
T+T right offset: 146
2018
2022

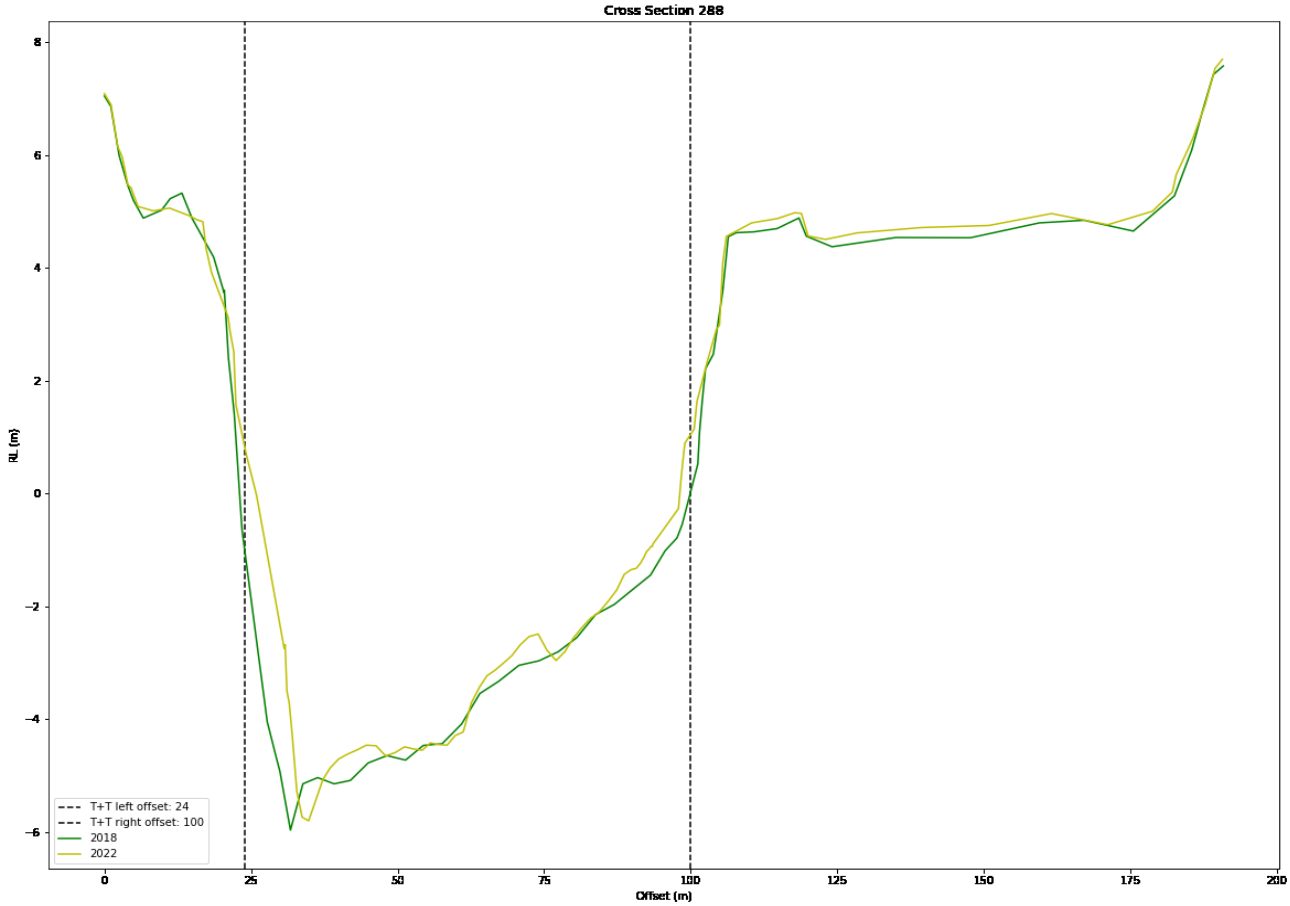

Cross Section 271
RL (m)
Offset (m)
T+T left offset: 40
T+T right offset: 111
2018
2022

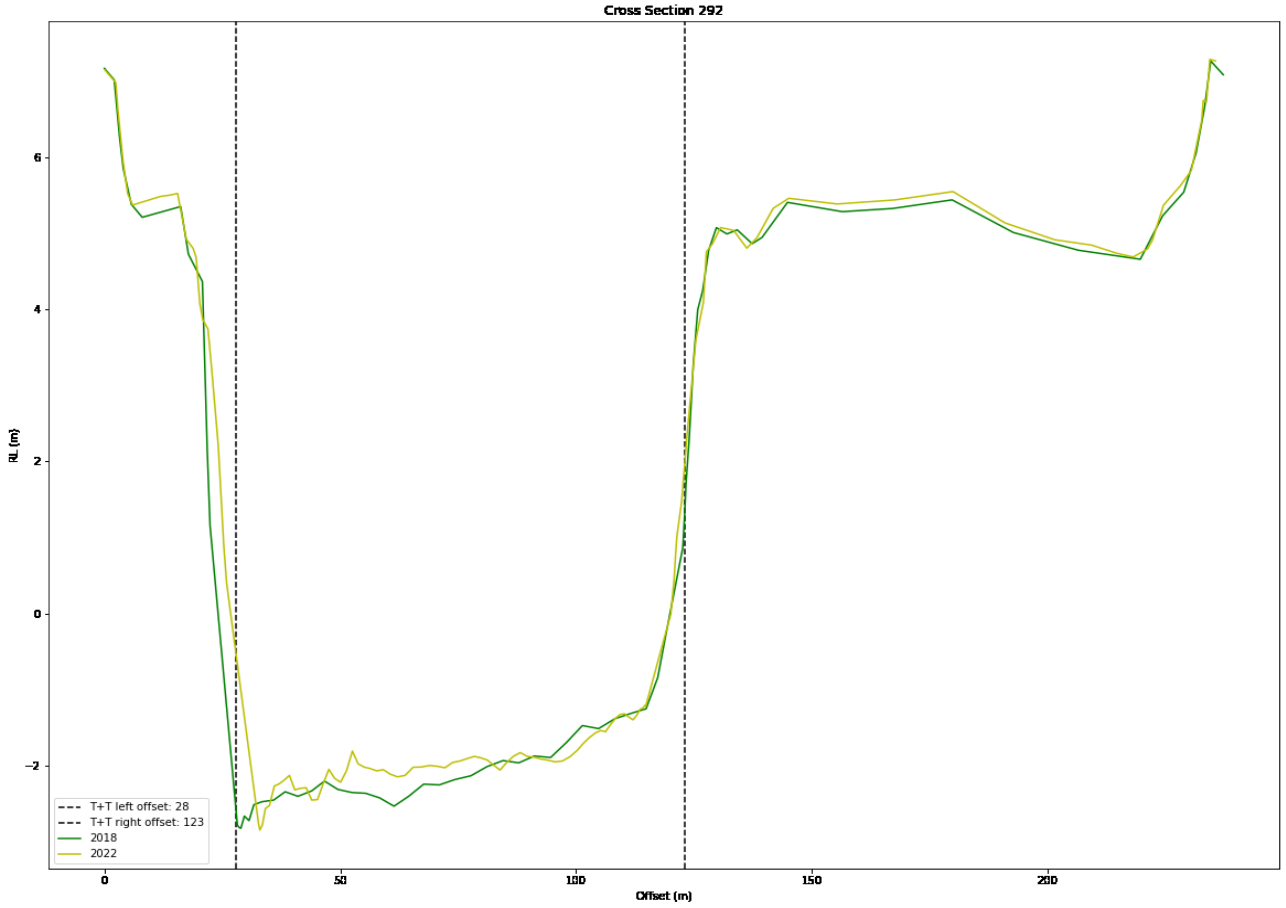

Cross Section 274
RL (m)
Offset (m)
T+T left offset: 145
T+T right offset: 227
2018
2022

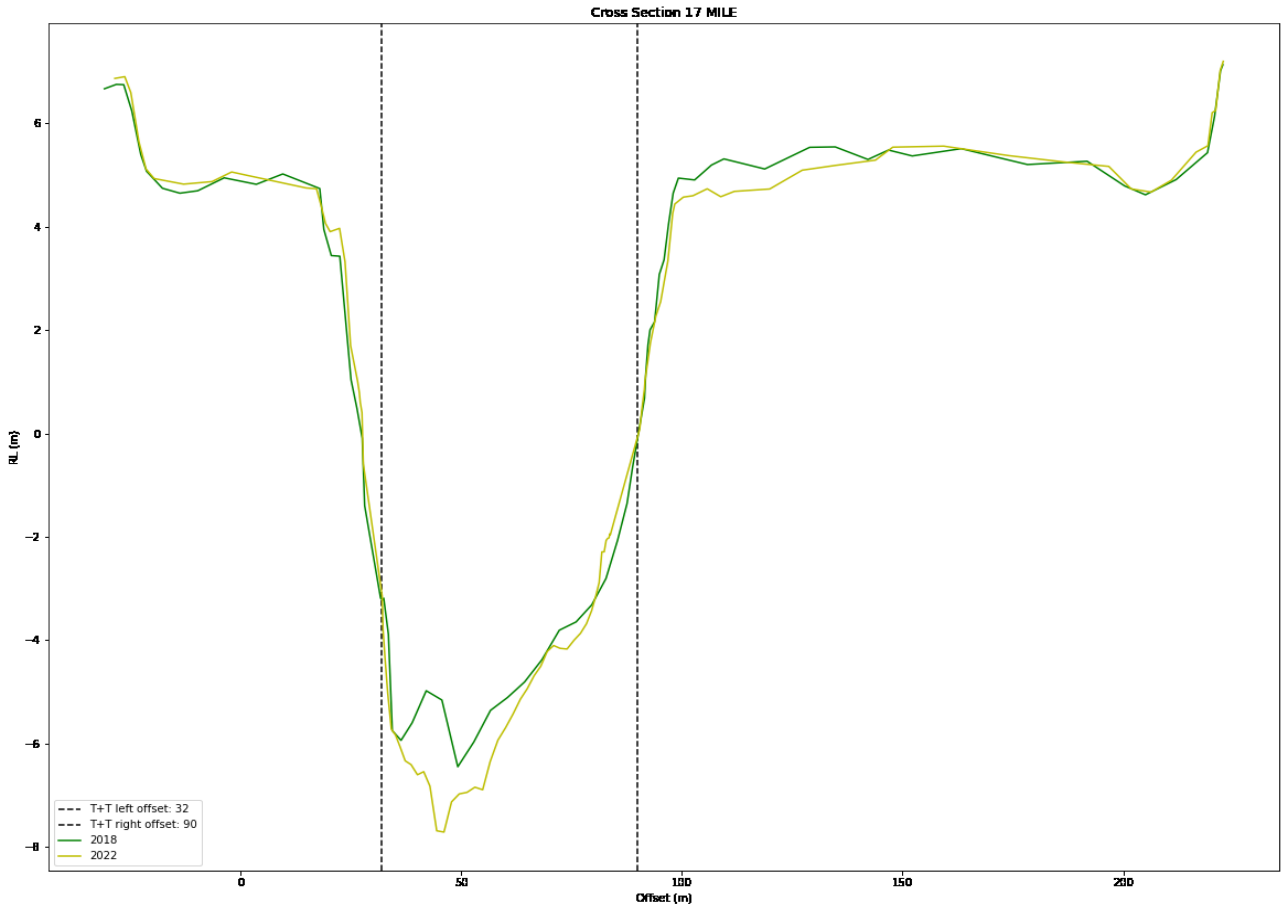

Cross Section 277
RL (m)
Offset (m)
T+T left offset: 45
T+T right offset: 130
2018
2022

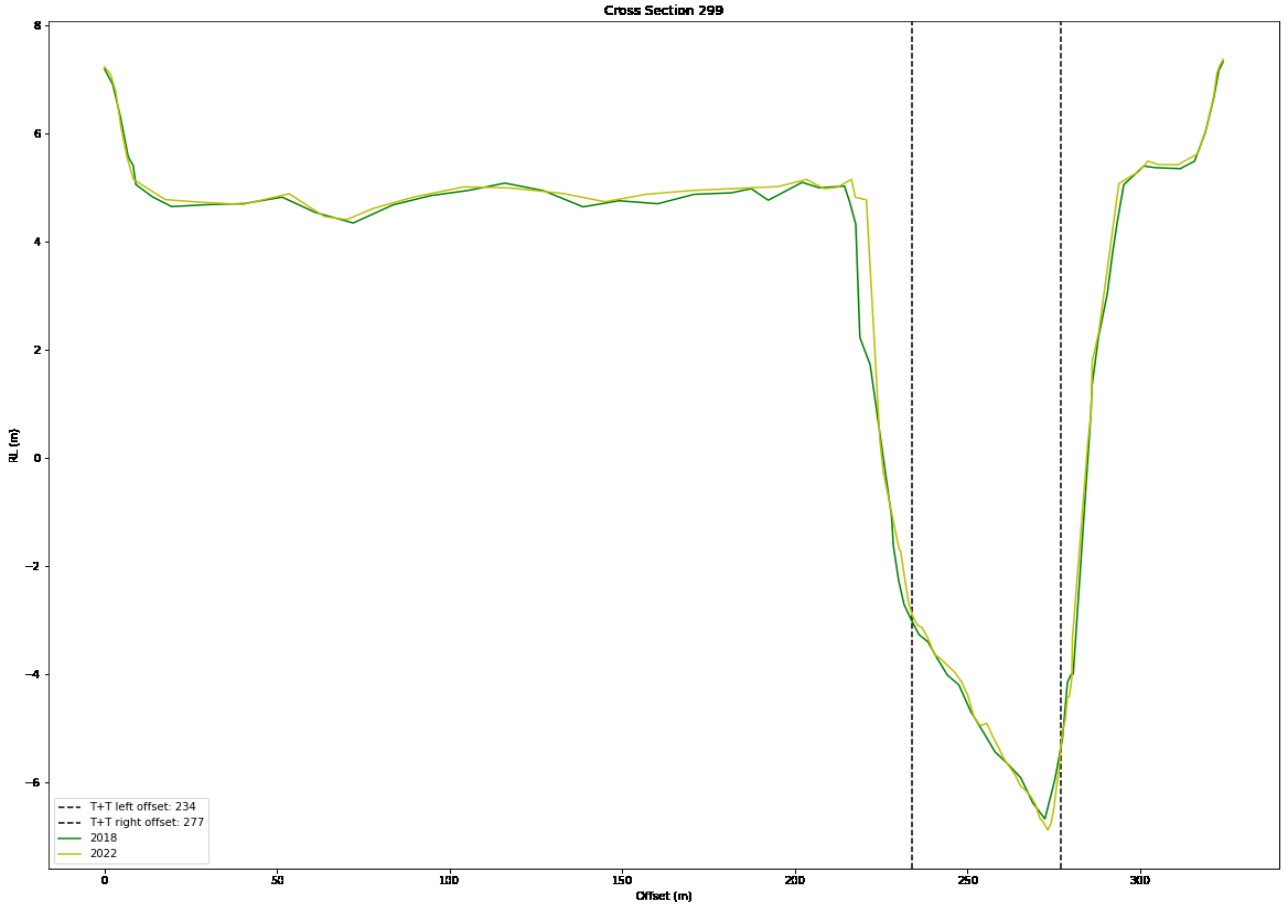

Cross Section 16 MILE
RL (m)
Offset (m)
T+T left offset: 75
T+T right offset: 153
2018
2022

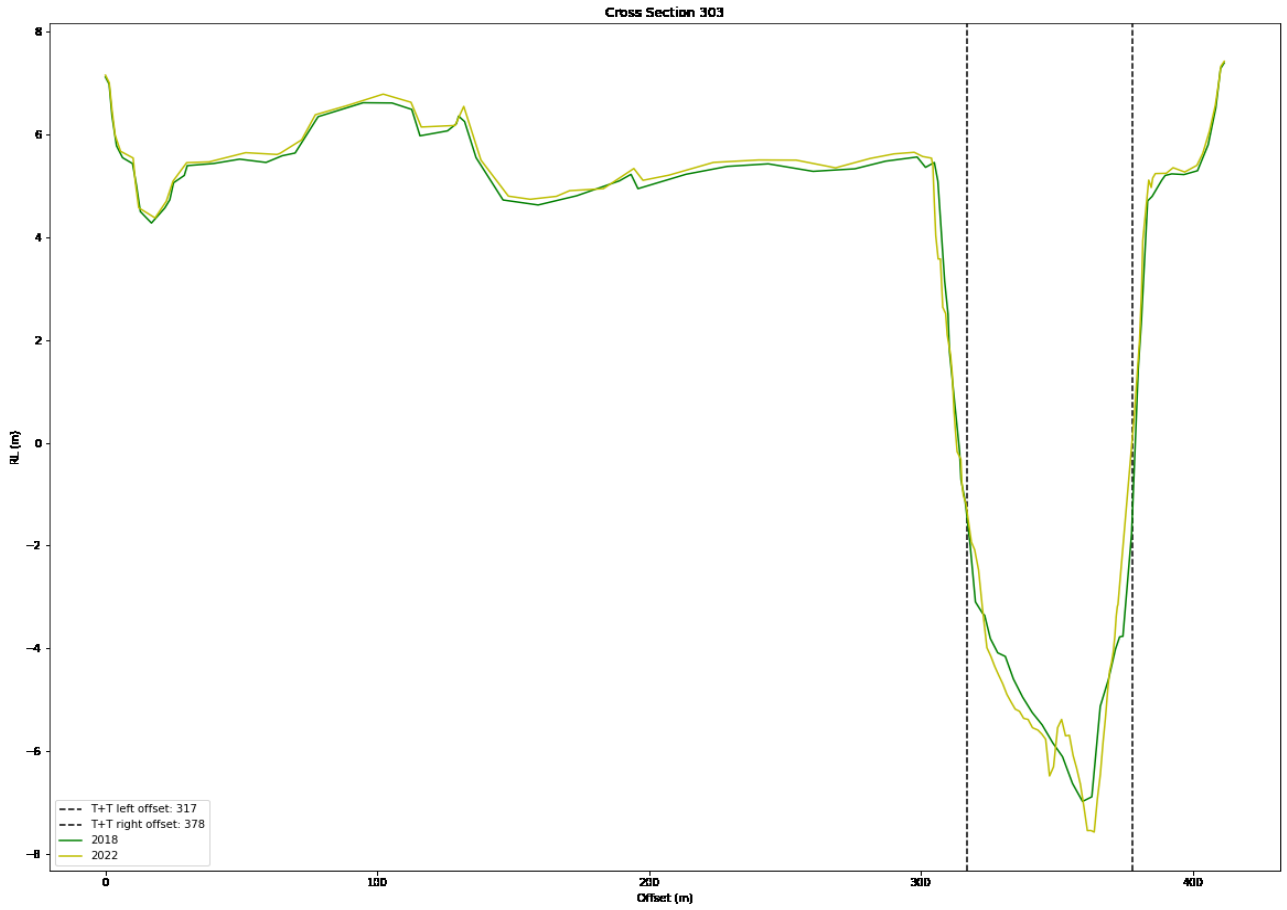

Cross Section 284
RL (m)
Offset (m)
T+T left offset: 50
T+T right offset: 150
2018
2022

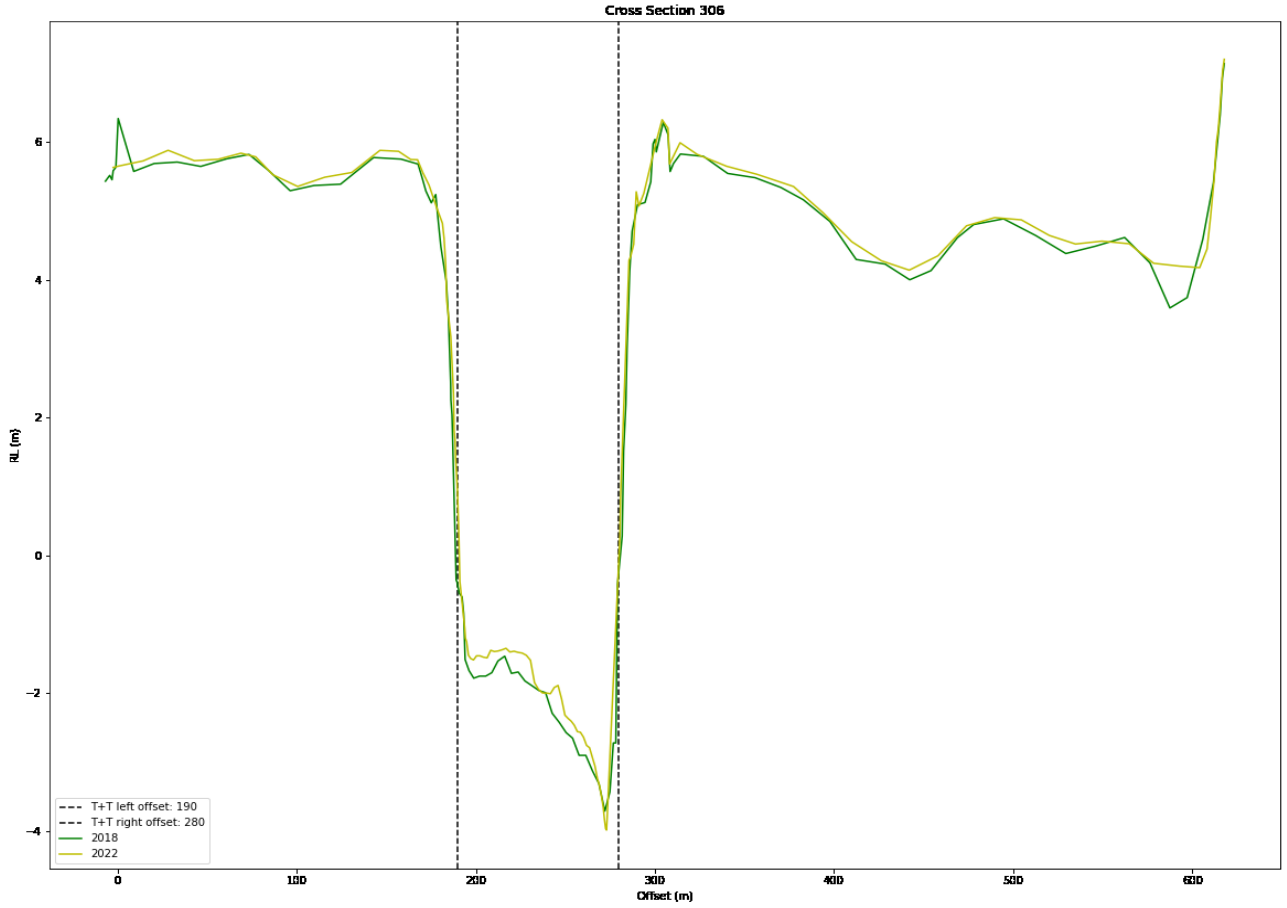

Cross Section 288
RL (m)
Offset (m)
T+T left offset: 24
T+T right offset: 100
2018
2022

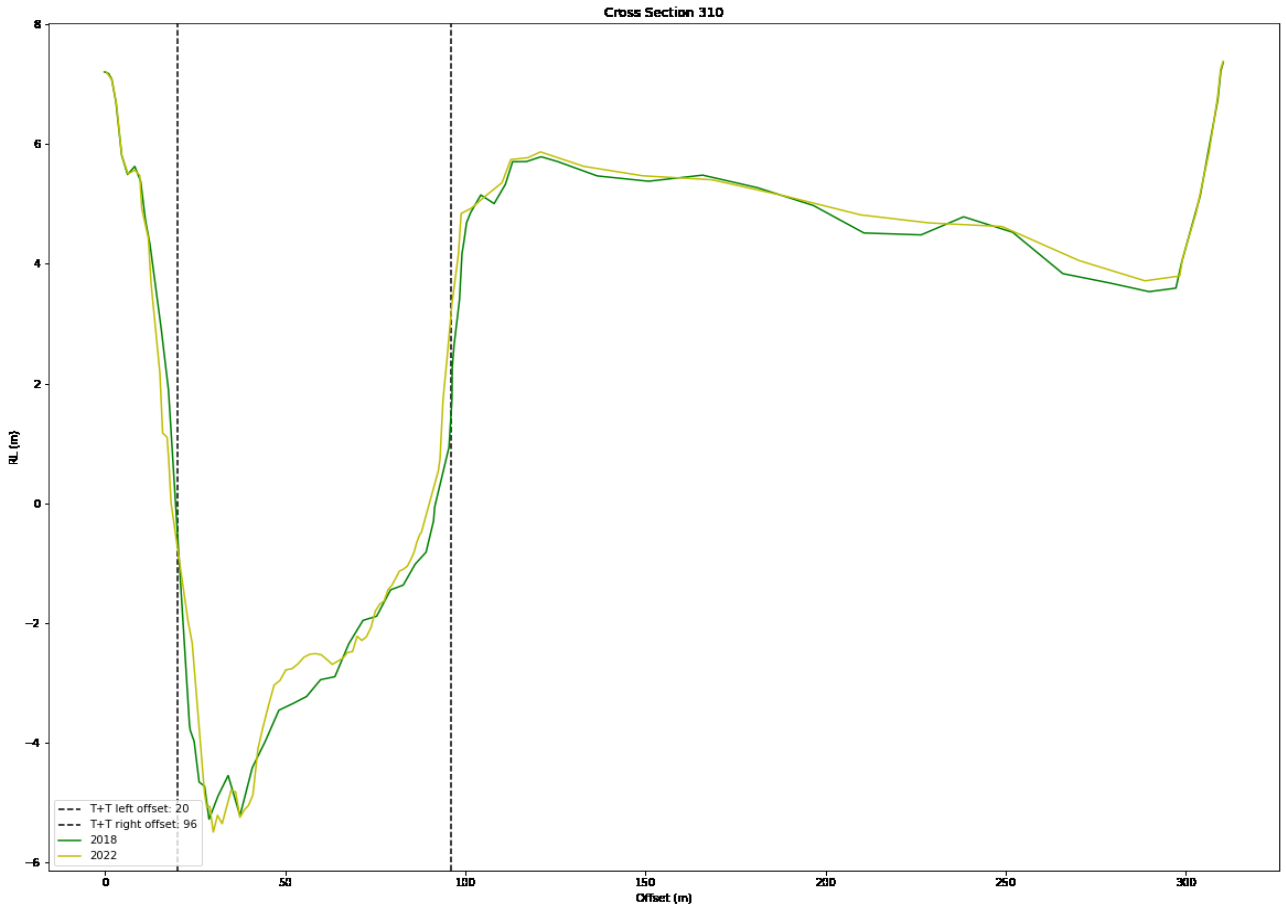

Cross Section 292
RL (m)
Offset (m)
T+T left offset: 28
T+T right offset: 123
2018
2022

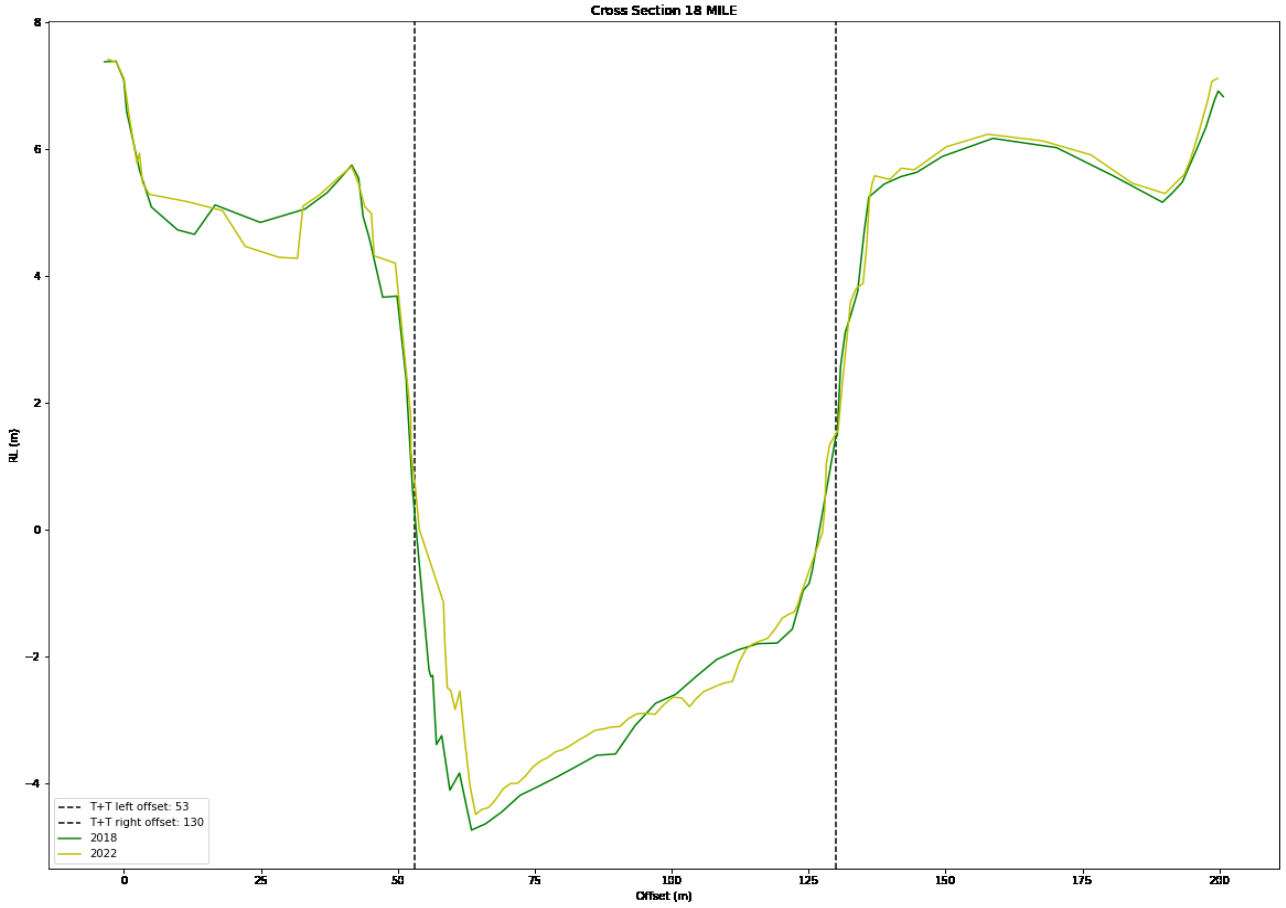

Cross Section 17 MILE
RL (m)
Offset (m)
T+T left offset: 32
T+T right offset: 90
2018
2022

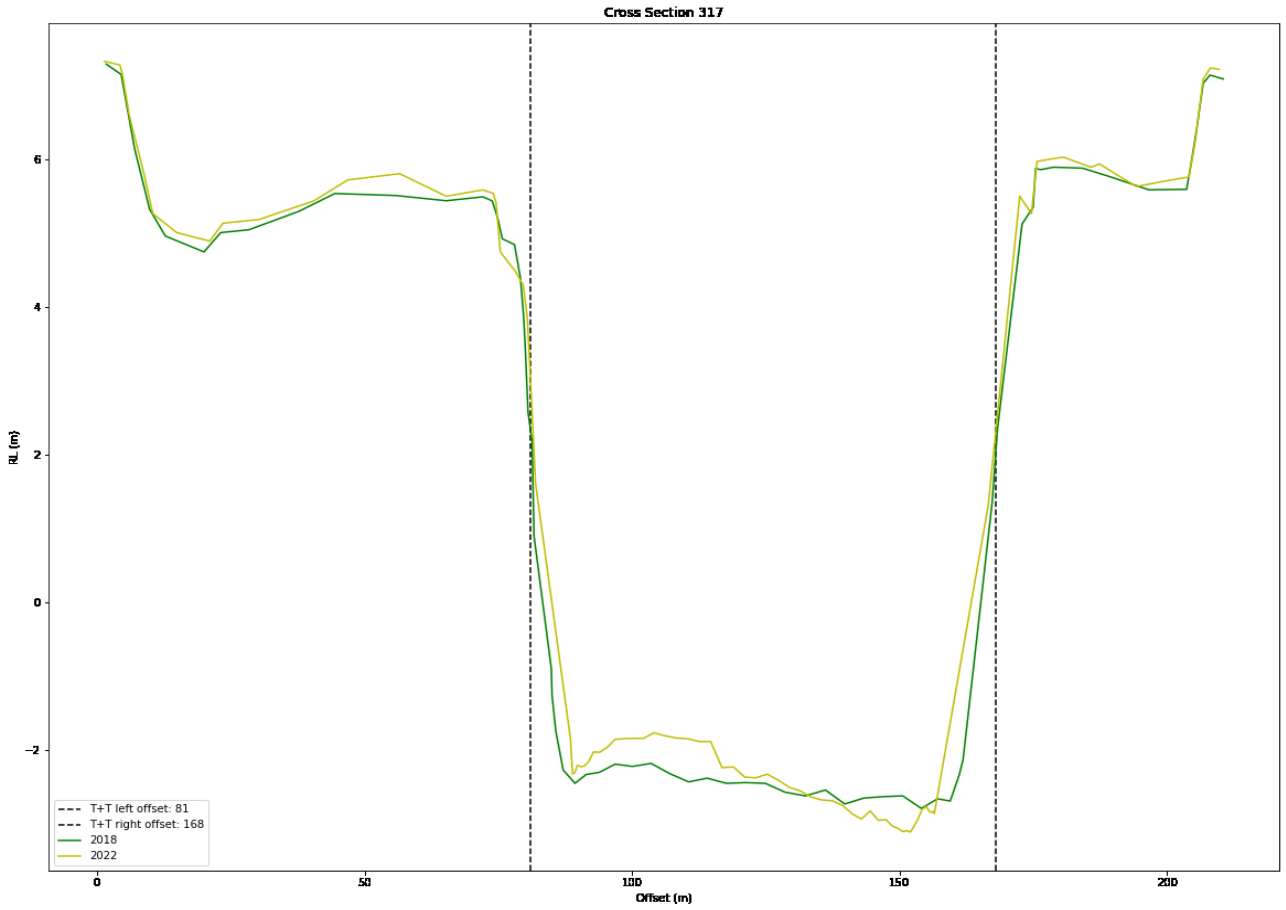

Cross Section 299
RL (m)
Offset (m)
T+T left offset: 234
T+T right offset: 277
2018
2022

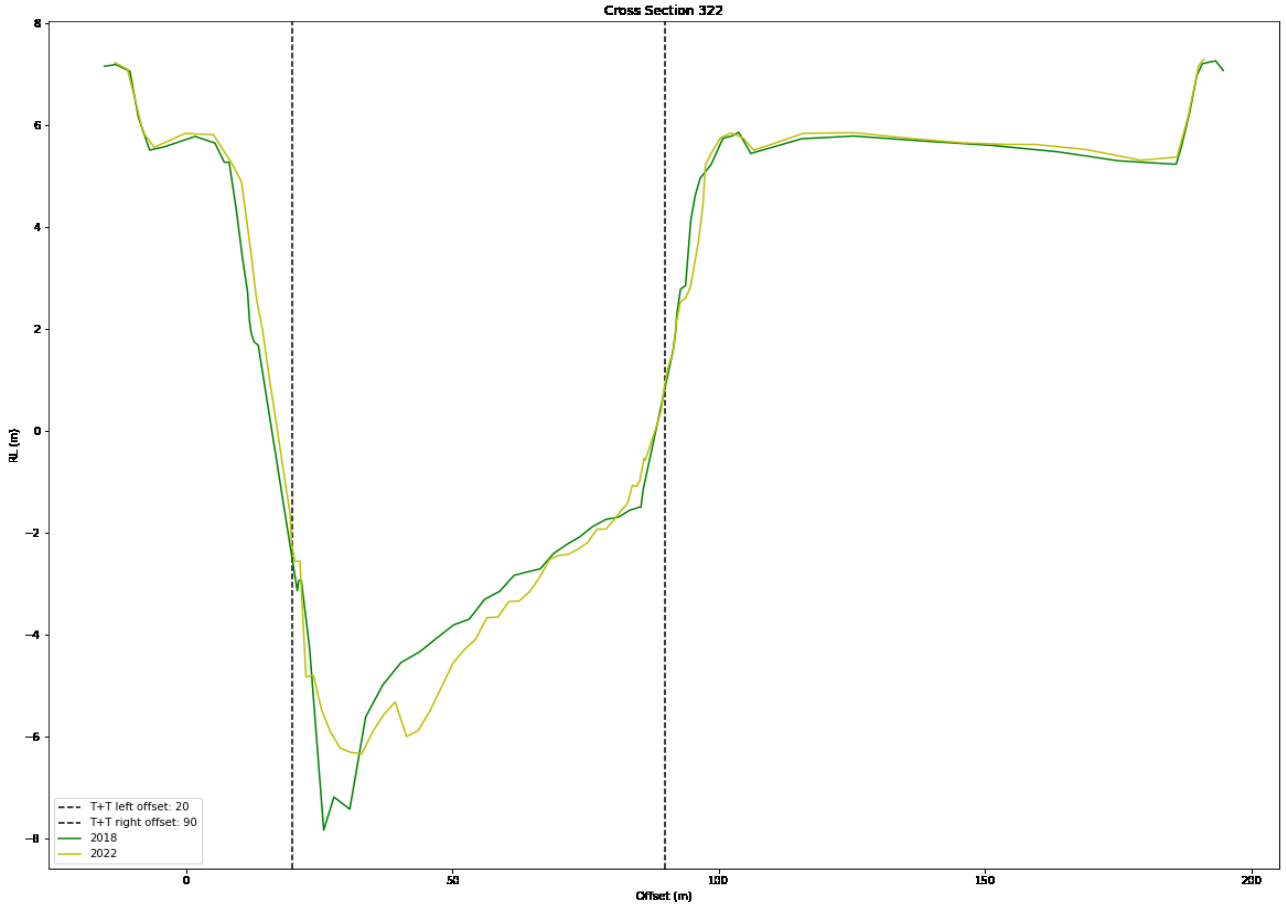

Cross Section 303
RL (m)
Offset (m)
T+T left offset: 317
T+T right offset: 378
2018
2022

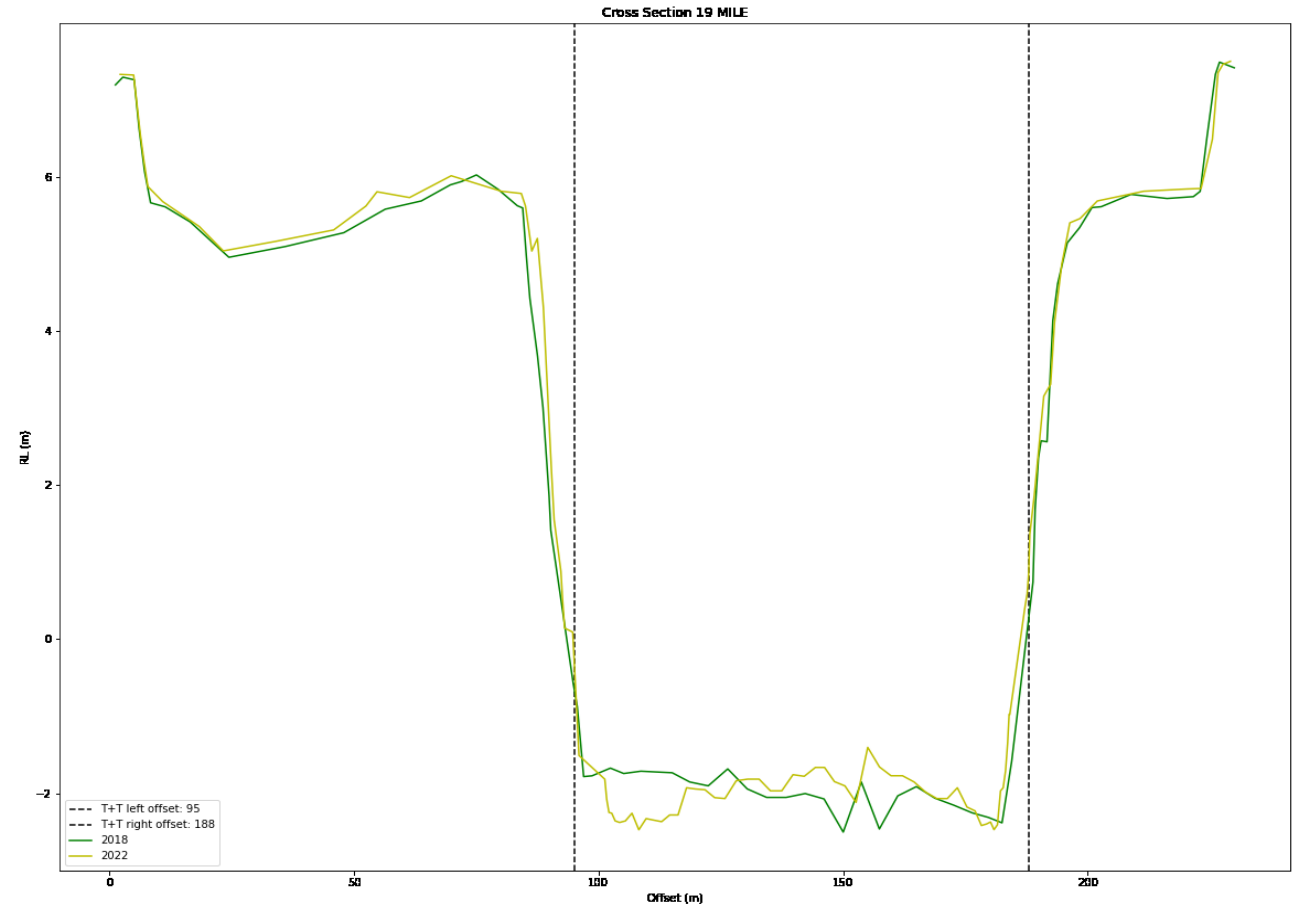

Cross Section 306
RL (m)
Offset (m)
T+T left offset: 190
T+T right offset: 280
2018
2022

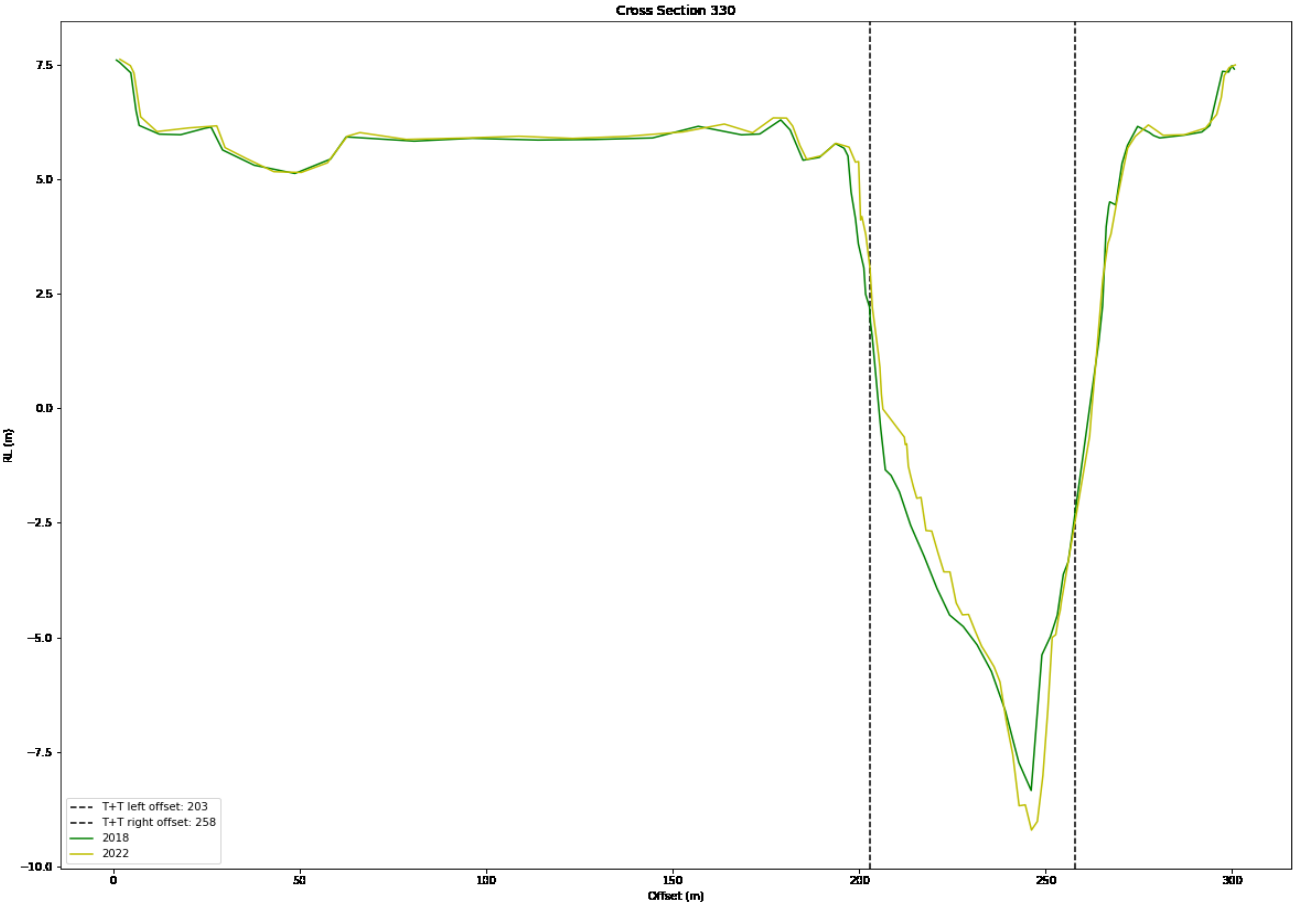

Cross Section 310
RL (m)
Offset (m)
T+T left offset: 20
T+T right offset: 96
2018
2022

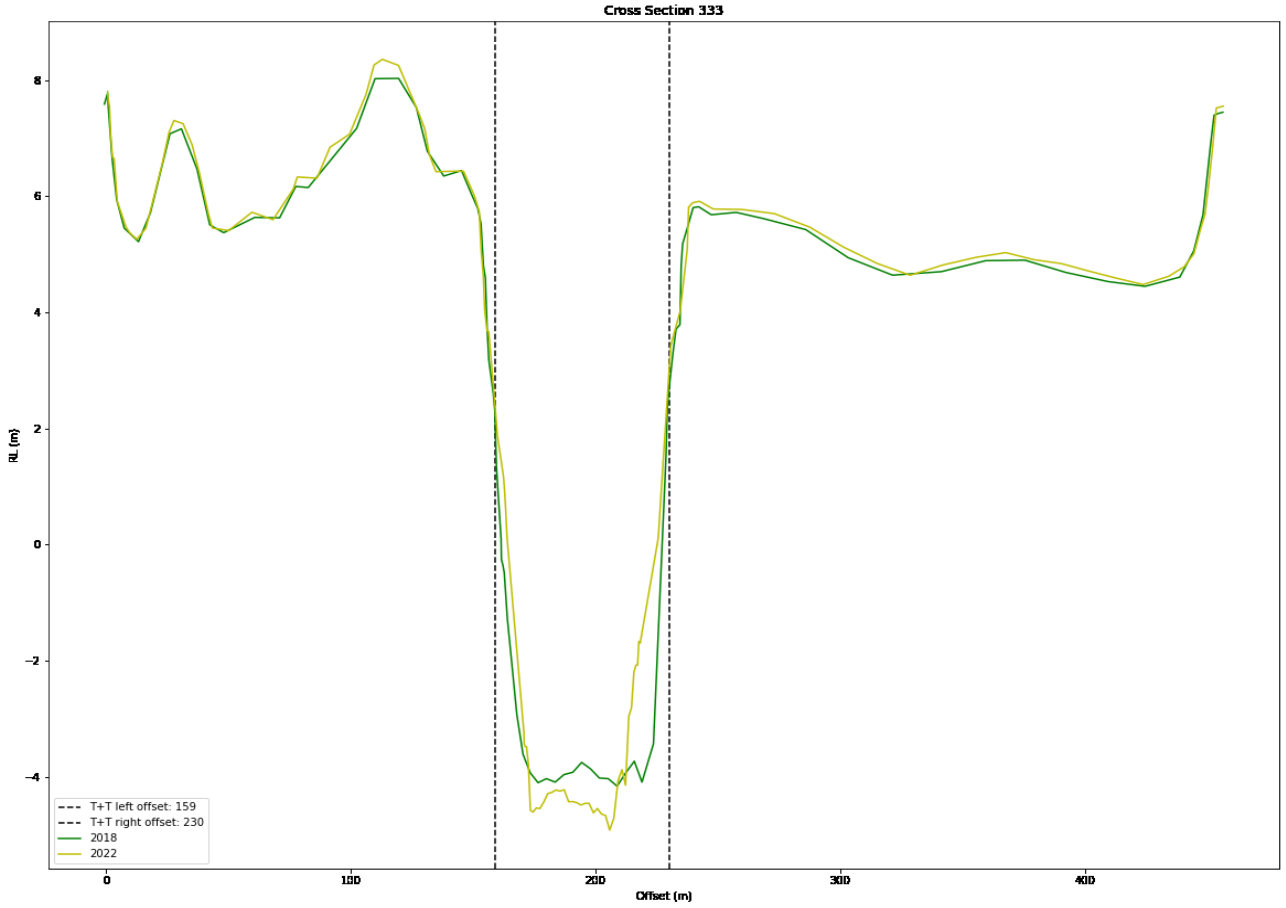

Cross Section 18 MILE
RL (m)
Offset (m)
T+T left offset: 53
T+T right offset: 130
2018
2022

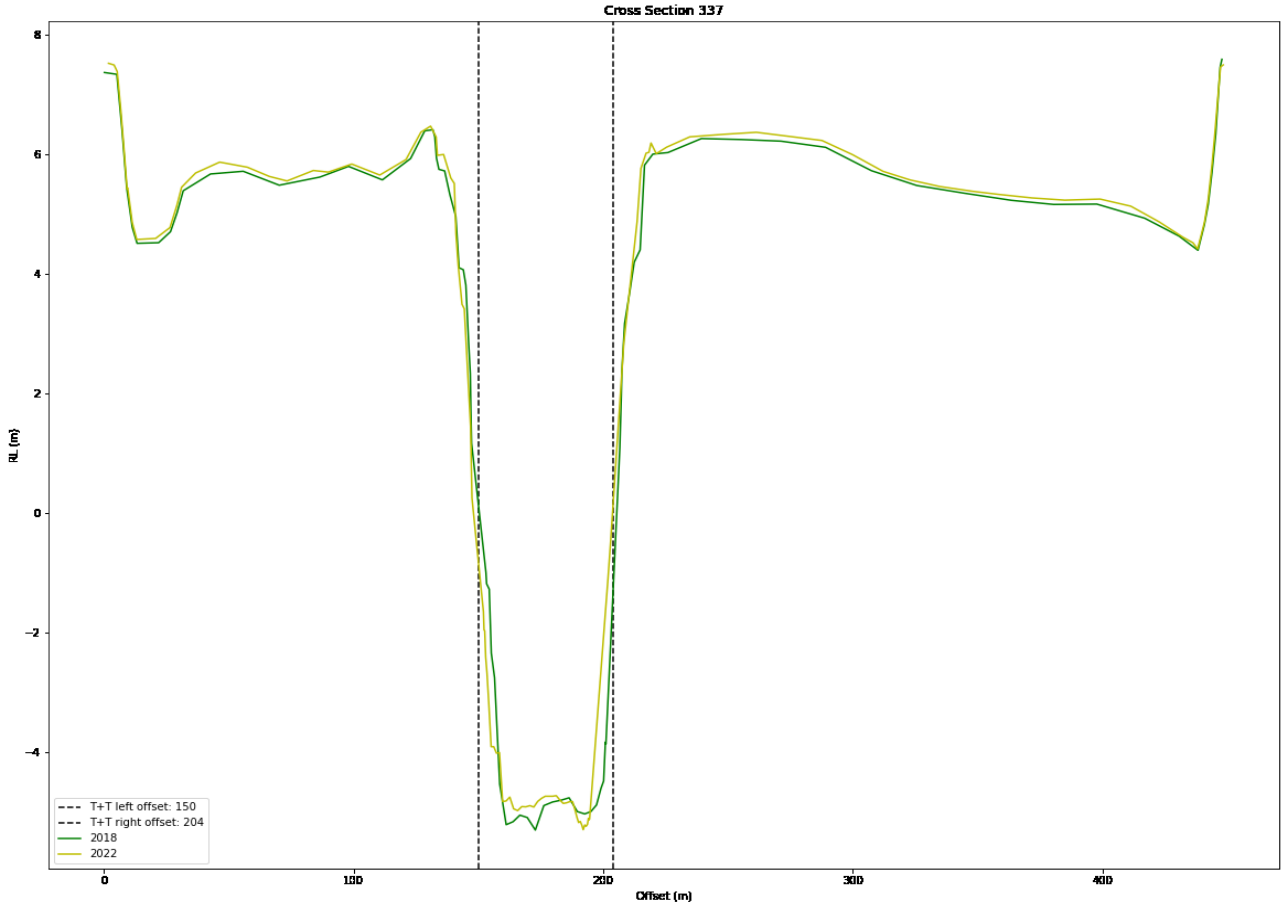

Cross Section 317
RL (m)
Offset (m)
T+T left offset: 81
T+T right offset: 168
2018
2022

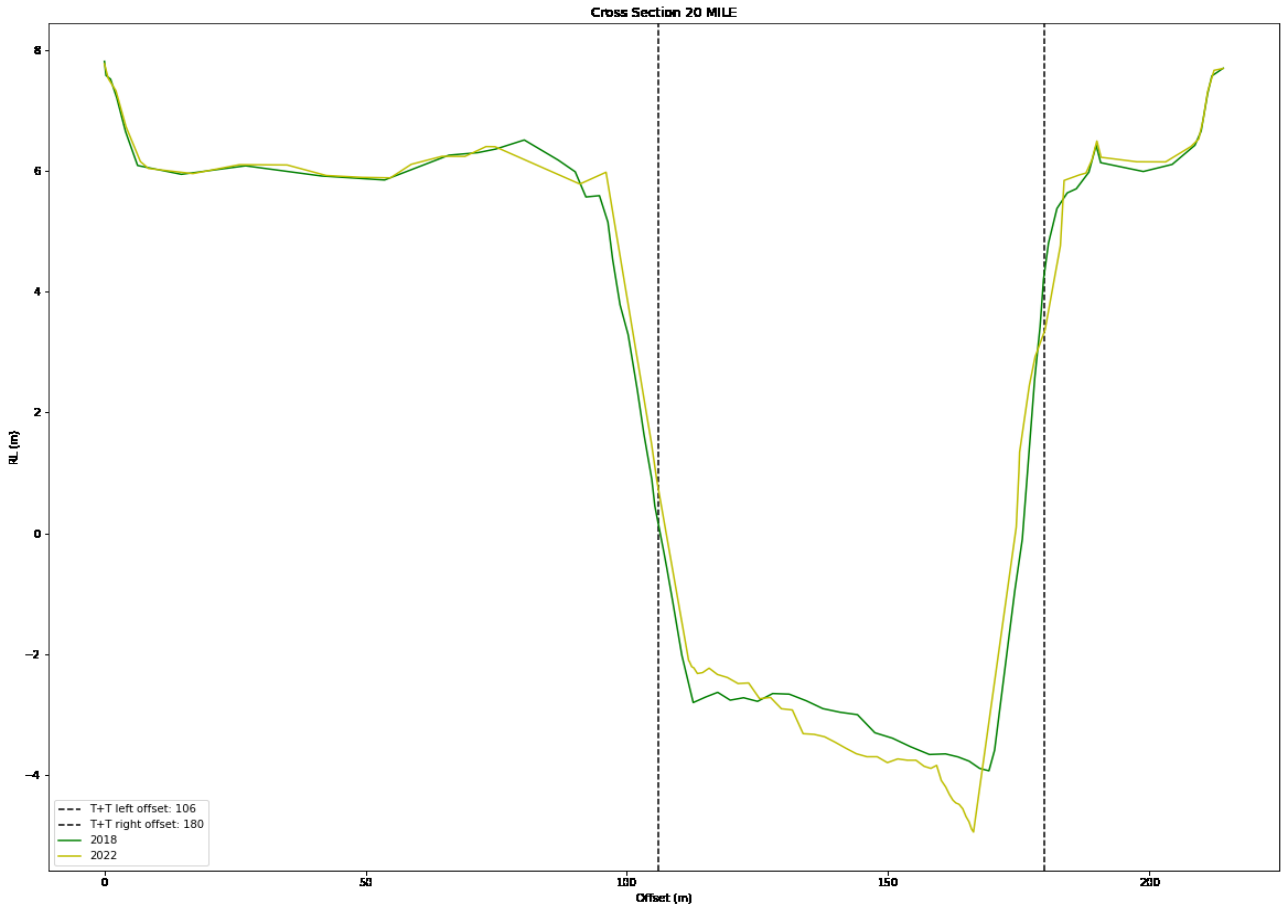

Cross Section 322
RL (m)
Offset (m)
T+T left offset: 20
T+T right offset: 90
2018
2022

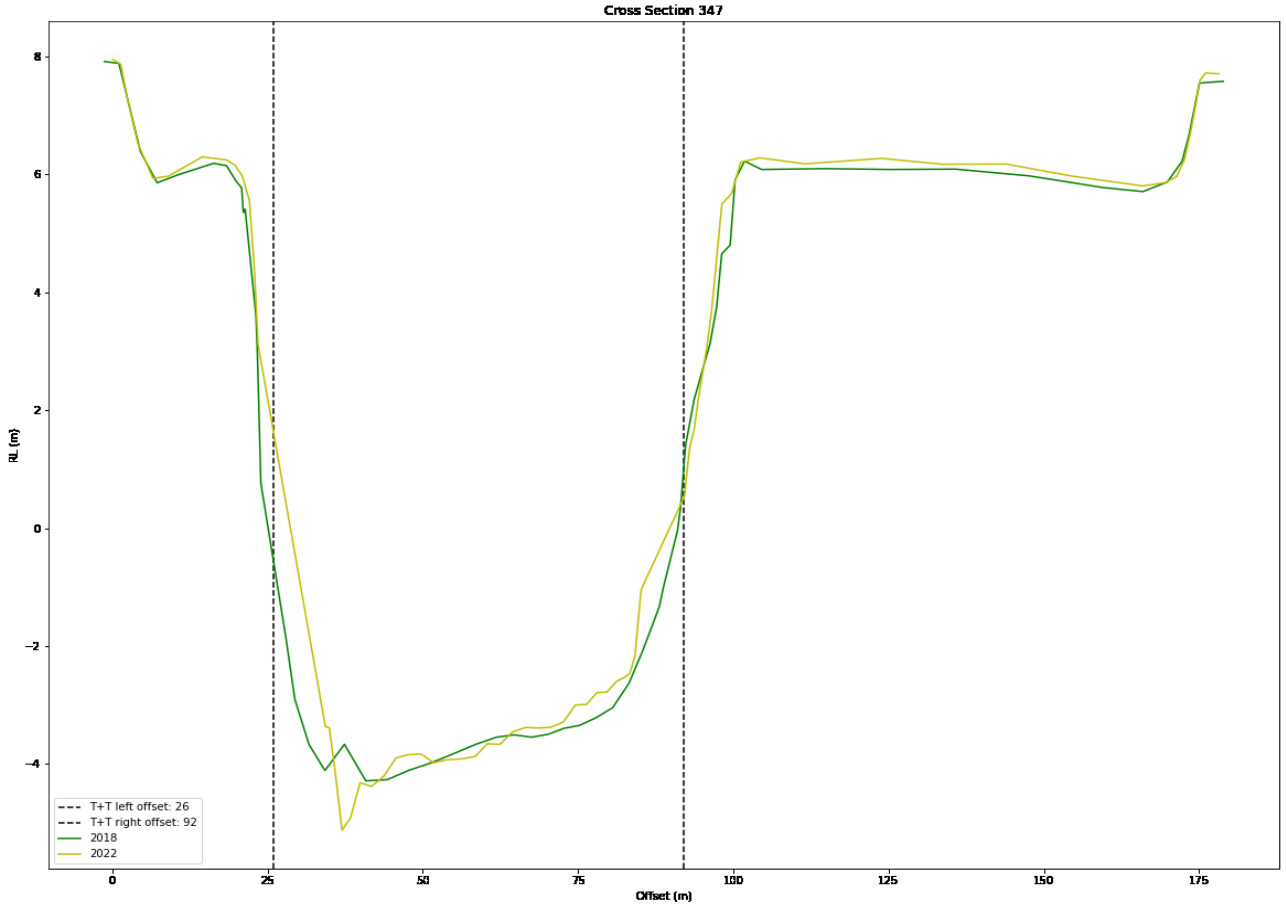

Cross Section 19 MILE
RL (m)
Offset (m)
T+T left offset: 95
T+T right offset: 188
2018
2022

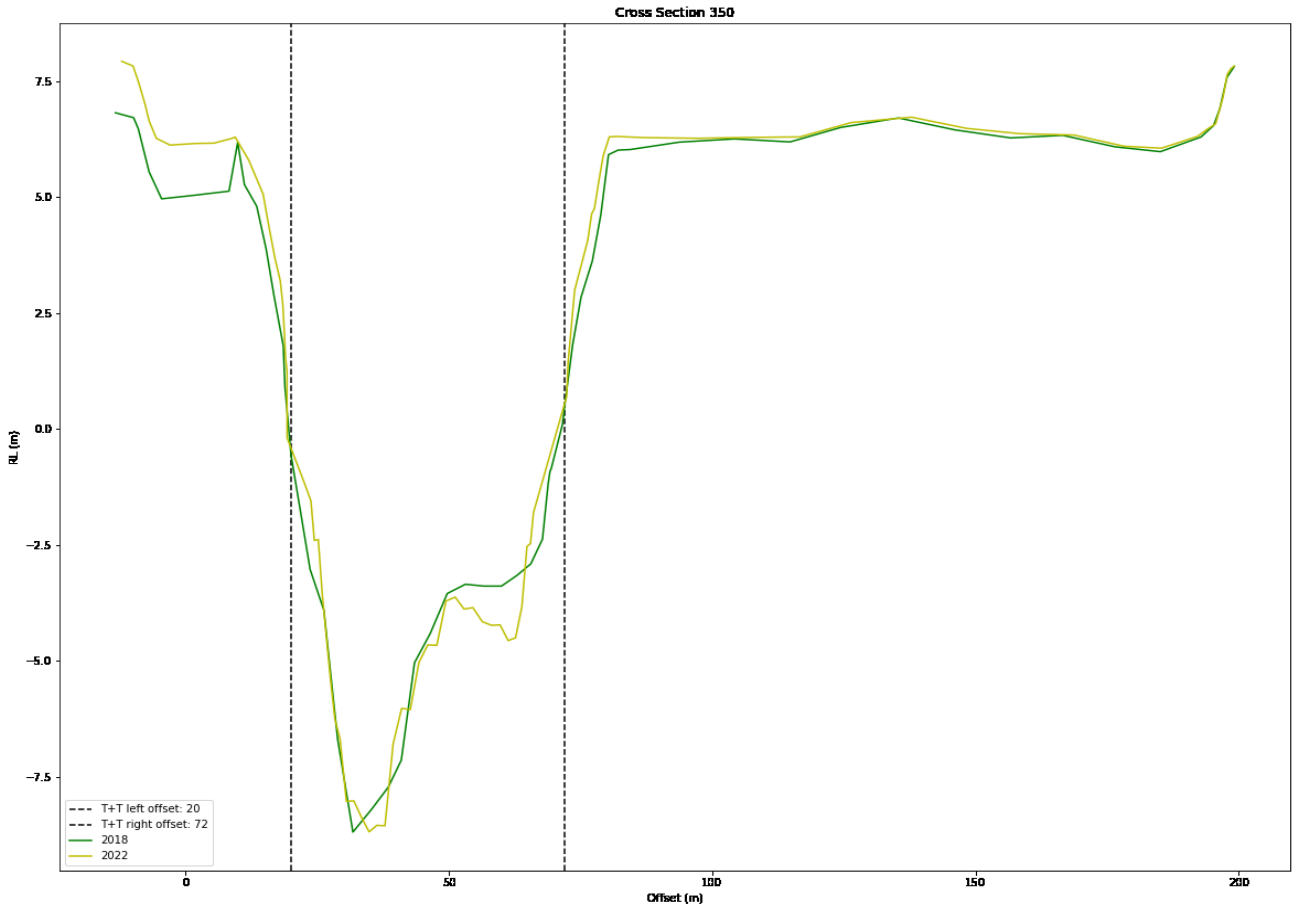

Cross Section 330
RL (m)
Offset (m)
T+T left offset: 203
T+T right offset: 258
2018
2022

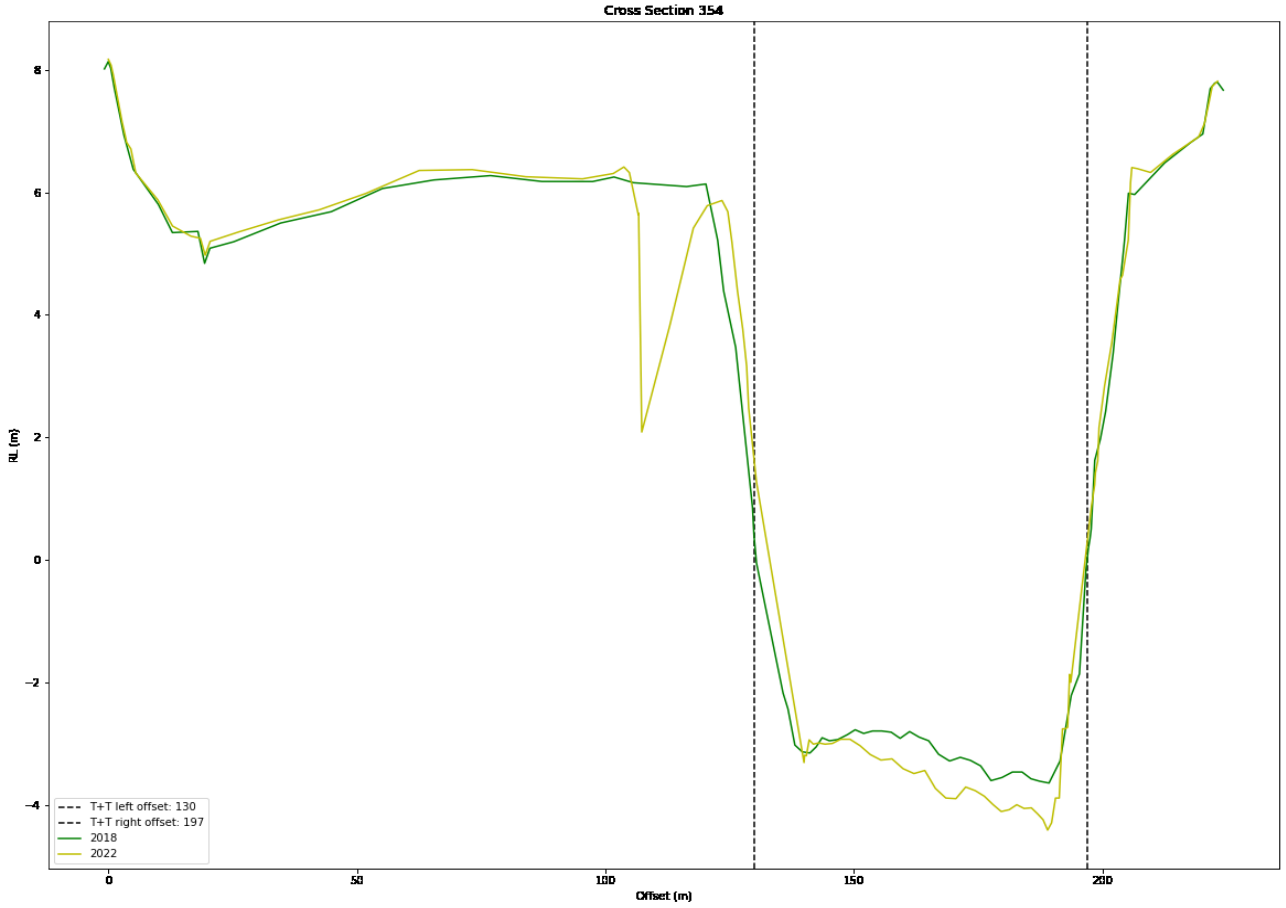

Cross Section 333
RL (m)
Offset (m)
T+T left offset: 159
T+T right offset: 230
2018
2022

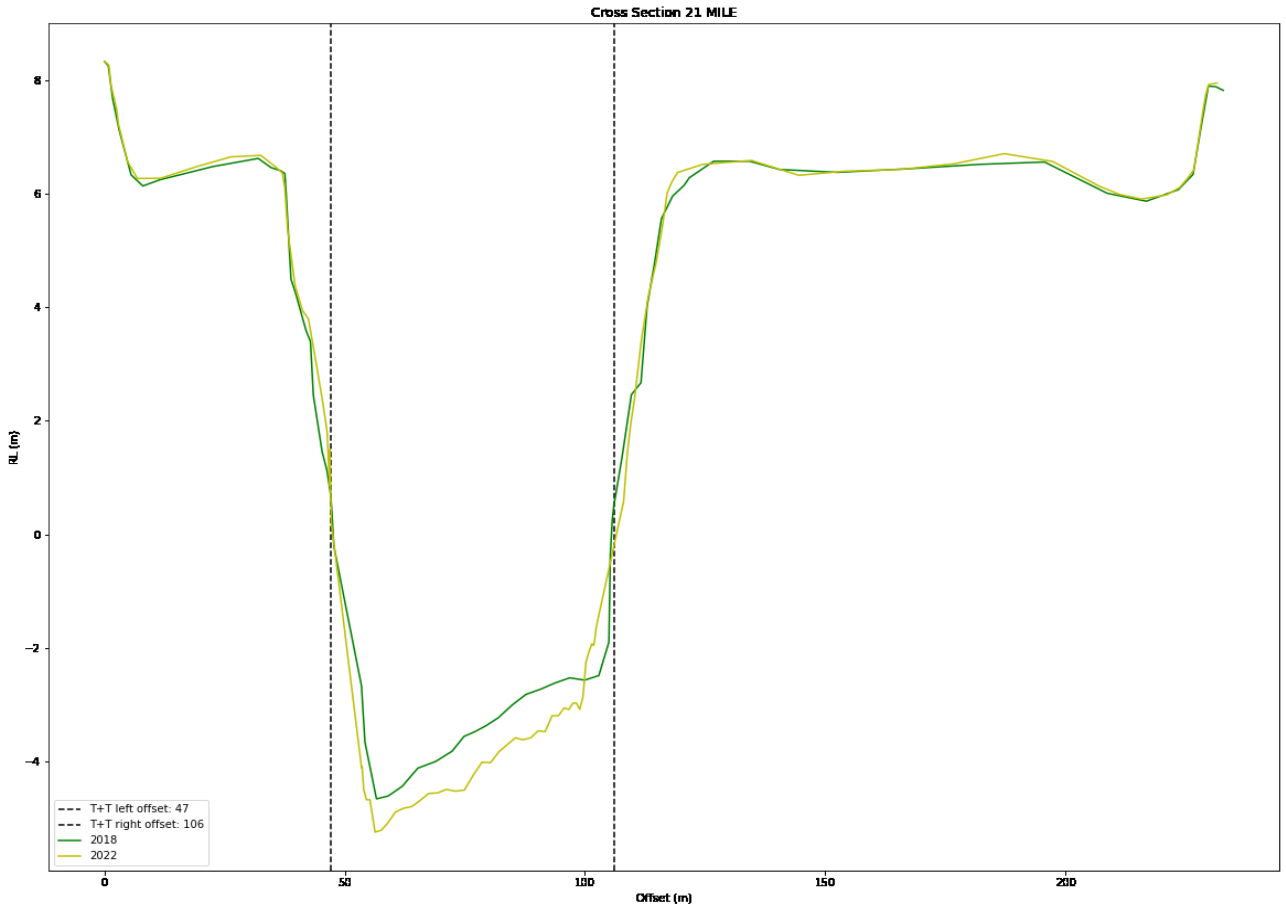

Cross Section 337
RL (m)
Offset (m)
T+T left offset: 150
T+T right offset: 204
2018
2022

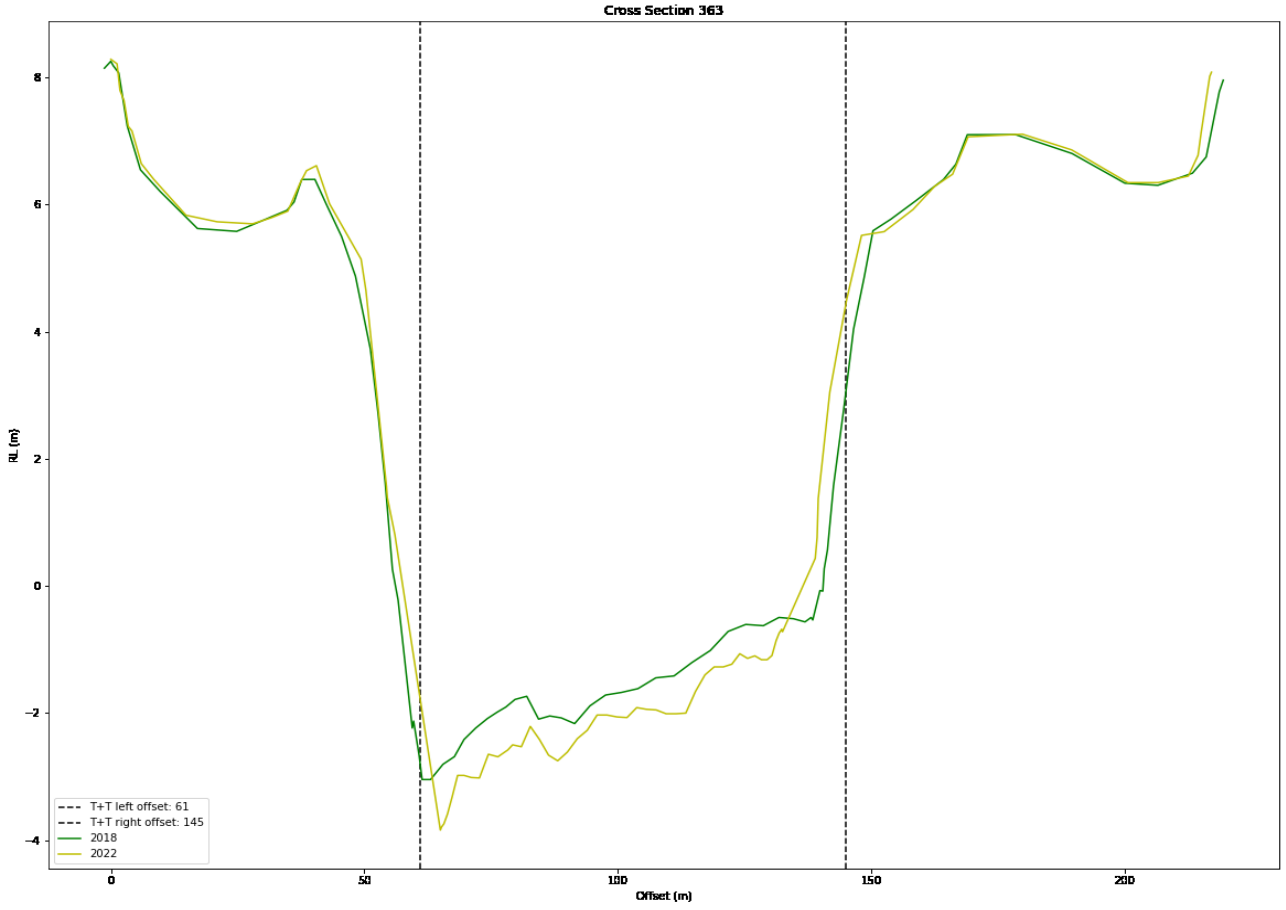

Cross Section 20 MILE
RL (m)
Offset (m)
T+T left offset: 106
T+T right offset: 180
2018
2022

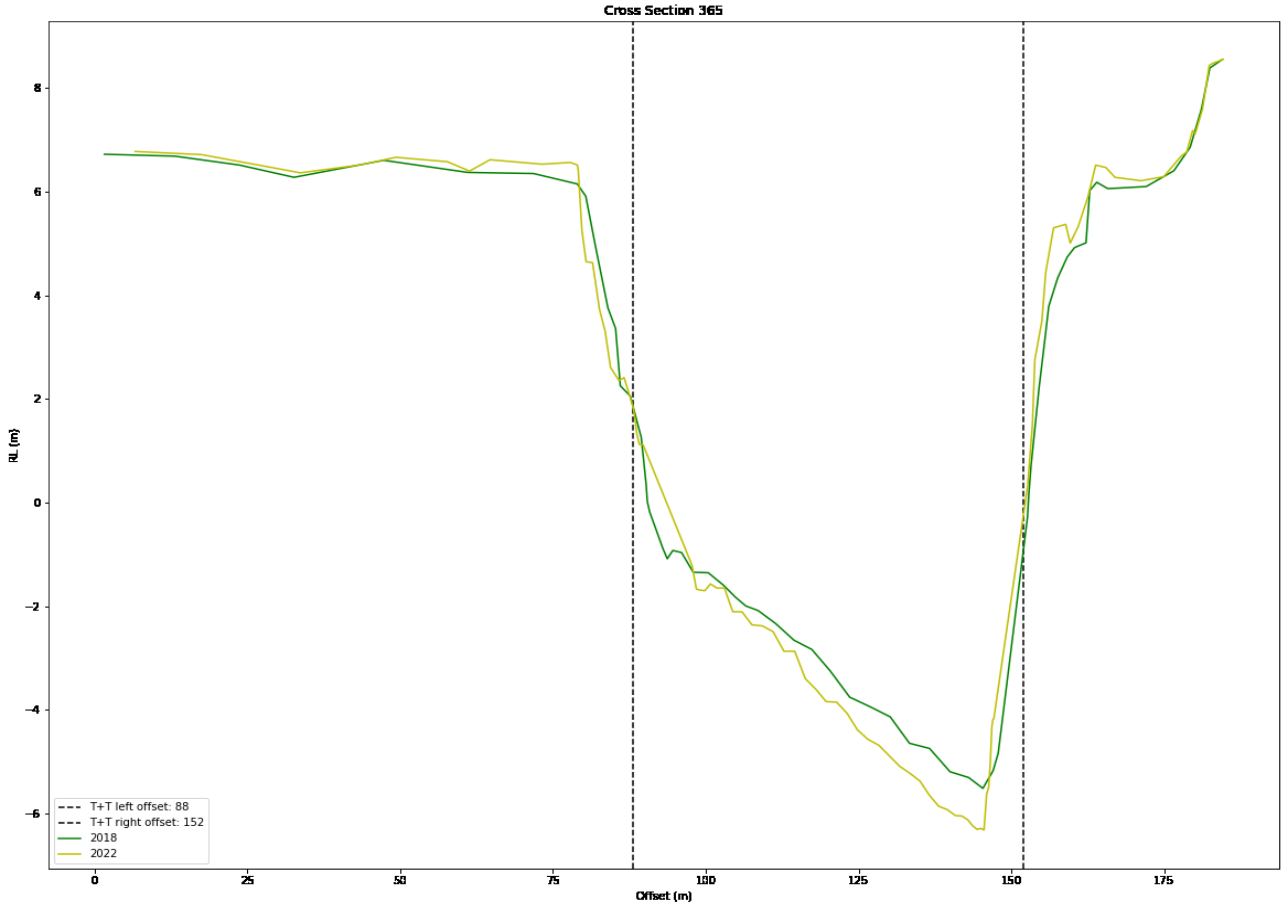

Cross Section 347
RL (m)
Offset (m)
T+T left offset: 26
T+T right offset: 92
2018
2022

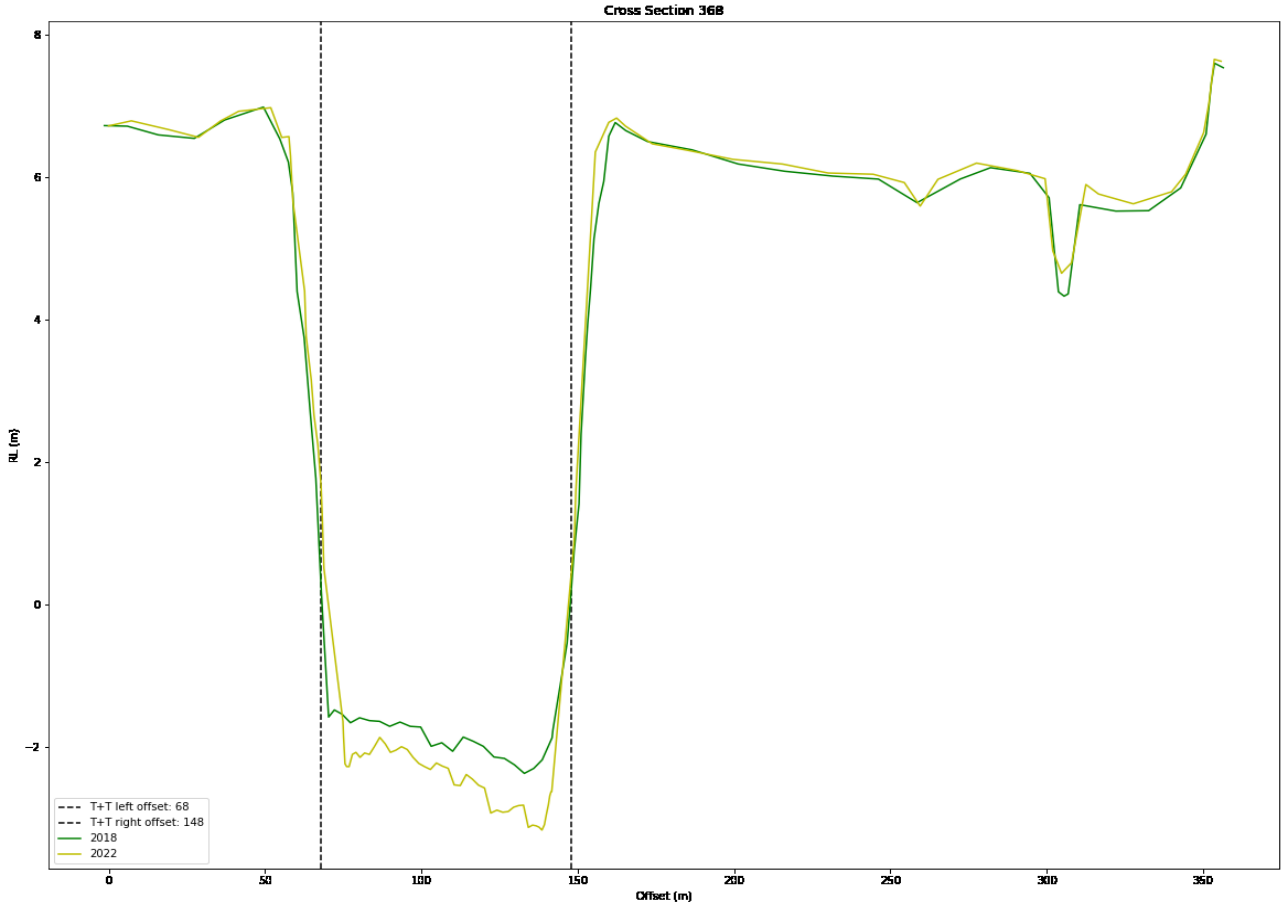

Cross Section 350
RL (m)
Offset (m)
T+T left offset: 20
T+T right offset: 72
2018
2022

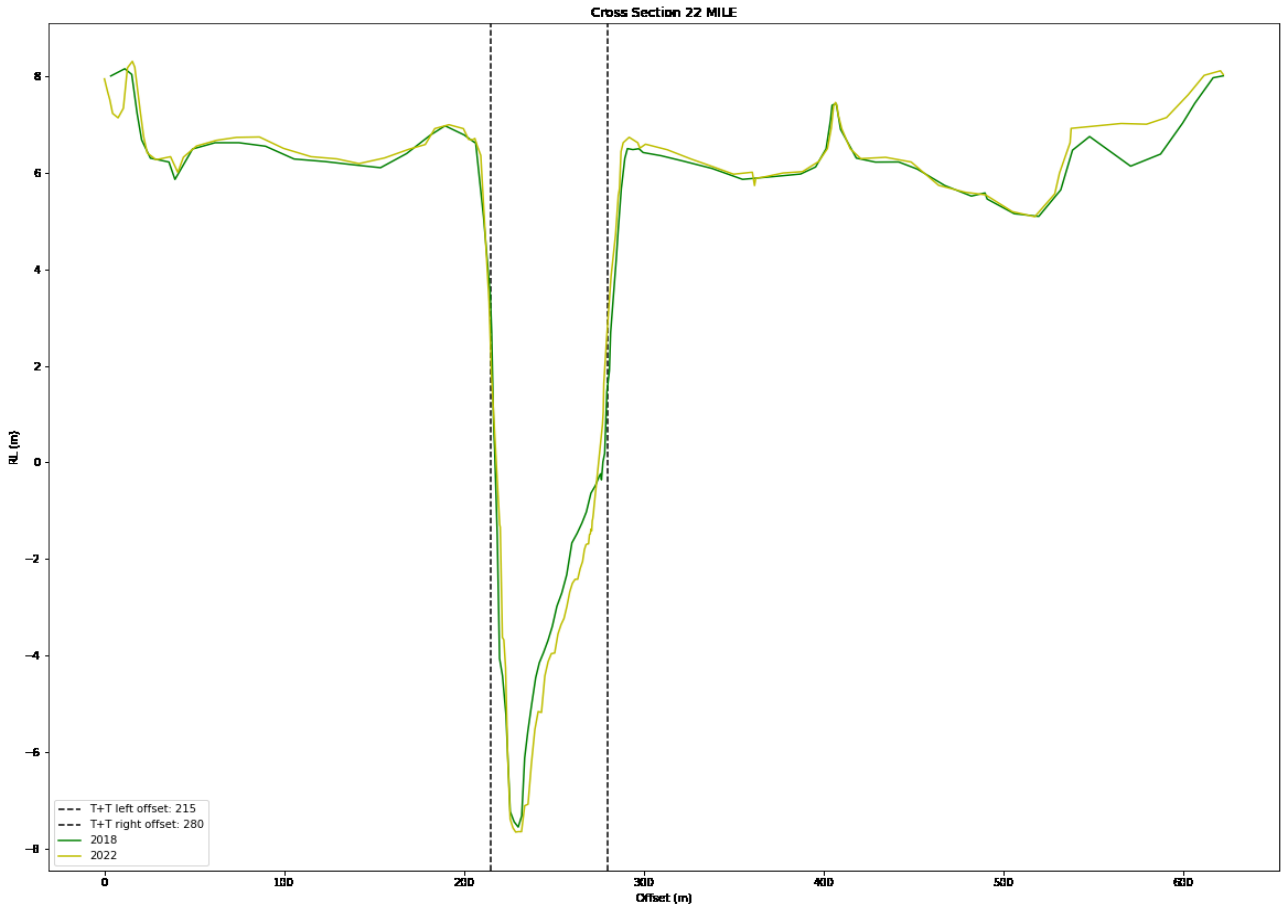

Cross Section 354
RL (m)
Offset (m)
T+T left offset: 130
T+T right offset: 197
2018
2022

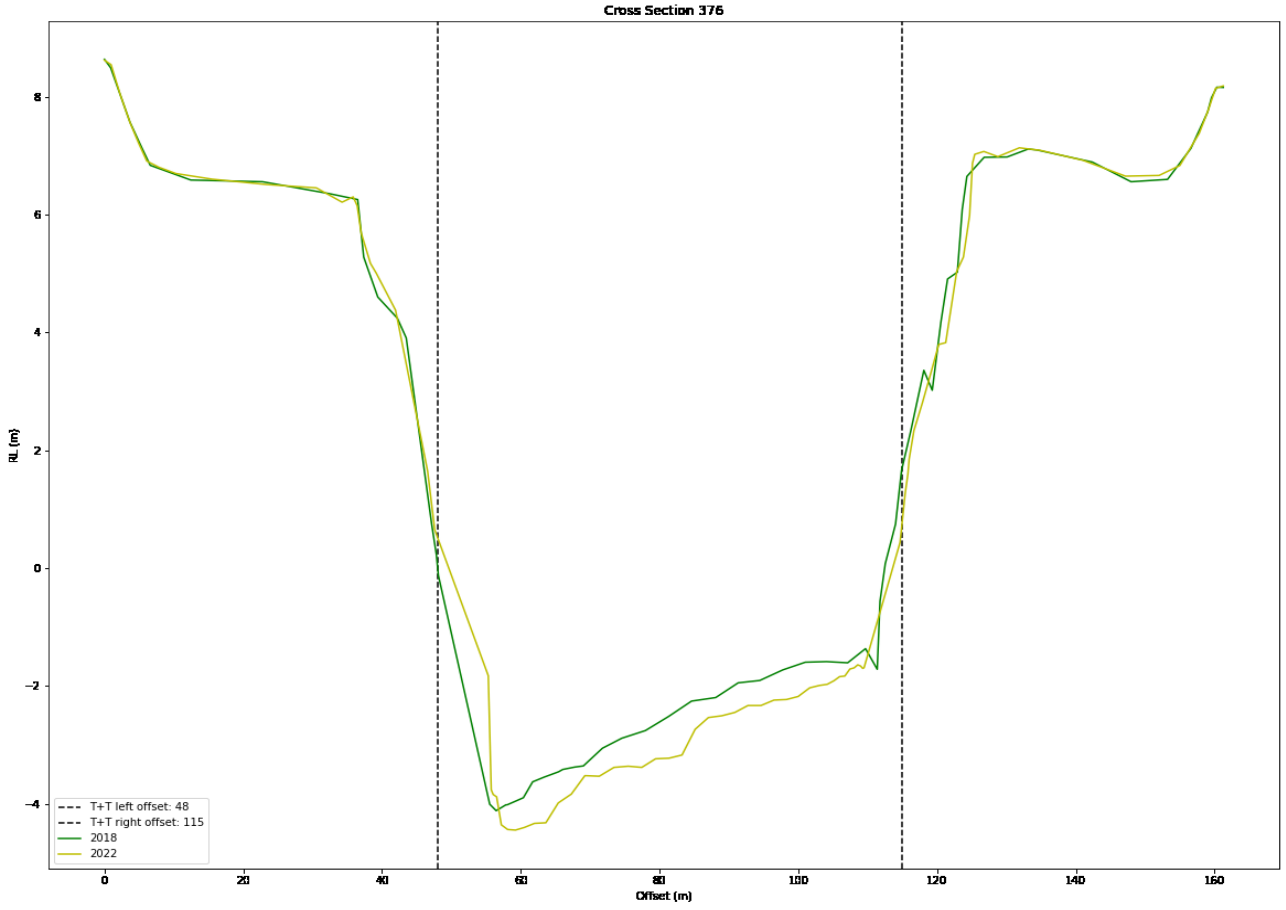

Cross Section 21 MILE
RL (m)
Offset (m)
T+T left offset: 47
T+T right offset: 106
2018
2022

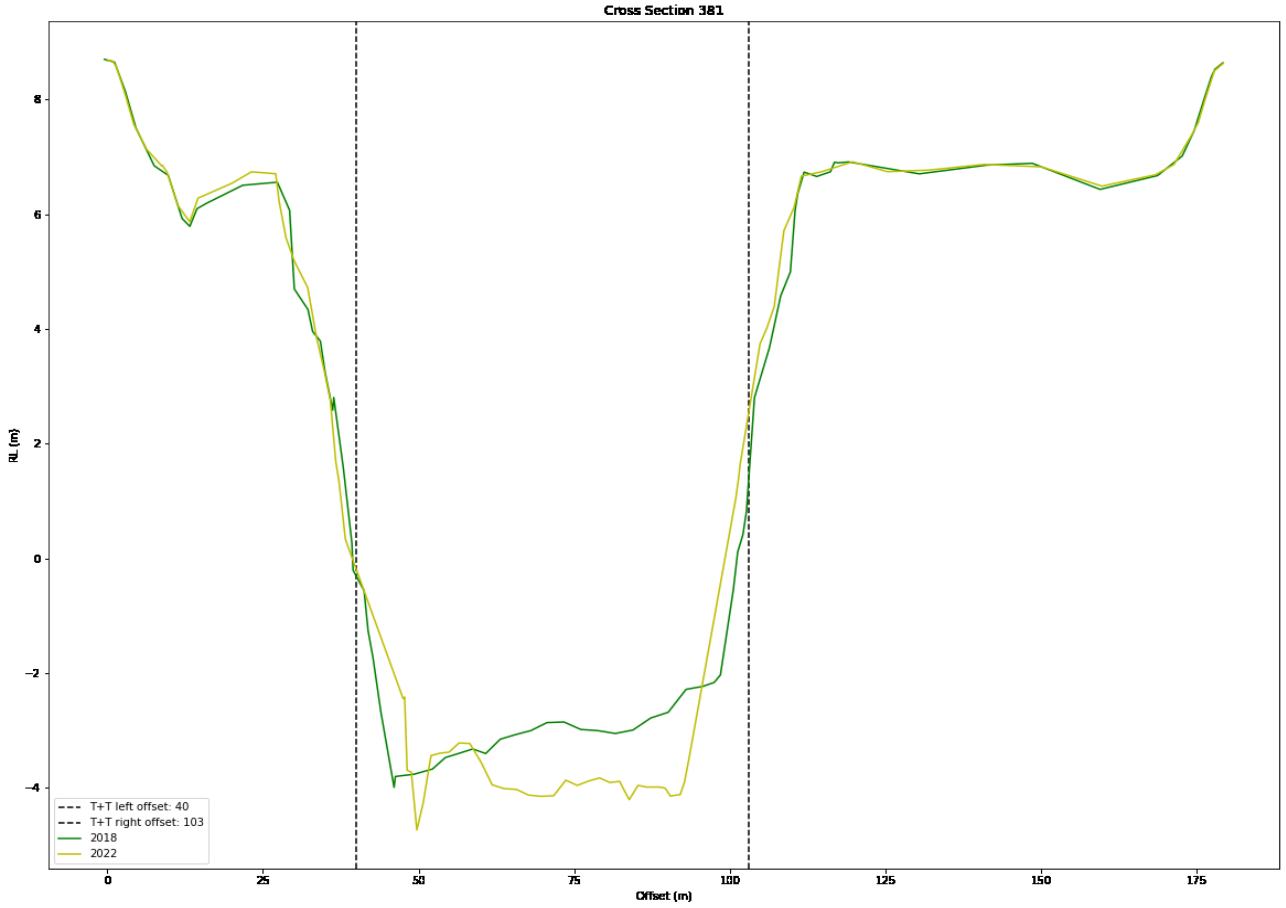

Cross Section 363
RL (m)
Offset (m)
T+T left offset: 61
T+T right offset: 145
2018
2022

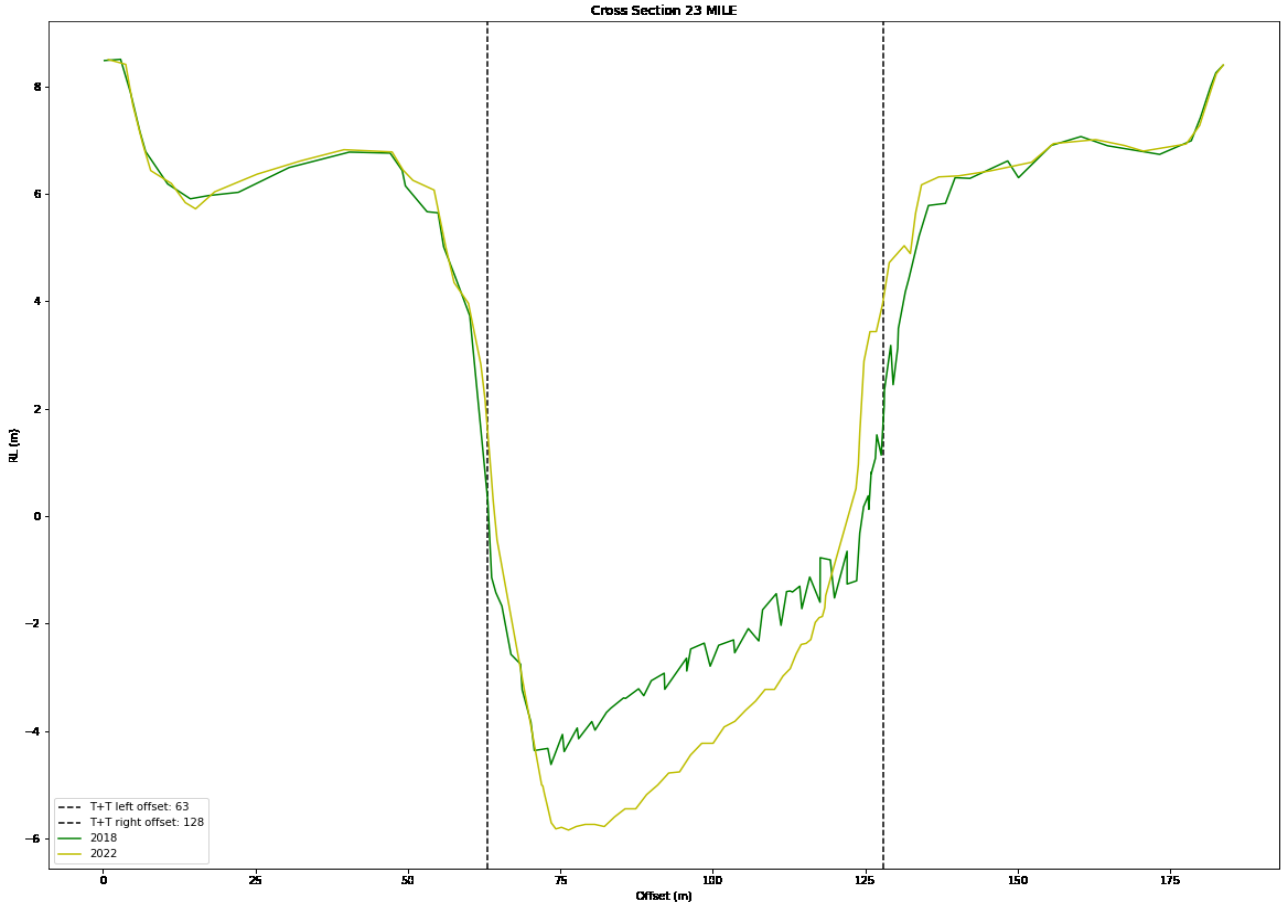

Cross Section 365
RL (m)
Offset (m)
T+T left offset: 88
T+T right offset: 152
2018
2022

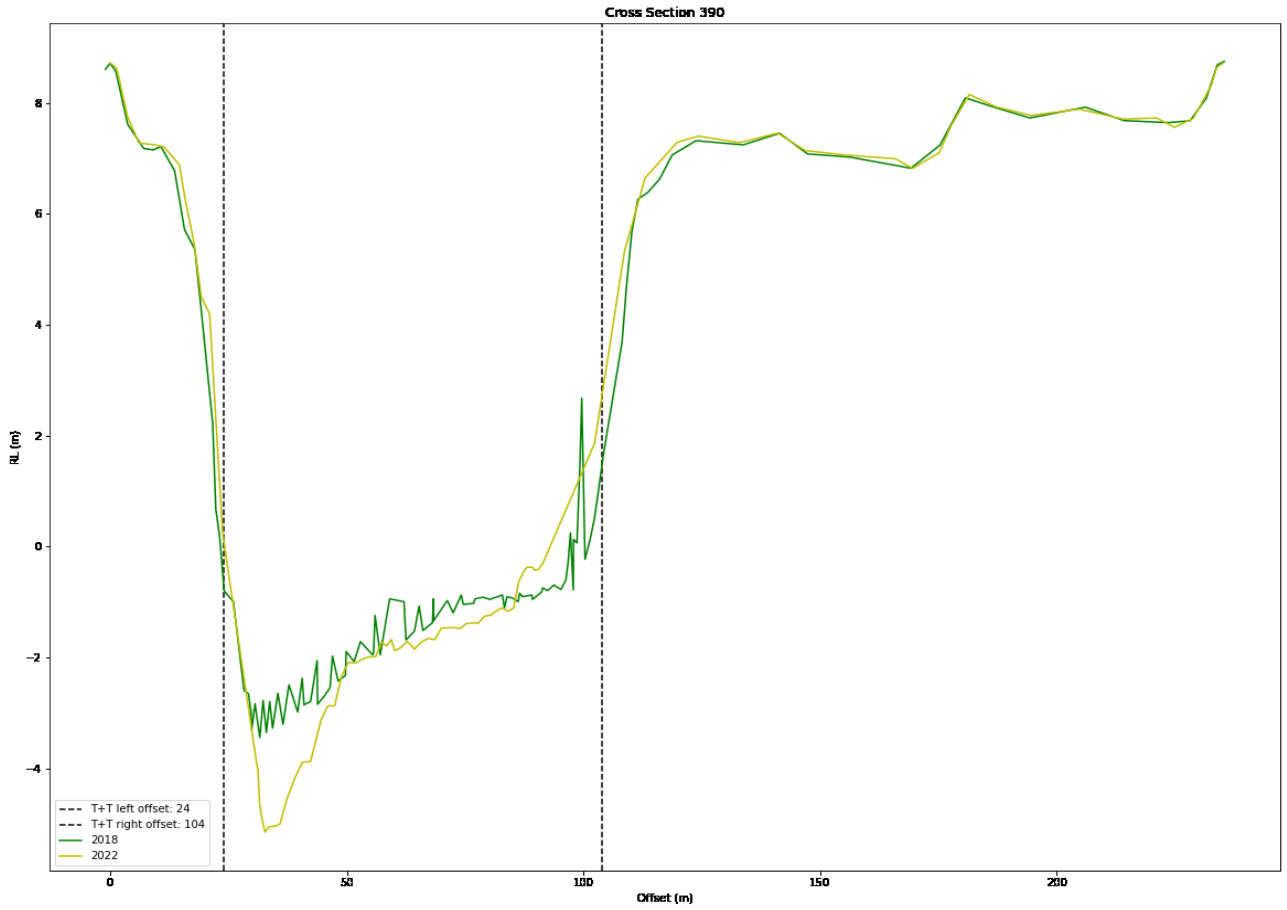

Cross Section 368
RL (m)
Offset (m)
T+T left offset: 68
T+T right offset: 148
2018
2022

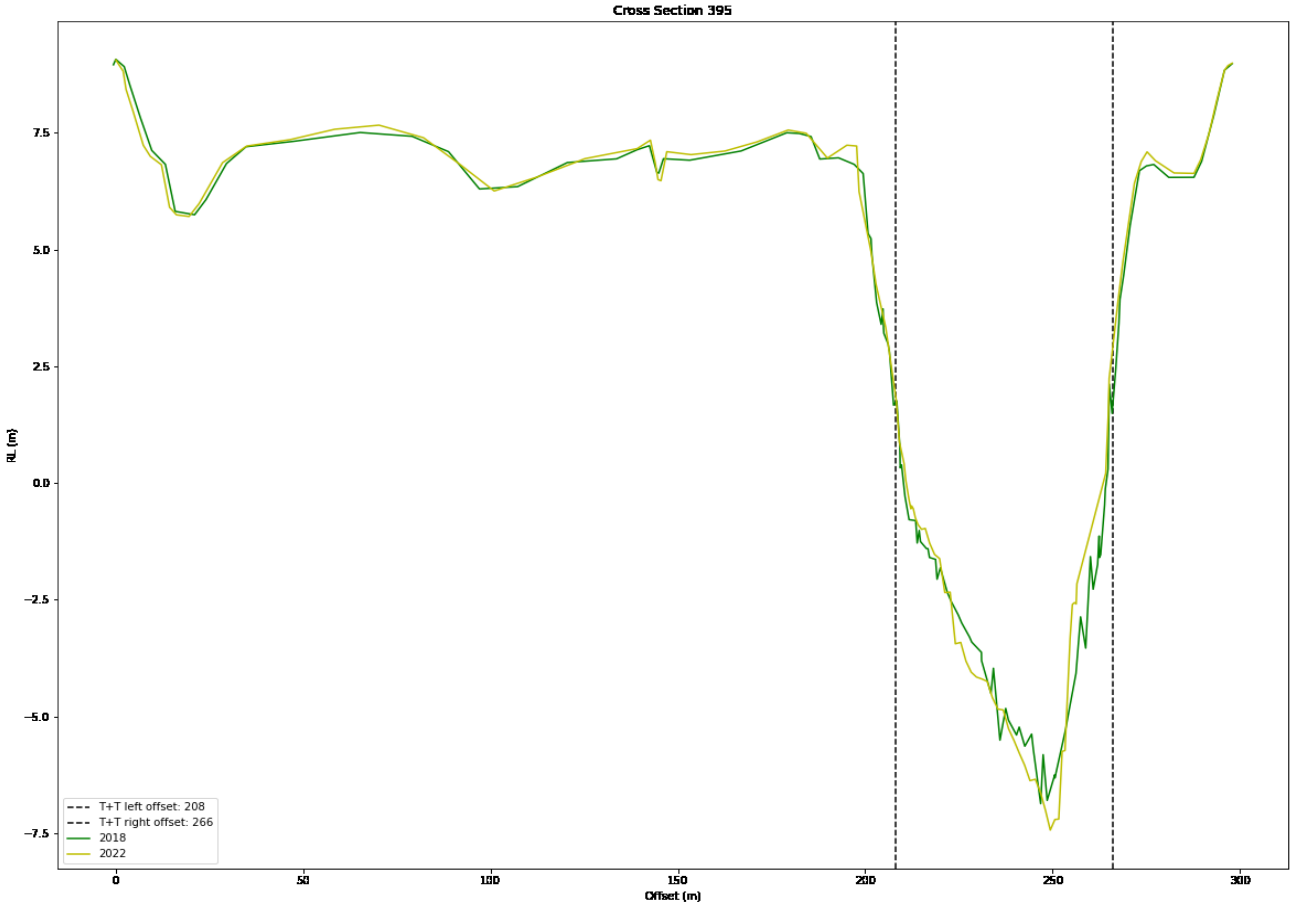

Cross Section 22 MILE
RL (m)
Offset (m)
T+T left offset: 215
T+T right offset: 280
2018
2022

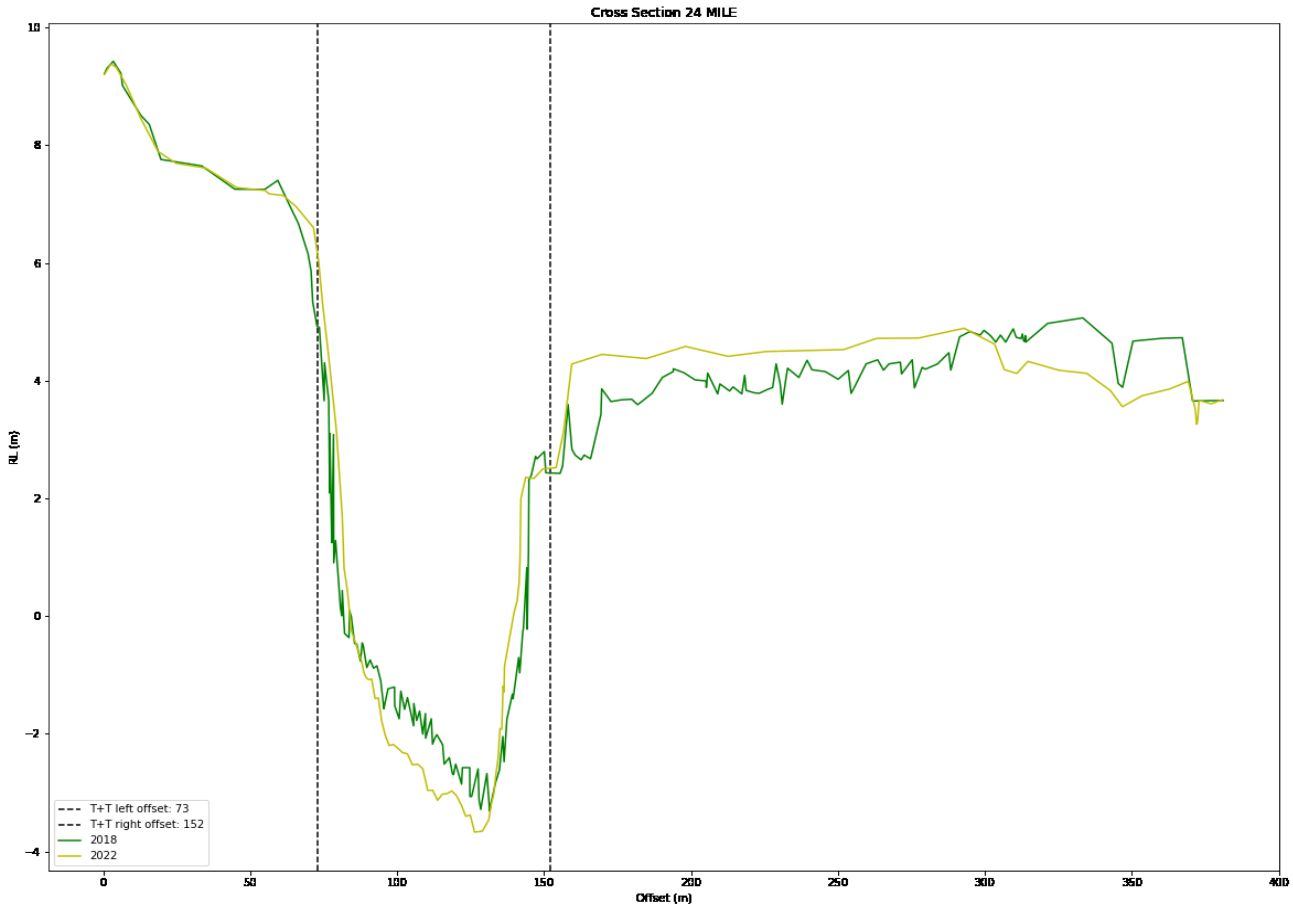

Cross Section 376
RL (m)
Offset (m)
T+T left offset: 48
T+T right offset: 115
2018
2022

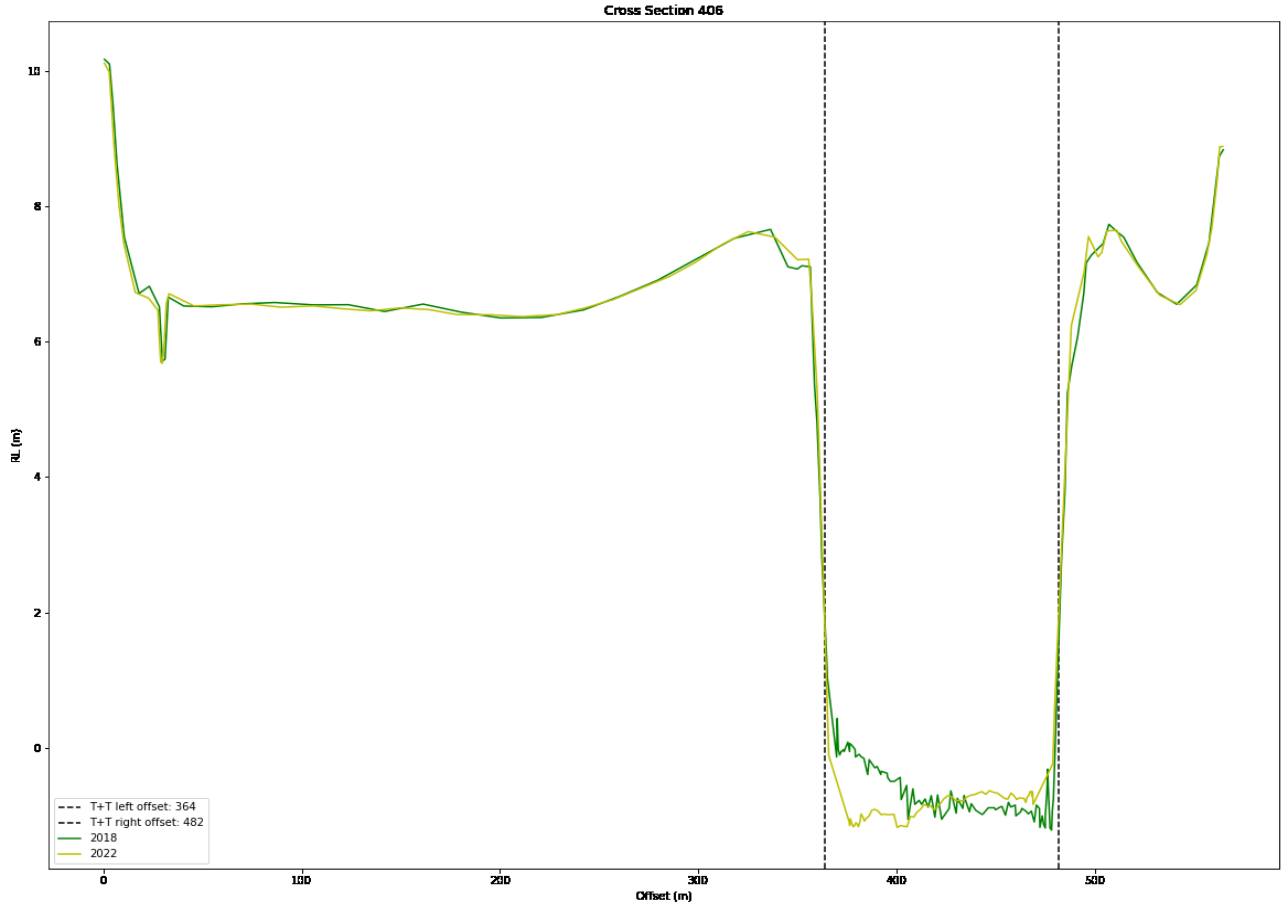

Cross Section 381
RL (m)
Offset (m)
T+T left offset: 40
T+T right offset: 103
2018
2022

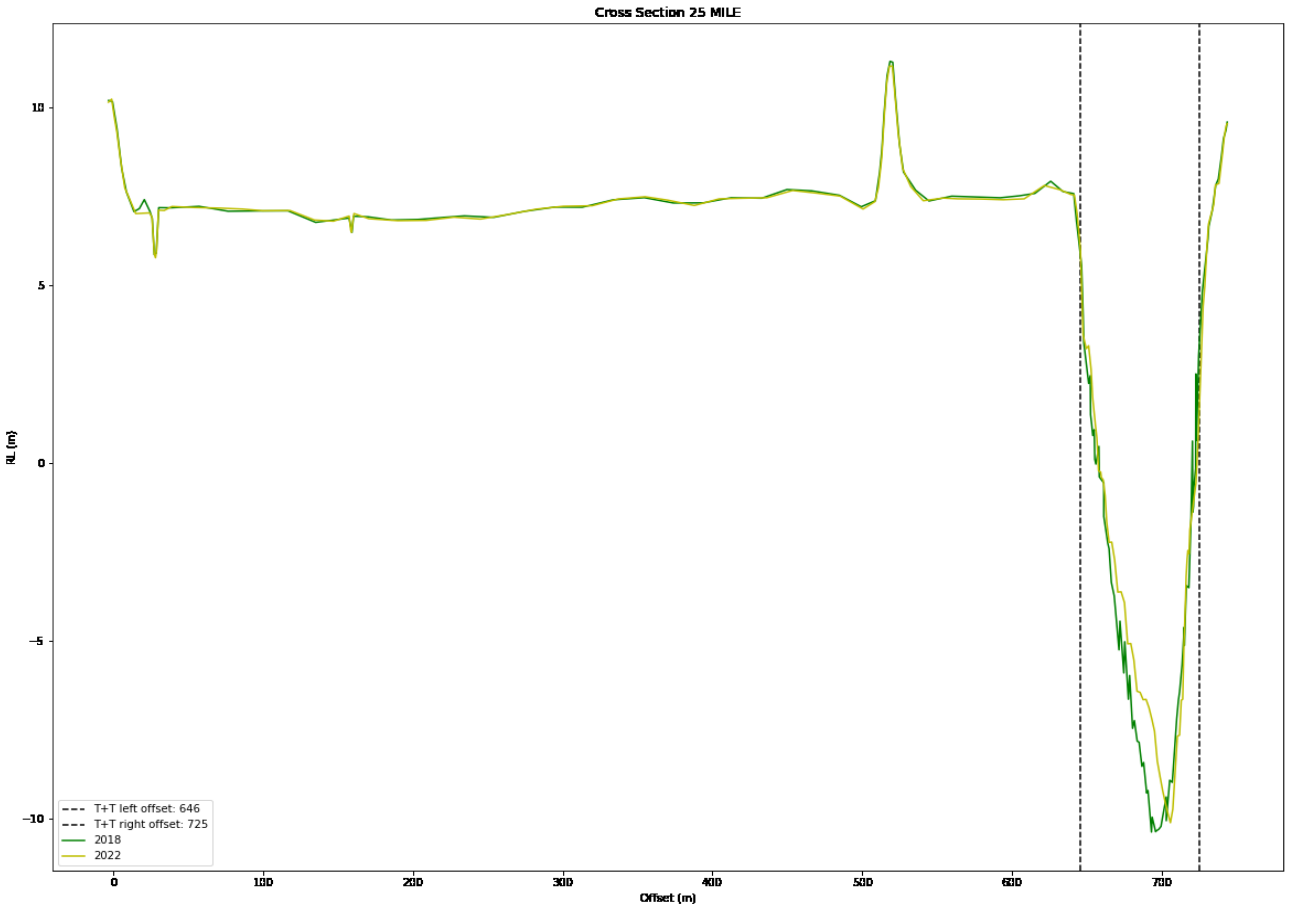

Cross Section 23 MILE
RL (m)
Offset (m)
T+T left offset: 63
T+T right offset: 128
2018
2022

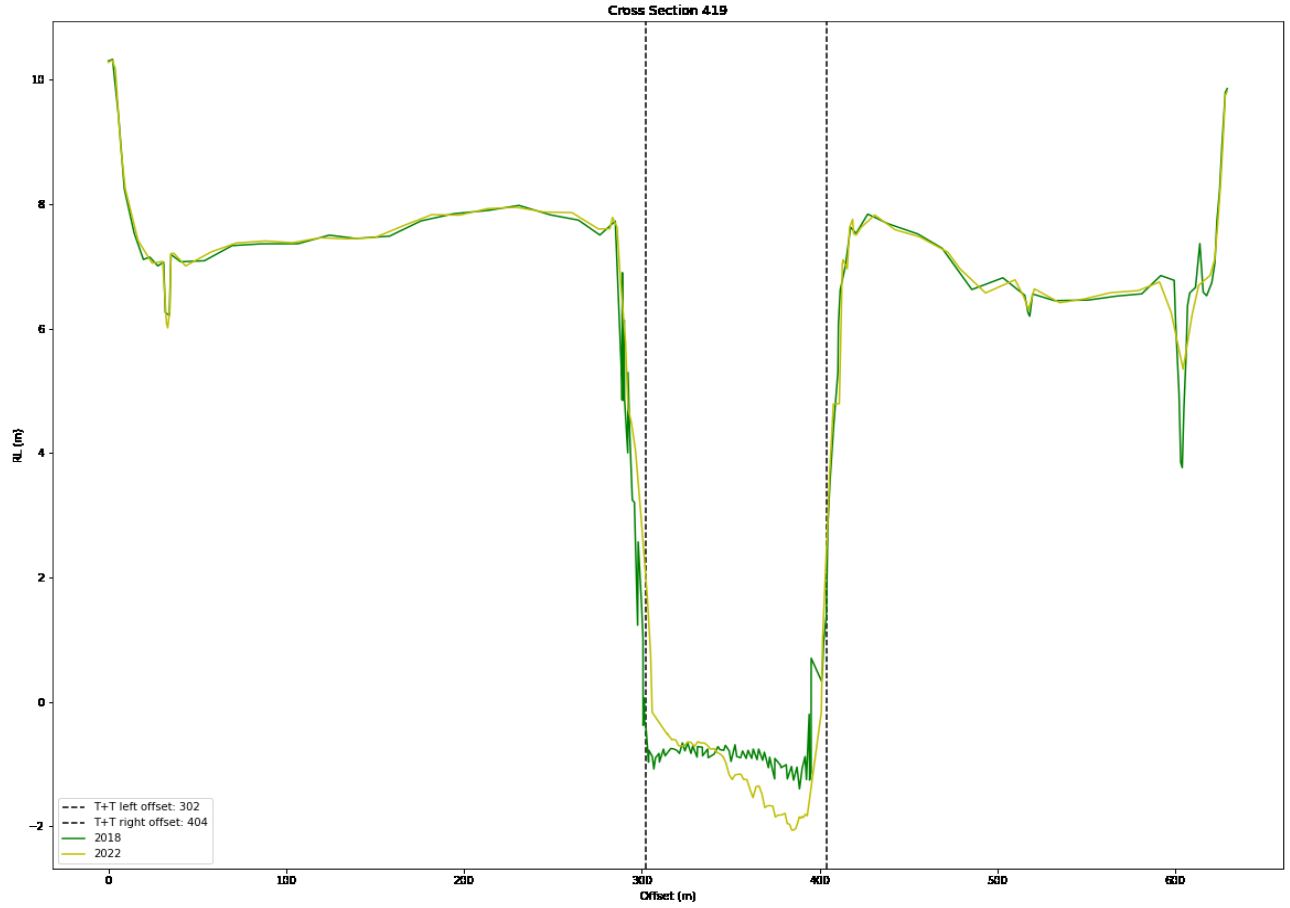

Cross Section 390
RL (m)
Offset (m)
T+T left offset: 24
T+T right offset: 104
2018
2022

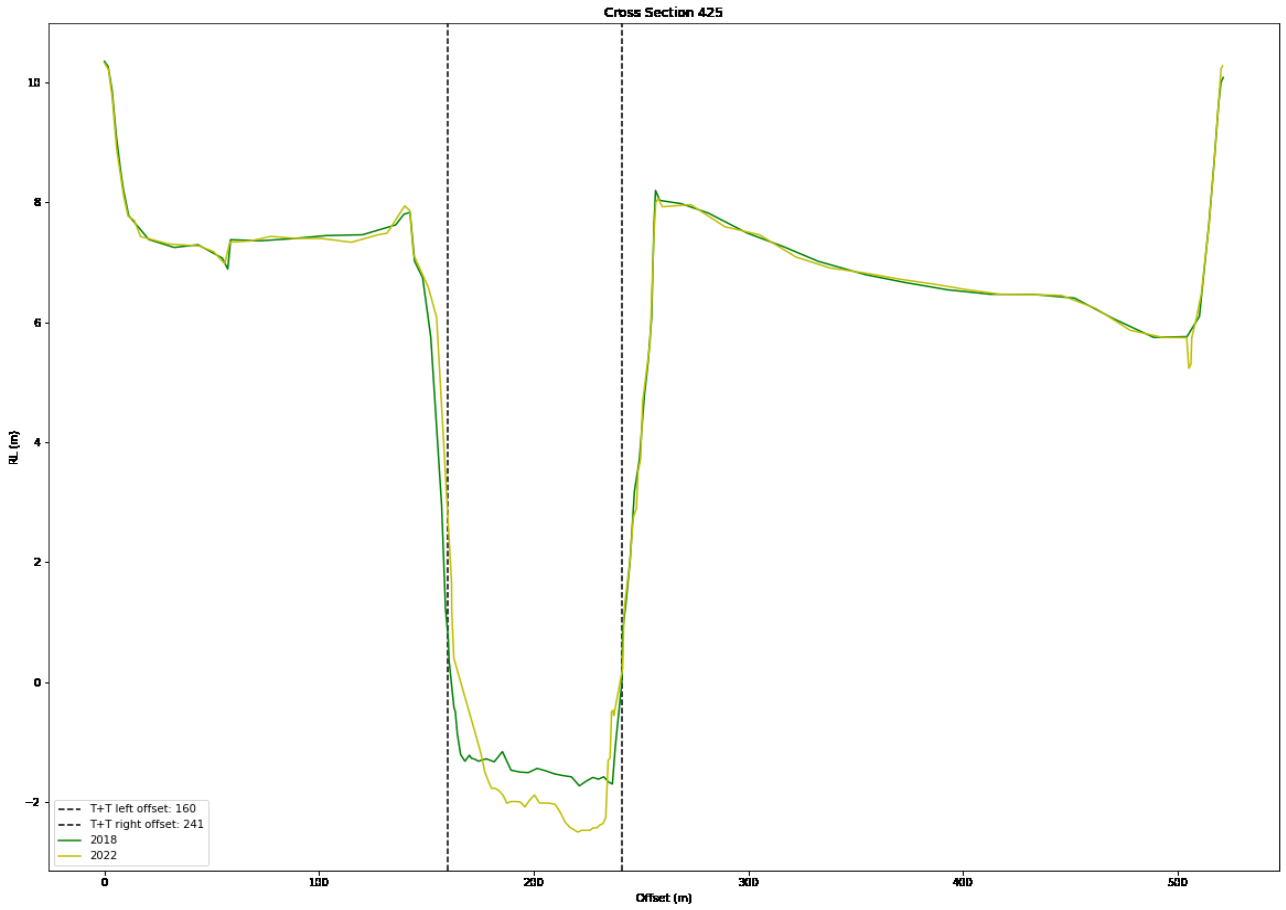

Cross Section 395
RL (m)
Offset (m)
T+T left offset: 208
T+T right offset: 266
2018
2022

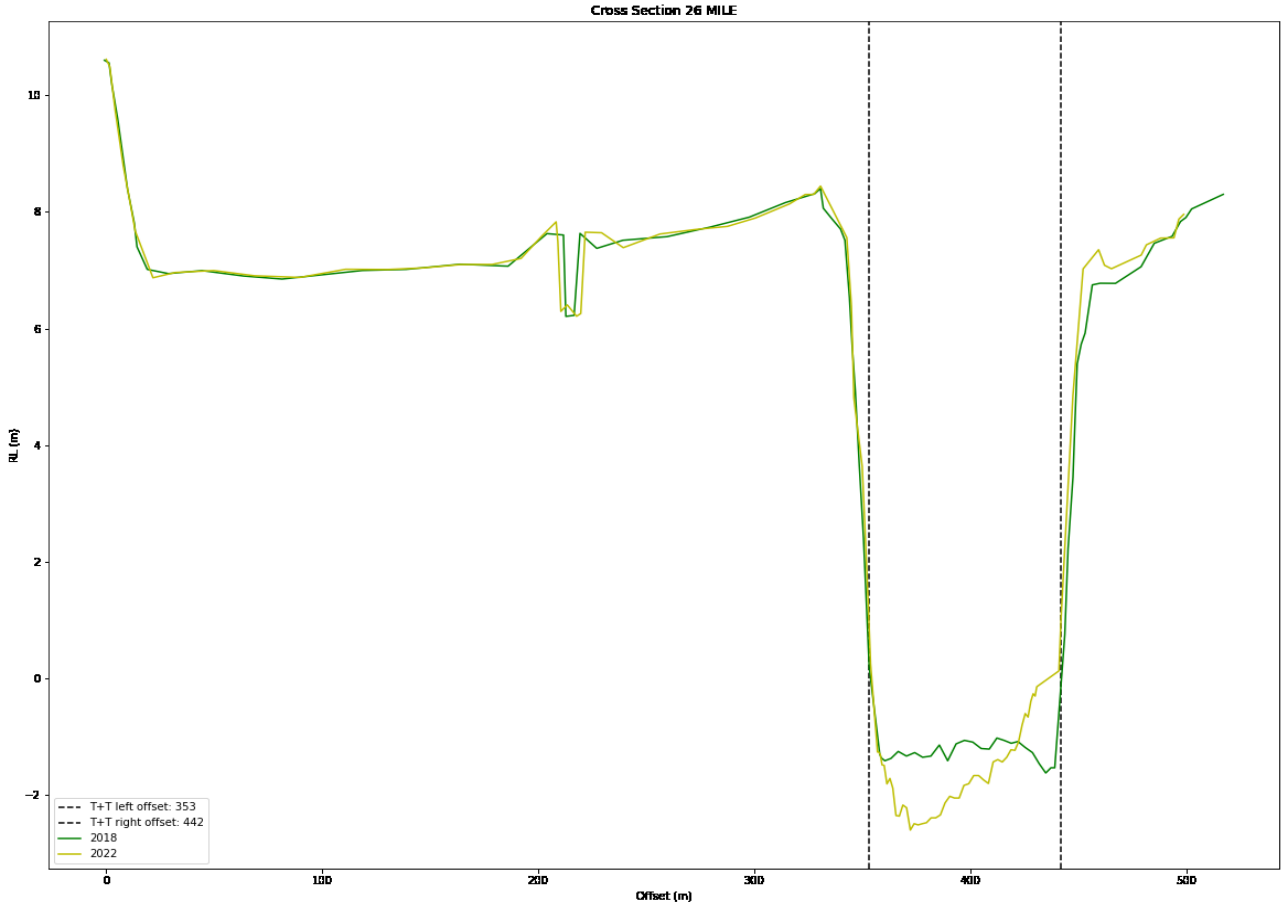

Cross Section 24 MILE
RL (m)
Offset (m)
T+T left offset: 73
T+T right offset: 152
2018
2022

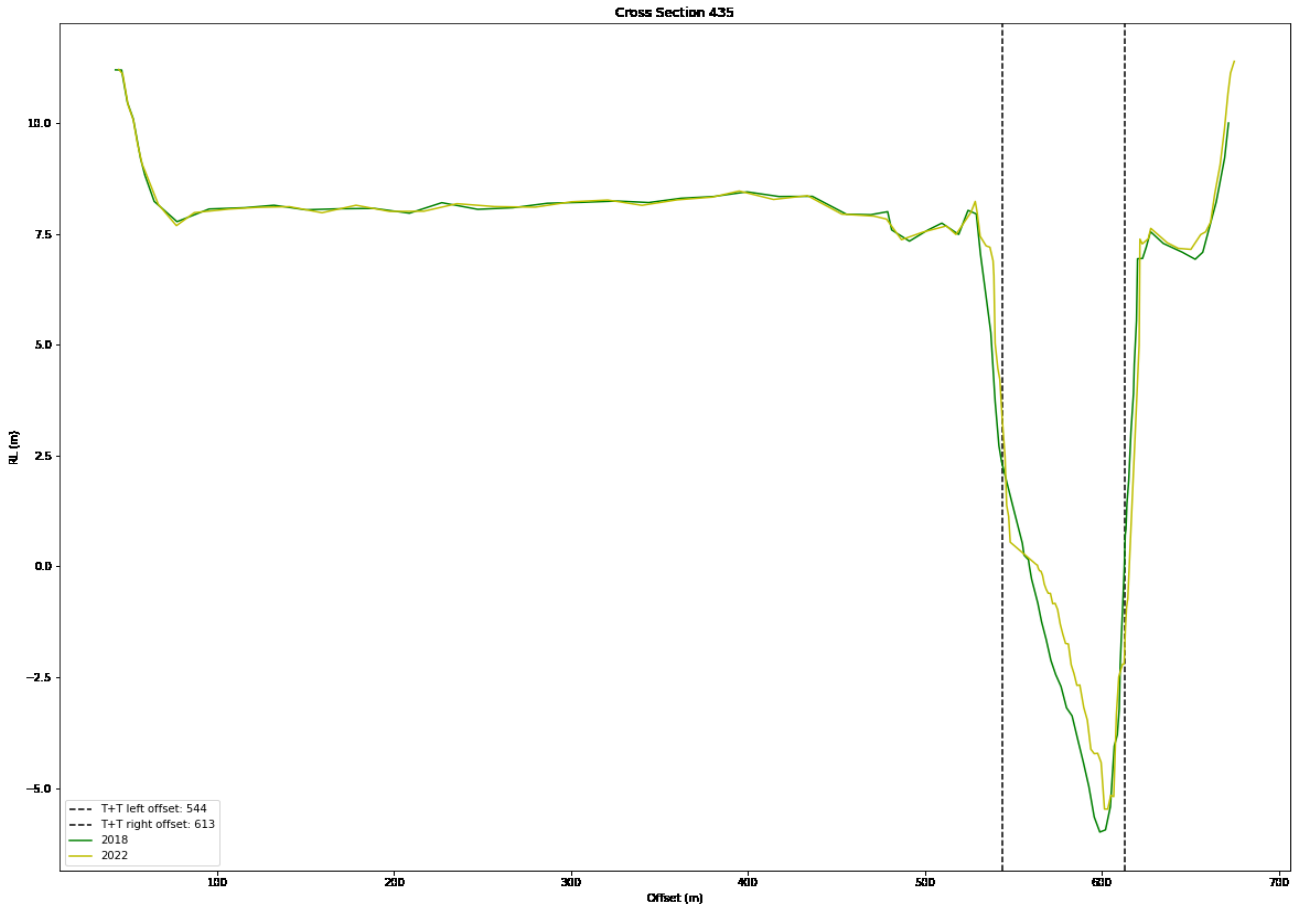

Cross Section 406
RL (m)
Offset (m)
T+T left offset: 364
T+T right offset: 482
2018
2022

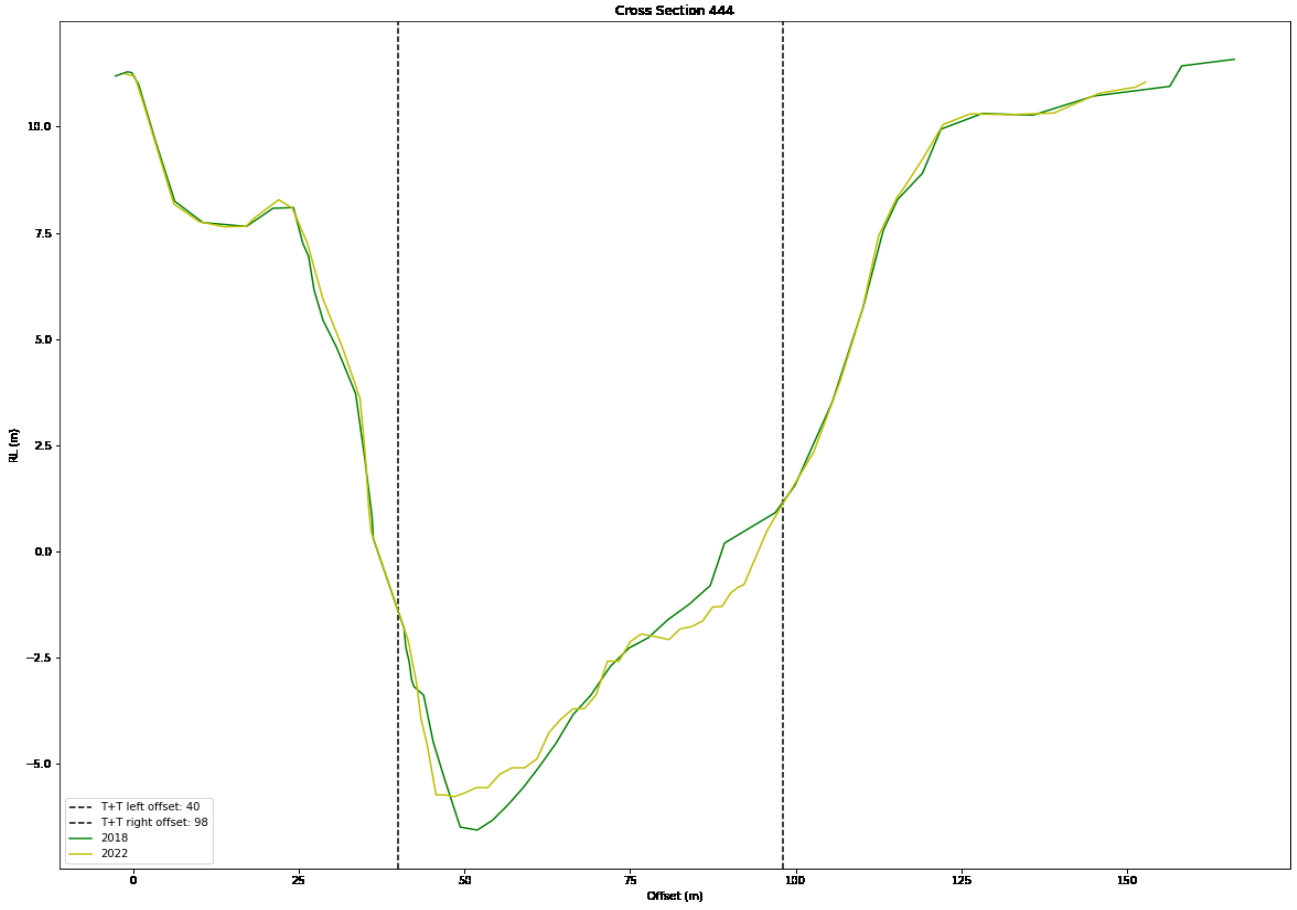

Cross Section 25 MILE
RL (m)
Offset (m)
T+T left offset: 646
T+T right offset: 725
2018
2022

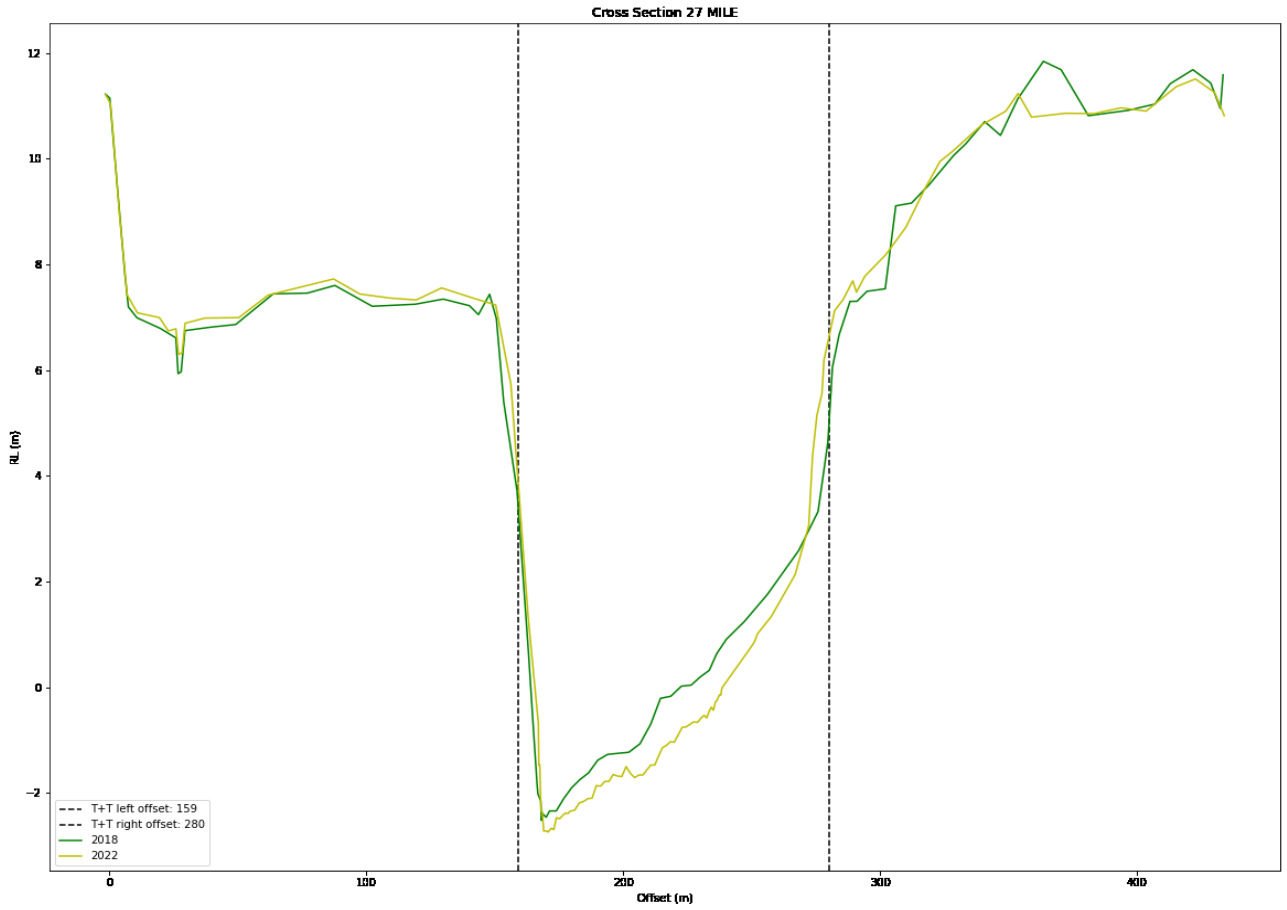

Cross Section 419
RL (m)
Offset (m)
T+T left offset: 302
T+T right offset: 404
2018
2022

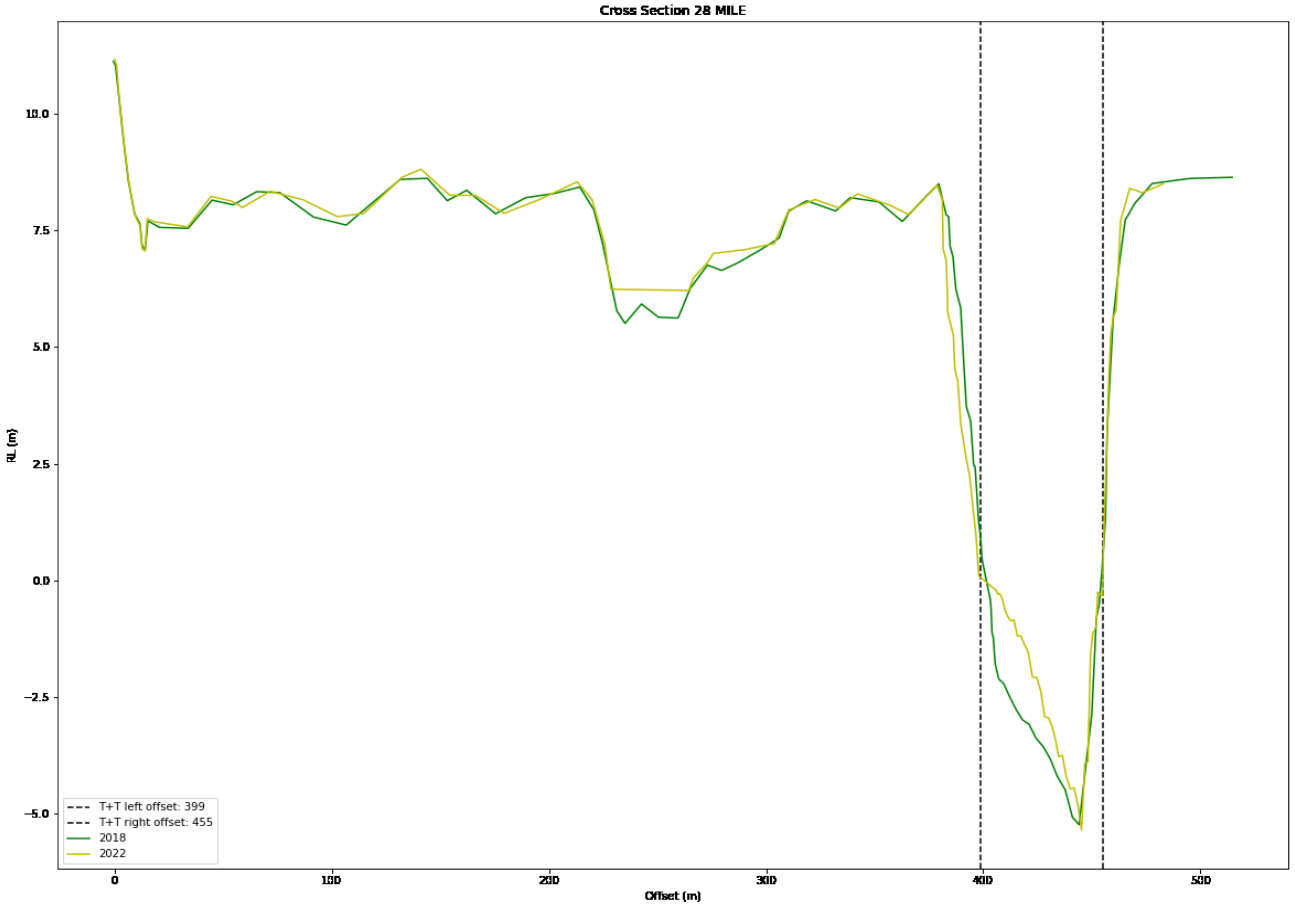

Cross Section 425
RL (m)
Offset (m)
T+T left offset: 160
T+T right offset: 241
2018
2022

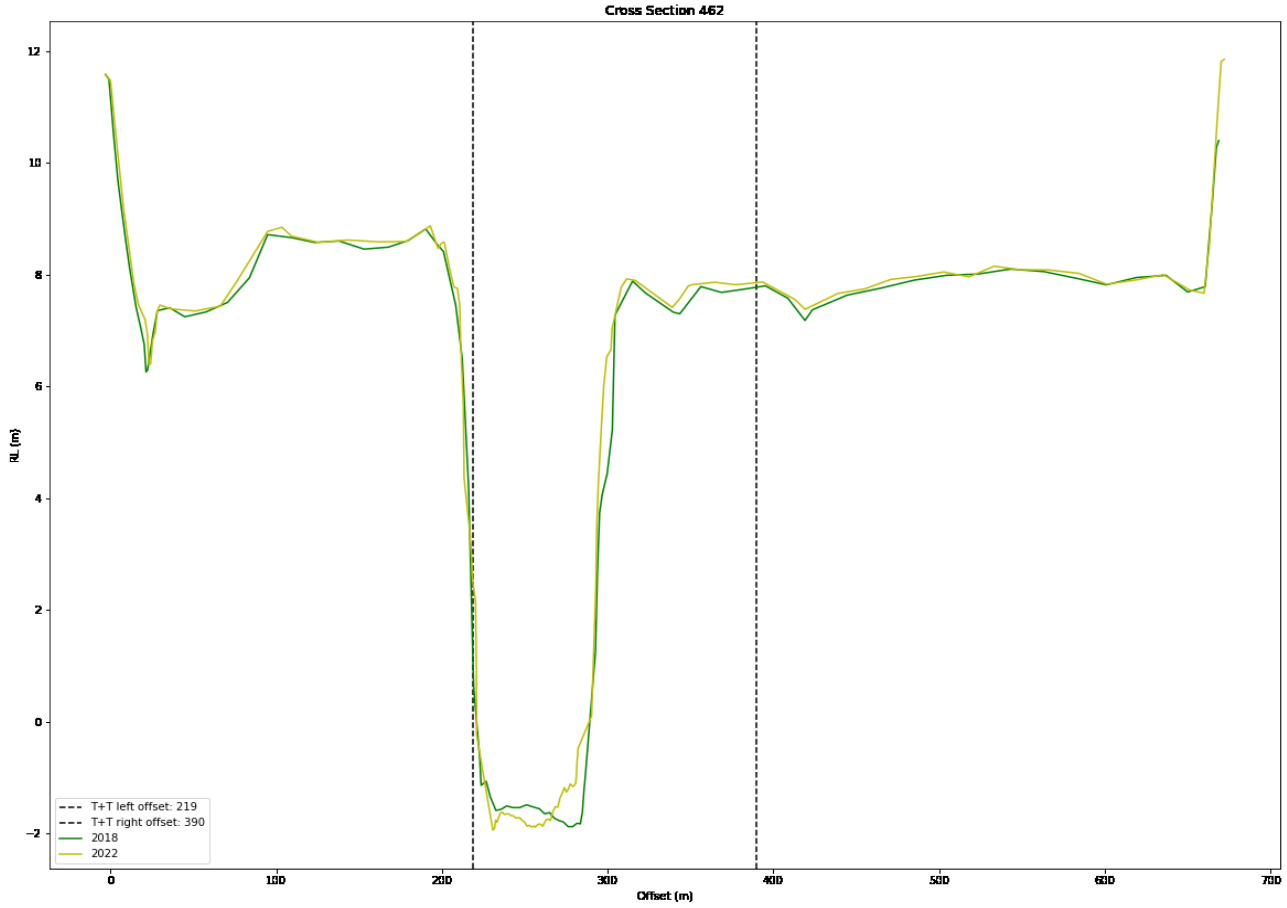

Cross Section 26 MILE
RL (m)
Offset (m)
T+T left offset: 353
T+T right offset: 442
2018
2022

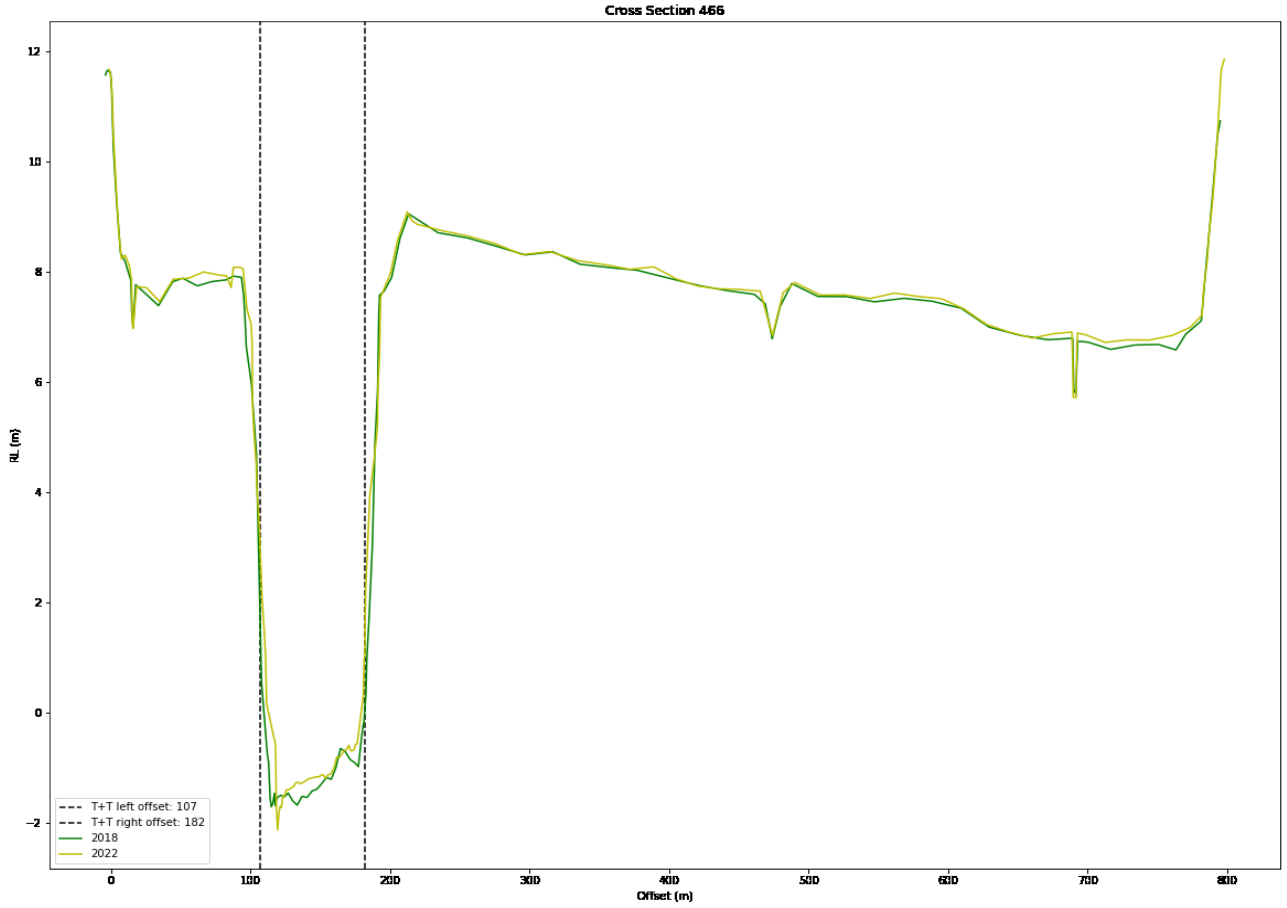

Cross Section 435
10.0
7.5
5.0
2.5
0.0
−2.5
−5.0
RL (m)
100
200
300
400
500
600
700
Offset (m)
T+T left offset: 544
T+T right offset: 613
2018
2022

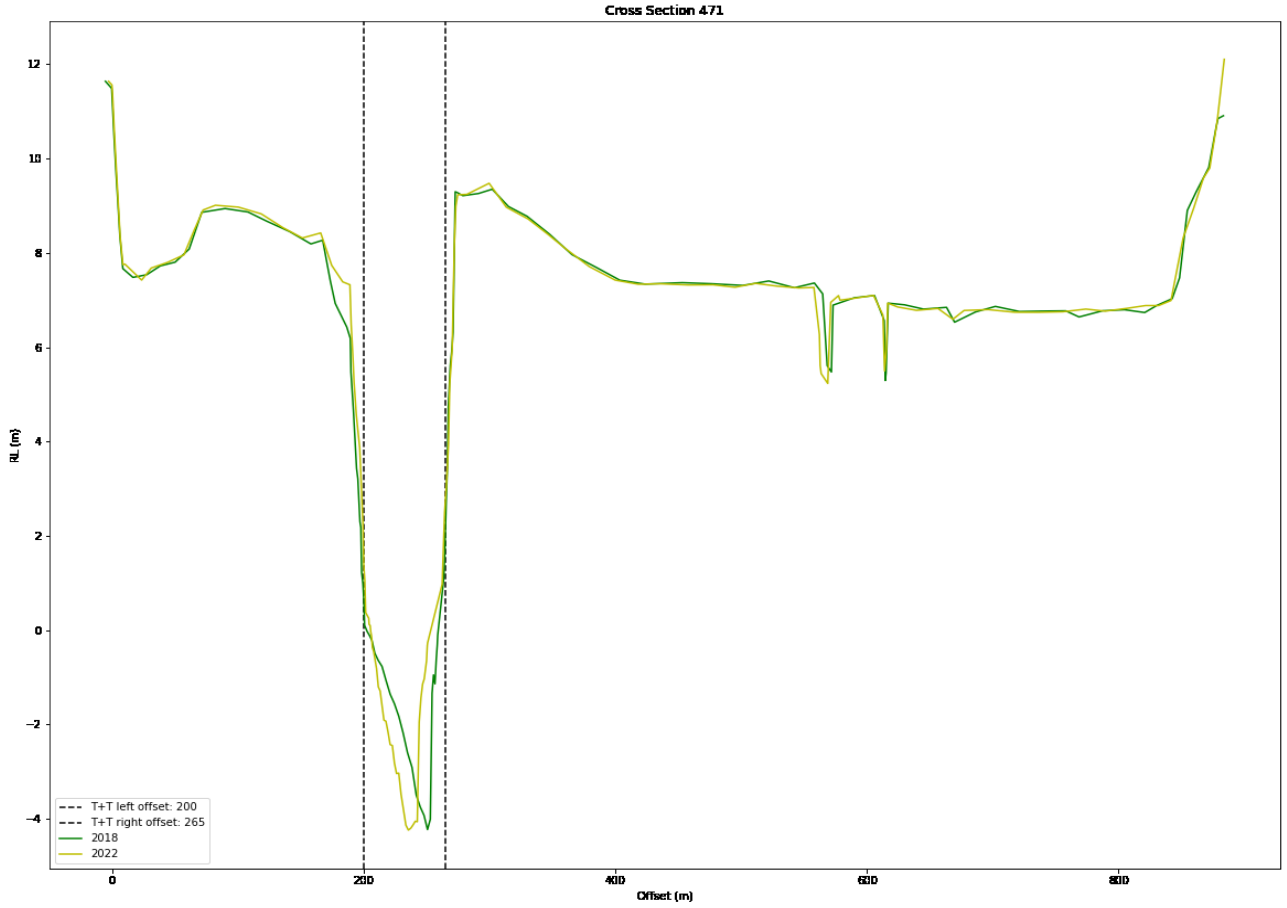

Cross Section 444
10.0
7.5
5.0
2.5
0.0
−2.5
−5.0
RL (m)
0
25
50
75
100
125
150
Offset (m)
T+T left offset: 40
T+T right offset: 98
2018
2022

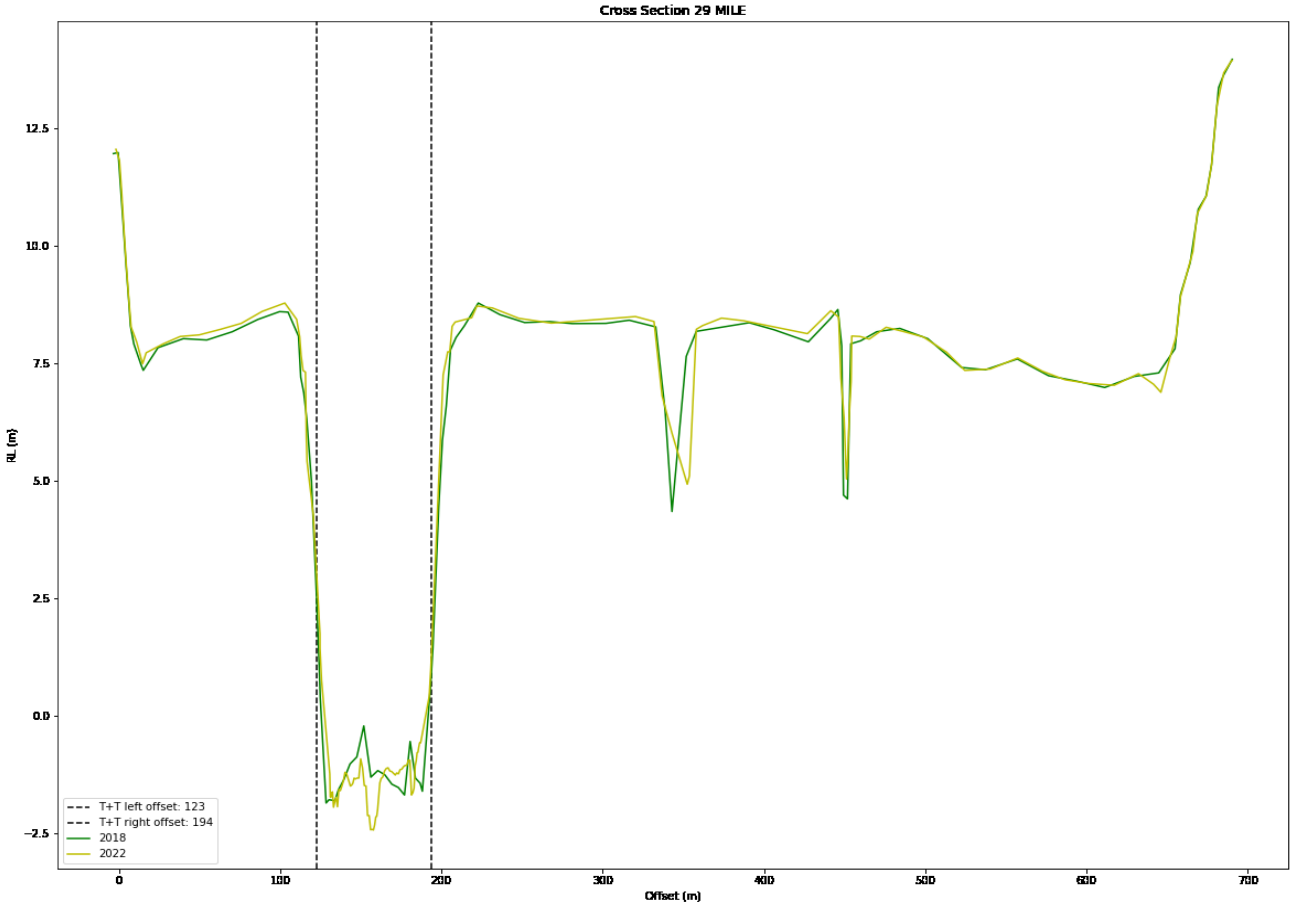

Cross Section 27 MILE
RL (m)
Offset (m)
T+T left offset: 159
T+T right offset: 280
2018
2022

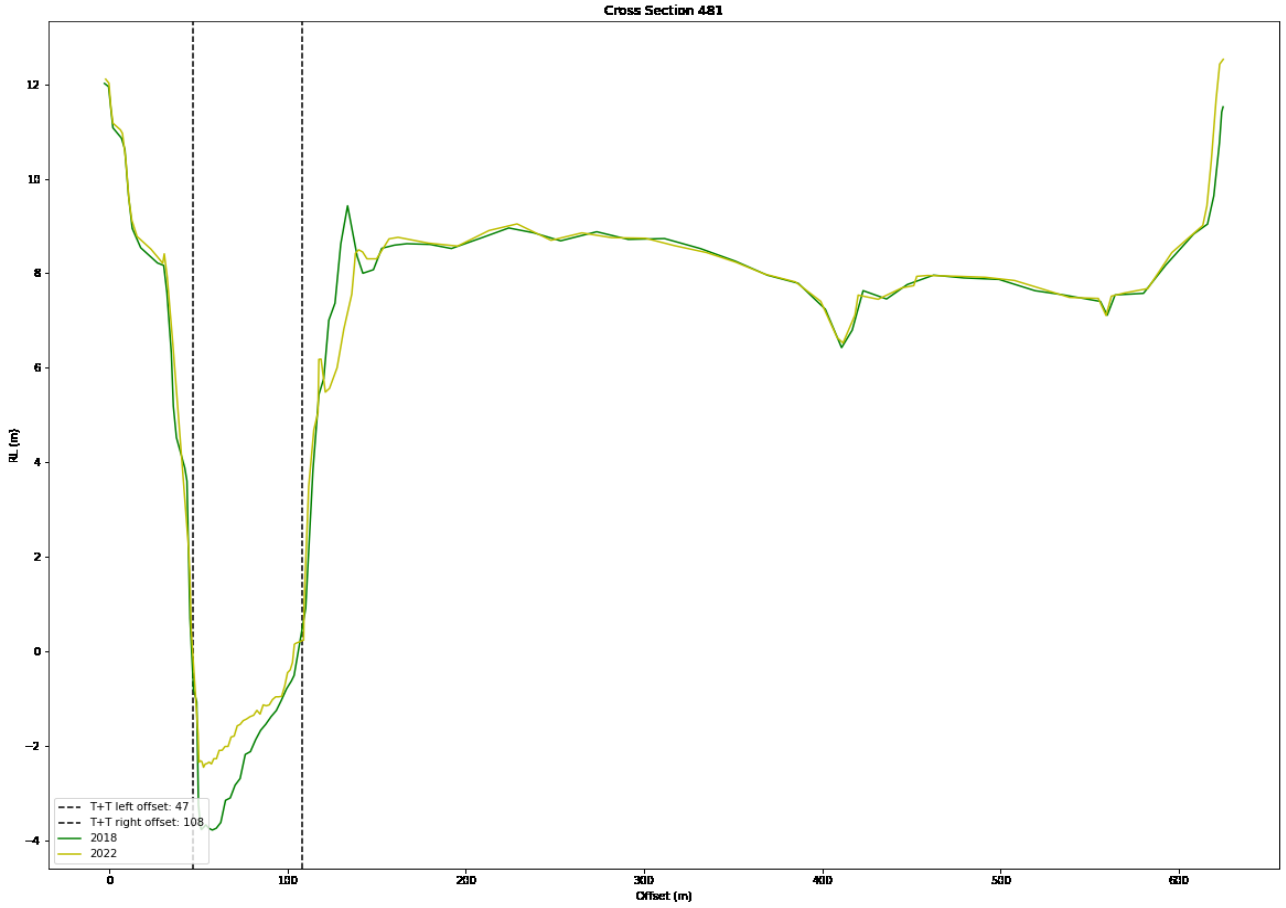

Cross Section 28 MILE
RL (m)
Offset (m)
T+T left offset: 399
T+T right offset: 455
2018
2022

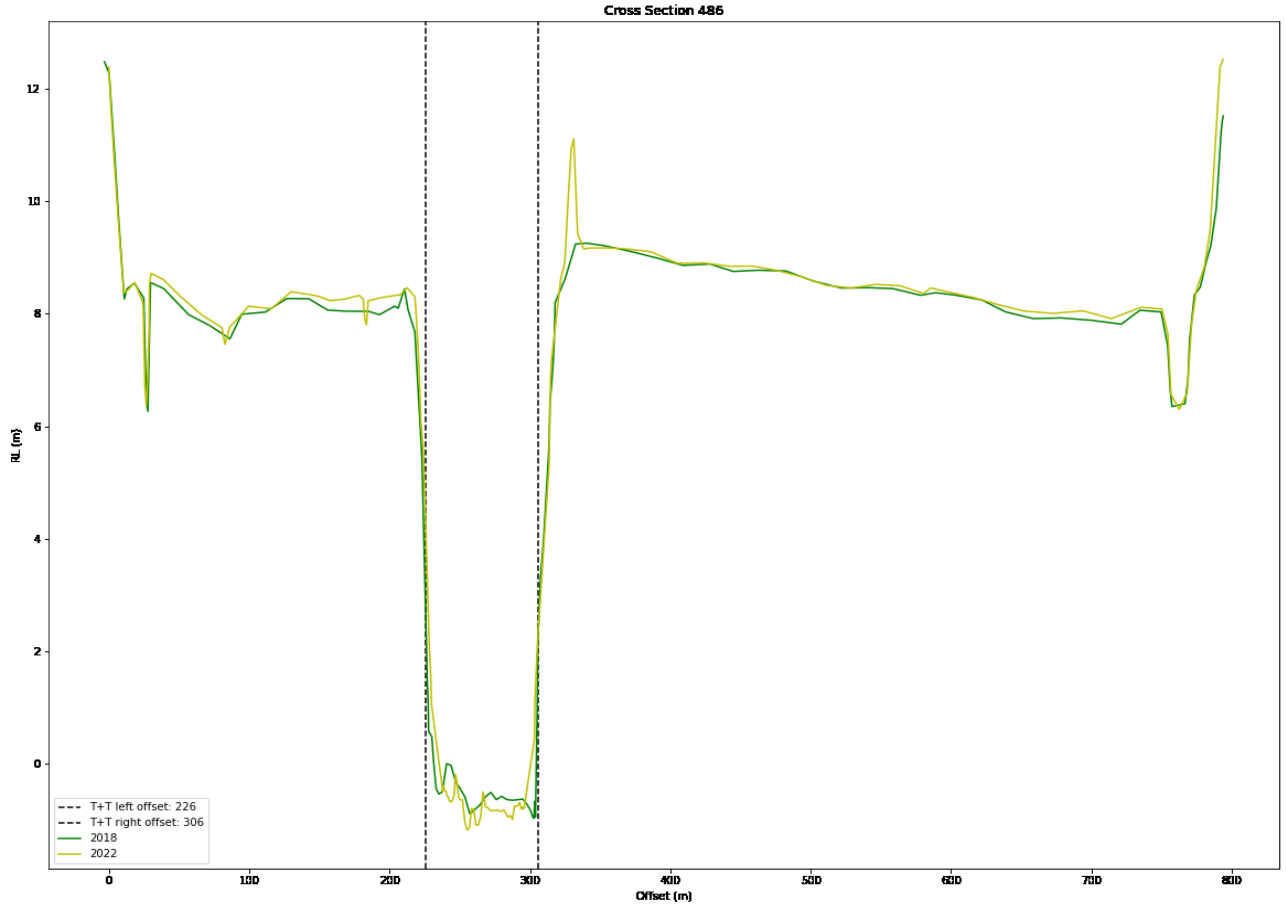

Cross Section 462
RL (m)
Offset (m)
T+T left offset: 219
T+T right offset: 390
2018
2022

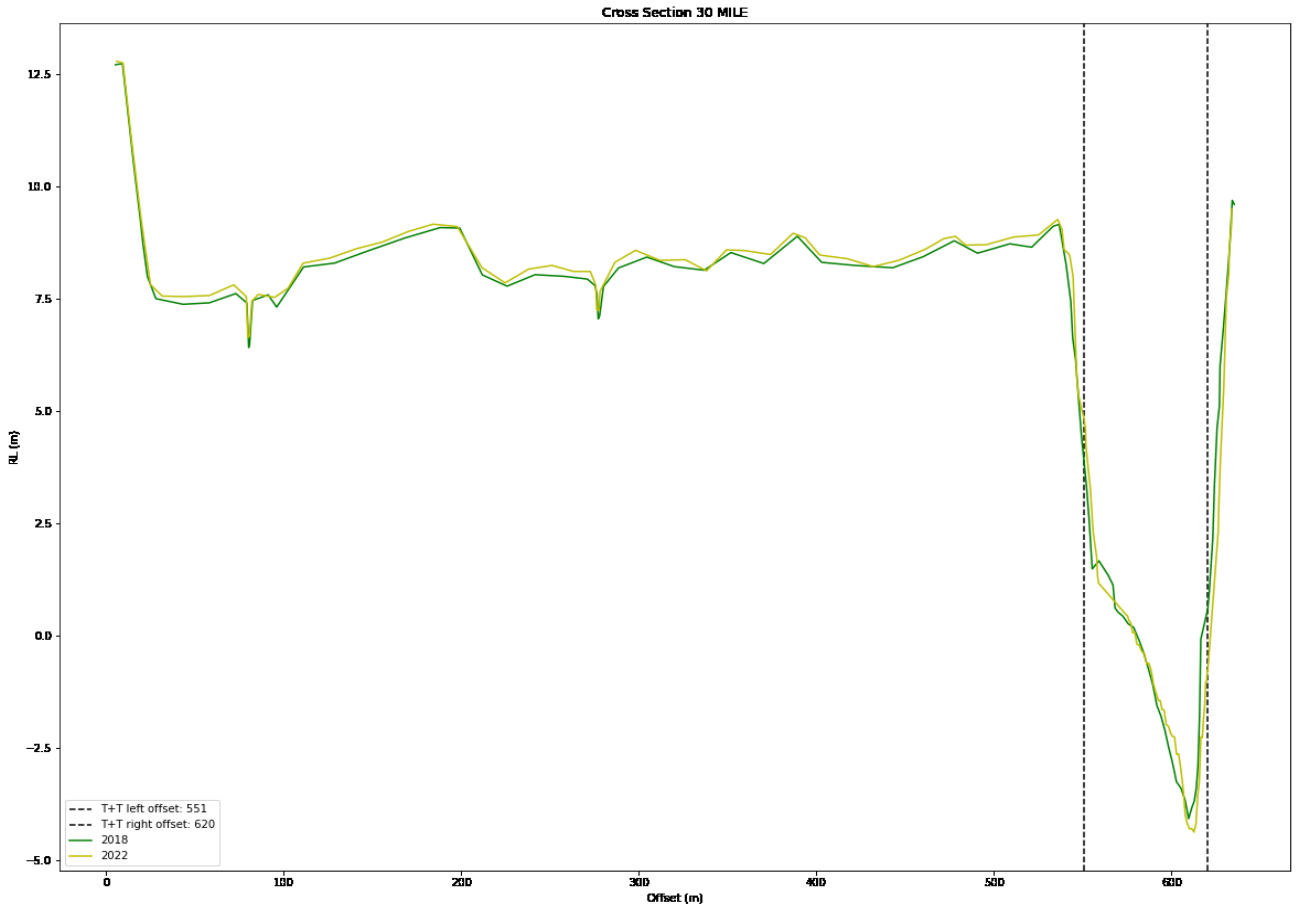

Cross Section 466
RL (m)
Offset (m)
T+T left offset: 107
T+T right offset: 182
2018
2022

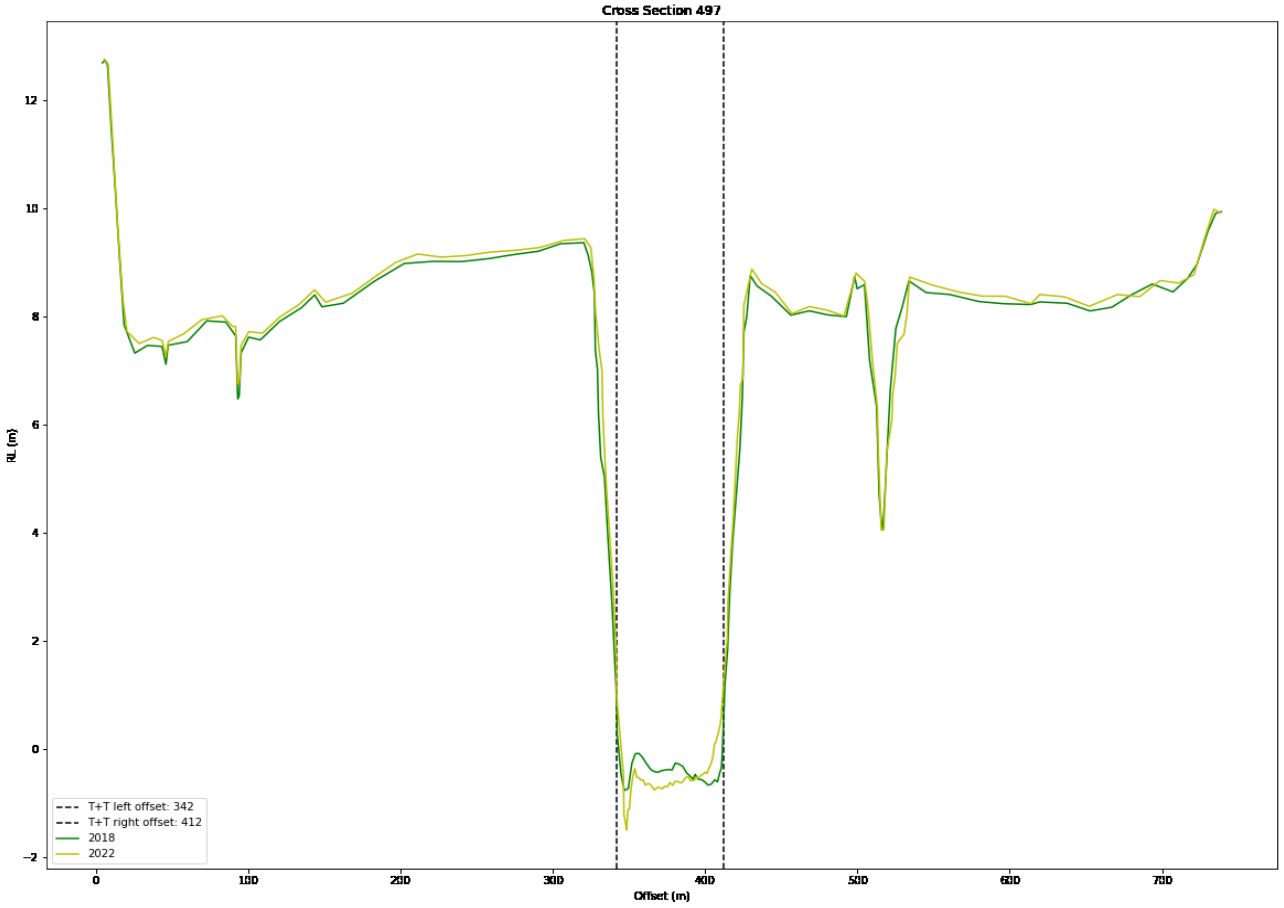

Cross Section 471
RL (m)
Offset (m)
T+T left offset: 200
T+T right offset: 265
2018
2022

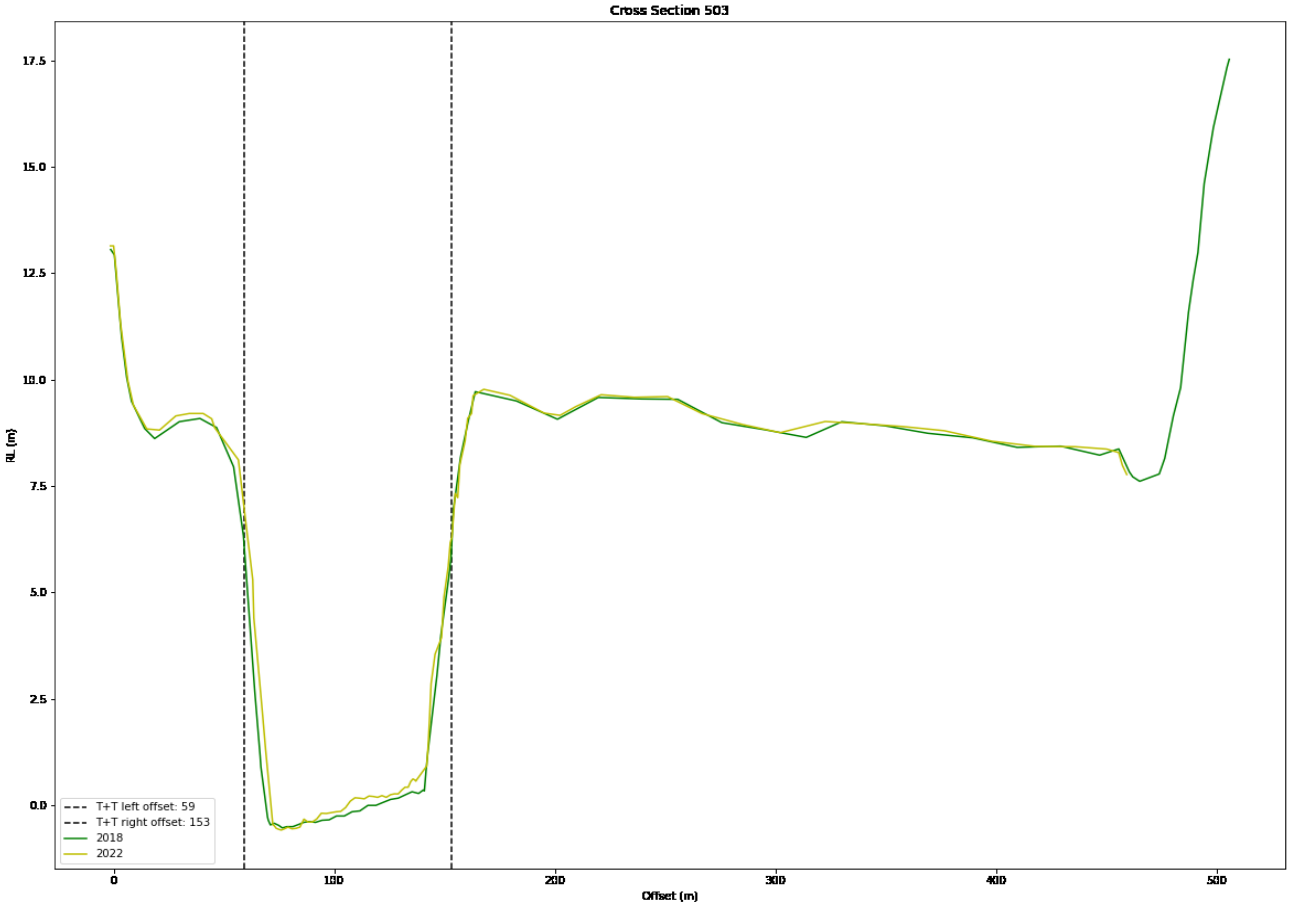

Cross Section 29 MILE
RL (m)
Offset (m)
T+T left offset: 123
T+T right offset: 194
2018
2022

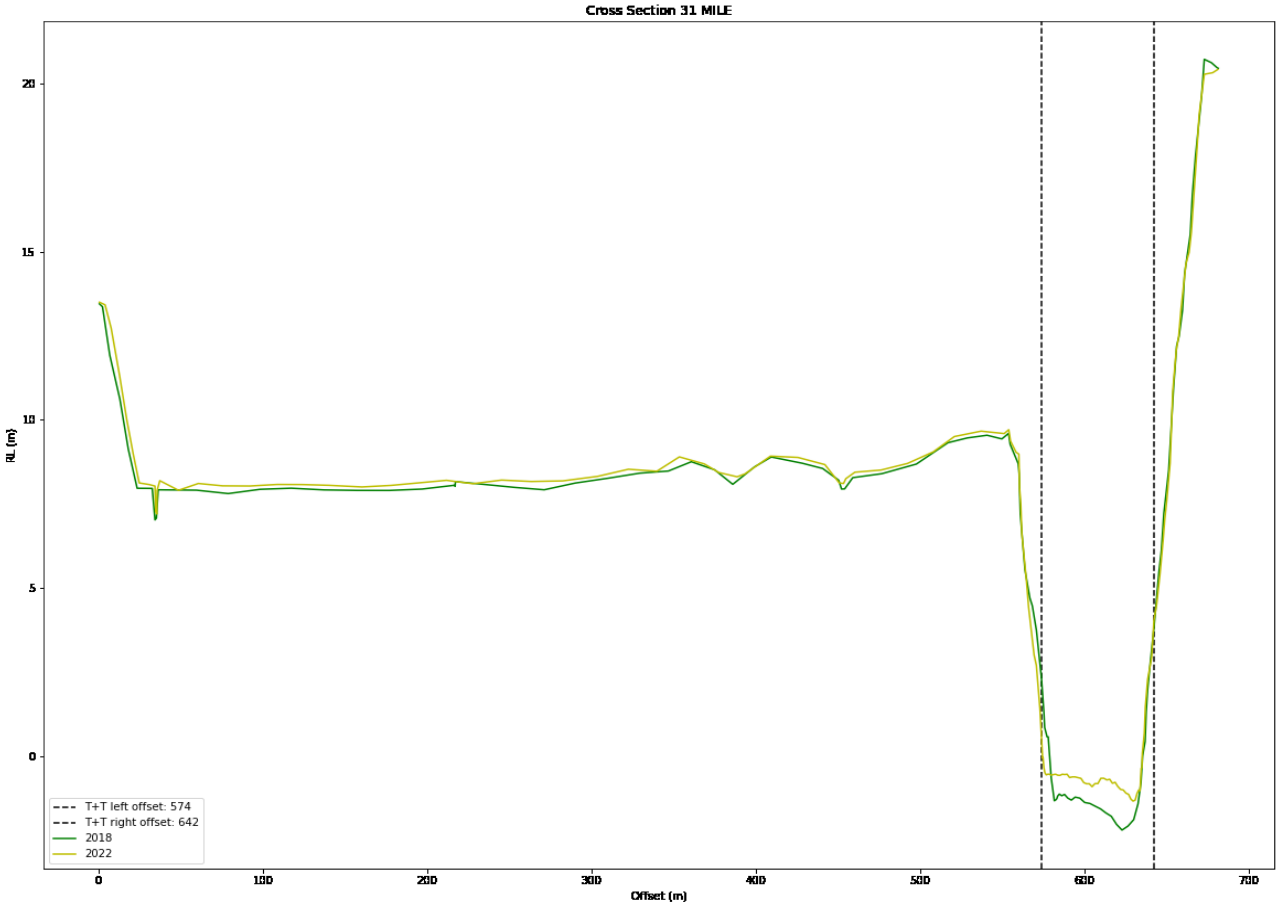

Cross Section 481
RL (m)
Offset (m)
T+T left offset: 47
T+T right offset: 108
2018
2022

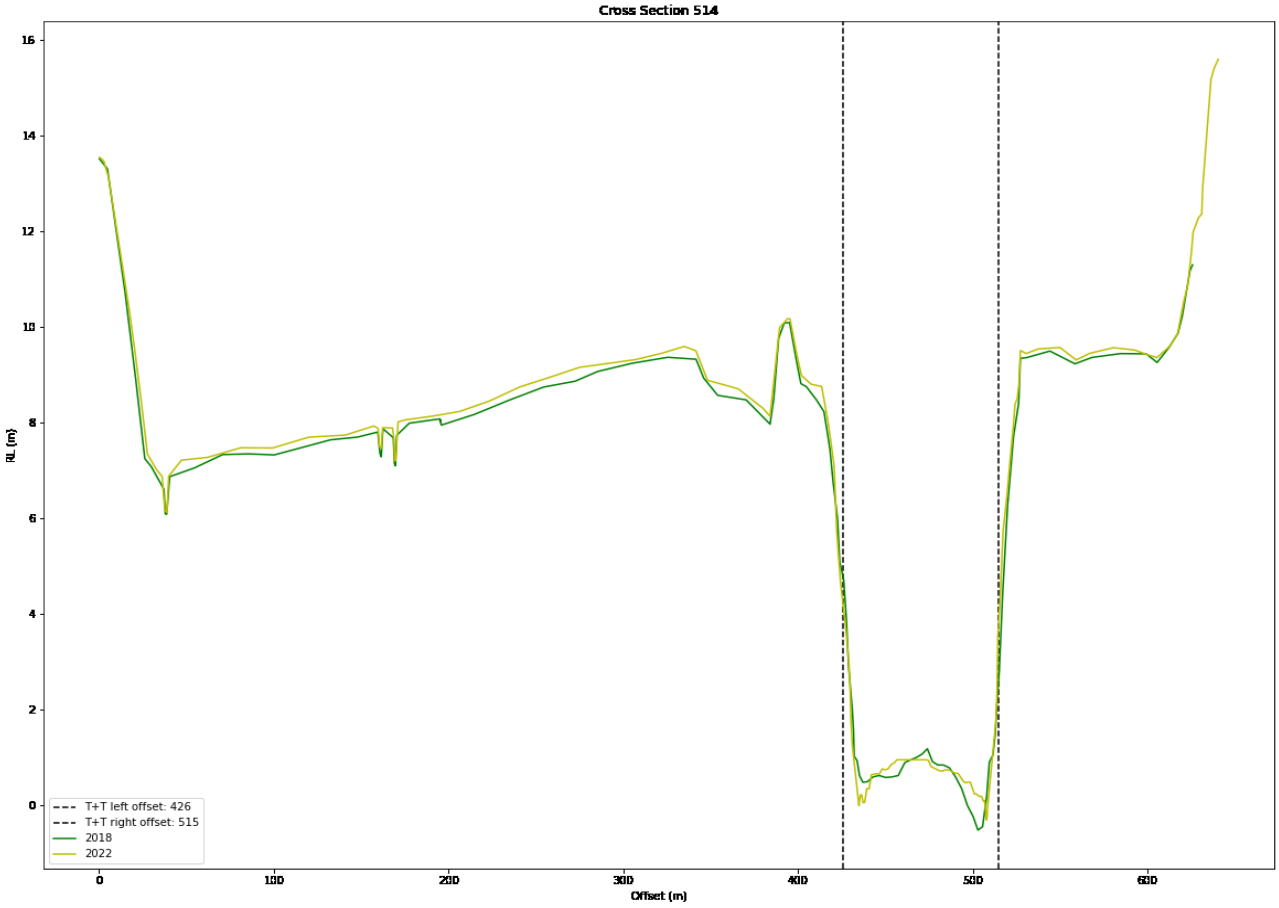

Cross Section 486
RL (m)
Offset (m)
T+T left offset: 226
T+T right offset: 306
2018
2022

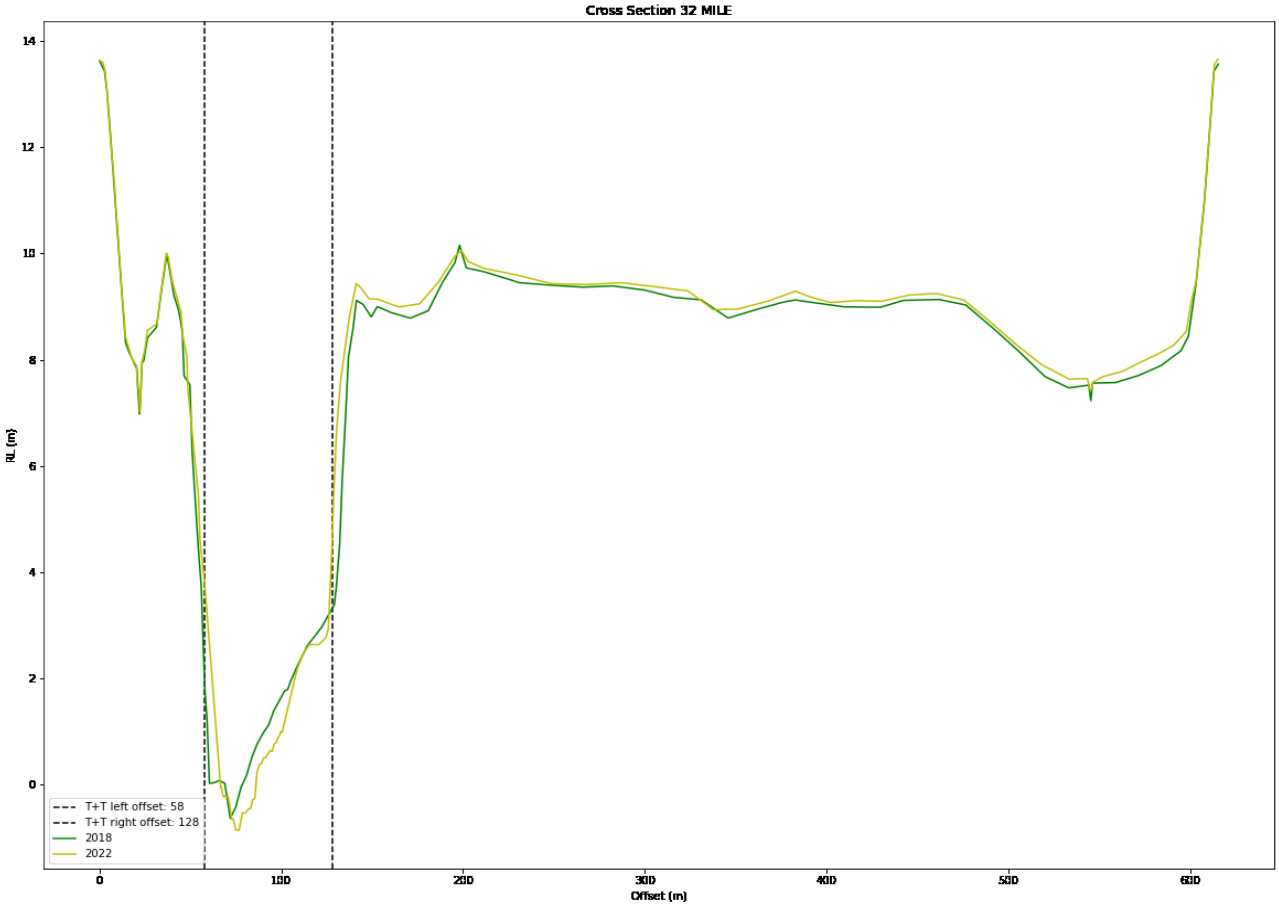

Cross Section 30 MILE
RL (m)
Offset (m)
T+T left offset: 551
T+T right offset: 620
2018
2022

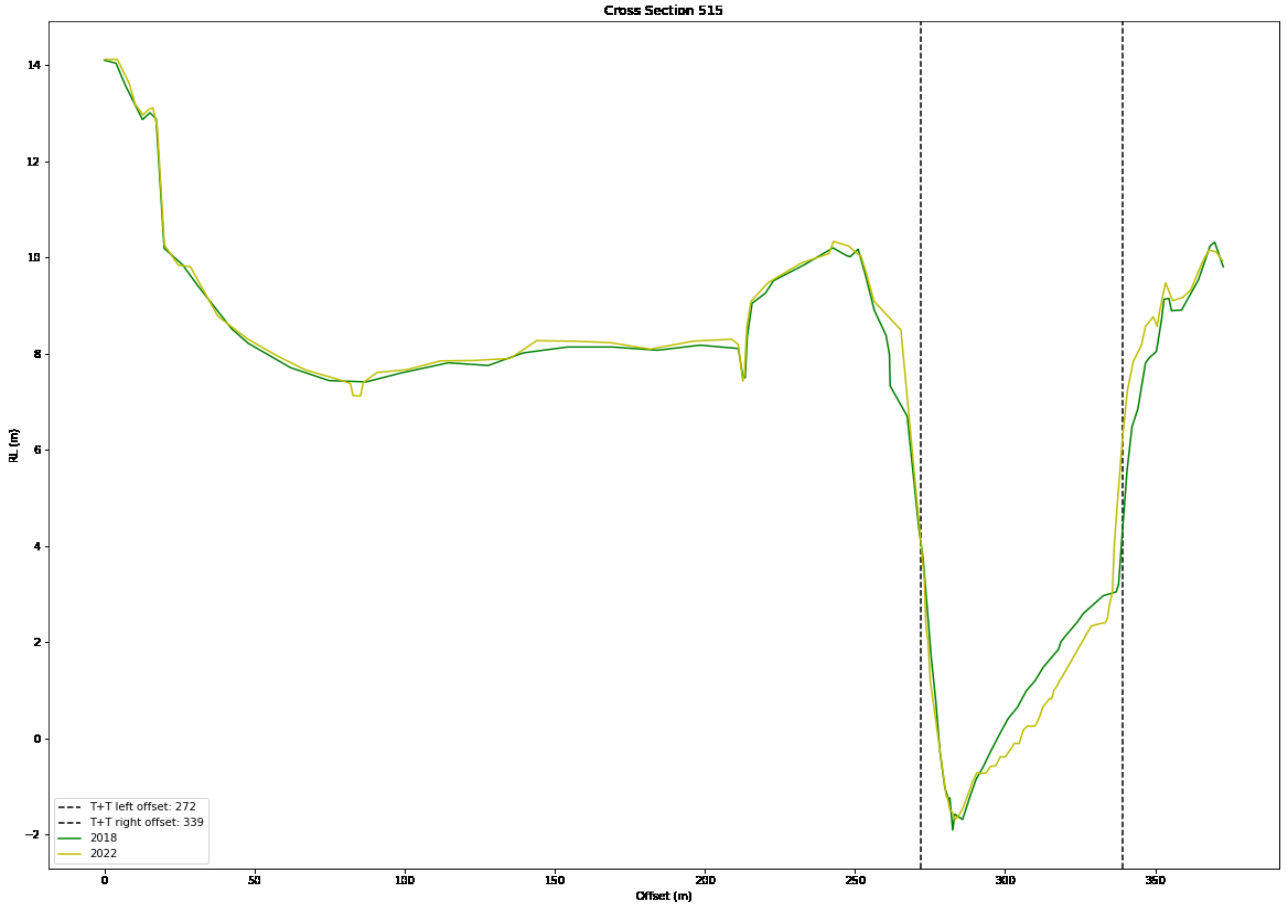

Cross Section 497
RL (m)
Offset (m)
T+T left offset: 342
T+T right offset: 412
2018
2022

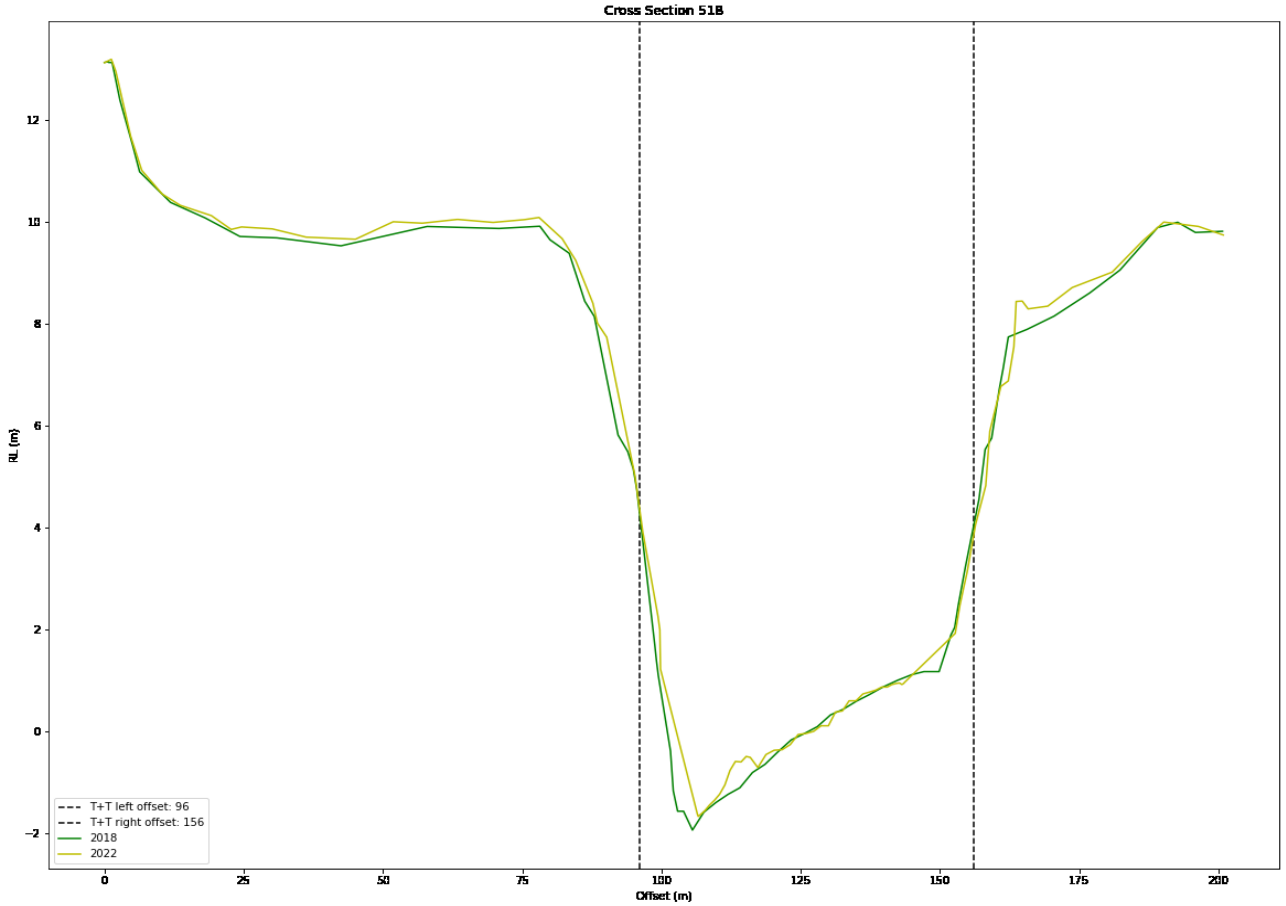

Cross Section 503
RL (m)
Offset (m)
T+T left offset: 59
T+T right offset: 153
2018
2022

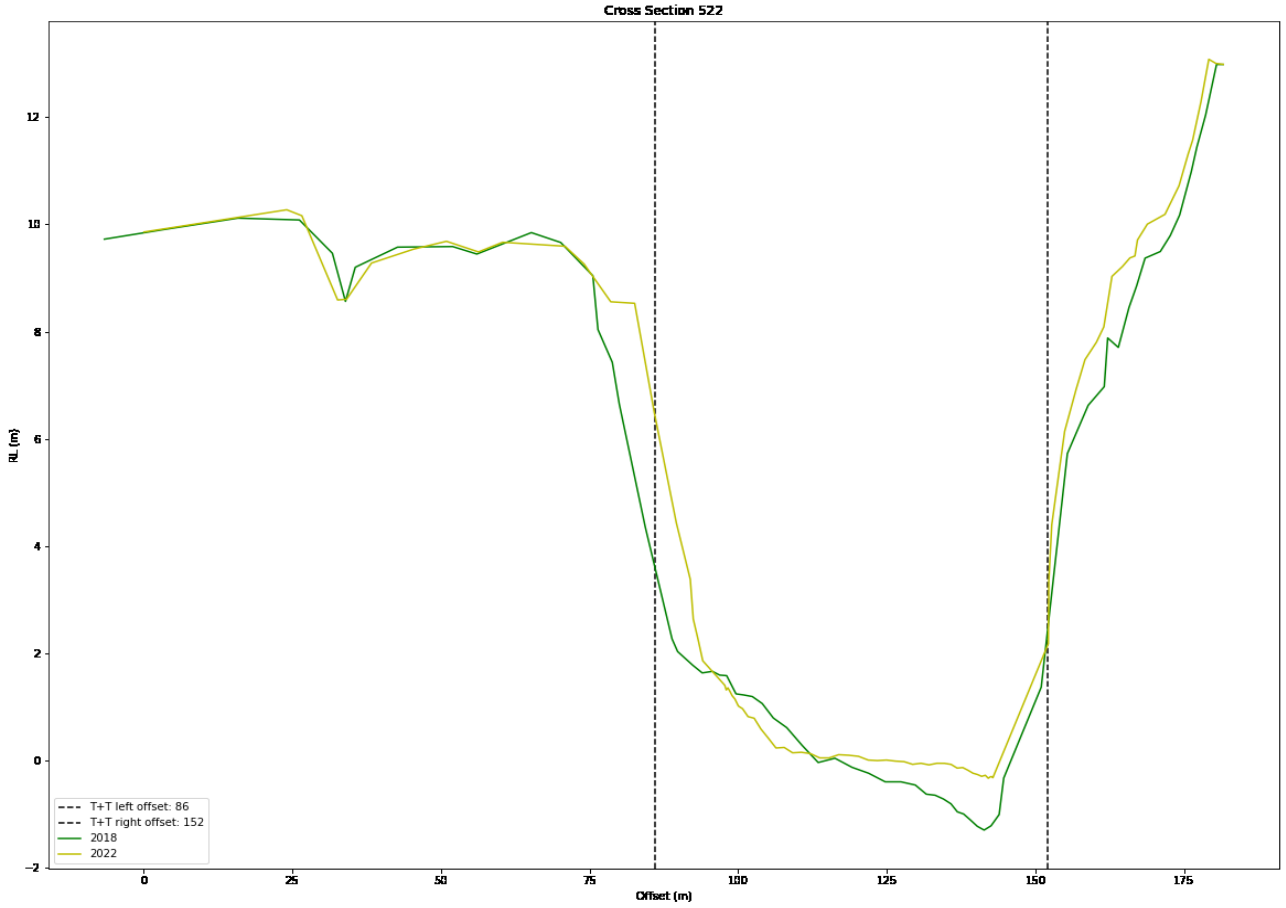

Cross Section 31 MILE
RL (m)
Offset (m)
T+T left offset: 574
T+T right offset: 642
2018
2022

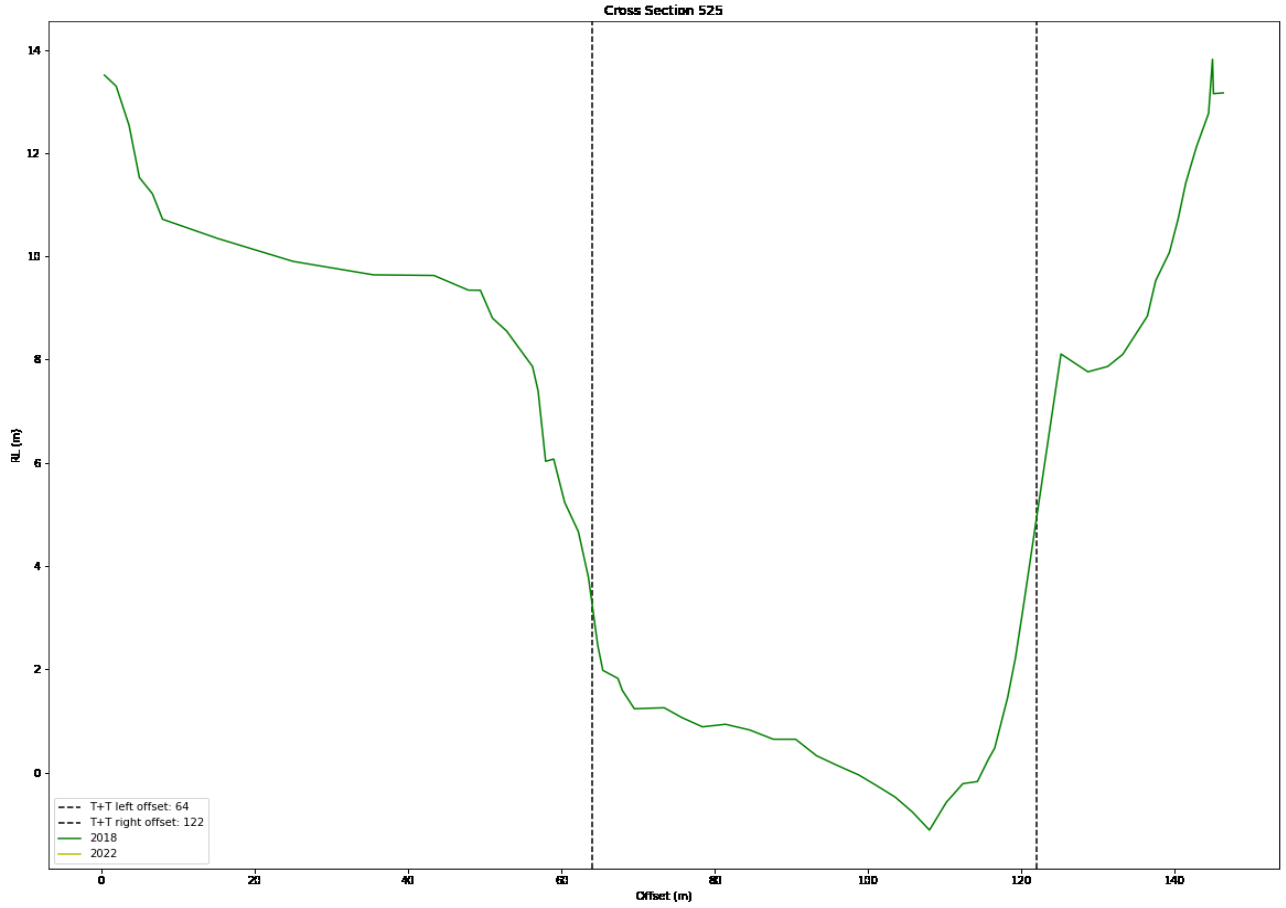

Cross Section 514
RL (m)
Offset (m)
T+T left offset: 426
T+T right offset: 515
2018
2022

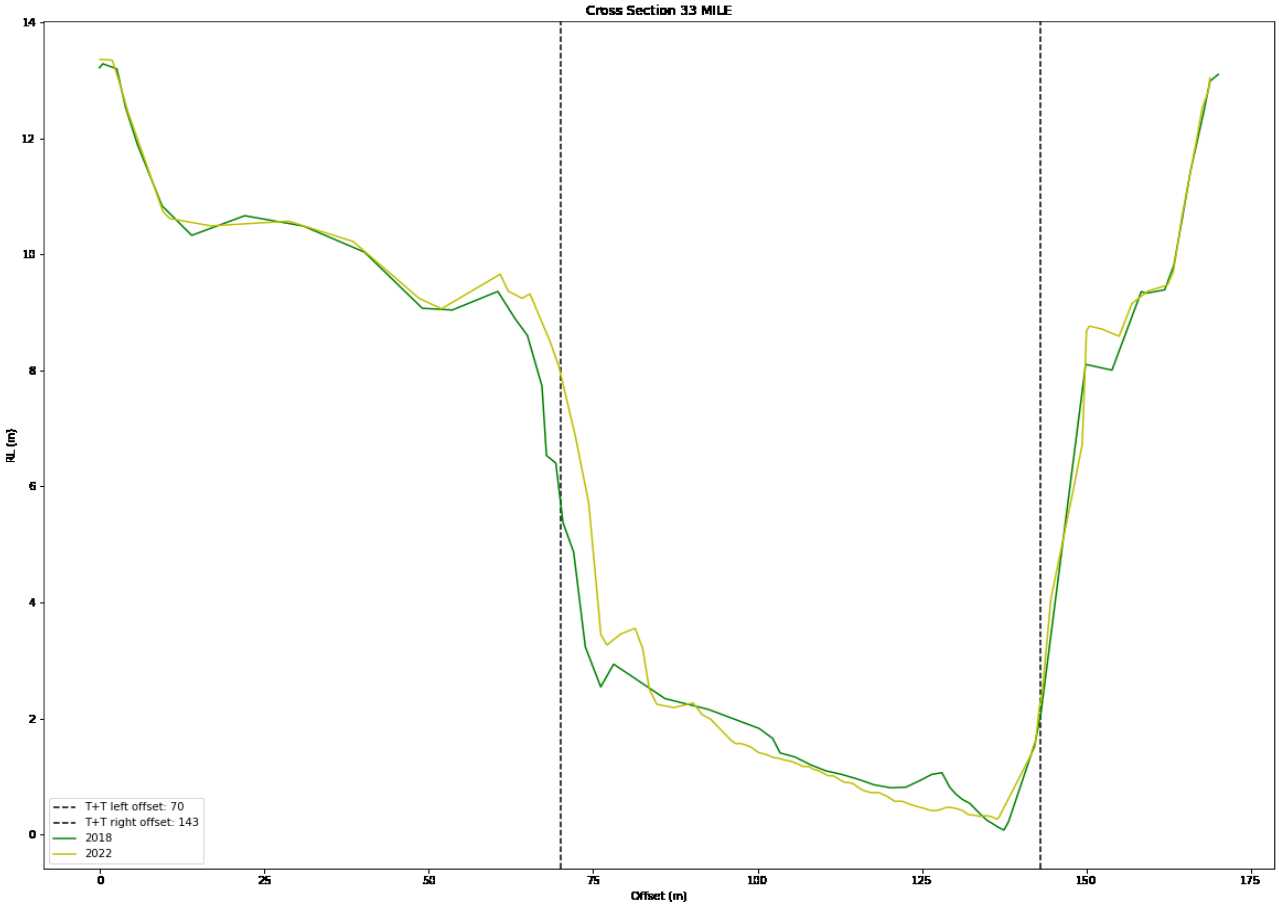

Cross Section 32 MILE
RL (m)
Offset (m)
T+T left offset: 58
T+T right offset: 128
2018
2022

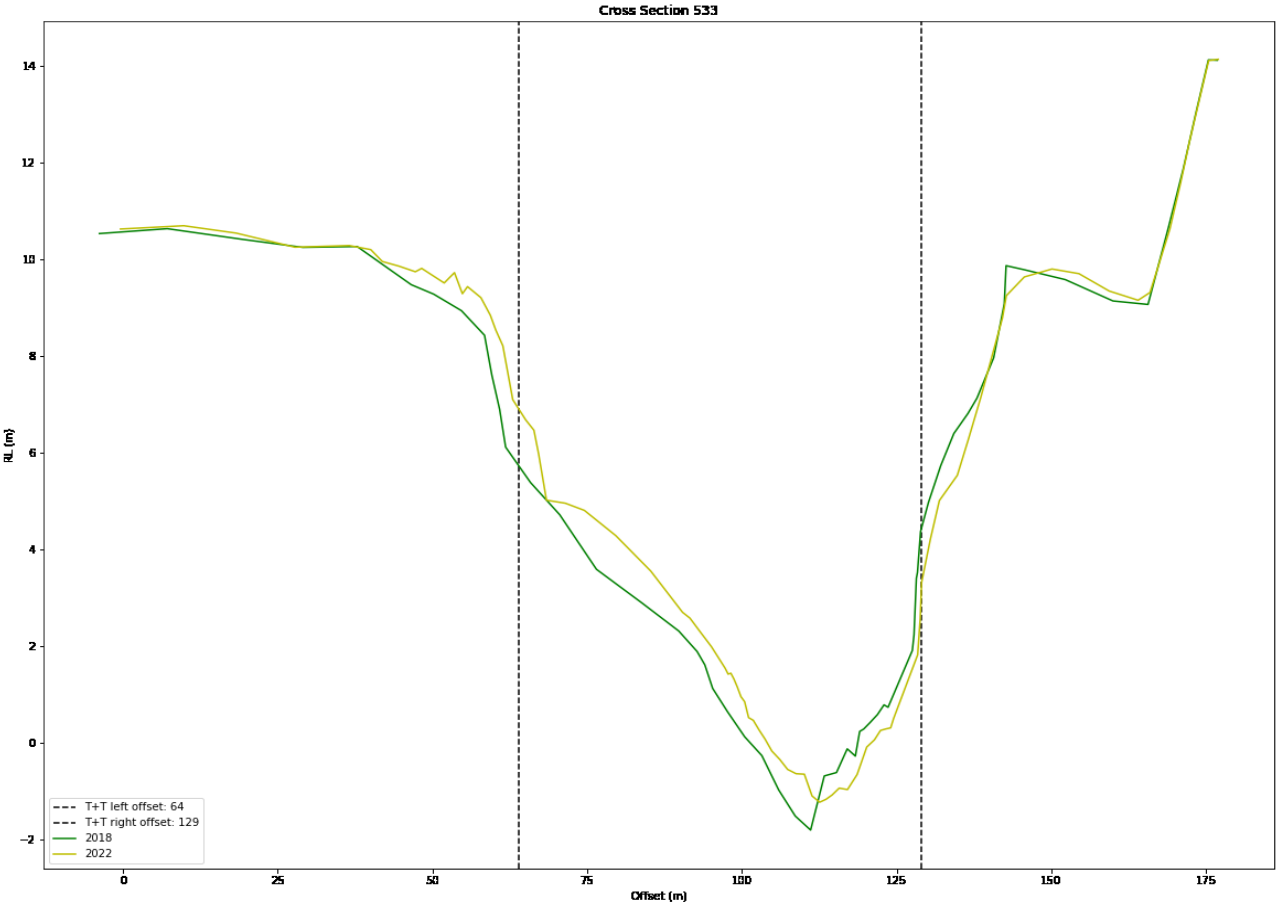

Cross Section 515
RL (m)
Offset (m)
T+T left offset: 272
T+T right offset: 339
2018
2022

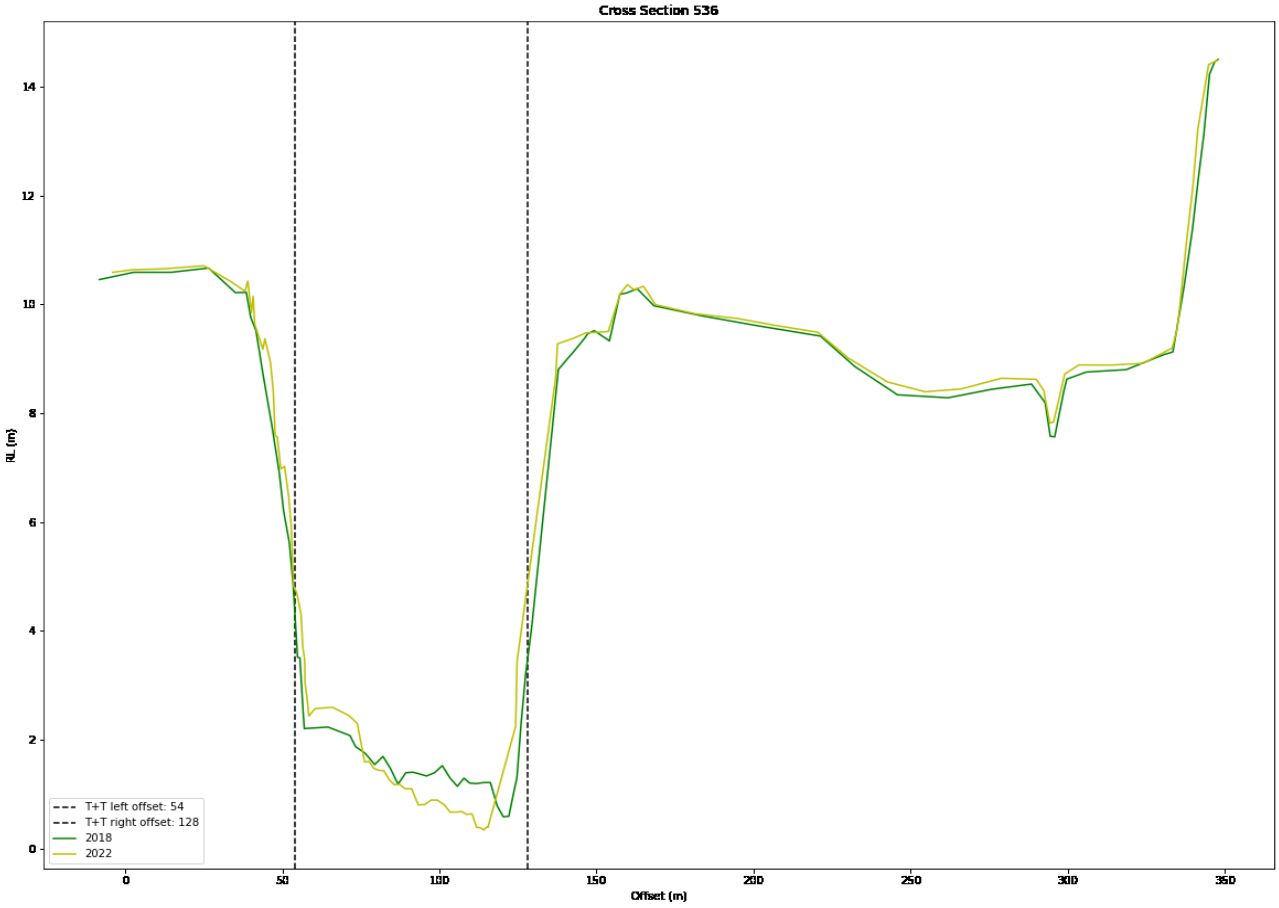

Cross Section 518
RL (m)
Offset (m)
T+T left offset: 96
T+T right offset: 156
2018
2022

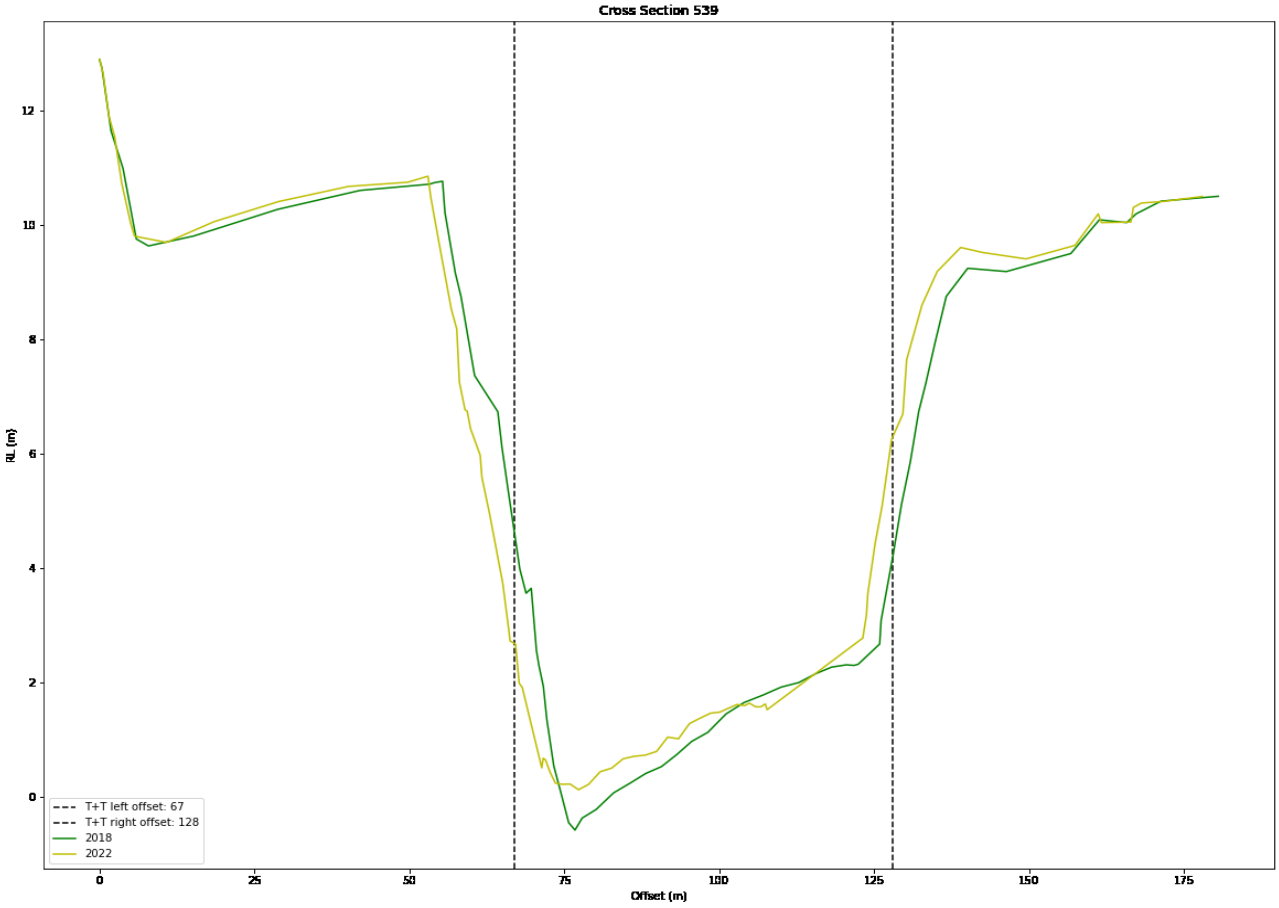

Cross Section 522
RL (m)
Offset (m)
T+T left offset: 86
T+T right offset: 152
2018
2022

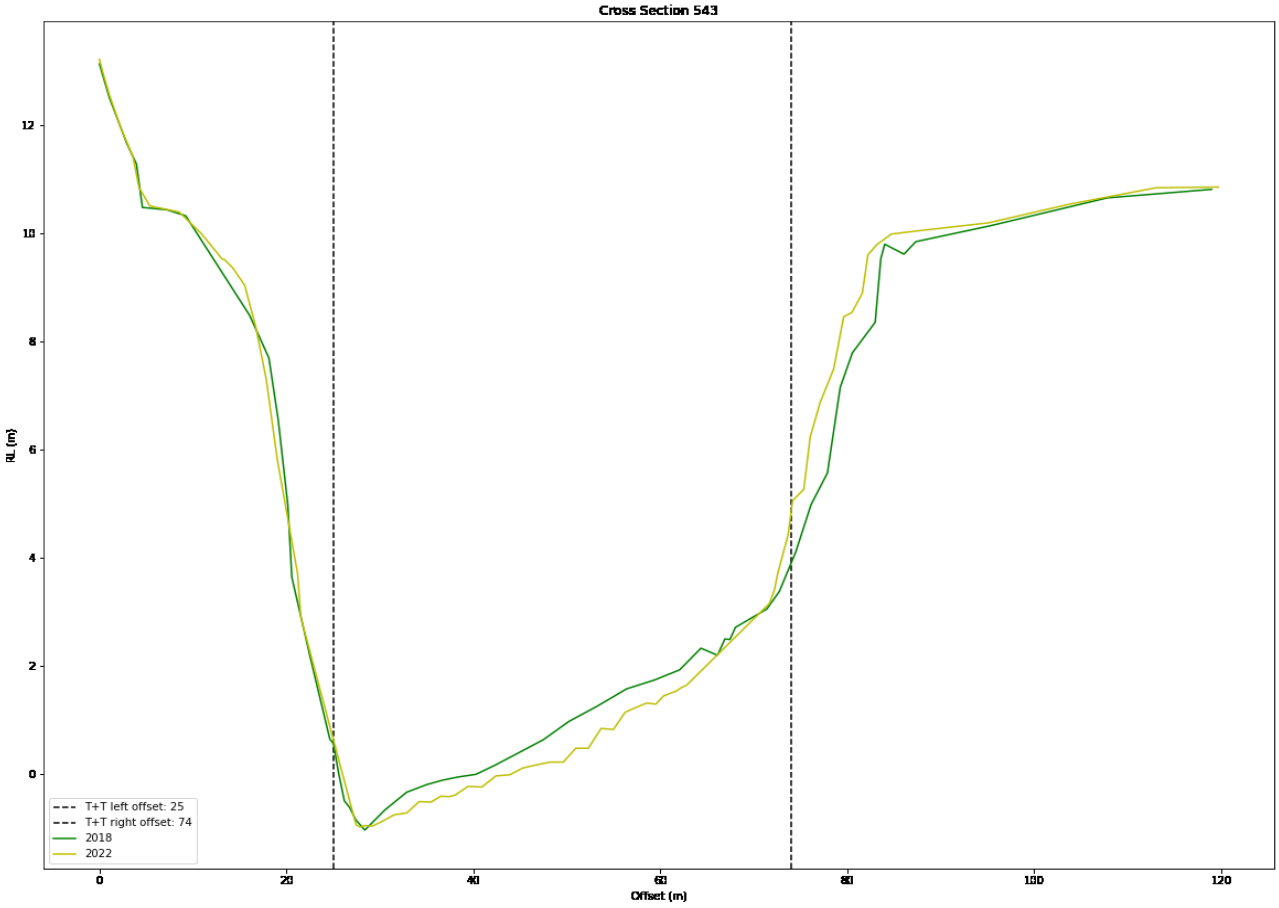

Cross Section 525
RL (m)
Offset (m)
T+T left offset: 64
T+T right offset: 122
2018
2022

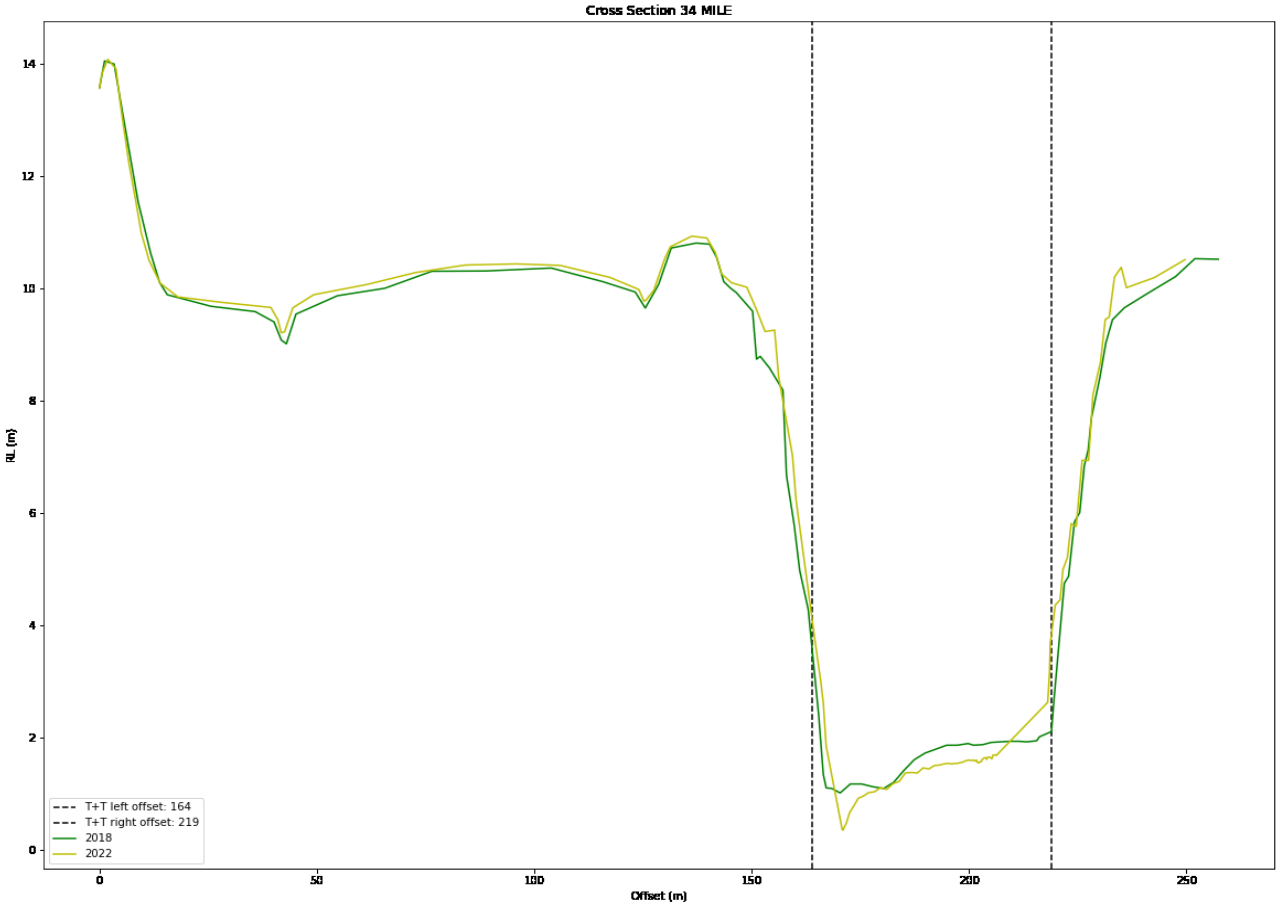

Cross Section 33 MILE
RL (m)
Offset (m)
T+T left offset: 70
T+T right offset: 143
2018
2022

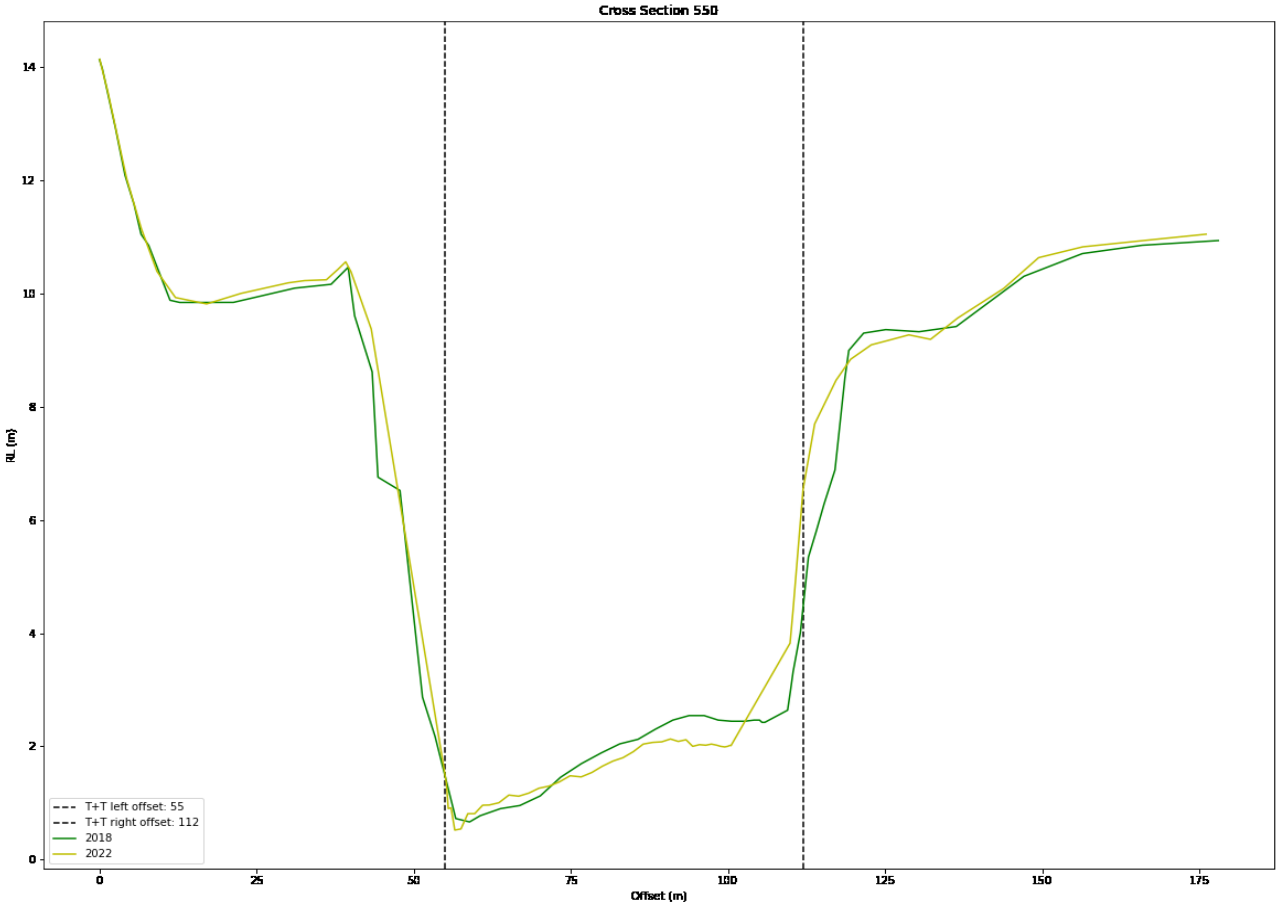

Cross Section 533
RL (m)
Offset (m)
T+T left offset: 64
T+T right offset: 129
2018
2022

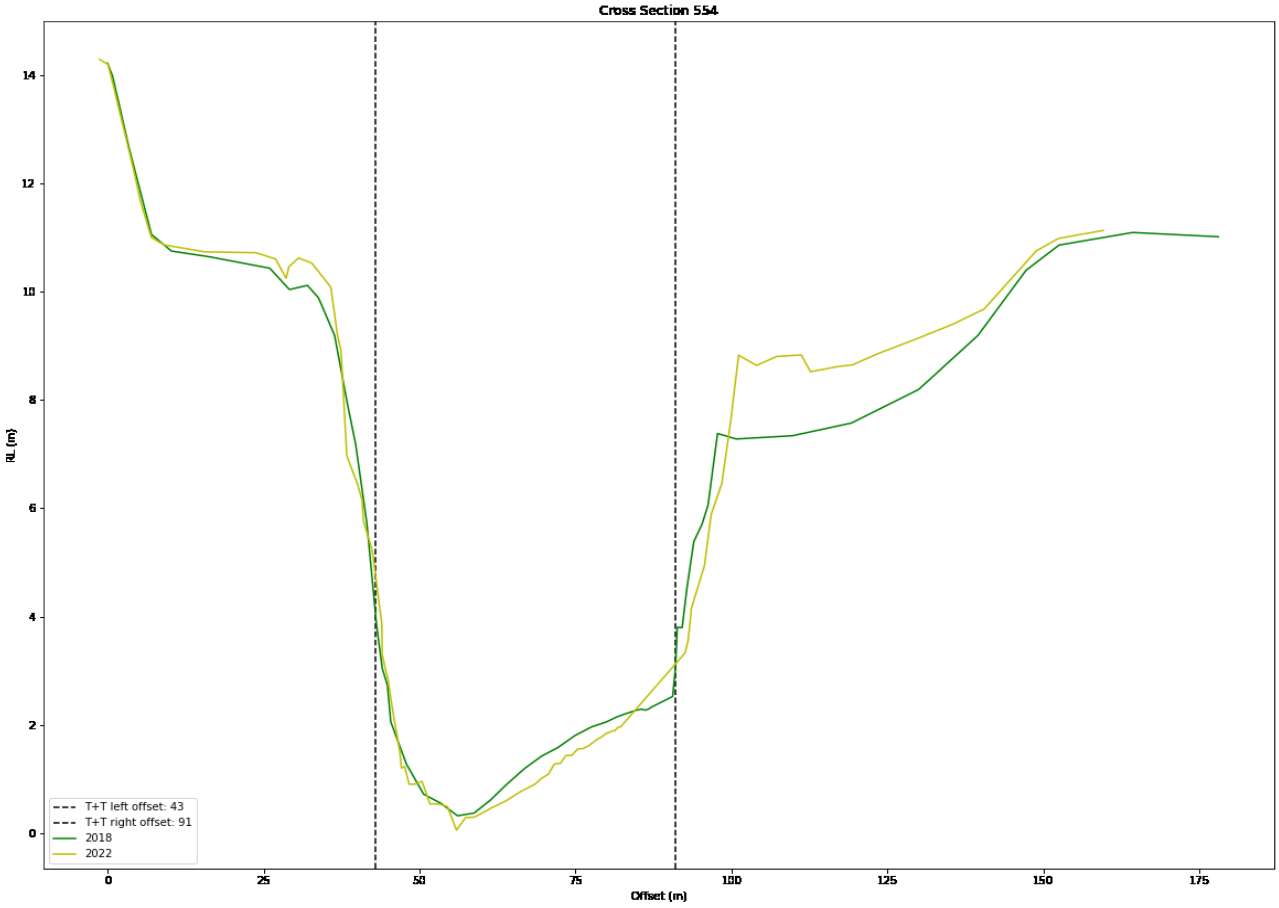

Cross Section 536
RL (m)
Offset (m)
T+T left offset: 54
T+T right offset: 128
2018
2022

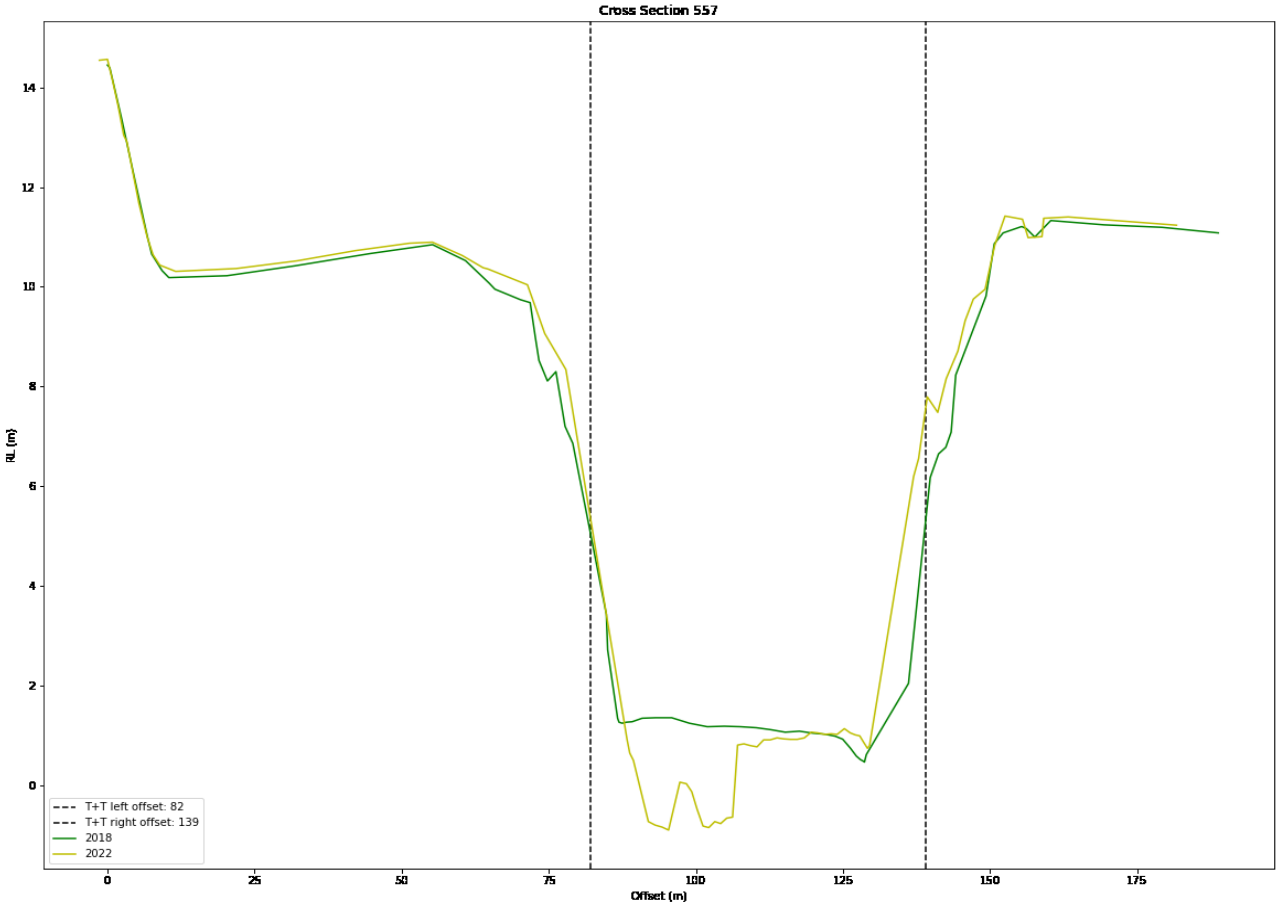

Cross Section 539
RL (m)
Offset (m)
T+T left offset: 67
T+T right offset: 128
2018
2022

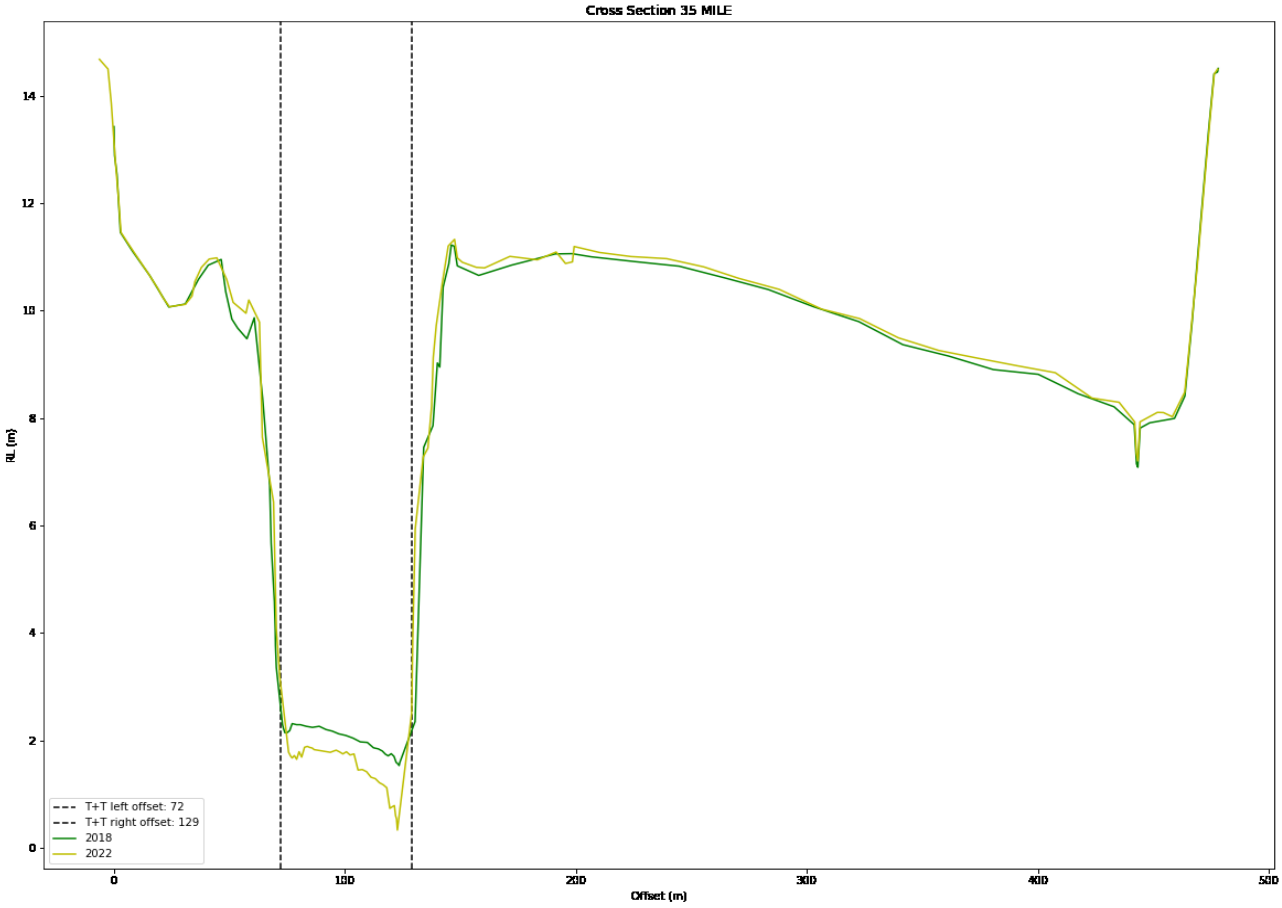

Cross Section 543
RL (m)
Offset (m)
T+T left offset: 25
T+T right offset: 74
2018
2022

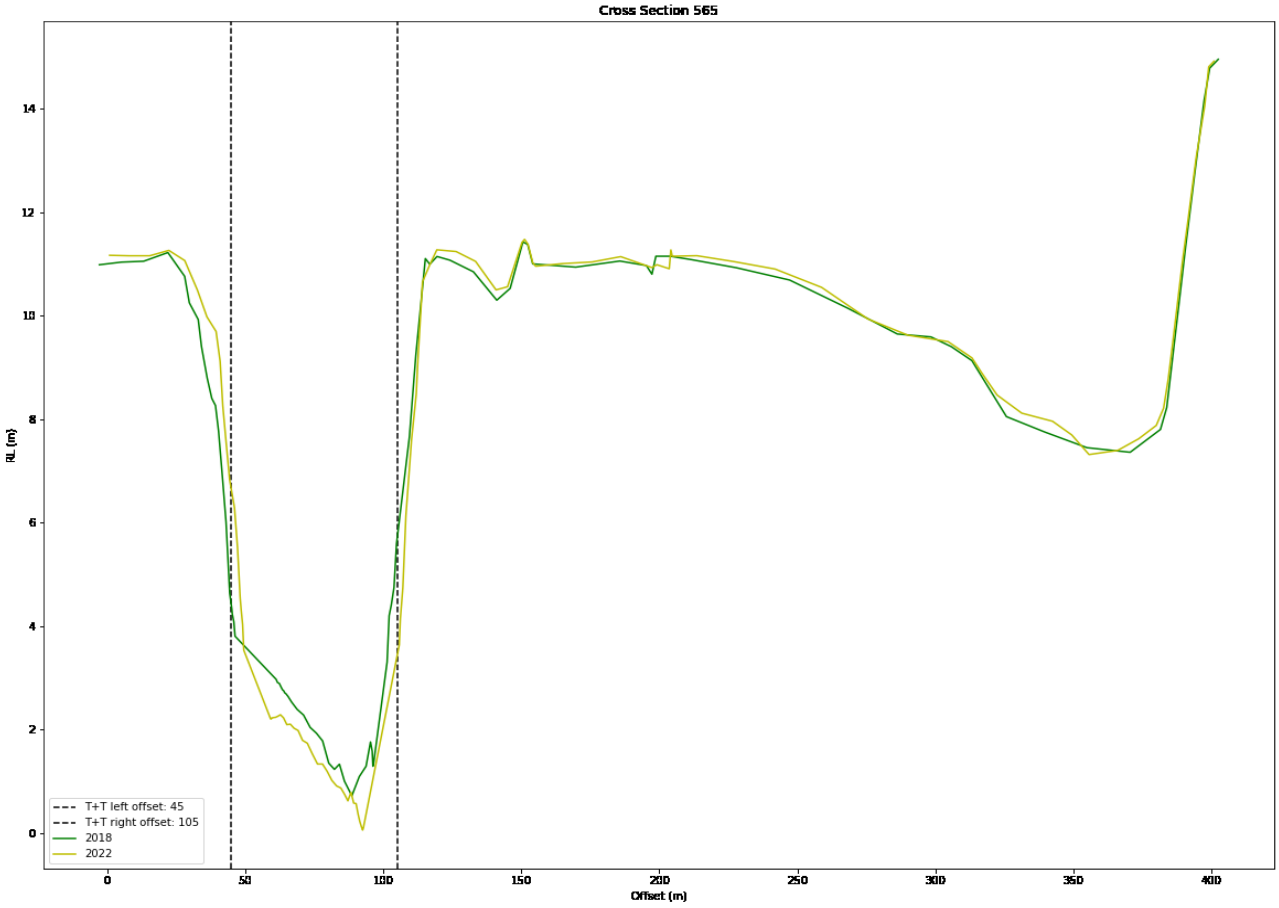

Cross Section 34 MILE
RL (m)
Offset (m)
T+T left offset: 164
T+T right offset: 219
2018
2022

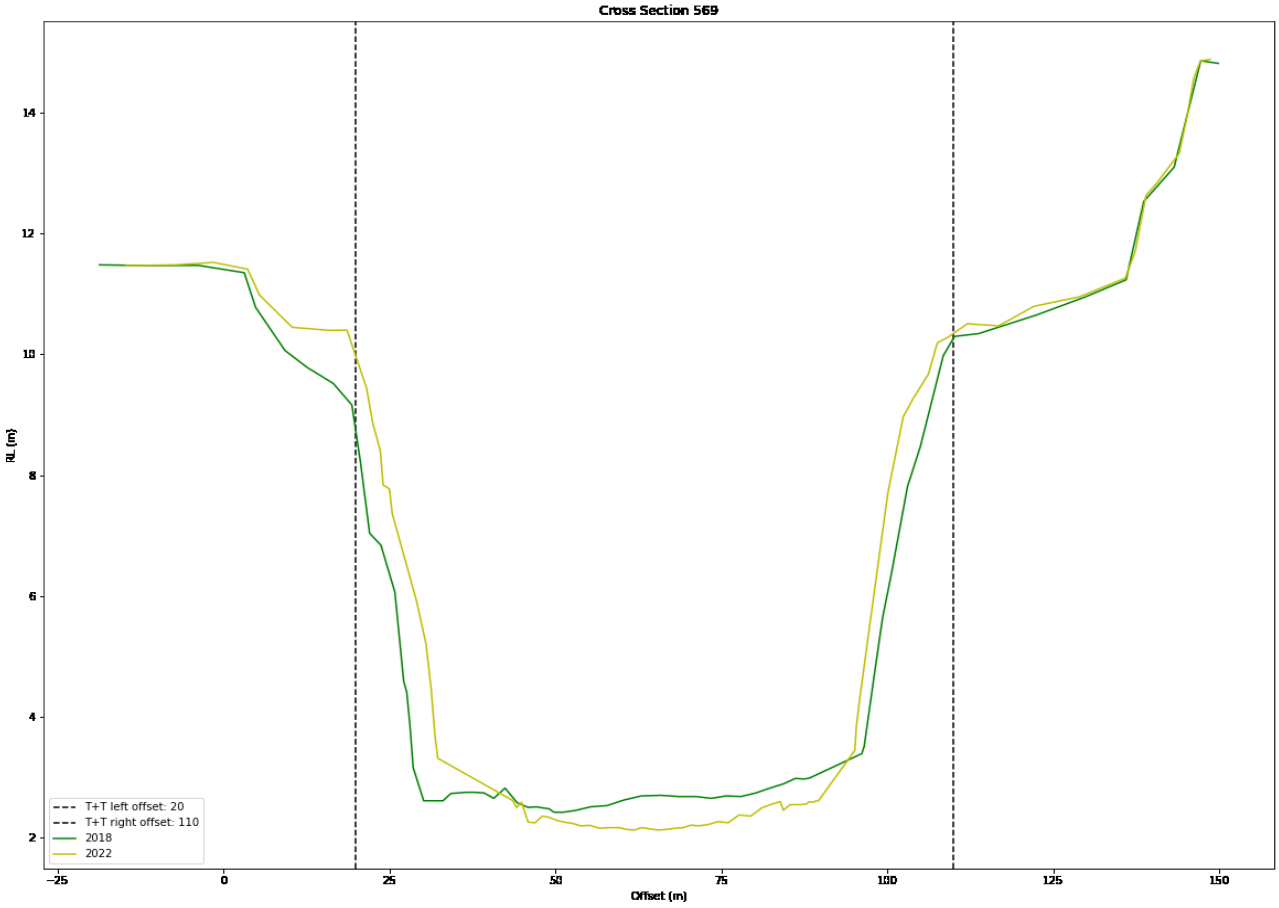

Cross Section 550
RL (m)
Offset (m)
T+T left offset: 55
T+T right offset: 112
2018
2022

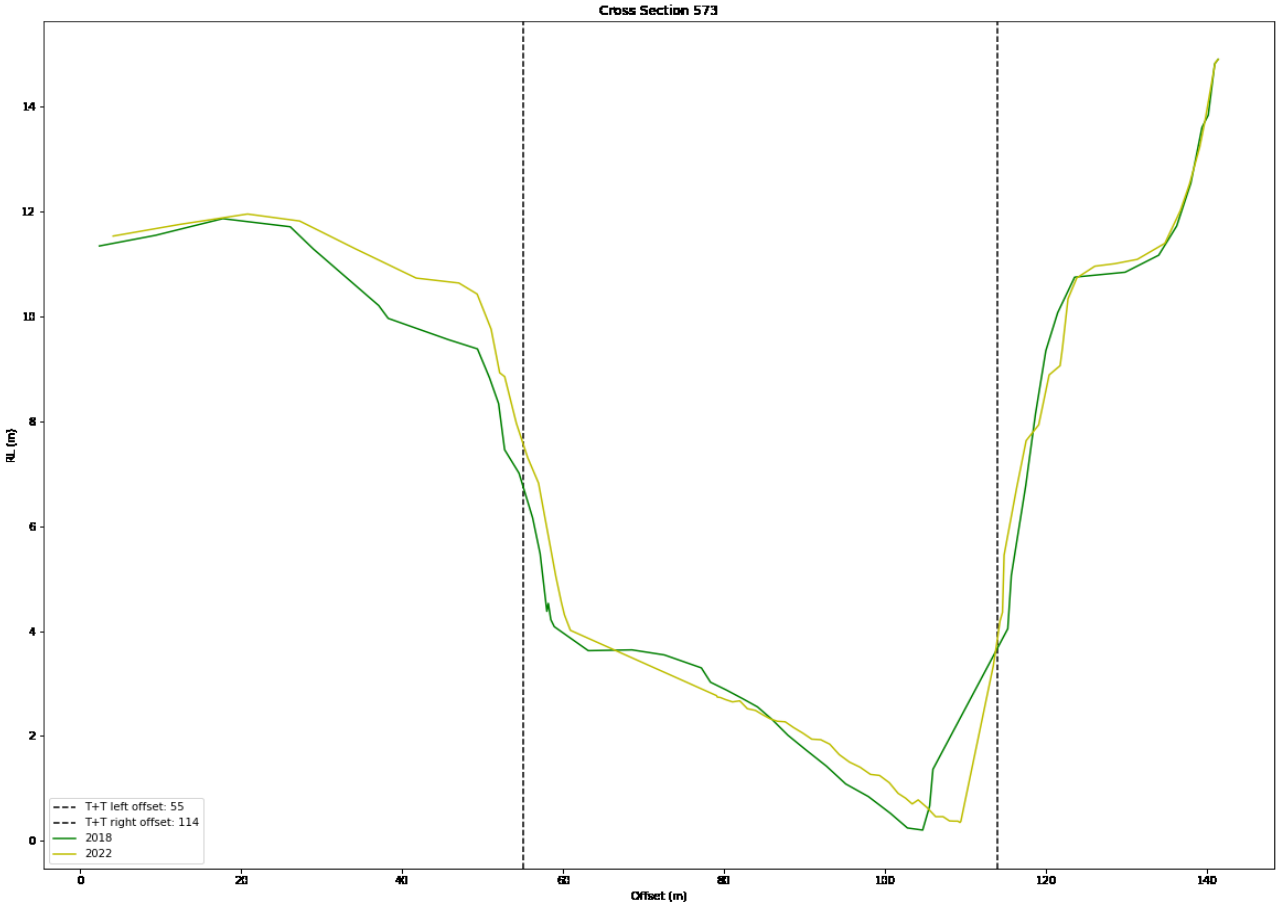

Cross Section 554
RL (m)
Offset (m)
T+T left offset: 43
T+T right offset: 91
2018
2022

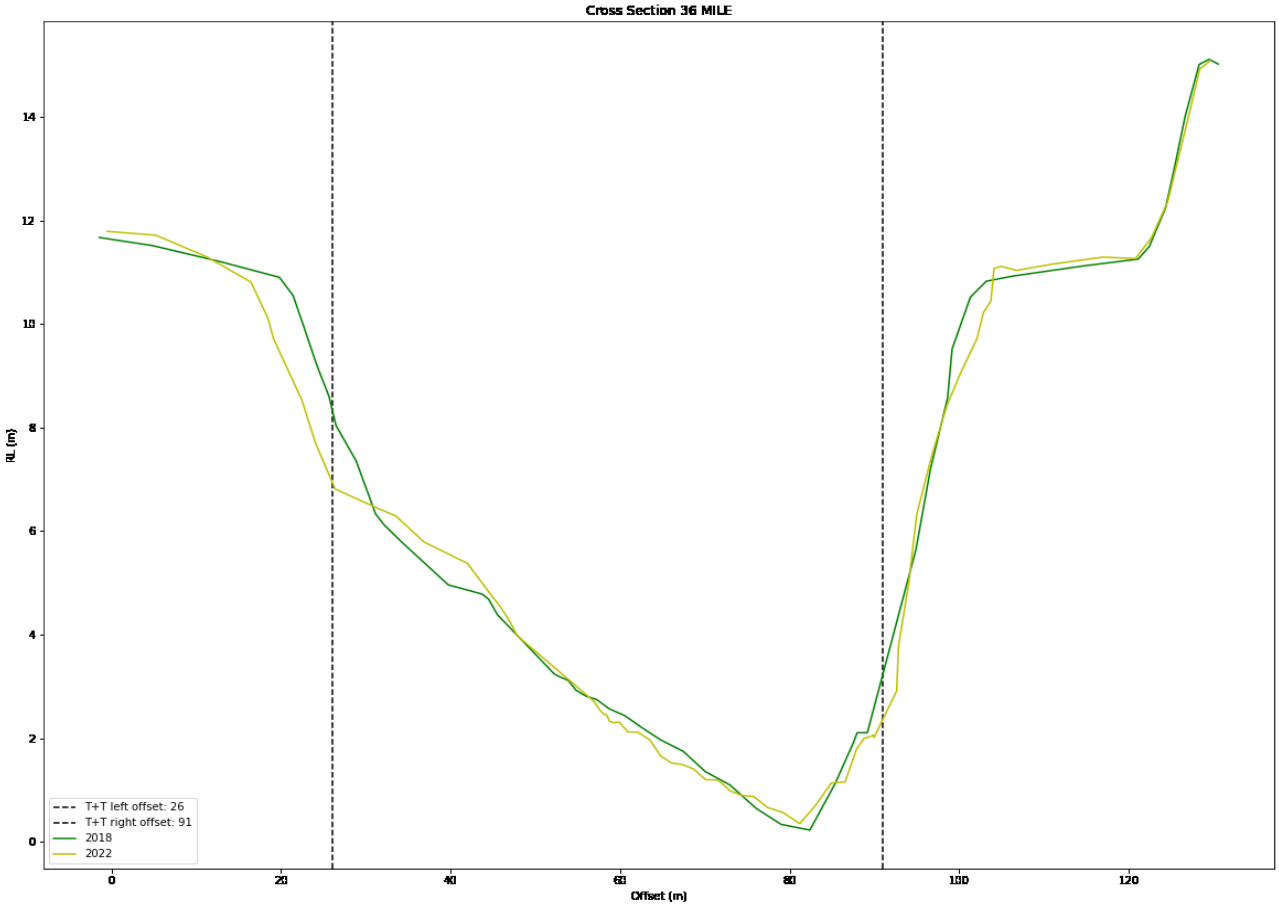

Cross Section 557
RL (m)
Offset (m)
T+T left offset: 82
T+T right offset: 139
2018
2022

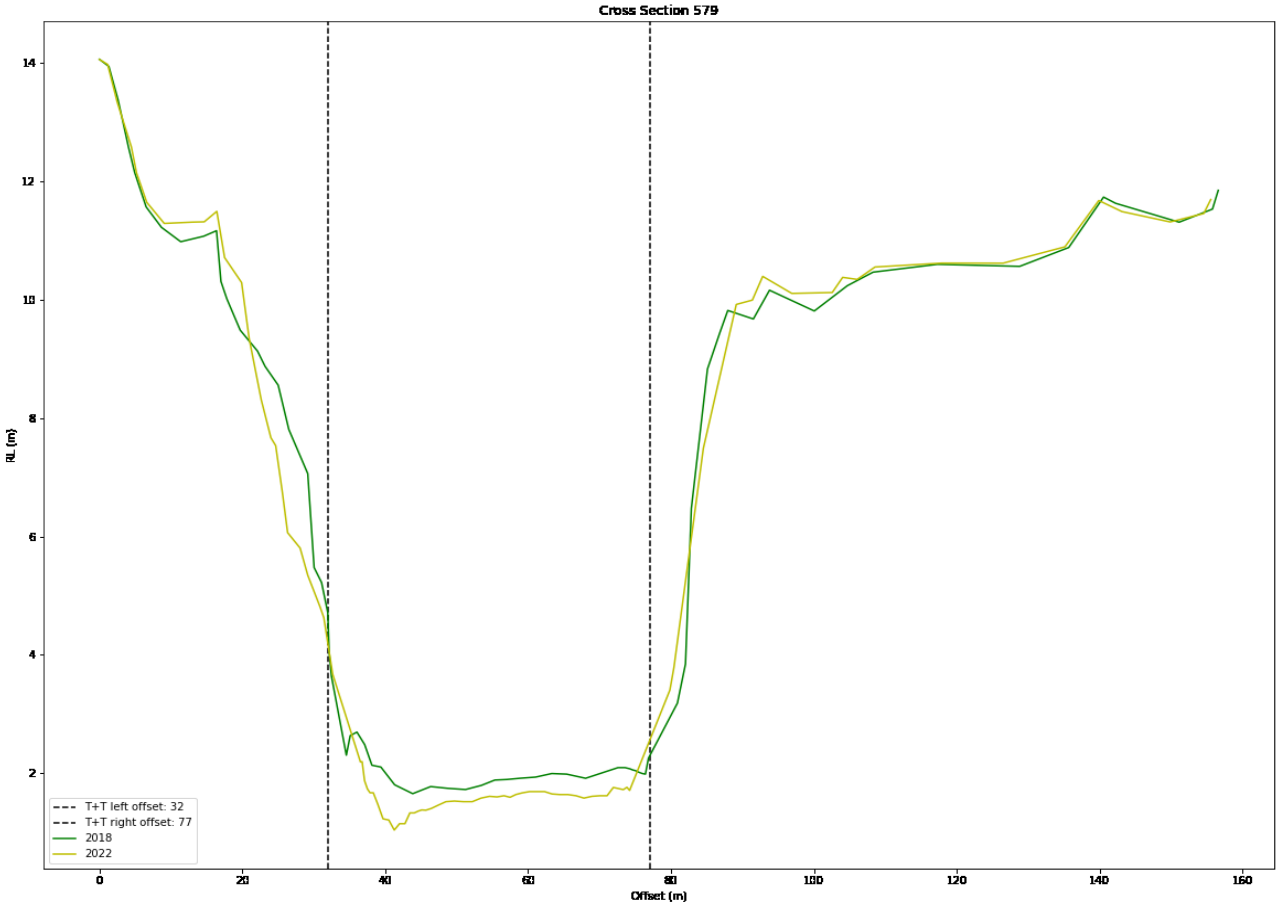

Cross Section 35 MILE
RL (m)
Offset (m)
T+T left offset: 72
T+T right offset: 129
2018
2022

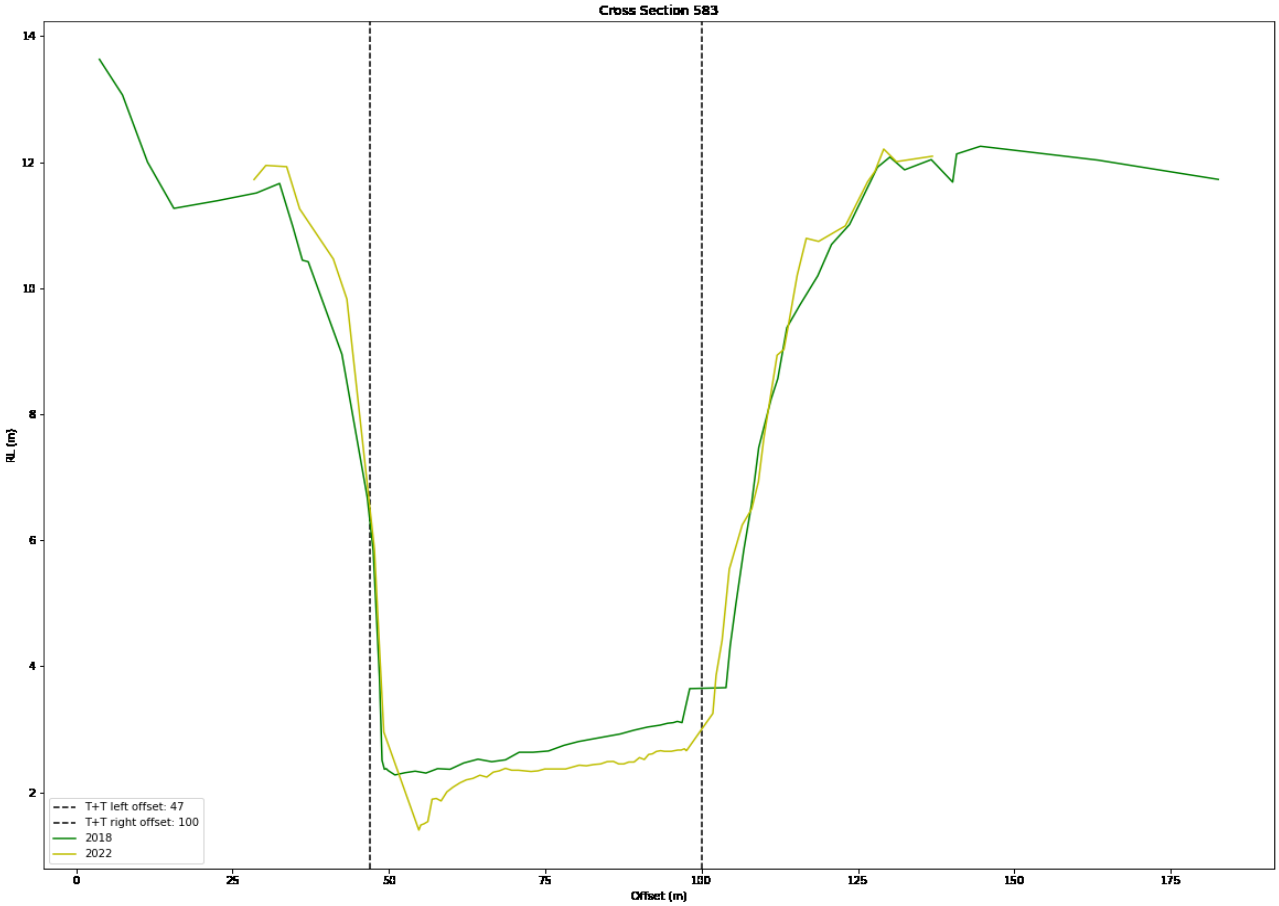

Cross Section 565
RL (m)
Offset (m)
T+T left offset: 45
T+T right offset: 105
2018
2022

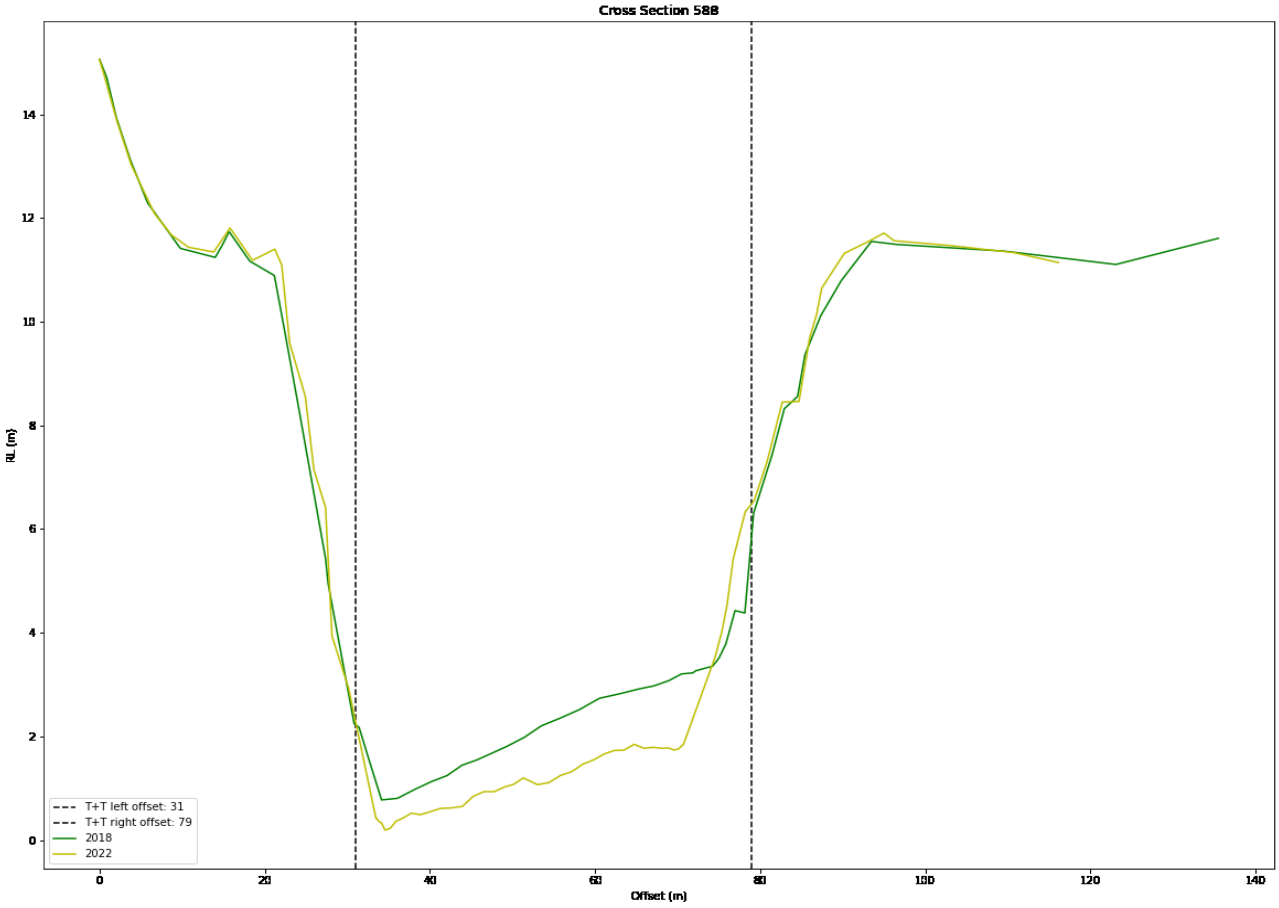

Cross Section 569
RL (m)
Offset (m)
T+T left offset: 20
T+T right offset: 110
2018
2022

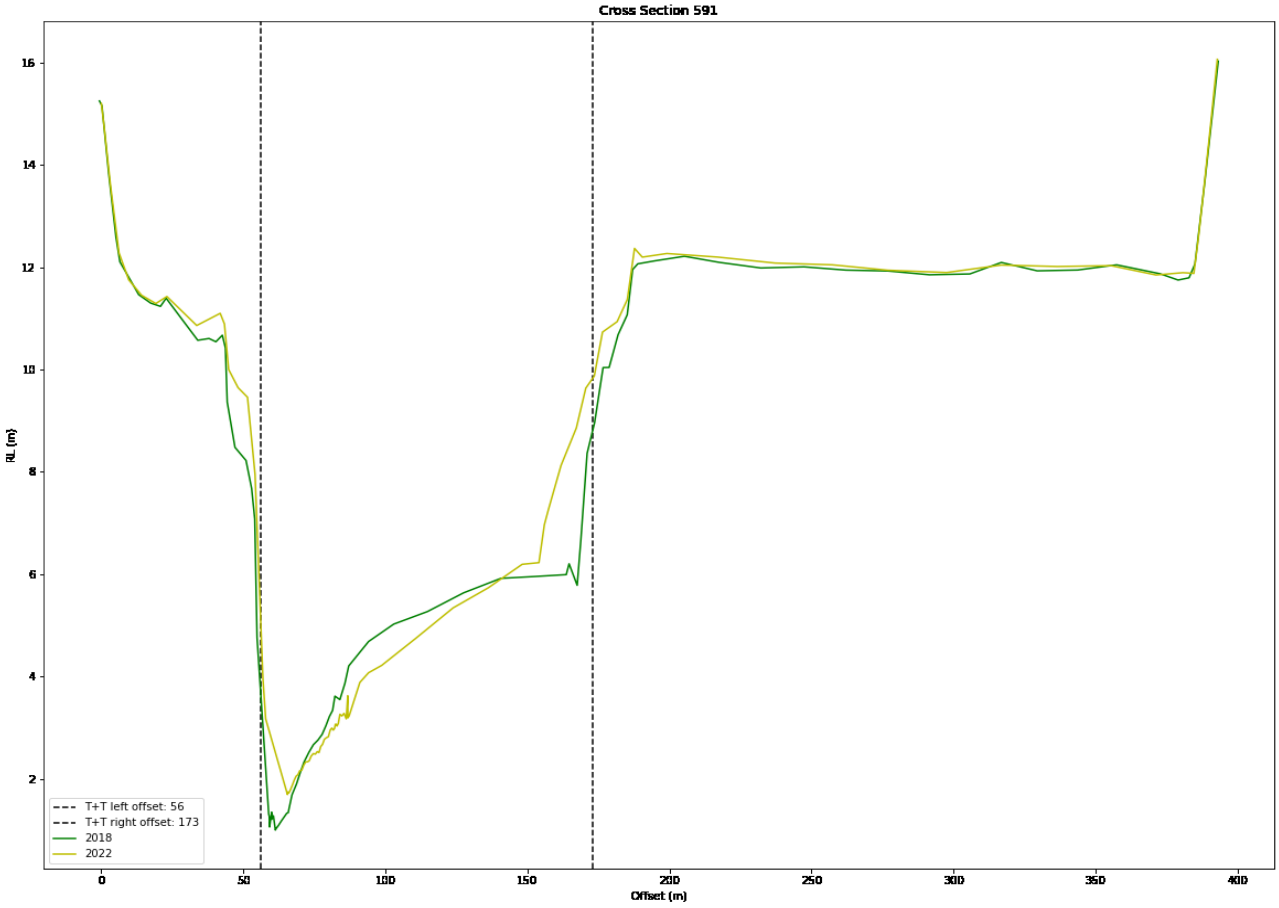

Cross Section 573
RL (m)
Offset (m)
T+T left offset: 55
T+T right offset: 114
2018
2022

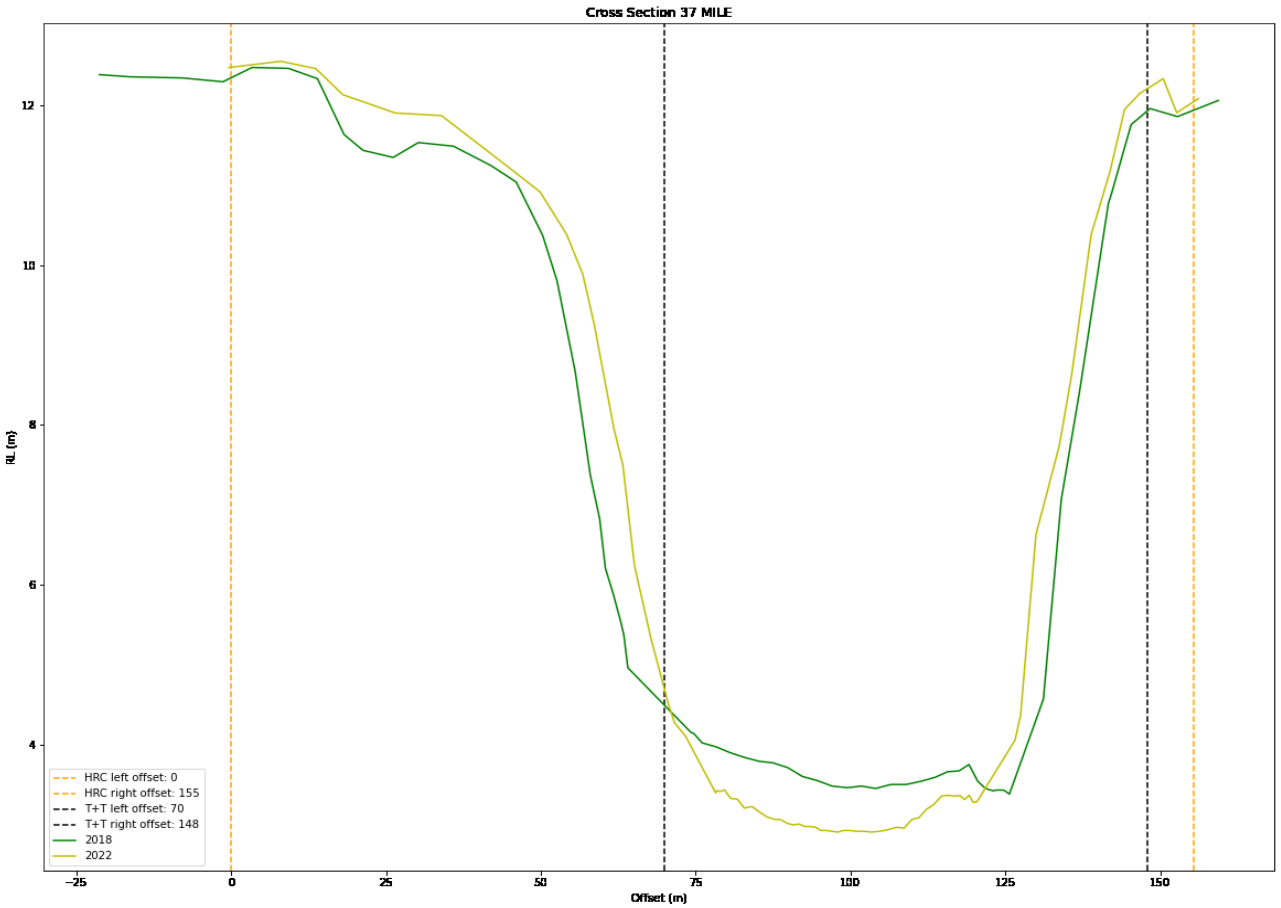

Cross Section 36 MILE
RL (m)
Offset (m)
T+T left offset: 26
T+T right offset: 91
2018
2022

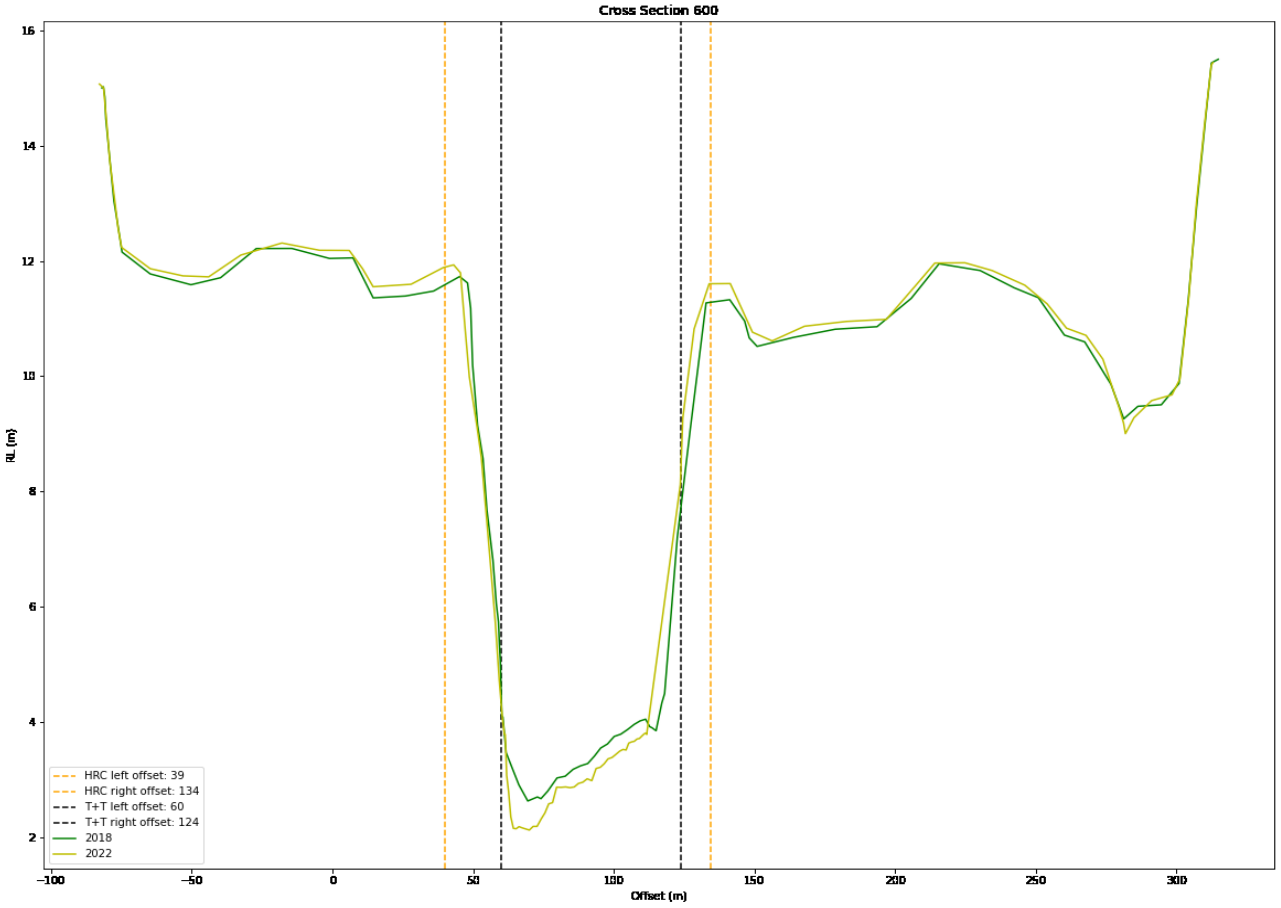

Cross Section 579
RL (m)
Offset (m)
T+T left offset: 32
T+T right offset: 77
2018
2022

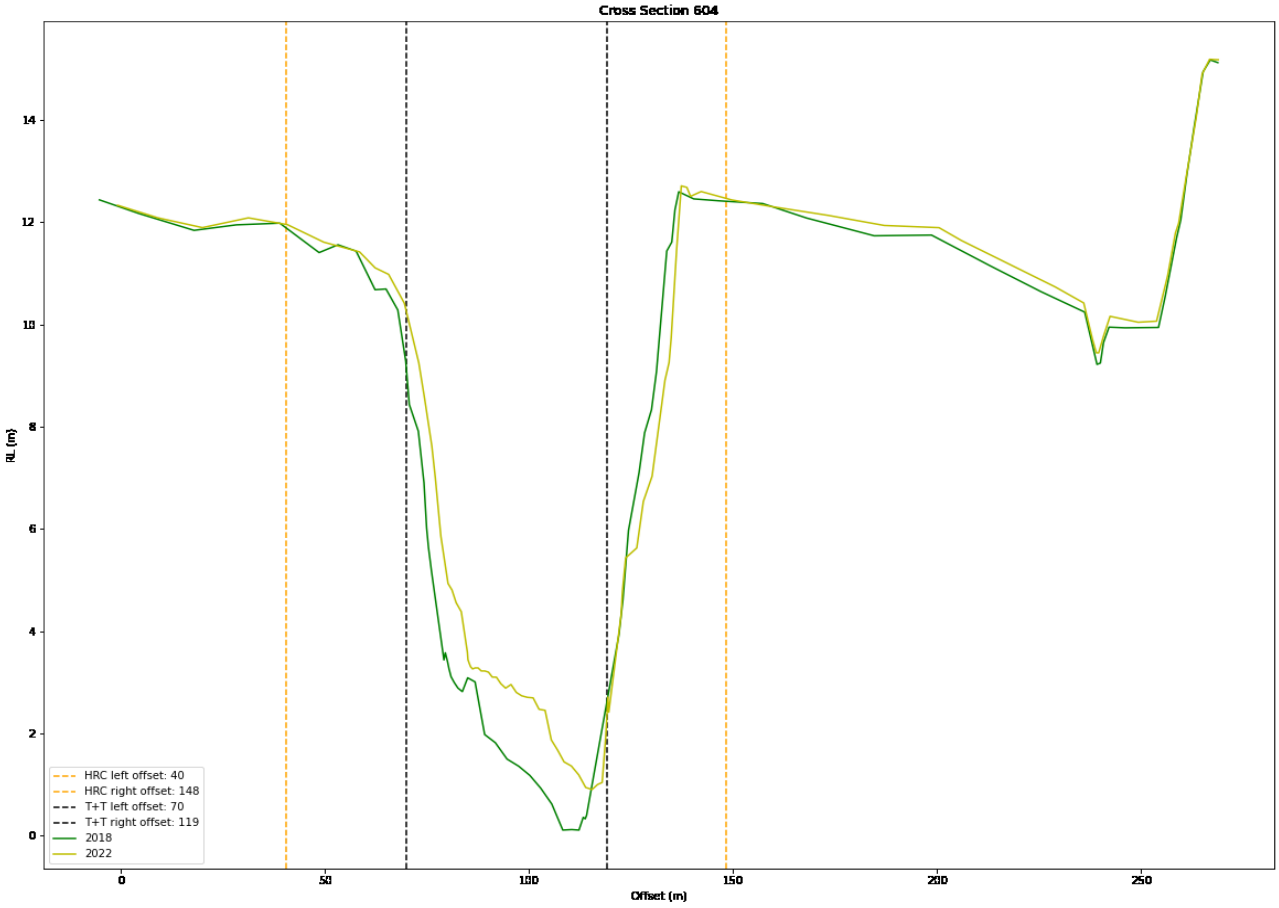

Cross Section 583
RL (m)
Offset (m)
T+T left offset: 47
T+T right offset: 100
2018
2022

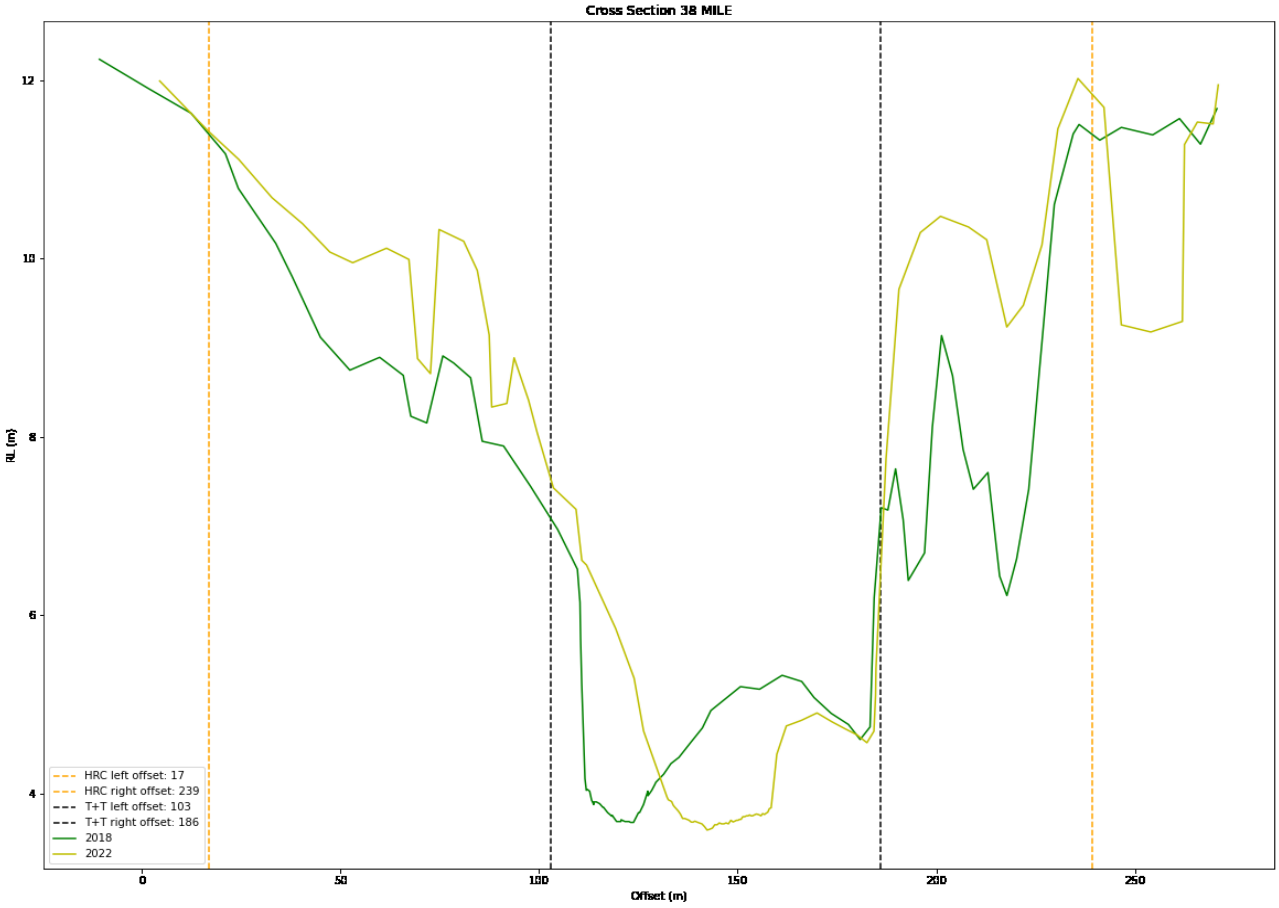

Cross Section 588
RL (m)
Offset (m)
T+T left offset: 31
T+T right offset: 79
2018
2022

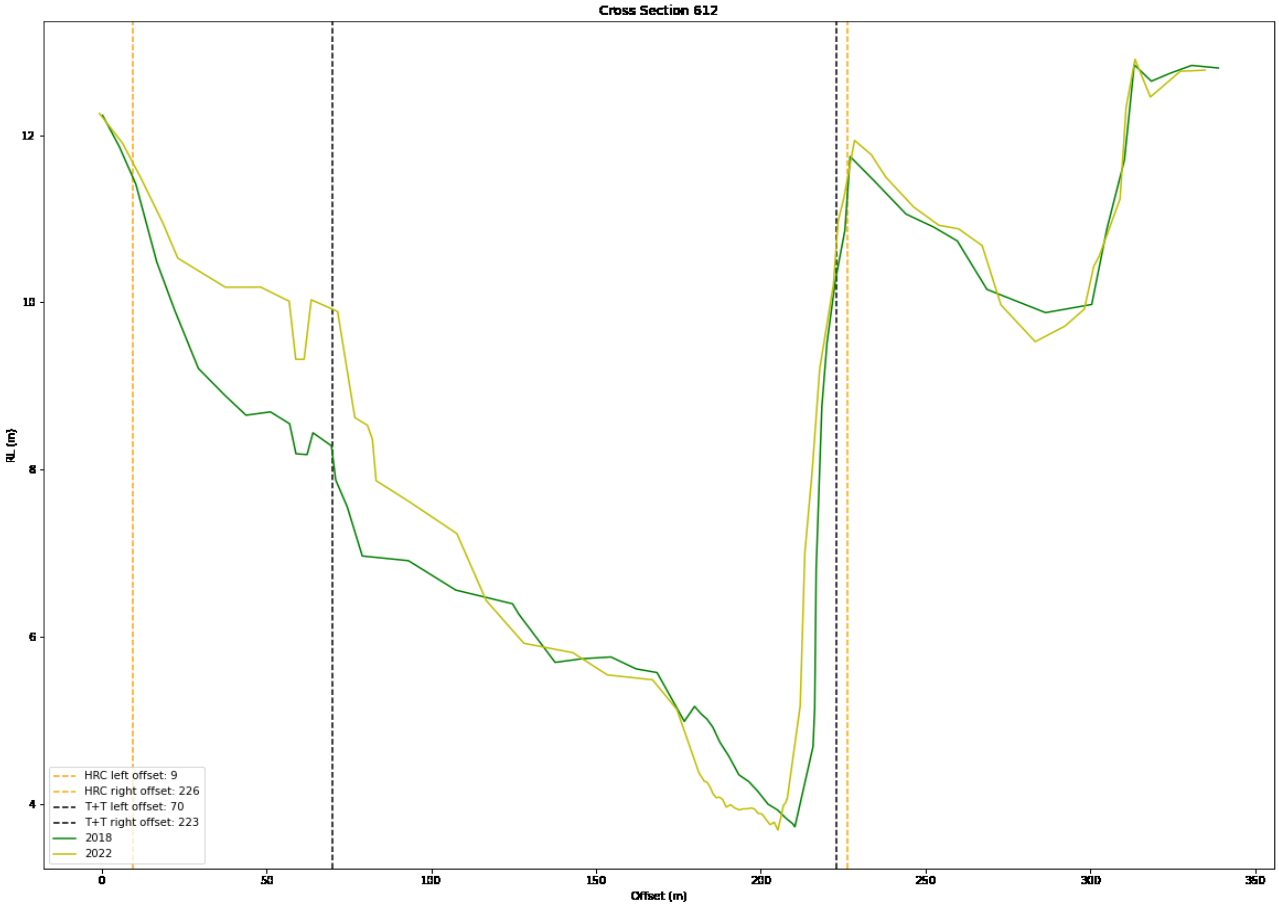

Cross Section 591
RL (m)
Offset (m)
T+T left offset: 56
T+T right offset: 173
2018
2022

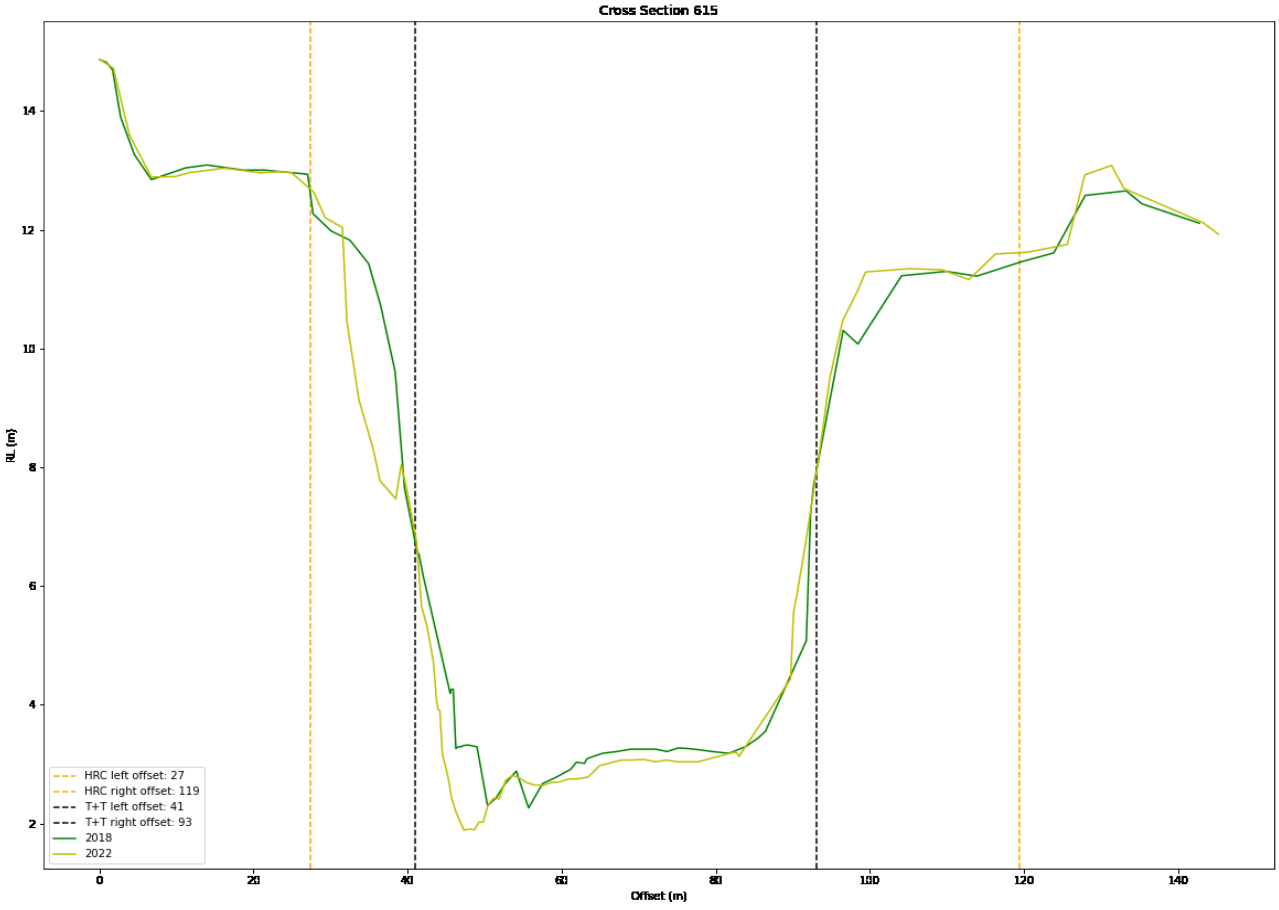

Cross Section 37 MILE
RL (m)
Offset (m)
HRC left offset: 0
HRC right offset: 155
T+T left offset: 70
T+T right offset: 148
2018
2022

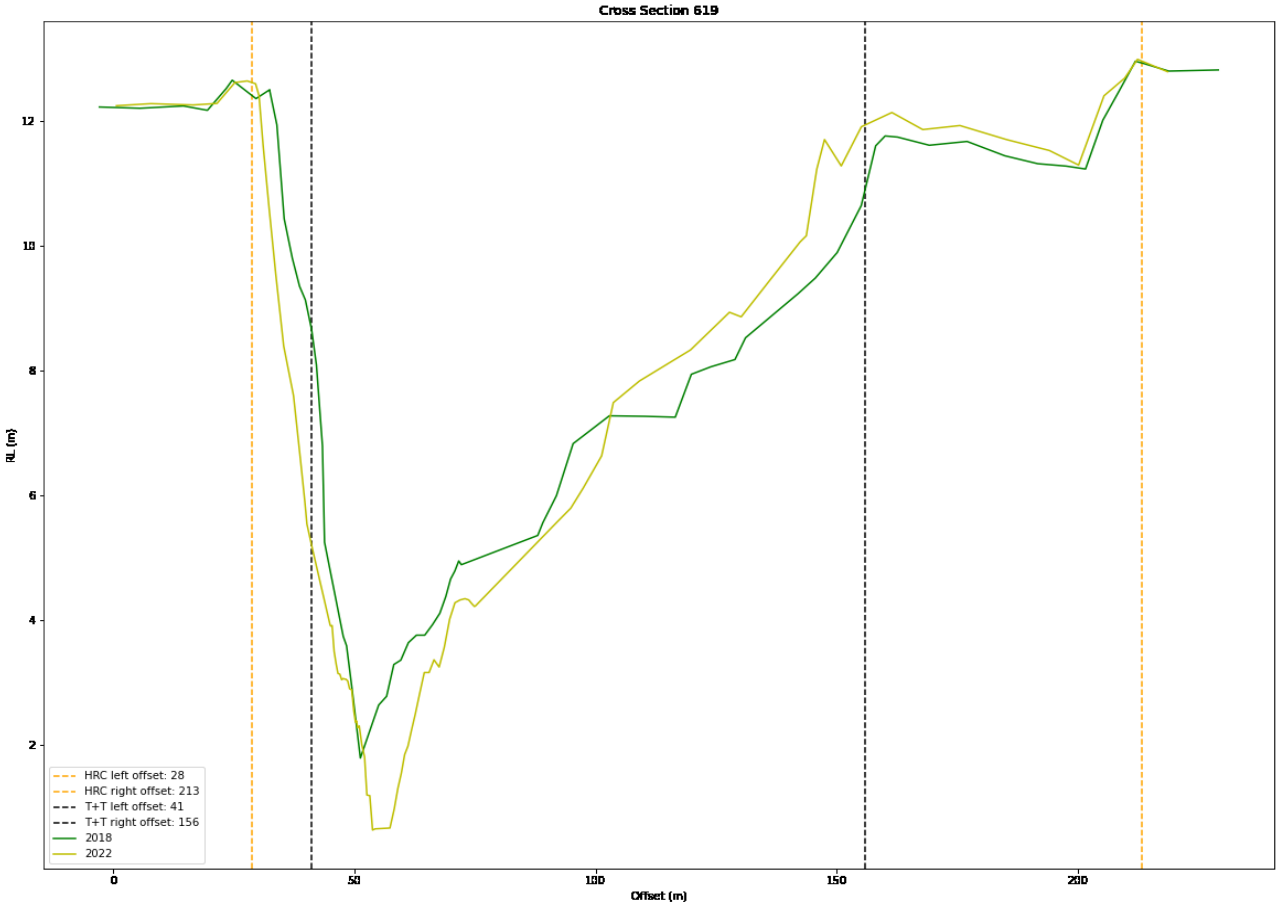

Cross Section 600
RL (m)
Offset (m)
HRC left offset: 39
HRC right offset: 134
T+T left offset: 60
T+T right offset: 124
2018
2022

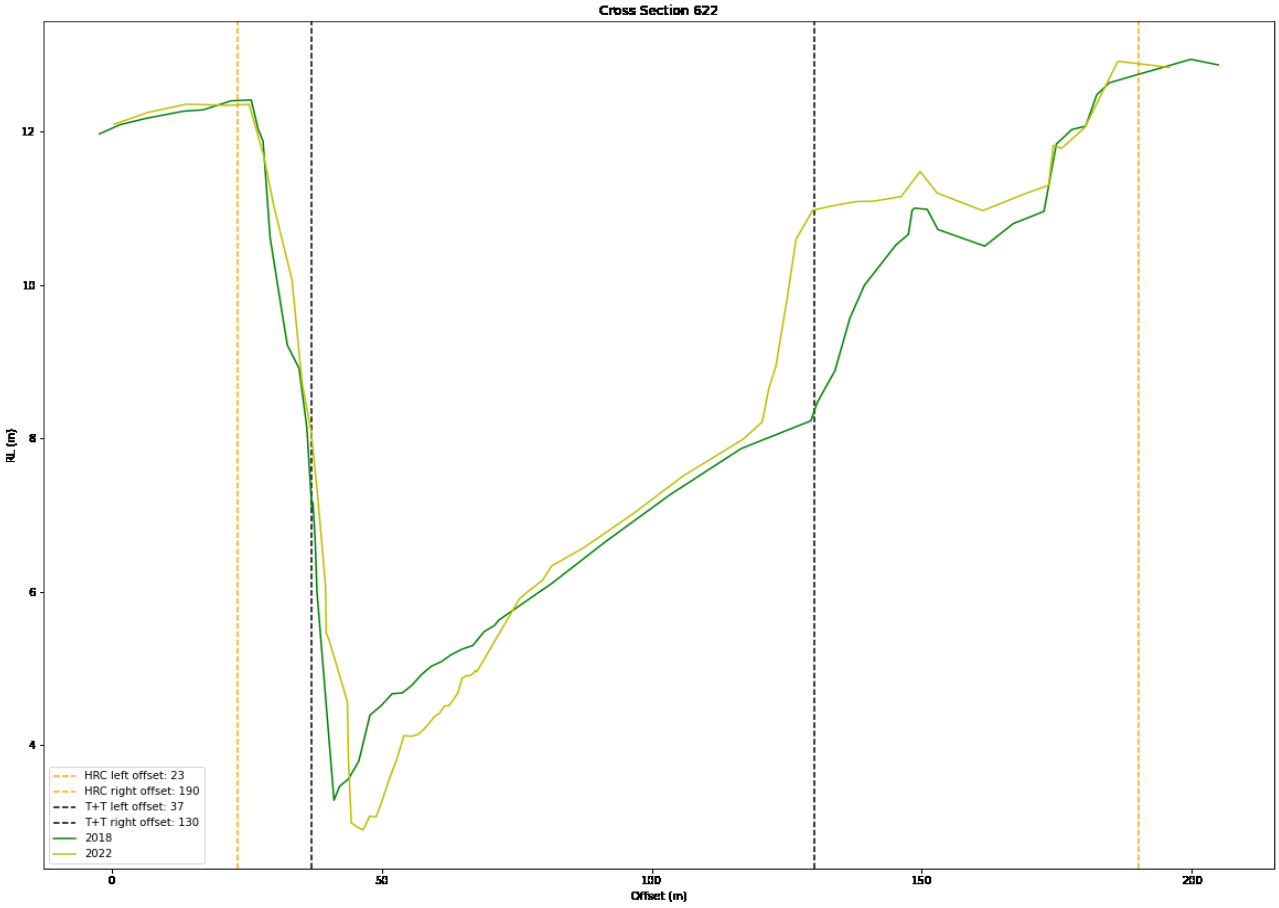

Cross Section 604
RL (m)
Offset (m)
HRC left offset: 40
HRC right offset: 148
T+T left offset: 70
T+T right offset: 119
2018
2022

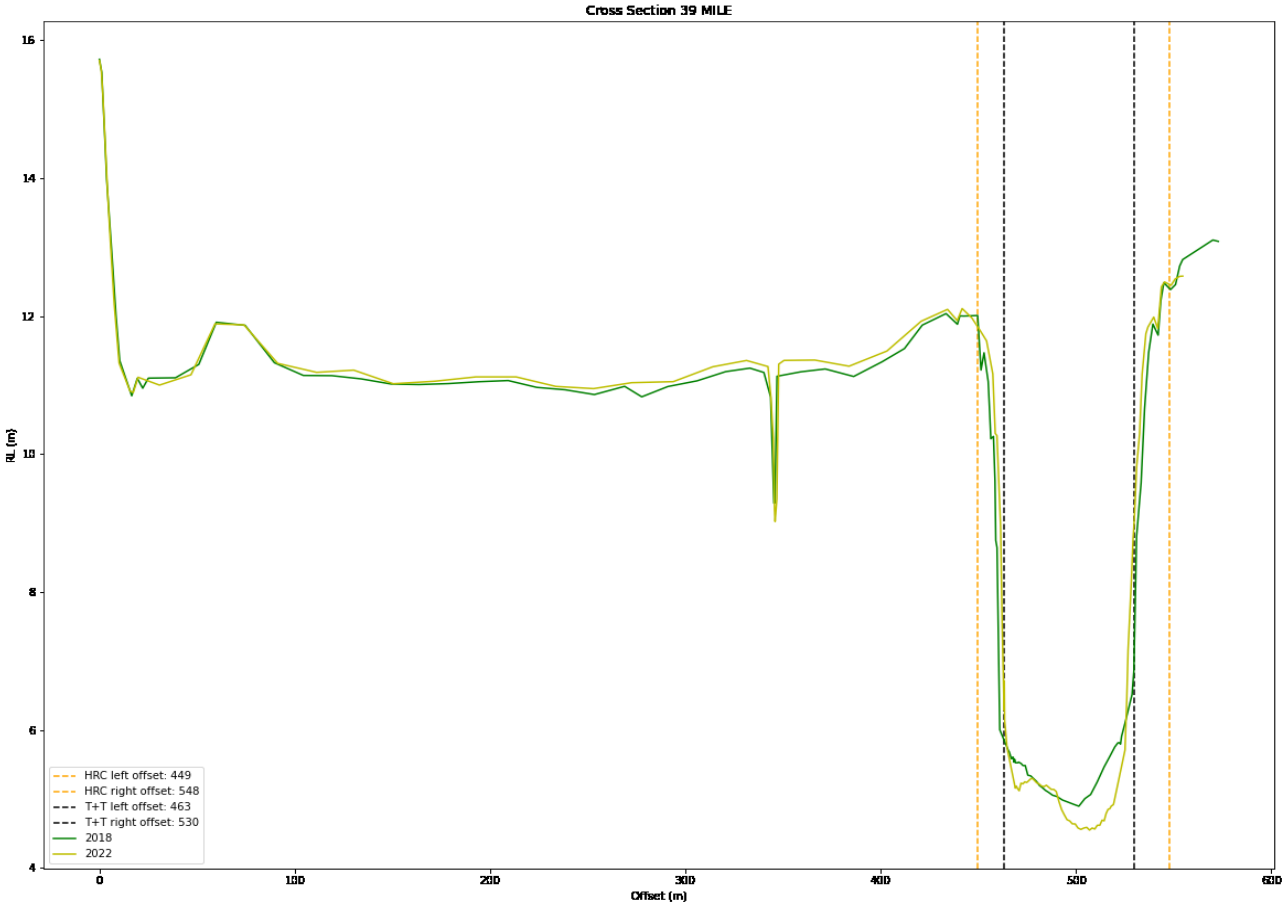

Cross Section 38 MILE
RL (m)
Offset (m)
HRC left offset: 17
HRC right offset: 239
T+T left offset: 103
T+T right offset: 186
2018
2022

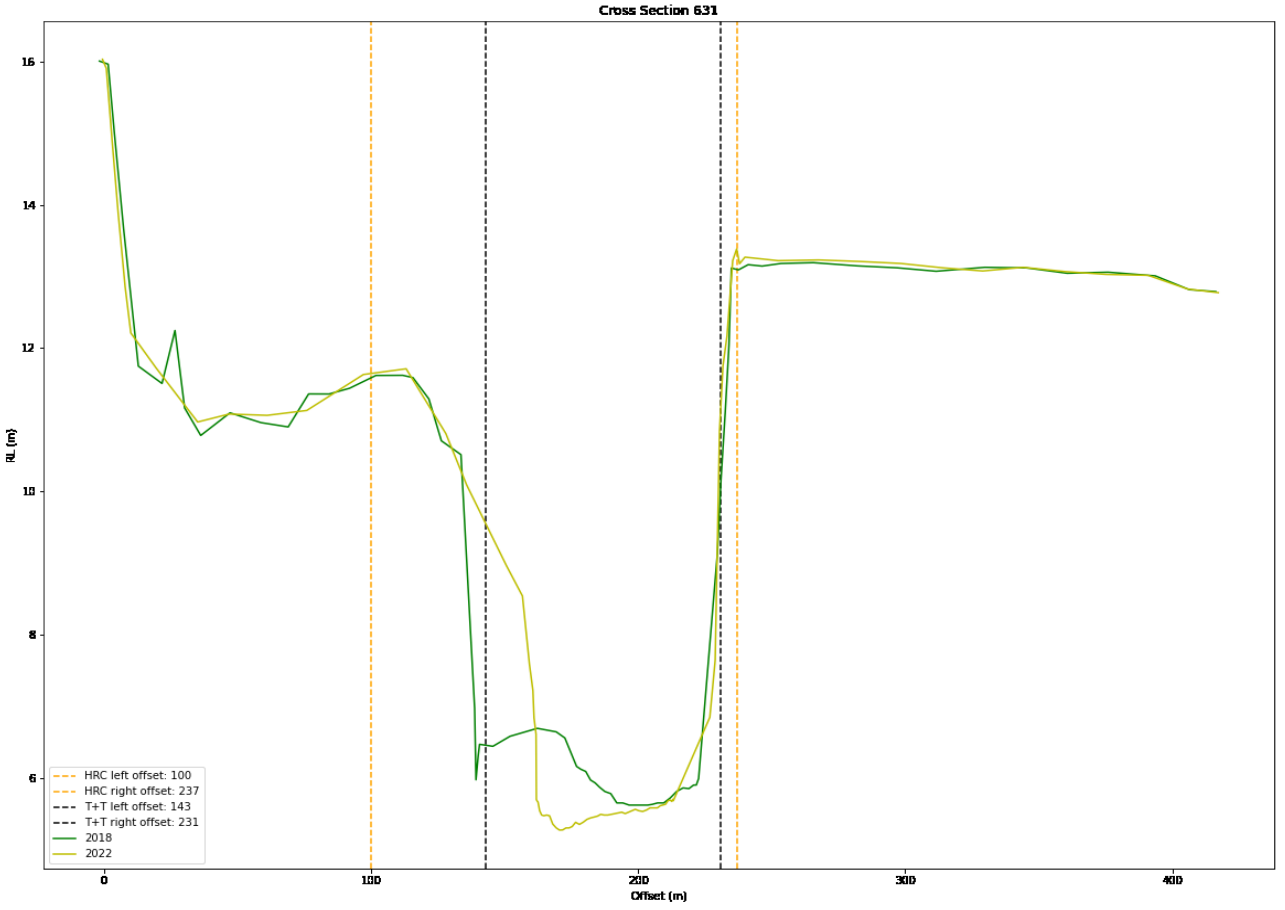

Cross Section 612
RL (m)
Offset (m)
HRC left offset: 9
HRC right offset: 226
T+T left offset: 70
T+T right offset: 223
2018
2022

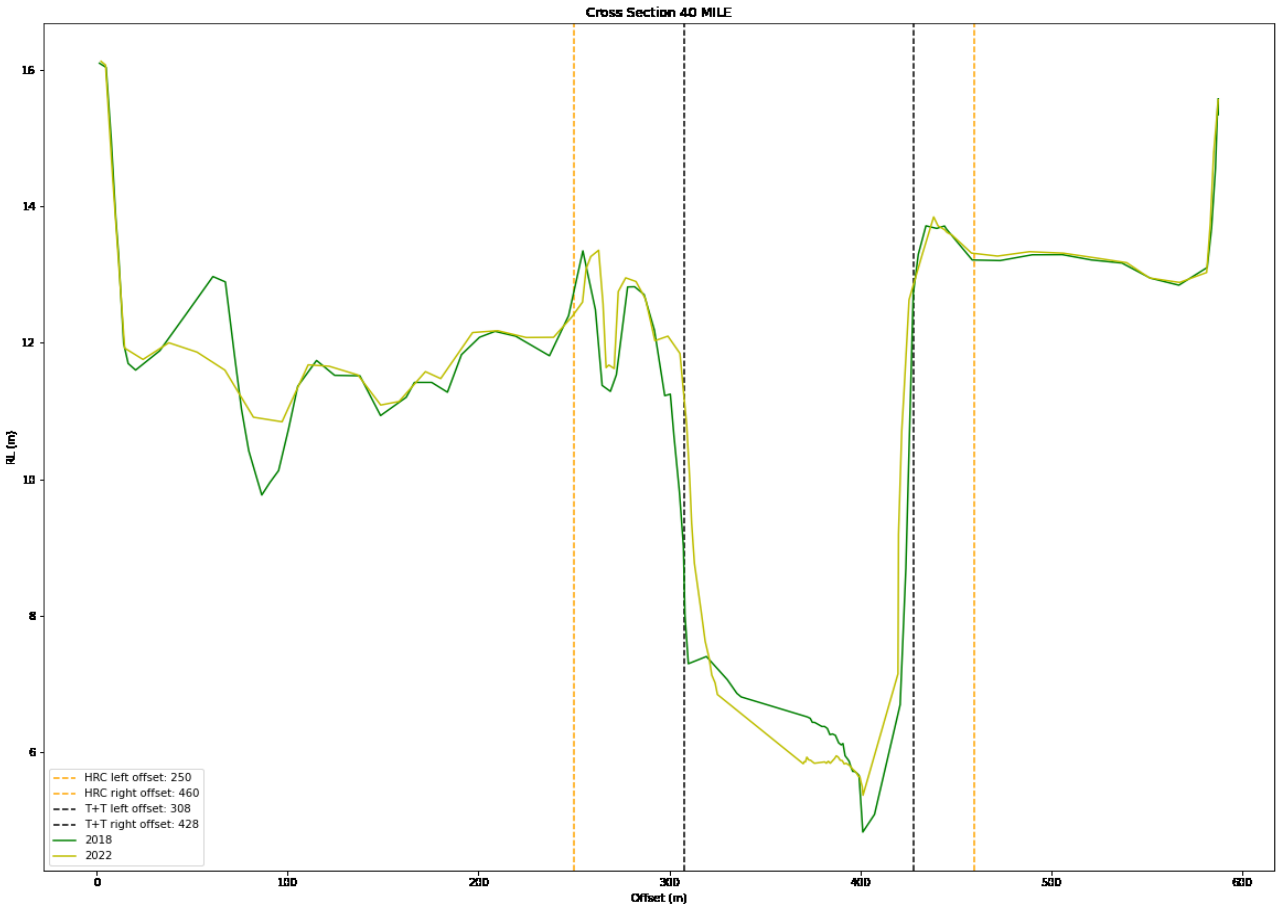

Cross Section 615
RL (m)
Offset (m)
HRC left offset: 27
HRC right offset: 119
T+T left offset: 41
T+T right offset: 93
2018
2022

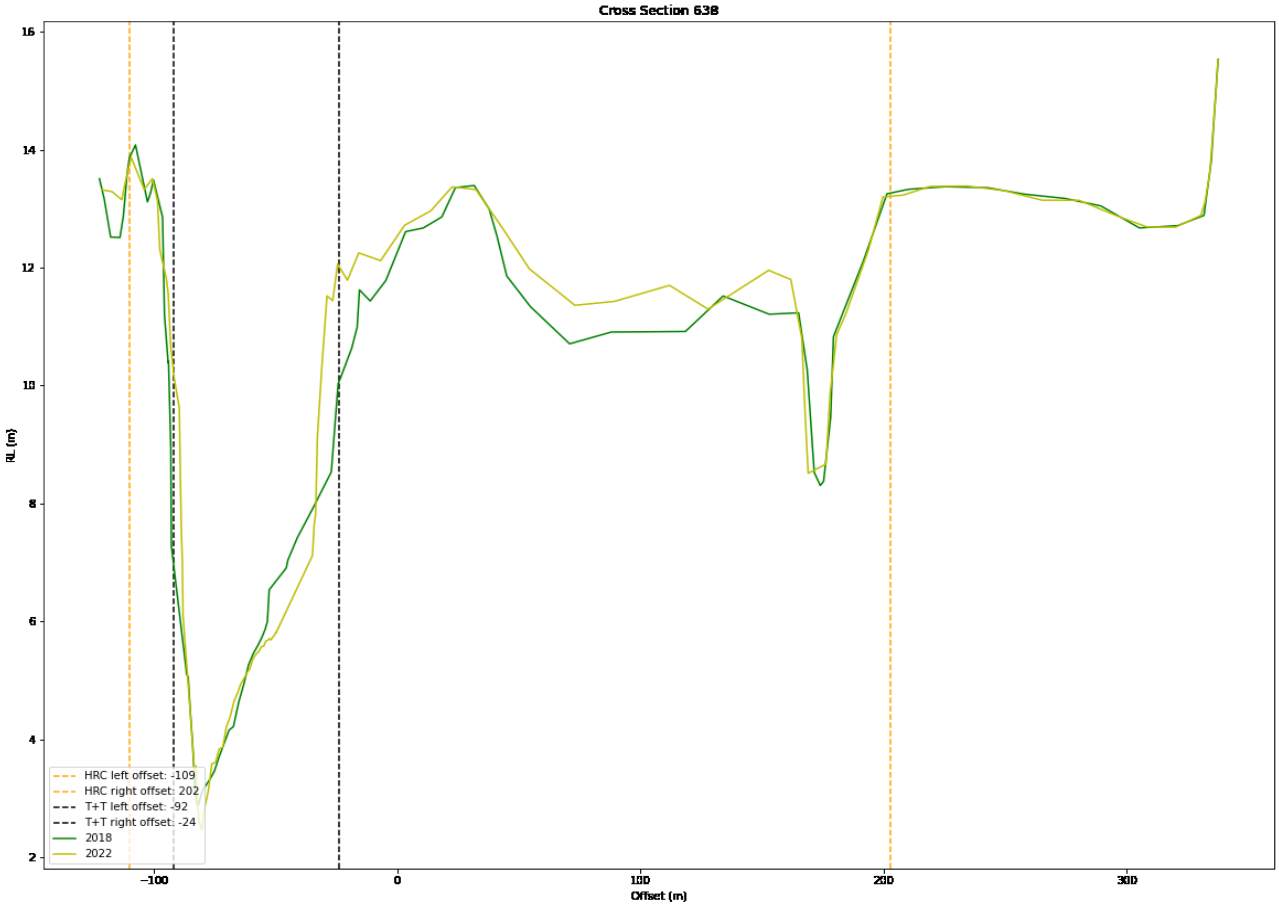

Cross Section 619
RL (m)
Offset (m)
HRC left offset: 28
HRC right offset: 213
T+T left offset: 41
T+T right offset: 156
2018
2022

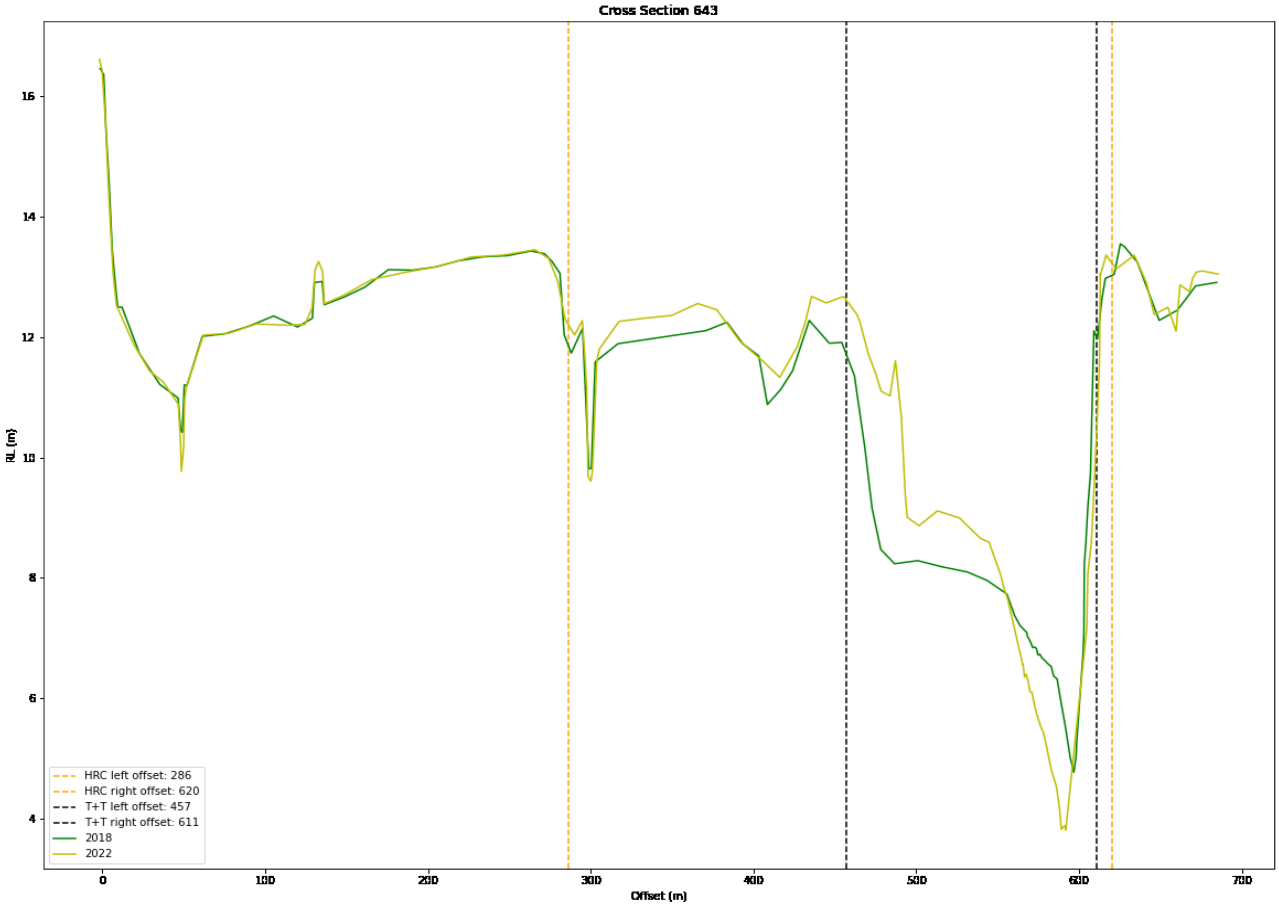

Cross Section 622
RL (m)
Offset (m)
HRC left offset: 23
HRC right offset: 190
T+T left offset: 37
T+T right offset: 130
2018
2022

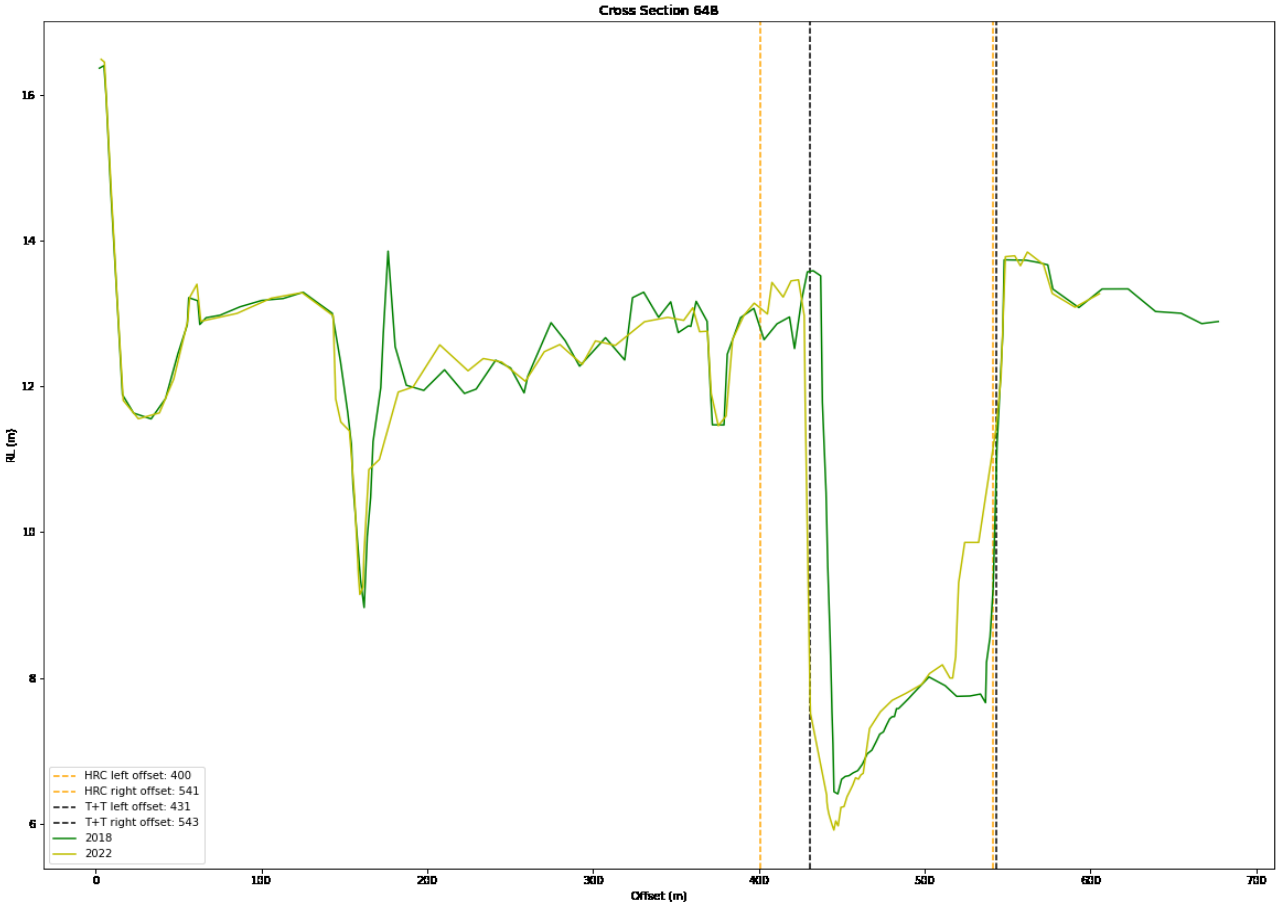

Cross Section 39 MILE
RL (m)
Offset (m)
HRC left offset: 449
HRC right offset: 548
T+T left offset: 463
T+T right offset: 530
2018
2022

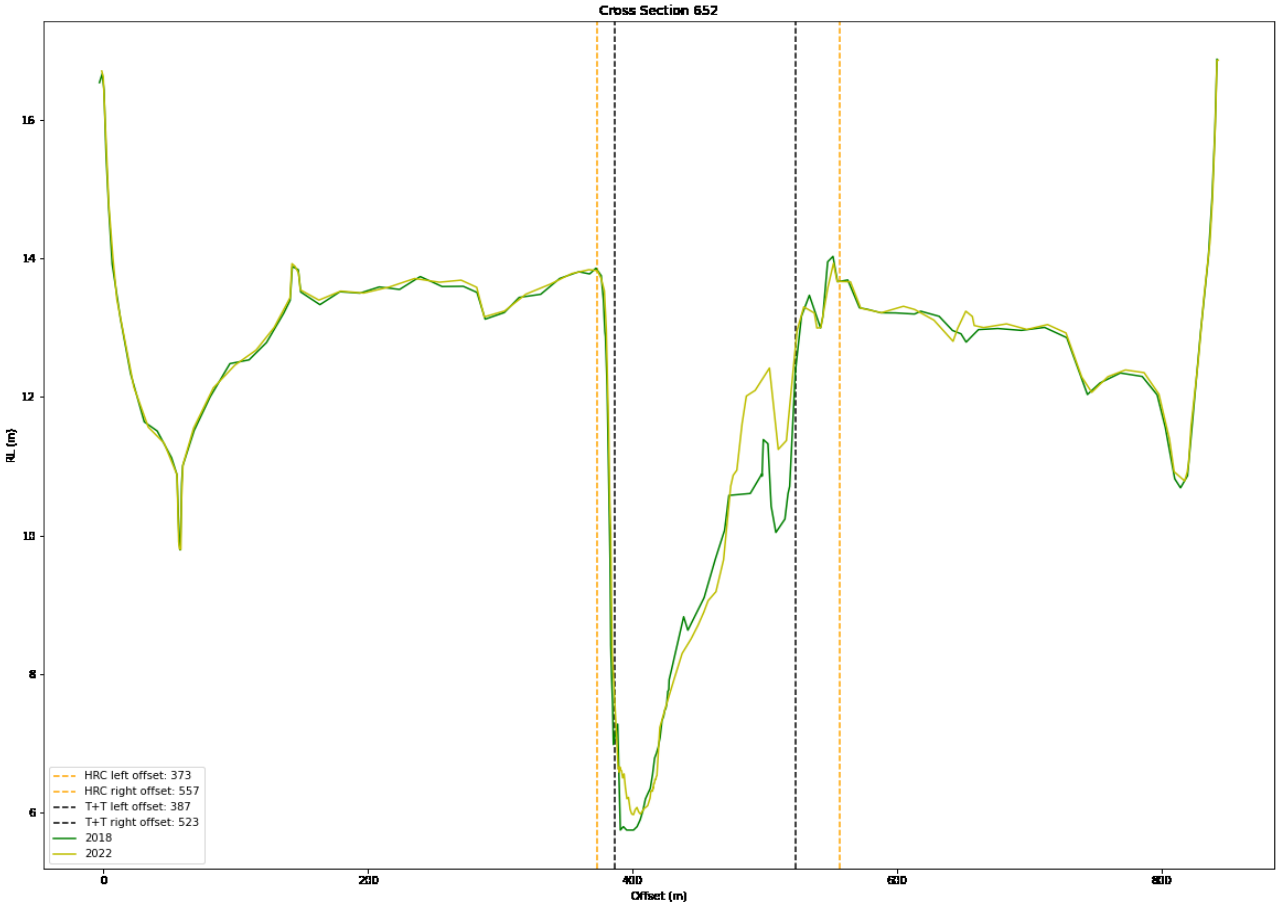

Cross Section 631
RL (m)
Offset (m)
HRC left offset: 100
HRC right offset: 237
T+T left offset: 143
T+T right offset: 231
2018
2022

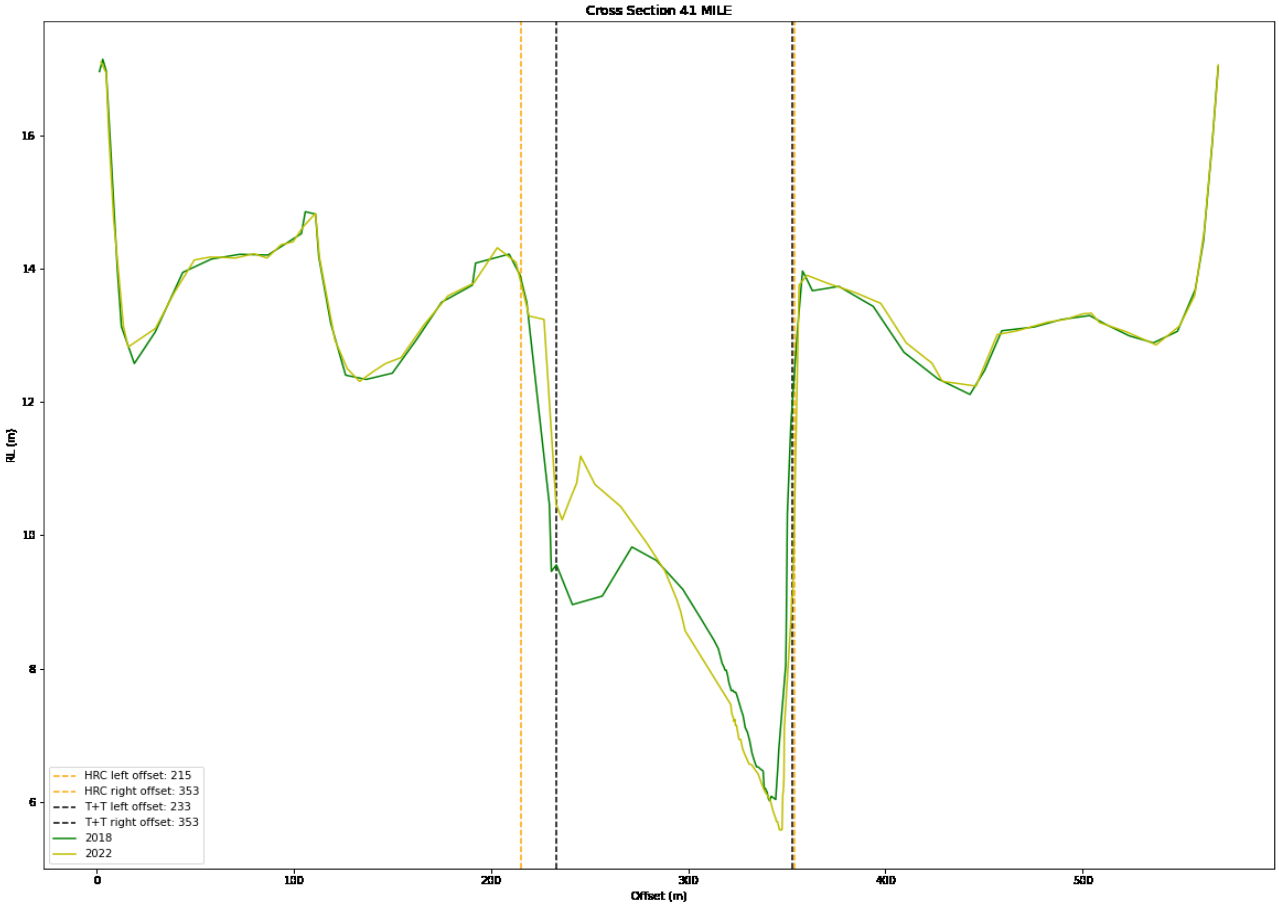

Cross Section 40 MILE
RL (m)
Offset (m)
HRC left offset: 250
HRC right offset: 460
T+T left offset: 308
T+T right offset: 428
2018
2022

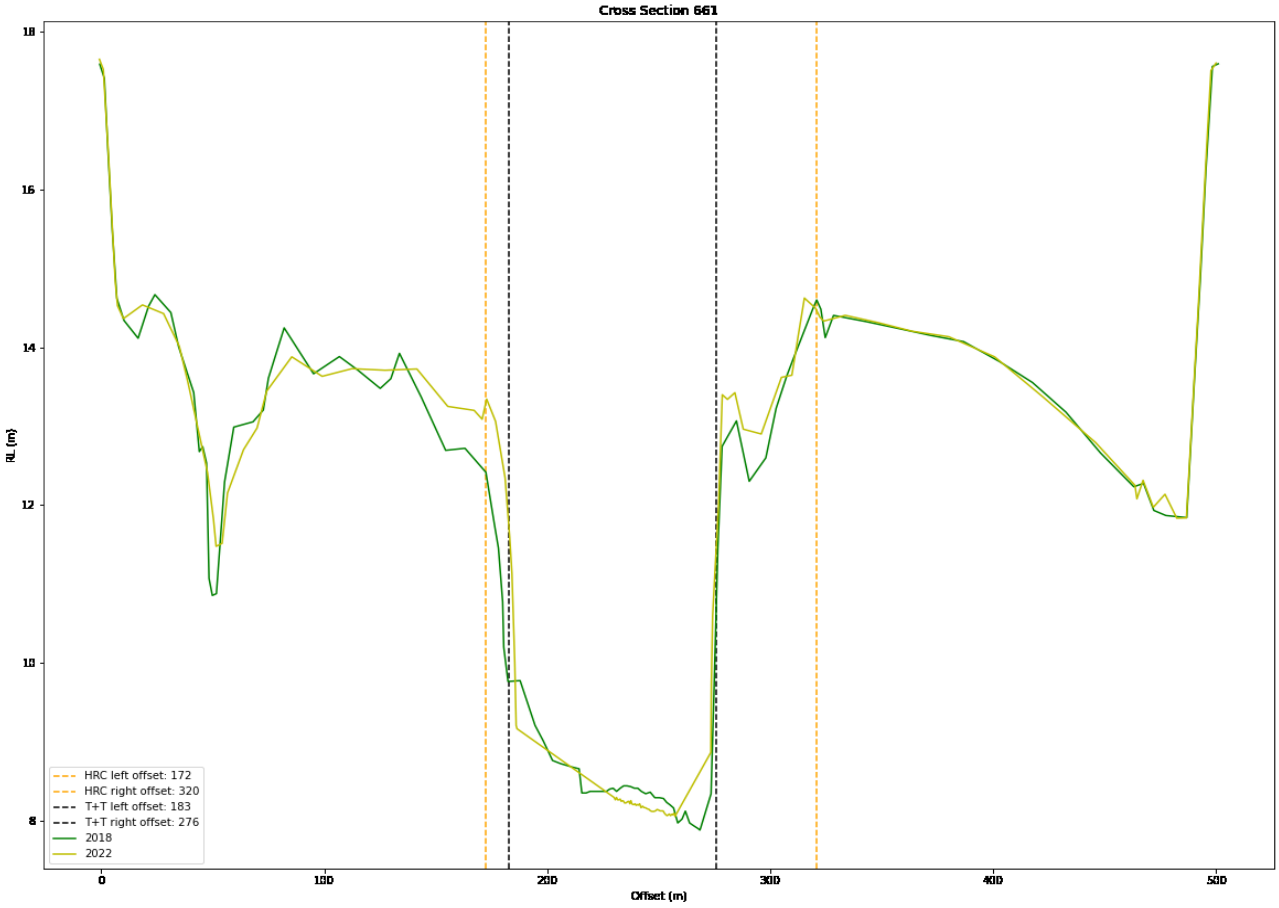

Cross Section 638
RL (m)
Offset (m)
HRC left offset: -109
HRC right offset: 202
T+T left offset: -92
T+T right offset: -24
2018
2022

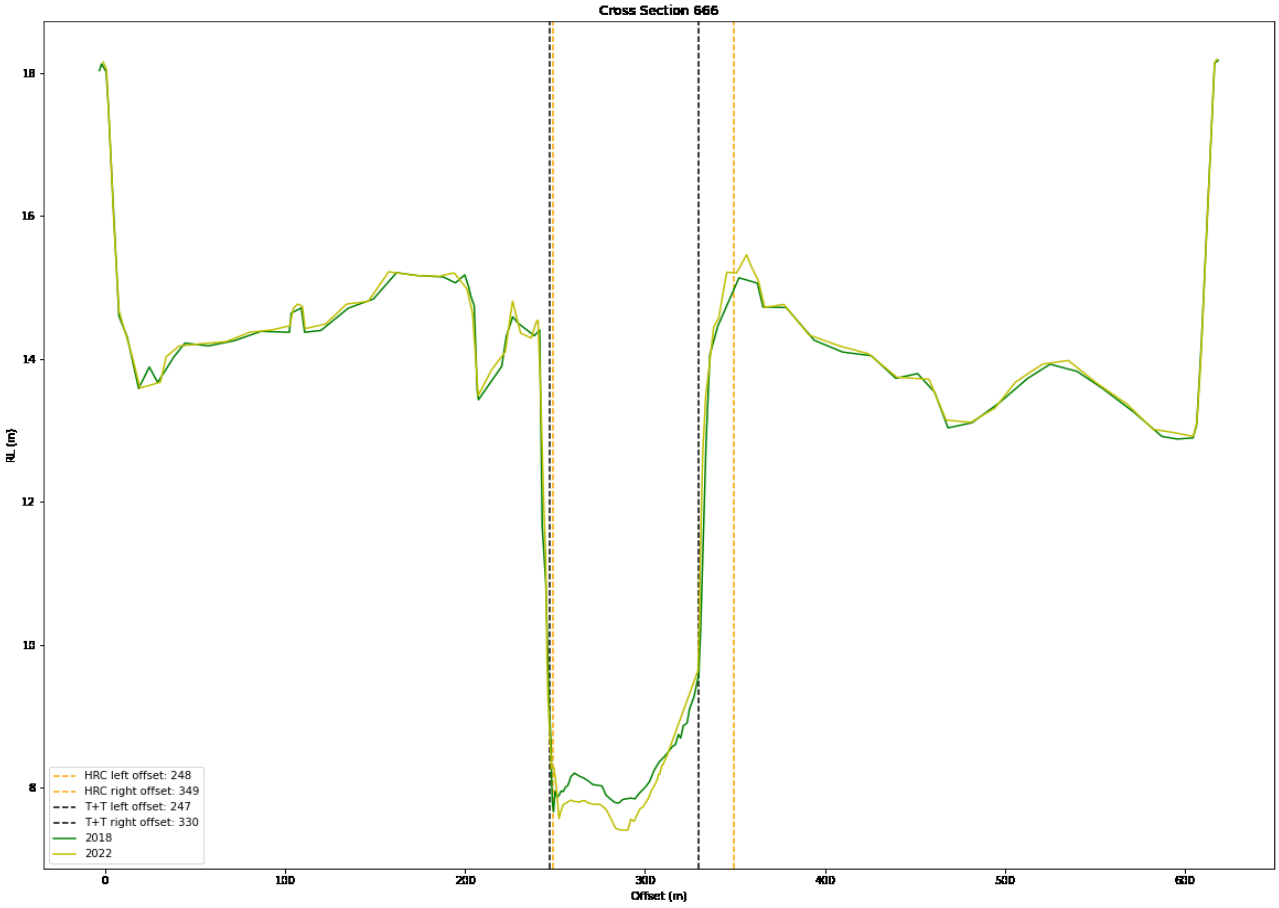

Cross Section 643
RL (m)
Offset (m)
HRC left offset: 286
HRC right offset: 620
T+T left offset: 457
T+T right offset: 611
2018
2022

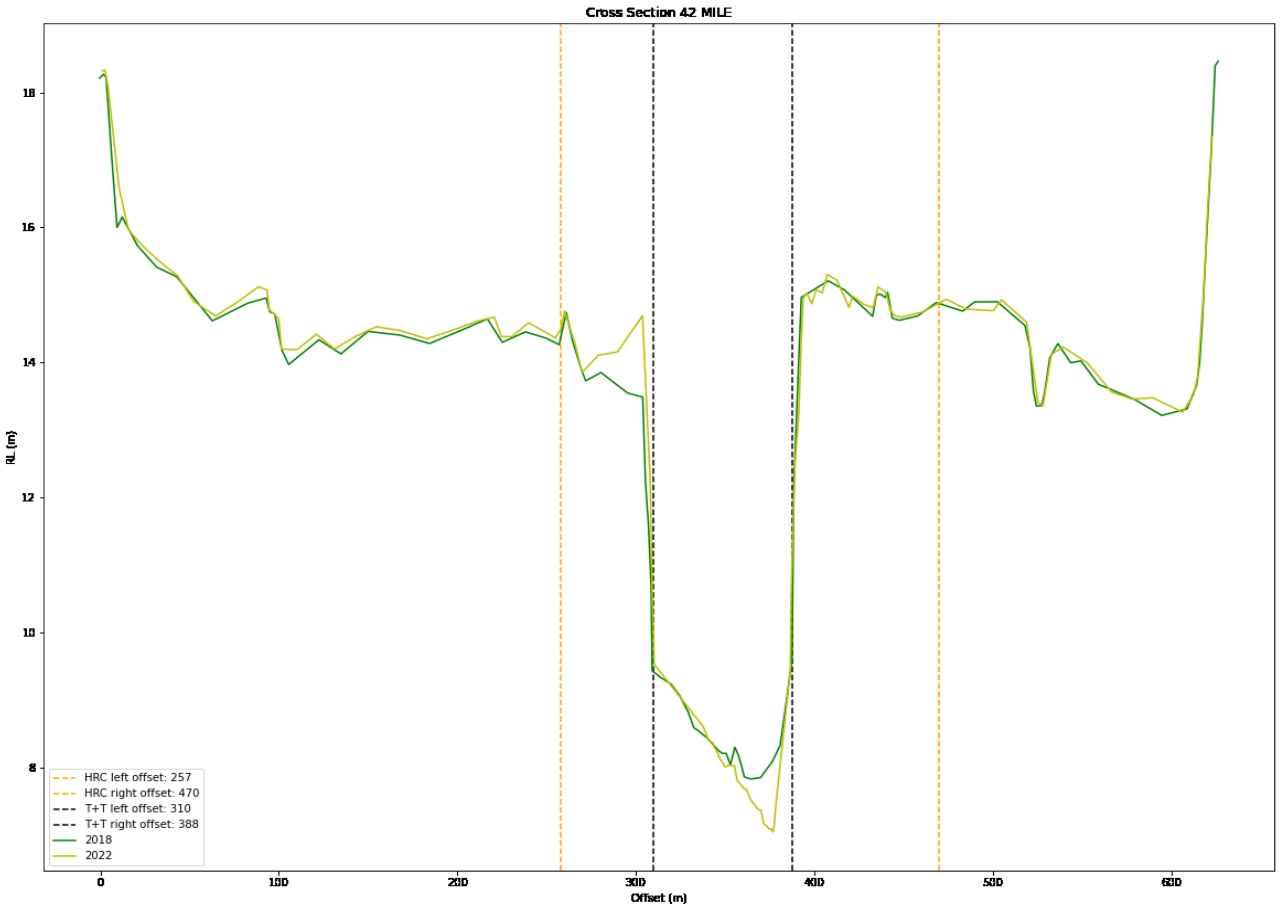

Cross Section 648
RL (m)
Offset (m)
HRC left offset: 400
HRC right offset: 541
T+T left offset: 431
T+T right offset: 543
2018
2022

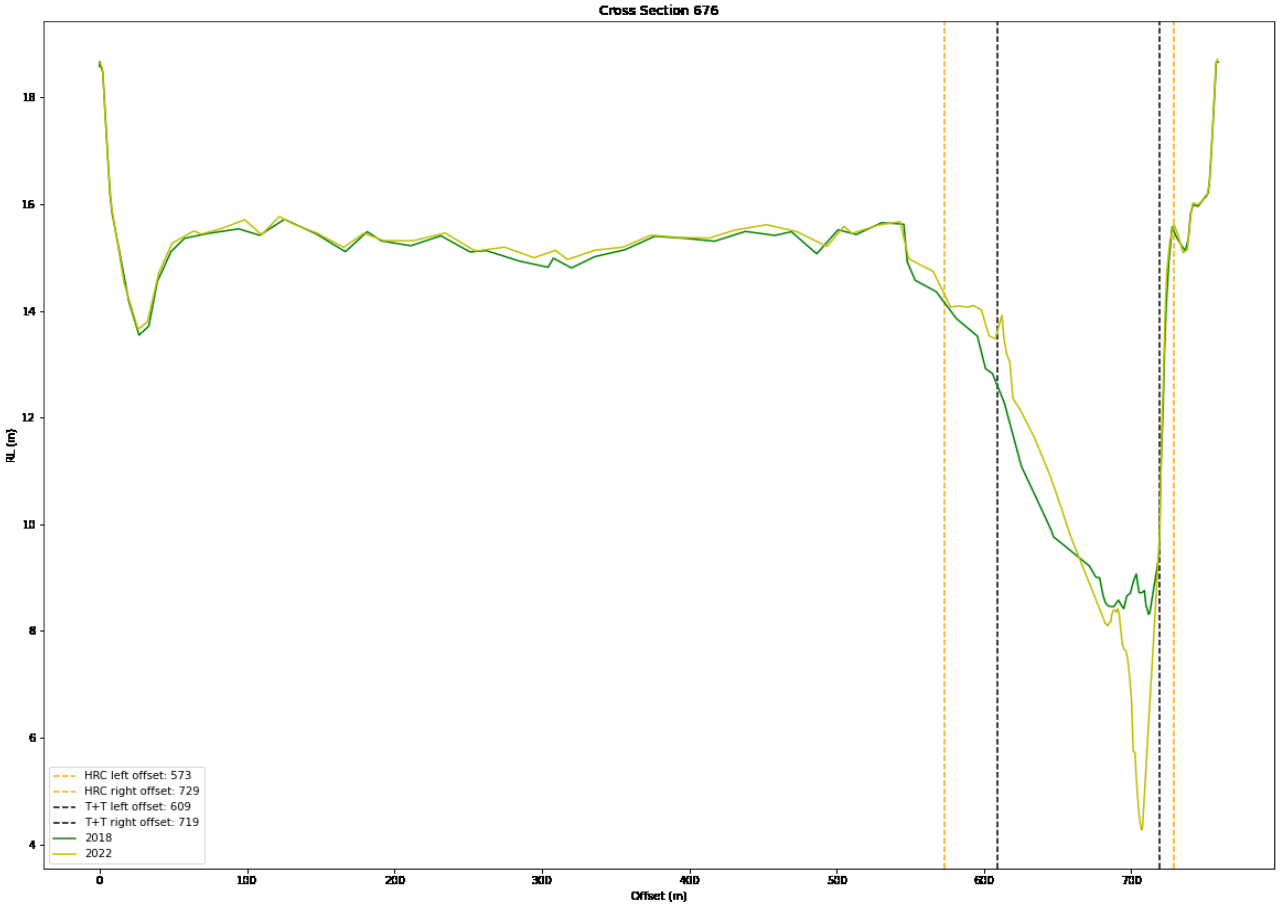

Cross Section 652
RL (m)
Offset (m)
HRC left offset: 373
HRC right offset: 557
T+T left offset: 387
T+T right offset: 523
2018
2022

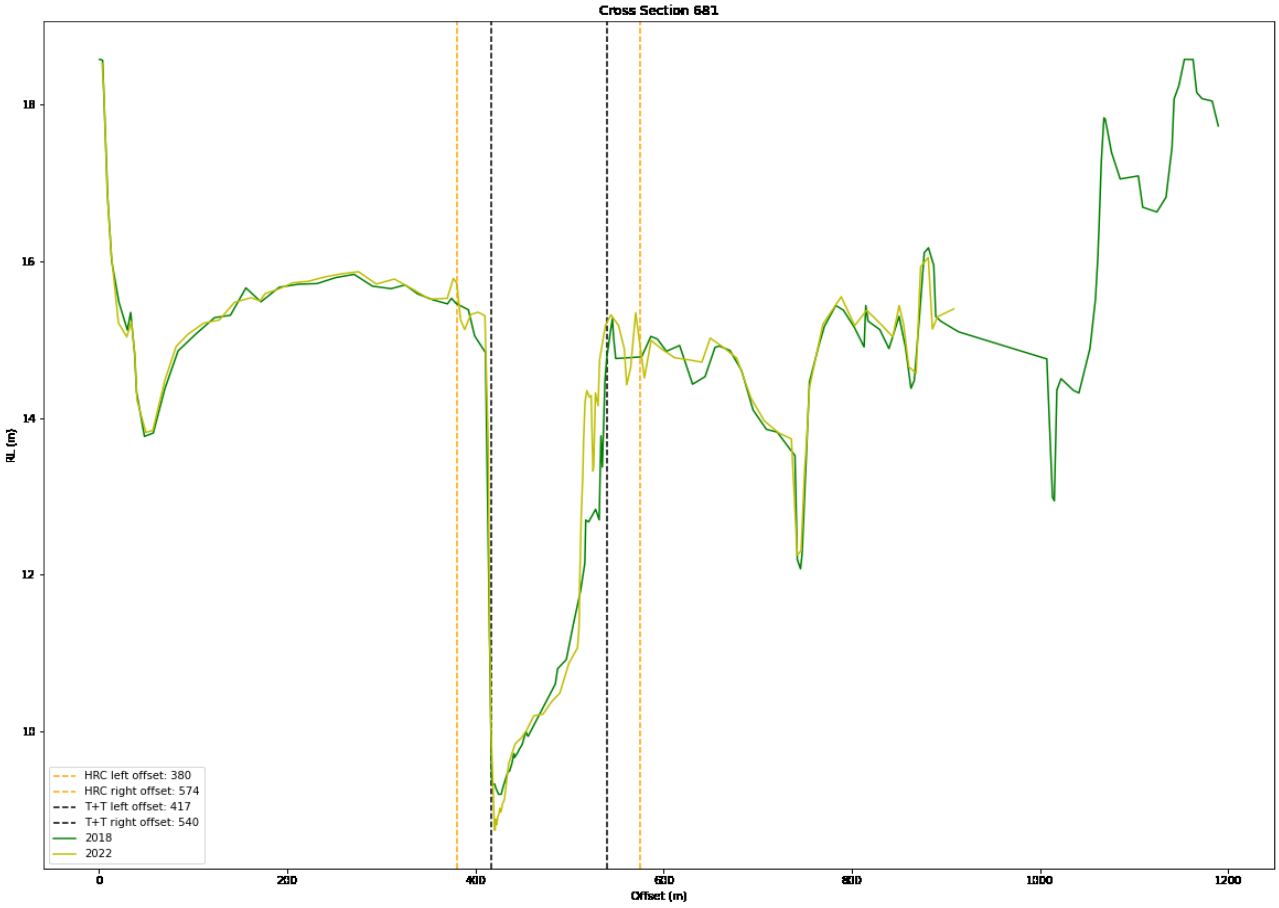

Cross Section 41 MILE
RL (m)
Offset (m)
HRC left offset: 215
HRC right offset: 353
T+T left offset: 233
T+T right offset: 353
2018
2022

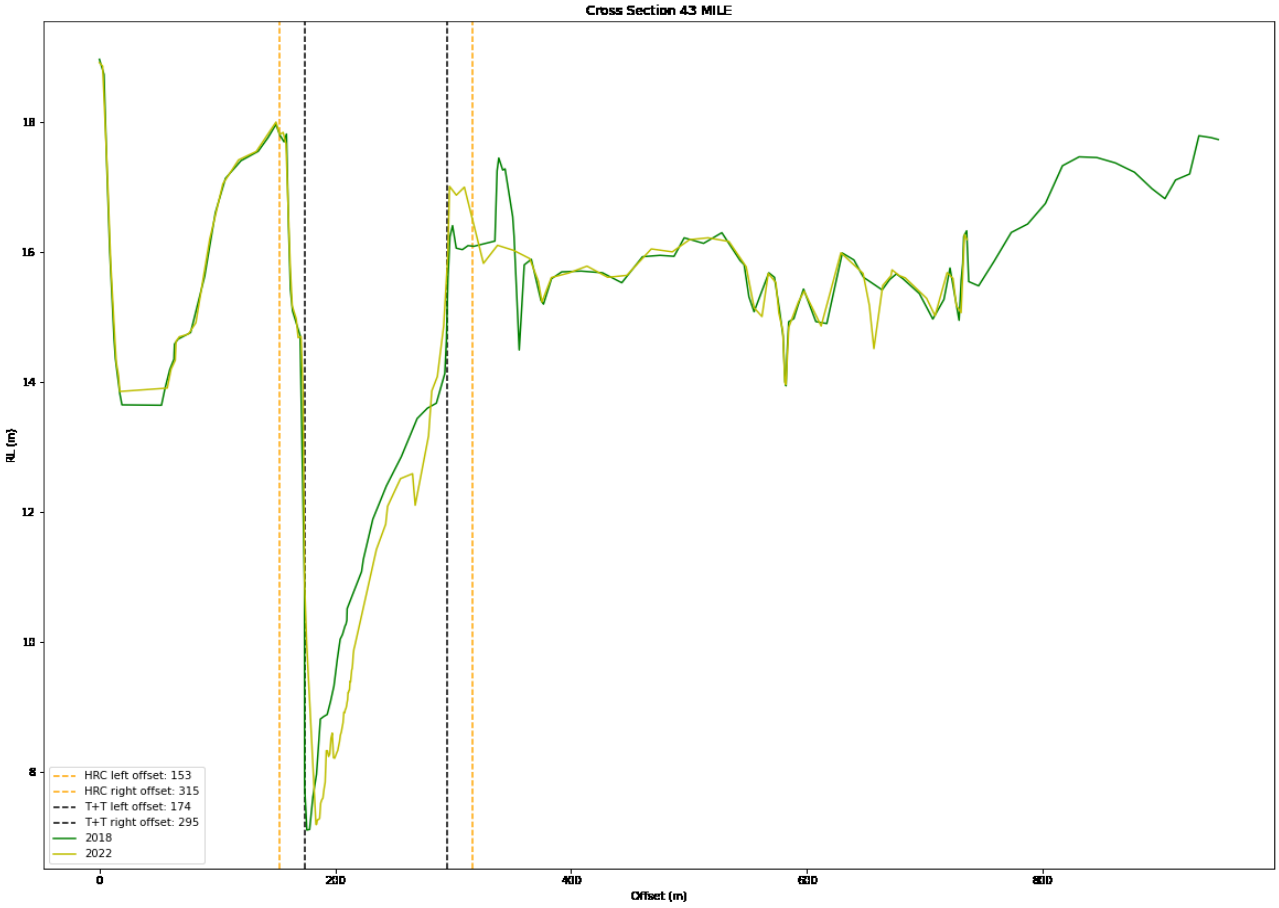

Cross Section 661
RL (m)
Offset (m)
HRC left offset: 172
HRC right offset: 320
T+T left offset: 183
T+T right offset: 276
2018
2022

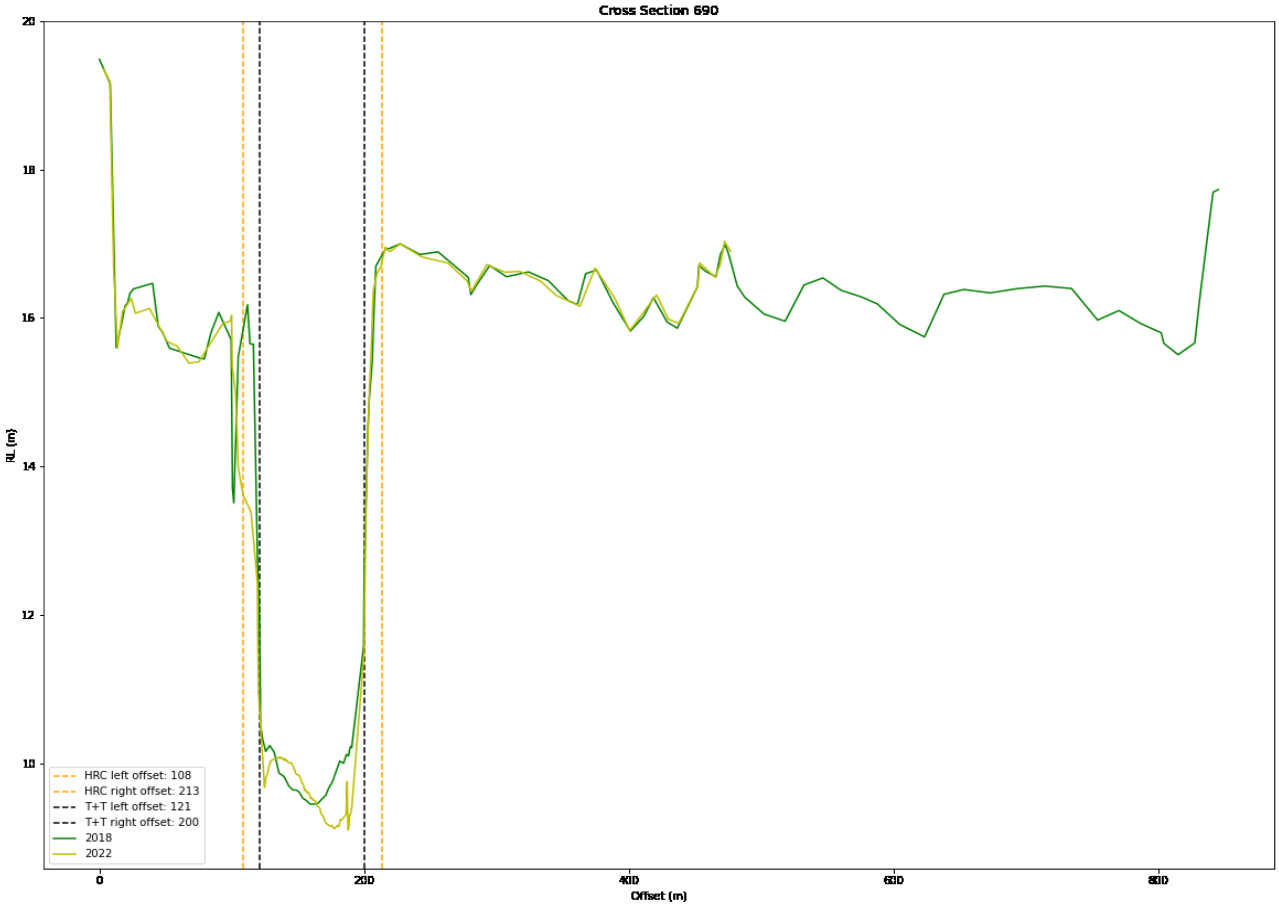

Cross Section 666
RL (m)
Offset (m)
HRC left offset: 248
HRC right offset: 349
T+T left offset: 247
T+T right offset: 330
2018
2022

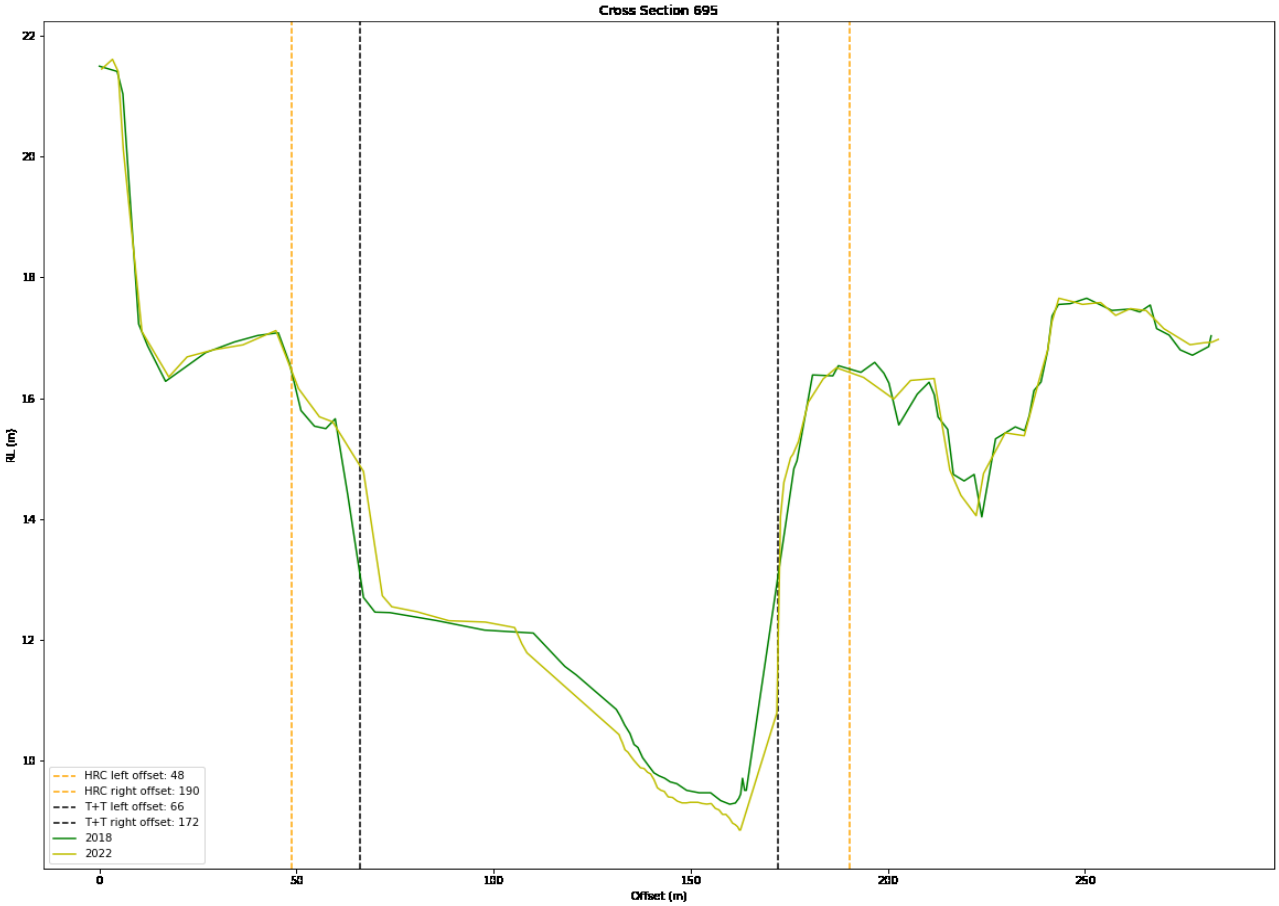

Cross Section 42 MILE
RL (m)
Offset (m)
HRC left offset: 257
HRC right offset: 470
T+T left offset: 310
T+T right offset: 388
2018
2022

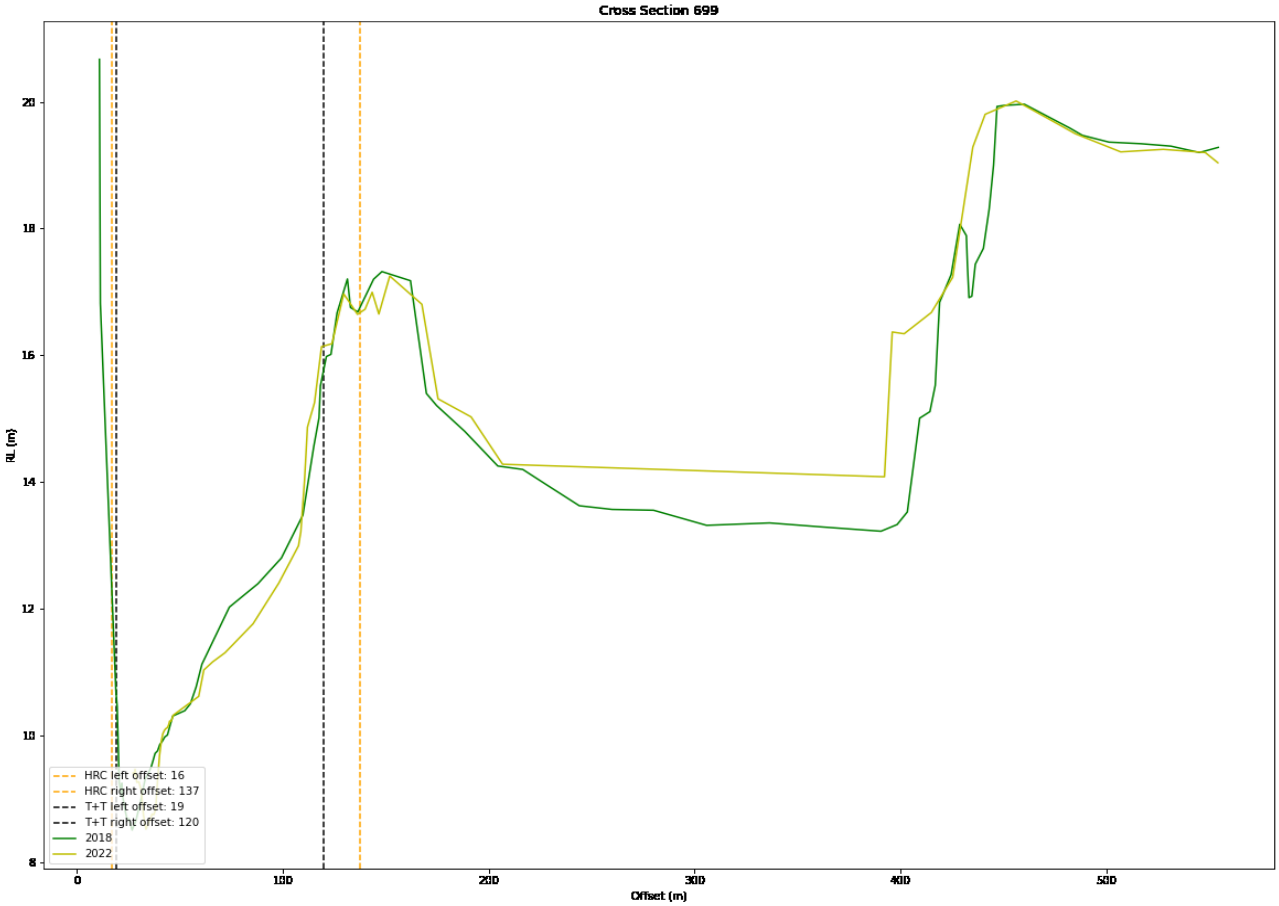

Cross Section 676
RL (m)
Offset (m)
HRC left offset: 573
HRC right offset: 729
T+T left offset: 609
T+T right offset: 719
2018
2022

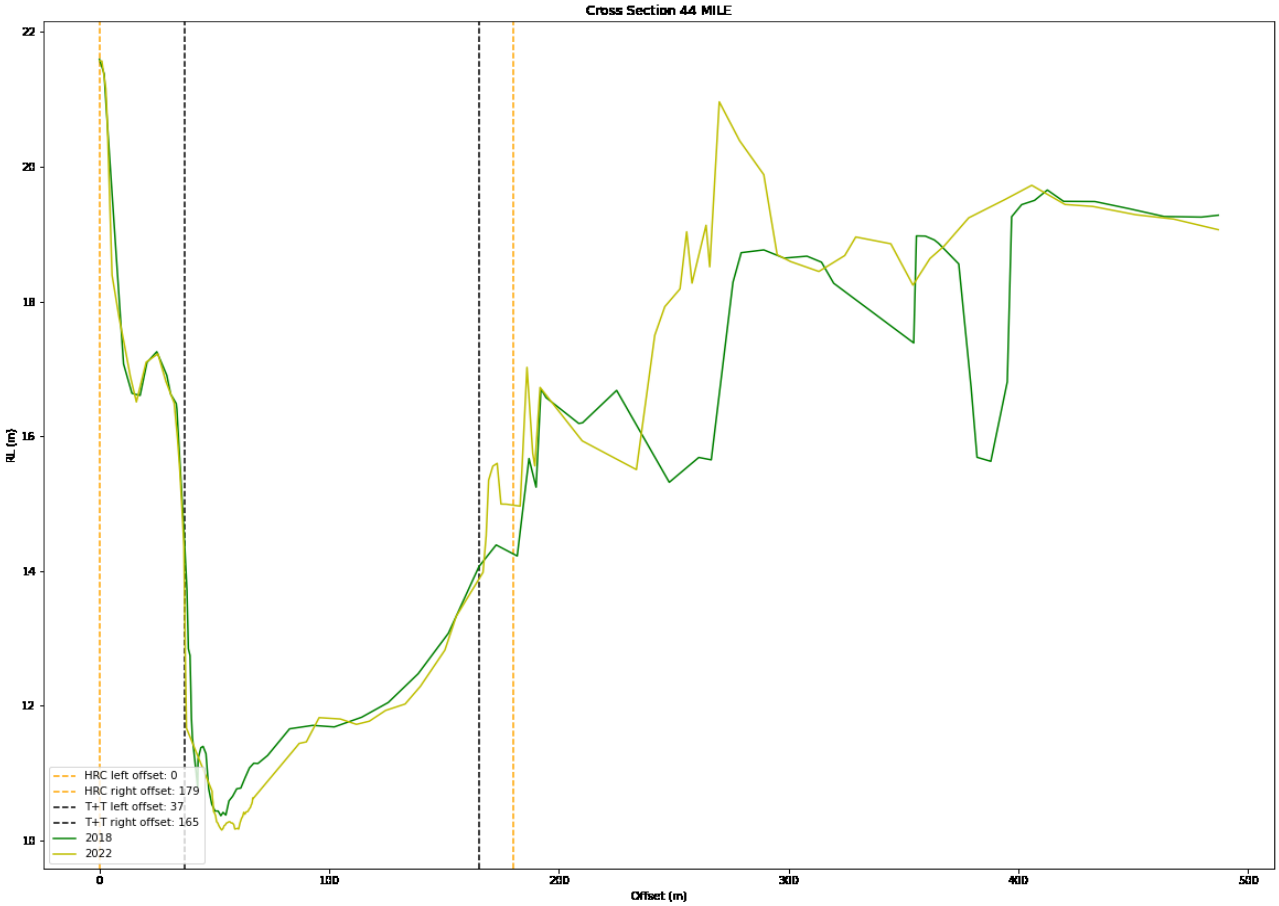

Cross Section 681
RL (m)
Offset (m)
HRC left offset: 380
HRC right offset: 574
T+T left offset: 417
T+T right offset: 540
2018
2022

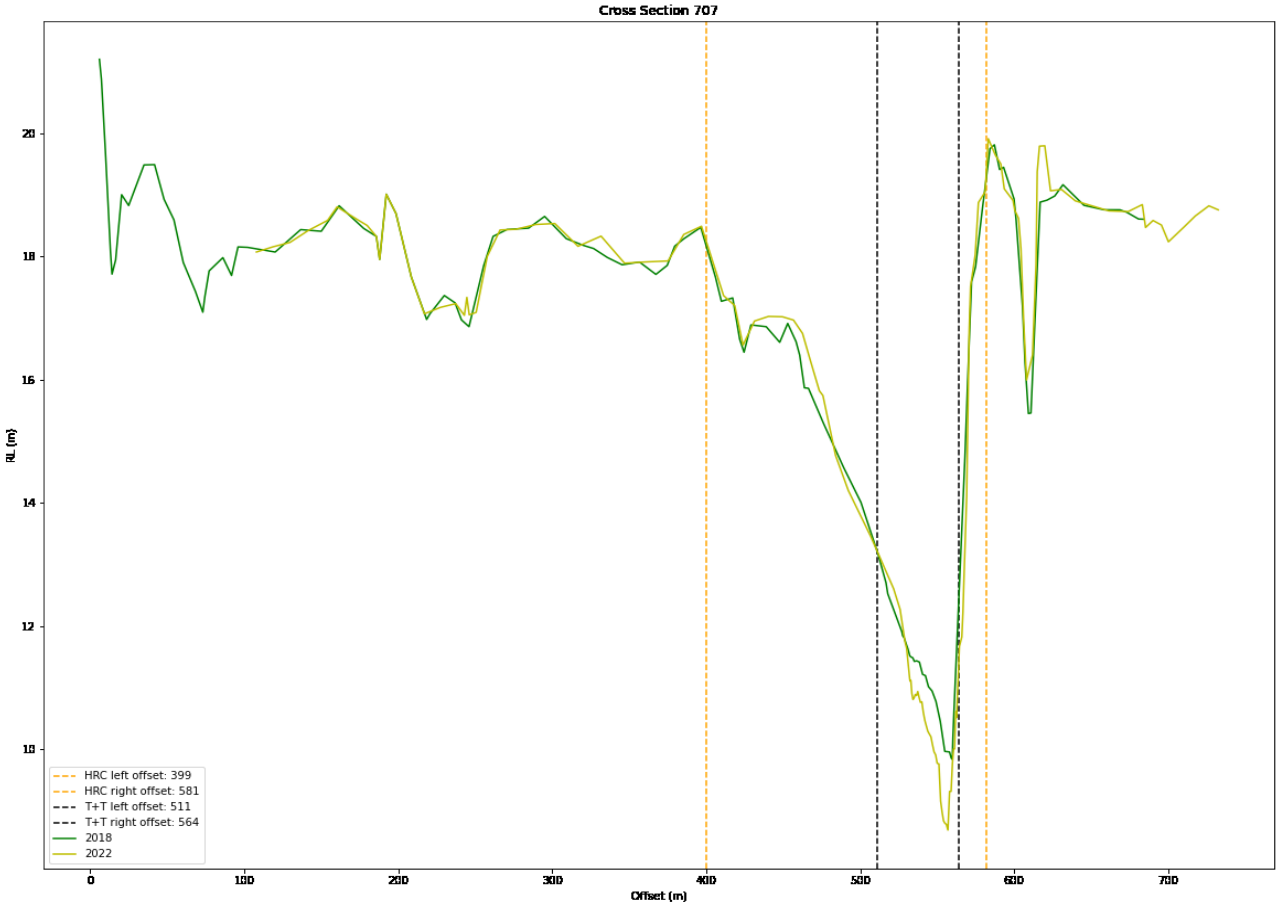

Cross Section 43 MILE
RL (m)
Offset (m)
HRC left offset: 153
HRC right offset: 315
T+T left offset: 174
T+T right offset: 295
2018
2022

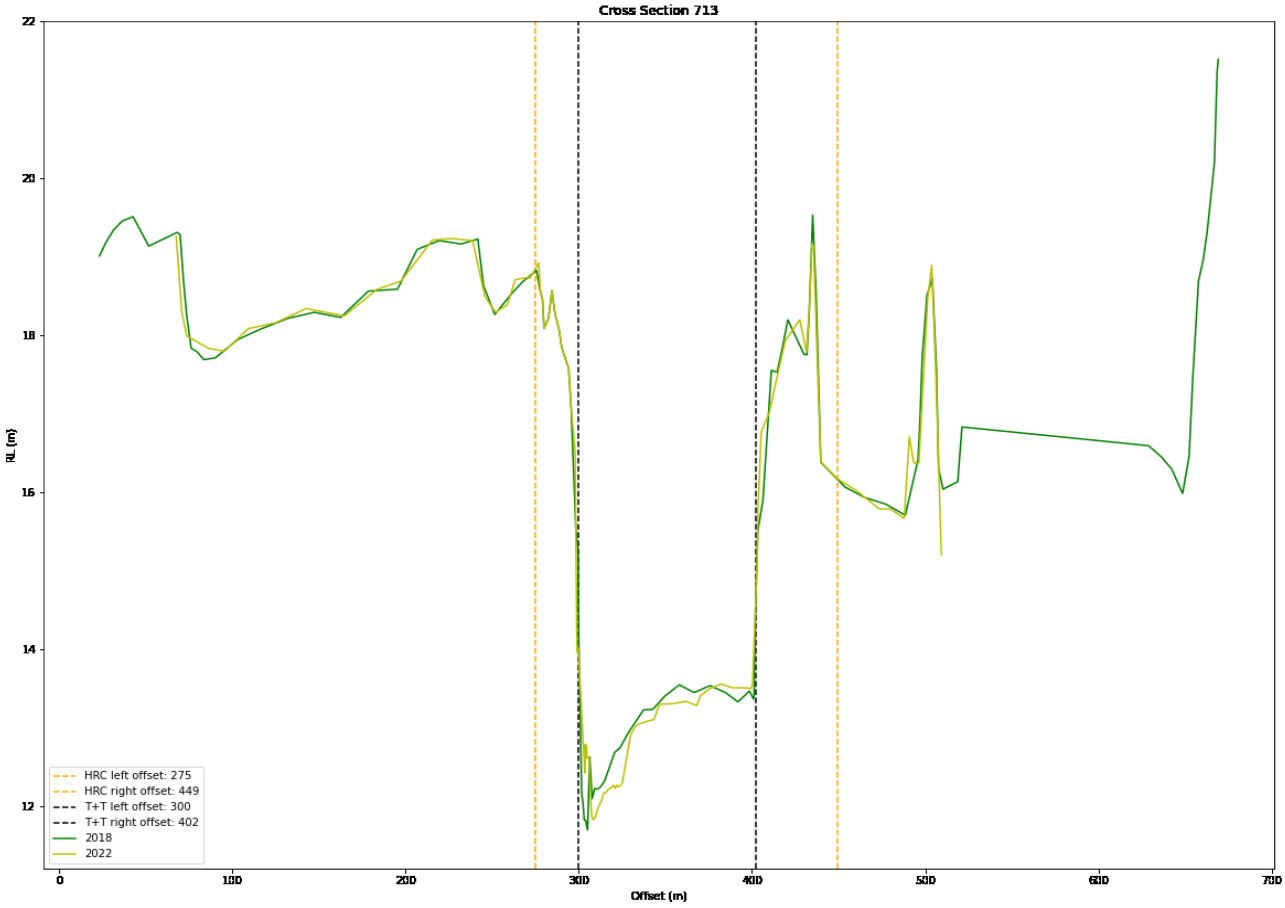

Cross Section 690
RL (m)
Offset (m)
HRC left offset: 108
HRC right offset: 213
T+T left offset: 121
T+T right offset: 200
2018
2022

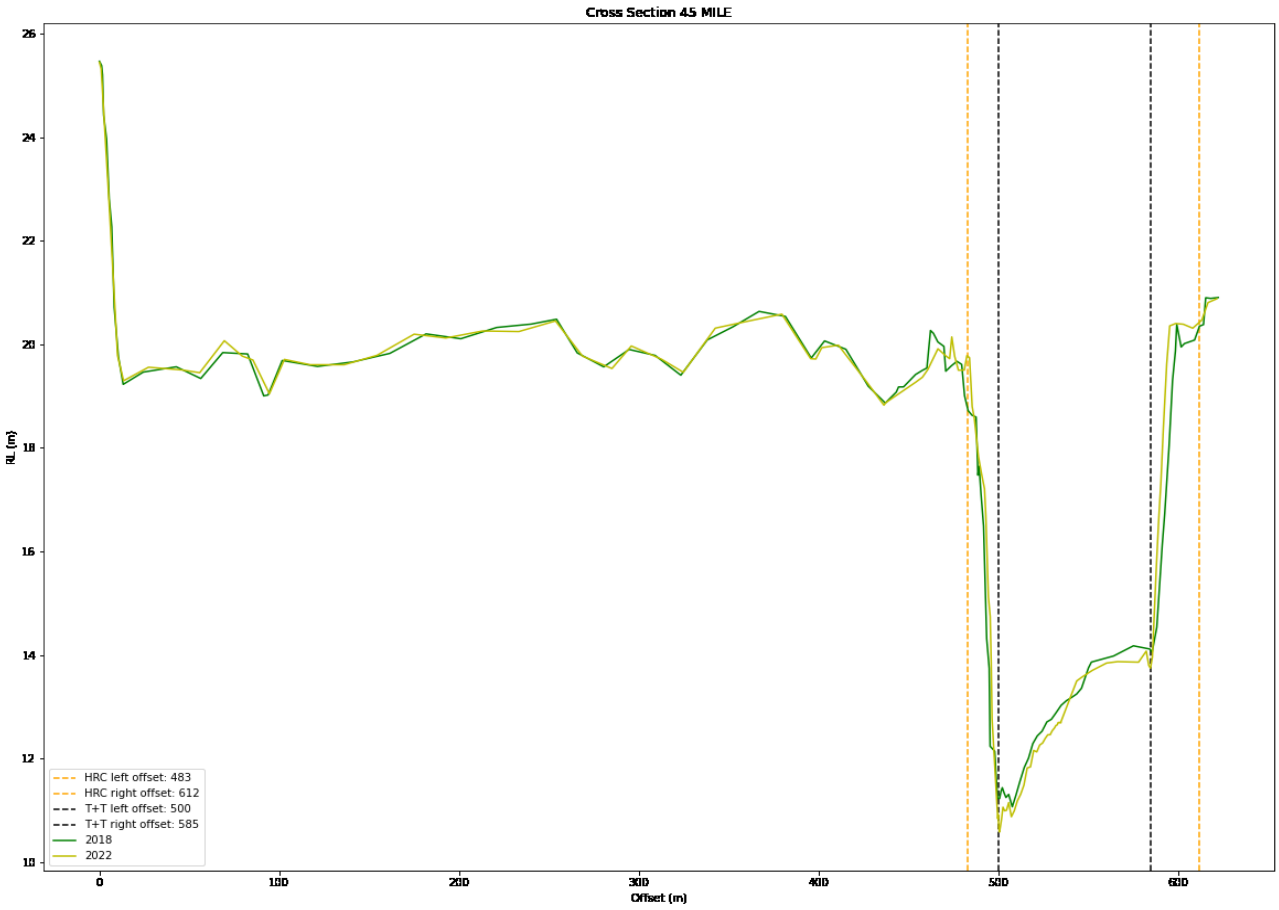

Cross Section 695
RL (m)
Offset (m)
HRC left offset: 48
HRC right offset: 190
T+T left offset: 66
T+T right offset: 172
2018
2022

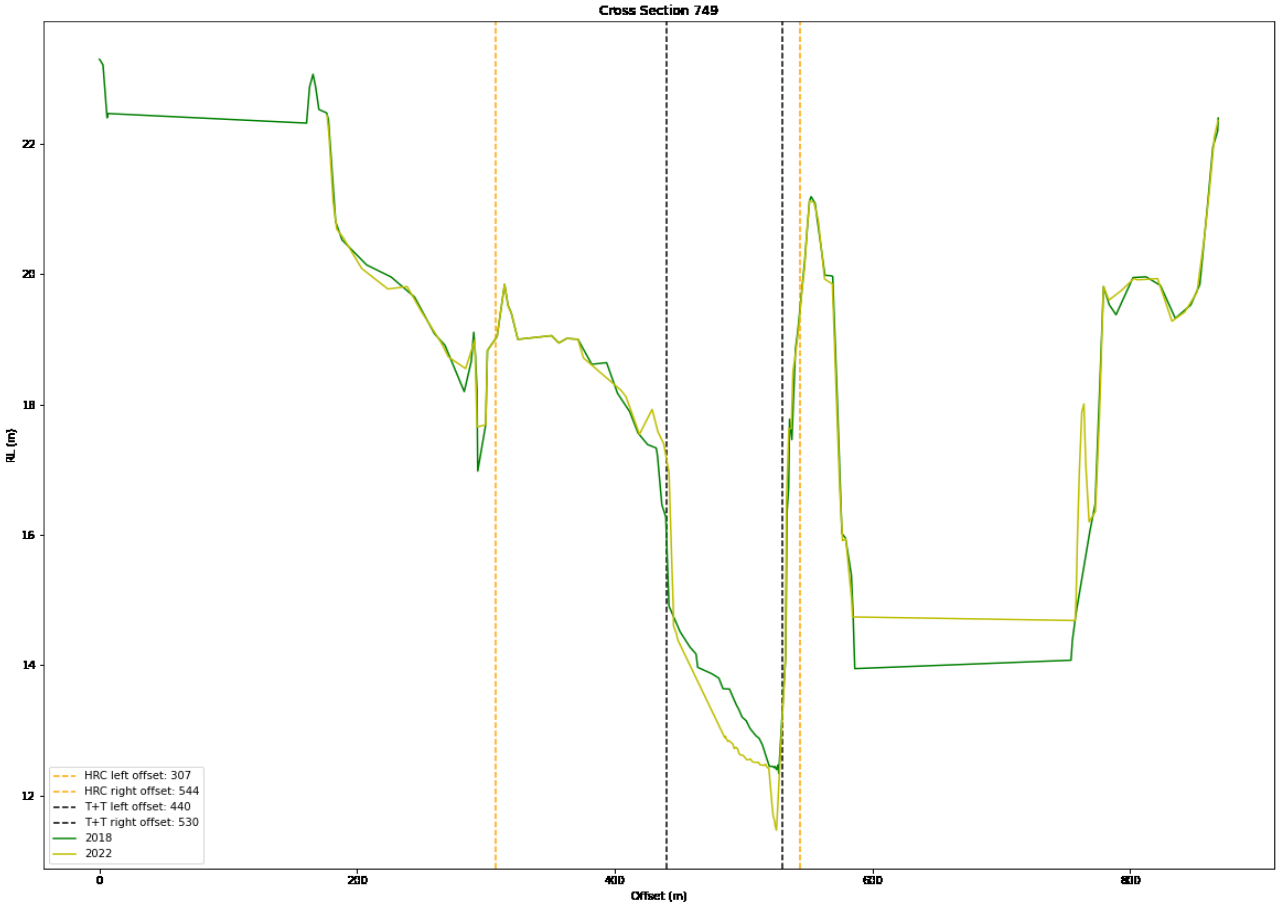

Cross Section 699
RL (m)
Offset (m)
HRC left offset: 16
HRC right offset: 137
T+T left offset: 19
T+T right offset: 120
2018
2022

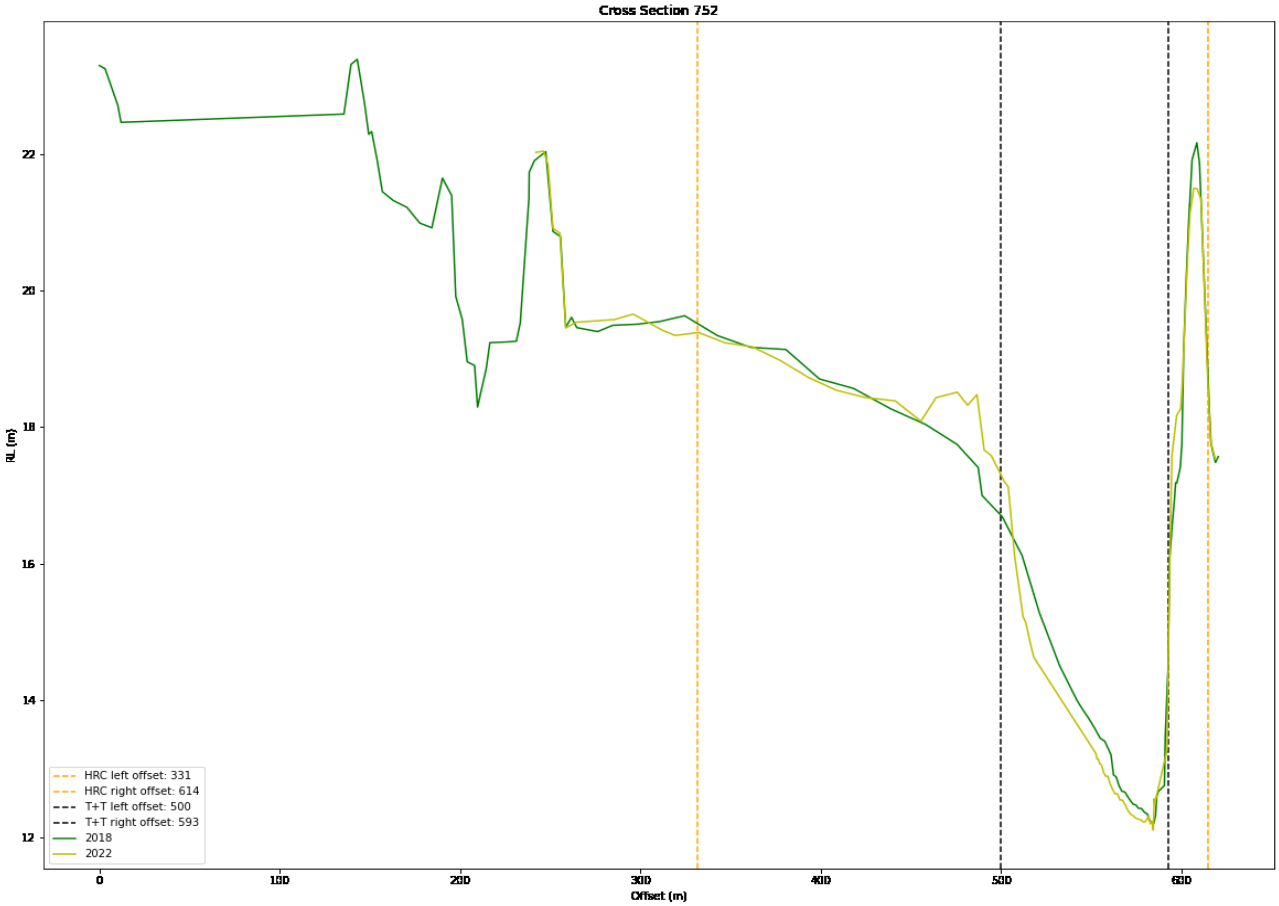

Cross Section 44 MILE
RL (m)
Offset (m)
HRC left offset: 0
HRC right offset: 179
T+T left offset: 37
T+T right offset: 165
2018
2022

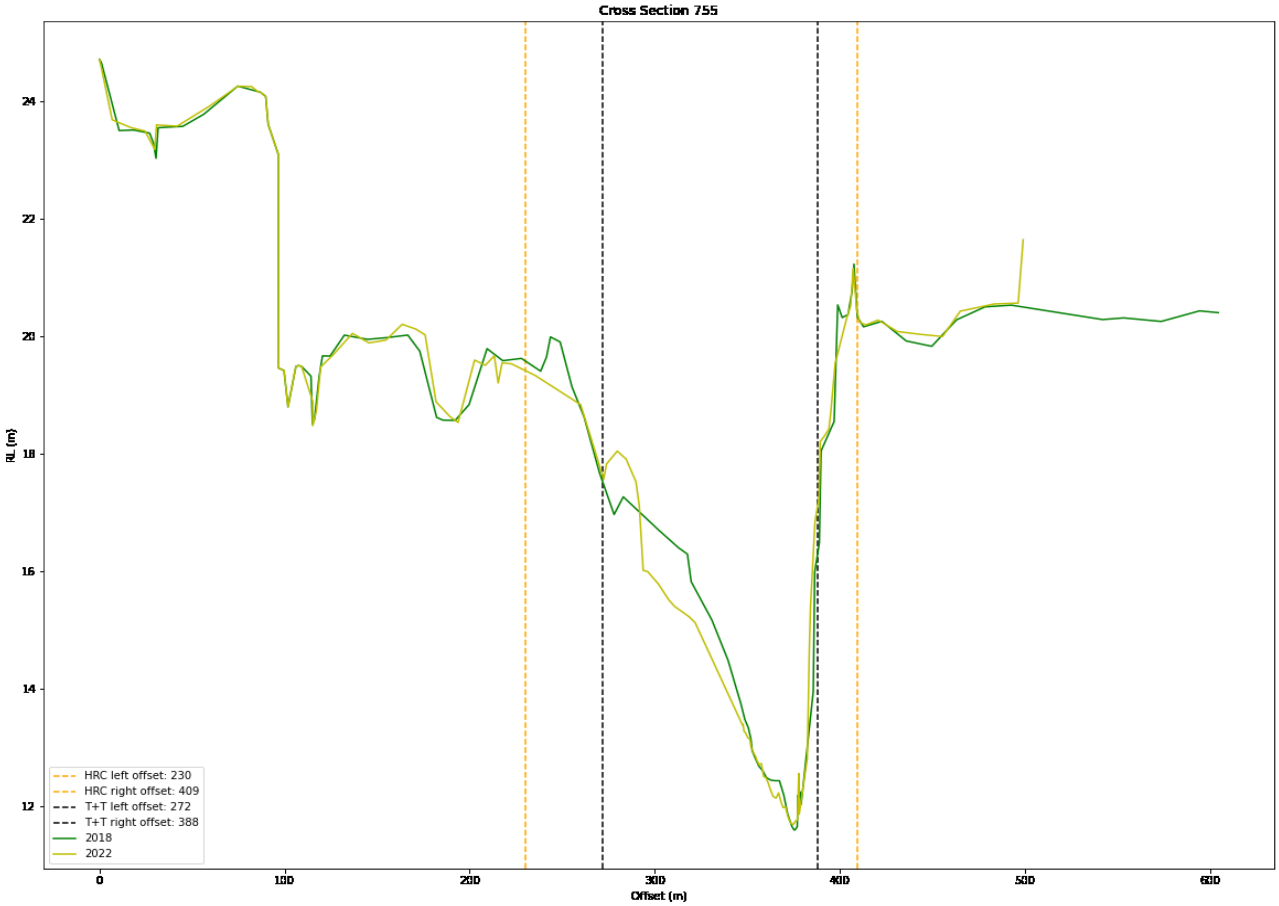

Cross Section 707
RL (m)
Offset (m)
HRC left offset: 399
HRC right offset: 581
T+T left offset: 511
T+T right offset: 564
2018
2022

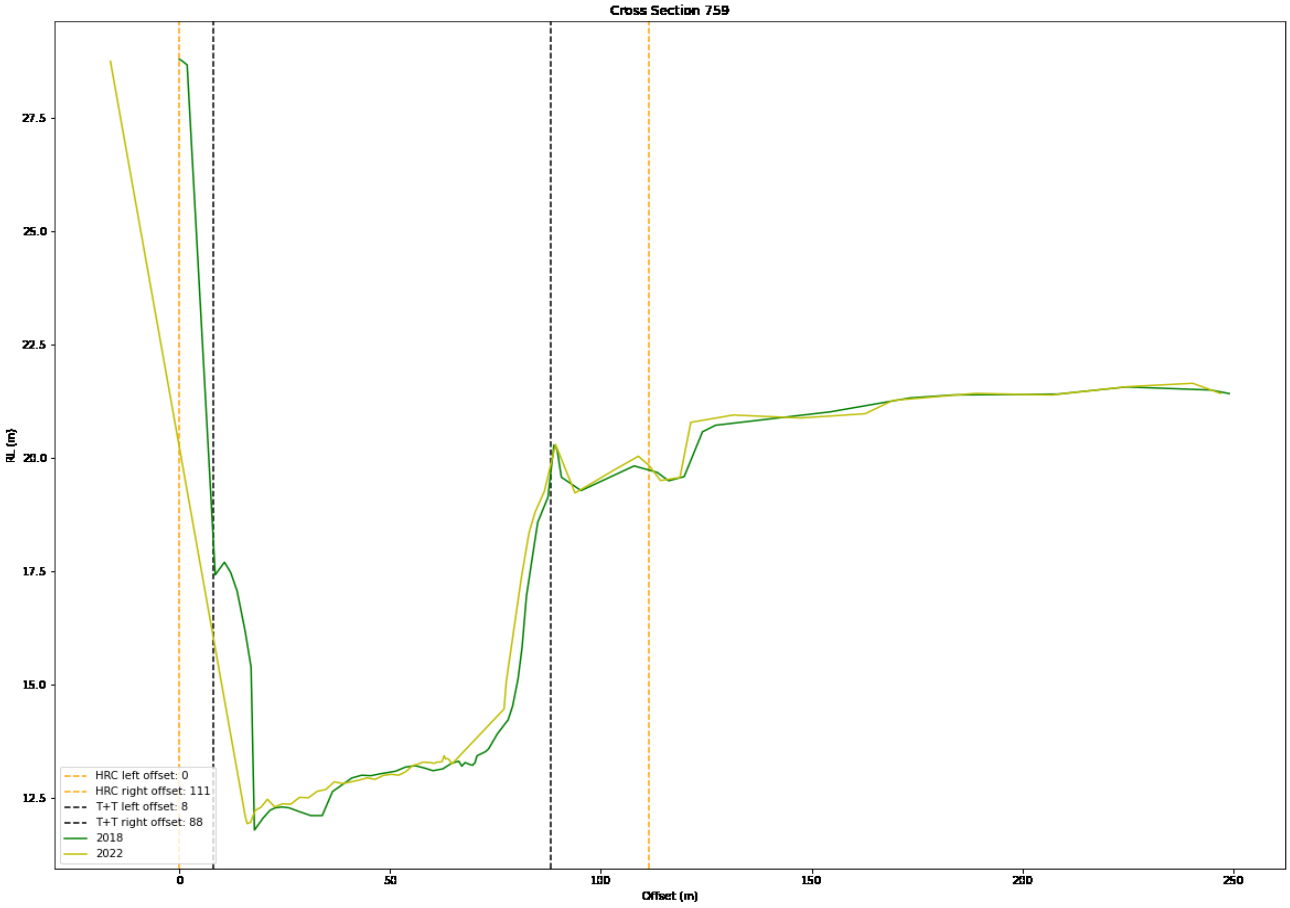

Cross Section 713
RL (m)
Offset (m)
HRC left offset: 275
HRC right offset: 449
T+T left offset: 300
T+T right offset: 402
2018
2022

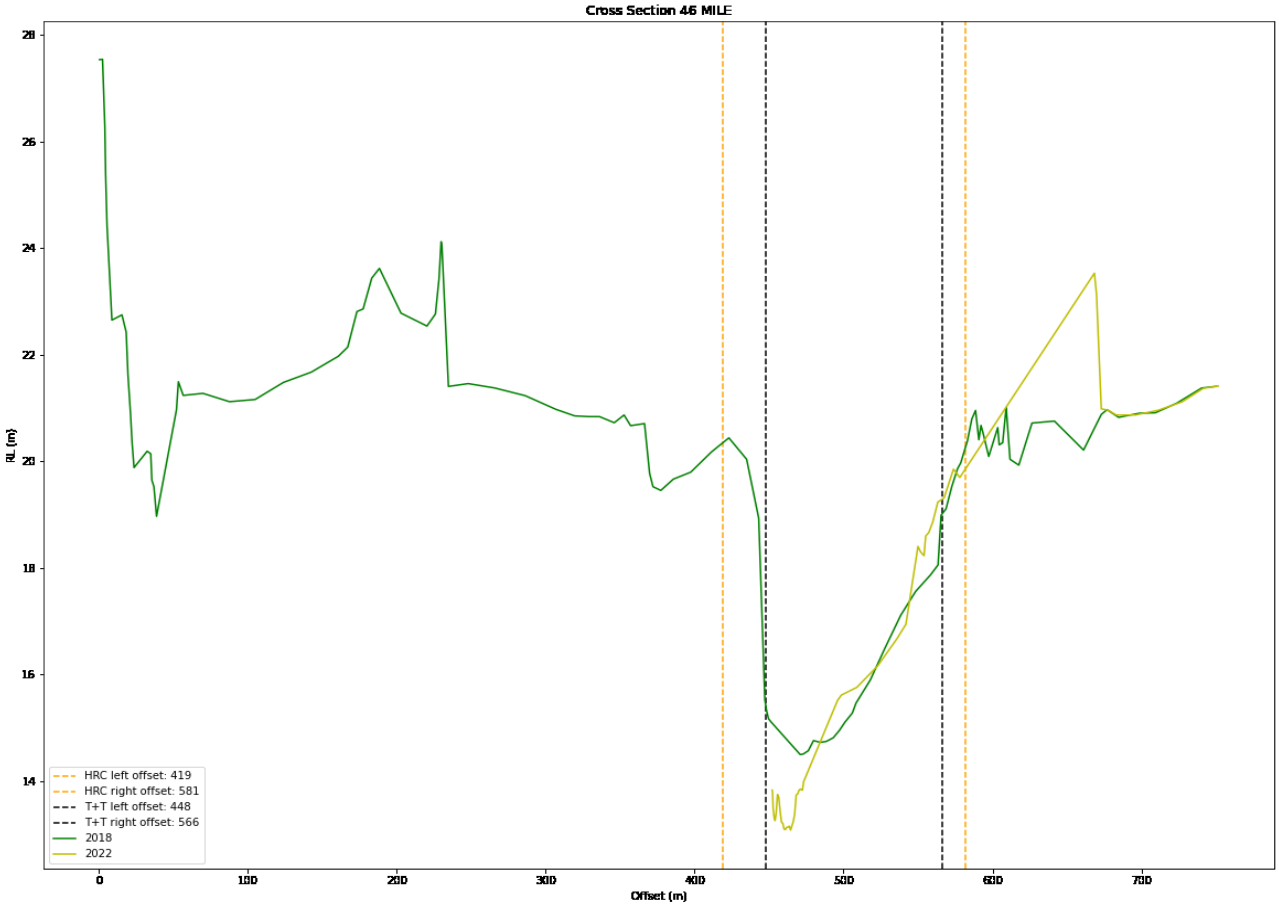

Cross Section 45 MILE
RL (m)
Offset (m)
HRC left offset: 483
HRC right offset: 612
T+T left offset: 500
T+T right offset: 585
2018
2022

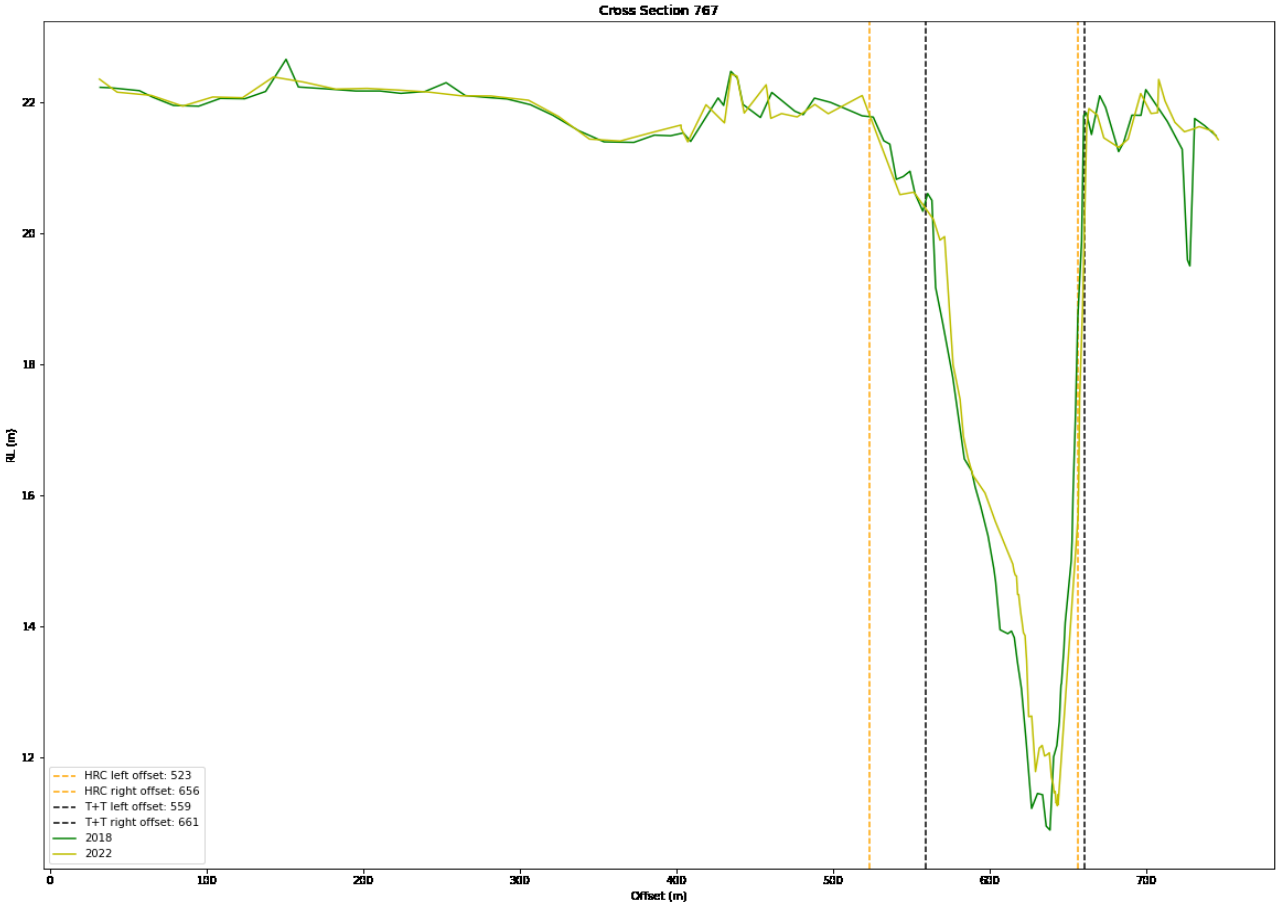

Cross Section 749
RL (m)
Offset (m)
HRC left offset: 307
HRC right offset: 544
T+T left offset: 440
T+T right offset: 530
2018
2022

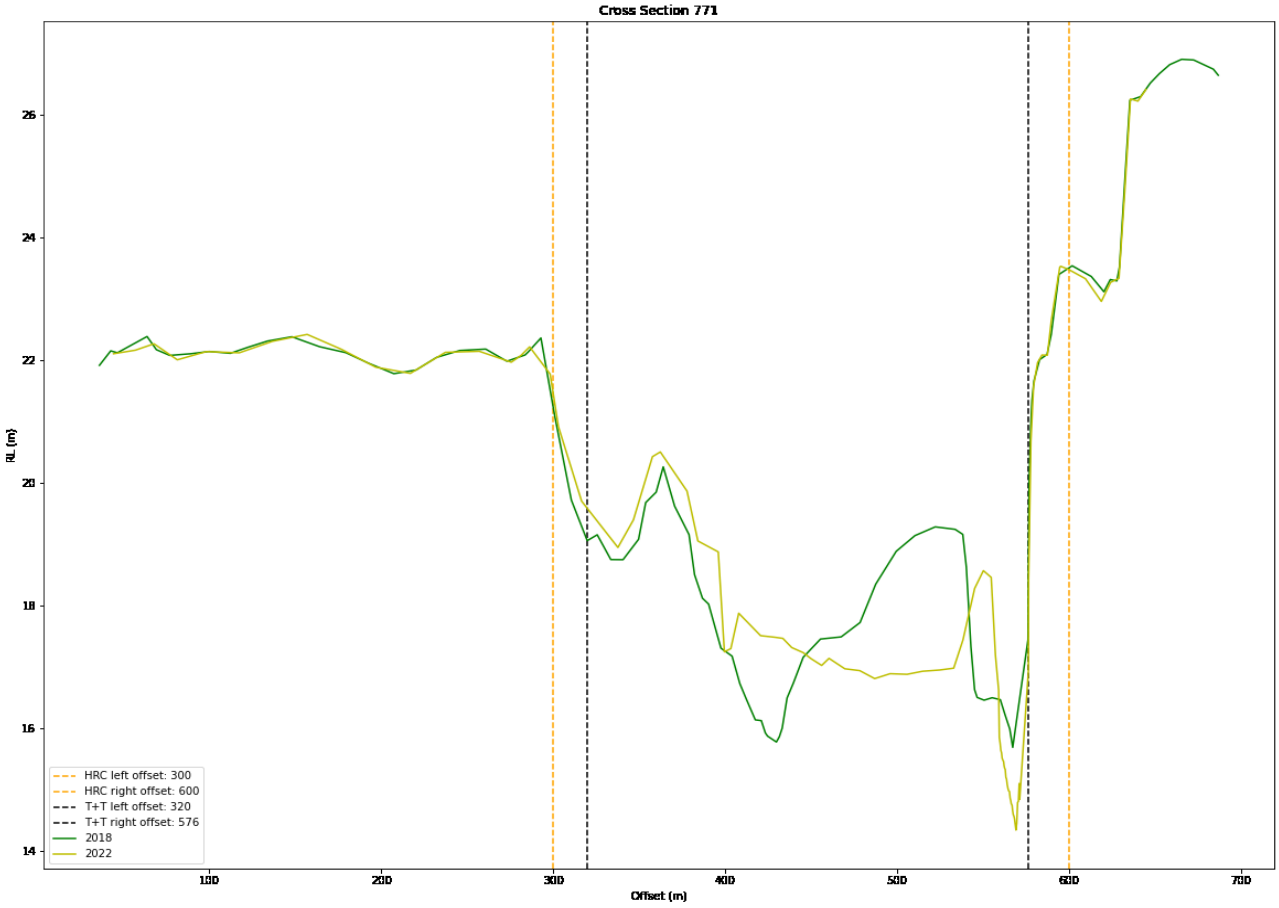

Cross Section 752
RL (m)
Offset (m)
HRC left offset: 331
HRC right offset: 614
T+T left offset: 500
T+T right offset: 593
2018
2022

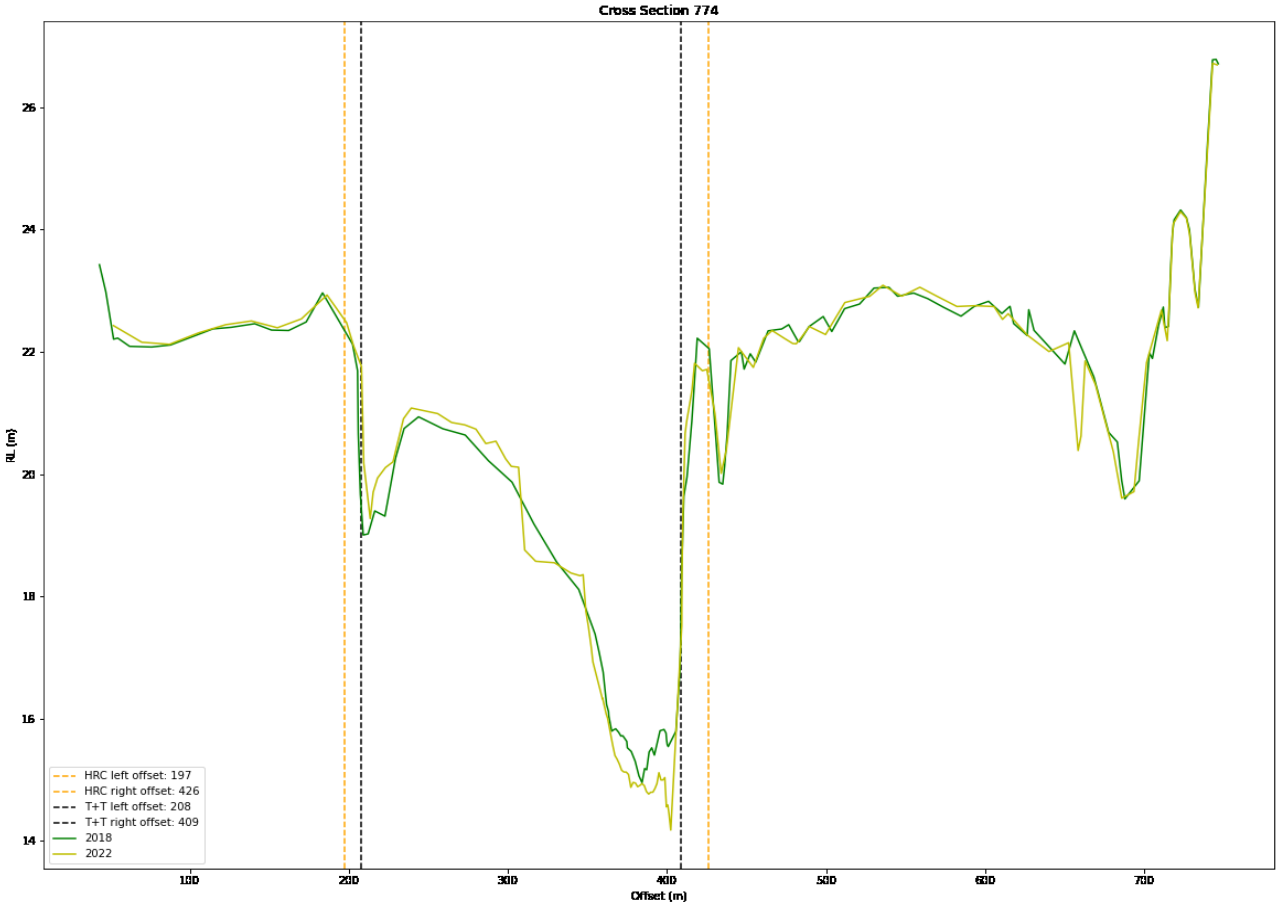

Cross Section 755
RL (m)
Offset (m)
HRC left offset: 230
HRC right offset: 409
T+T left offset: 272
T+T right offset: 388
2018
2022

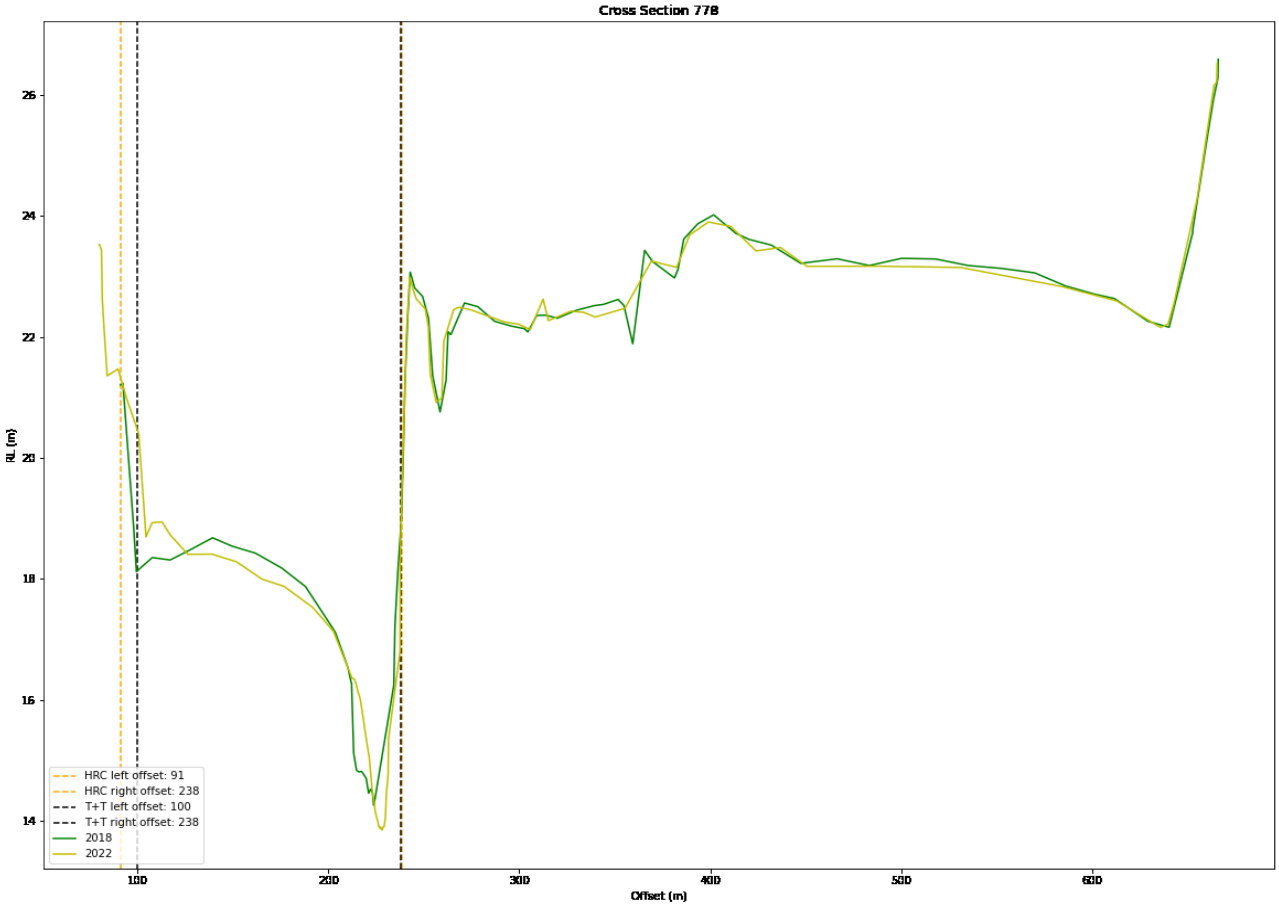

Cross Section 759
RL (m)
Offset (m)
HRC left offset: 0
HRC right offset: 111
T+T left offset: 8
T+T right offset: 88
2018
2022

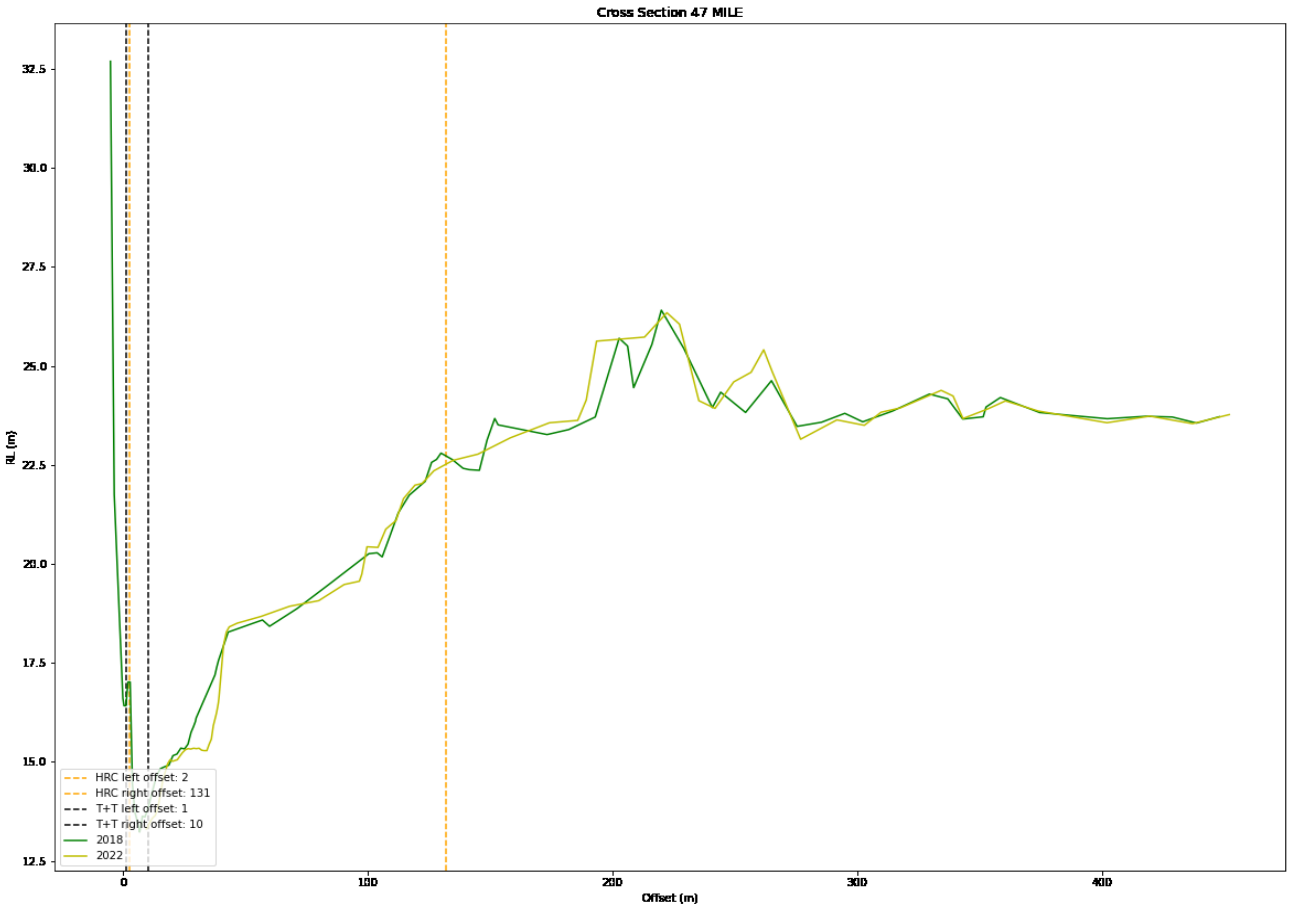

Cross Section 46 MILE
RL (m)
Offset (m)
HRC left offset: 419
HRC right offset: 581
T+T left offset: 448
T+T right offset: 566
2018
2022

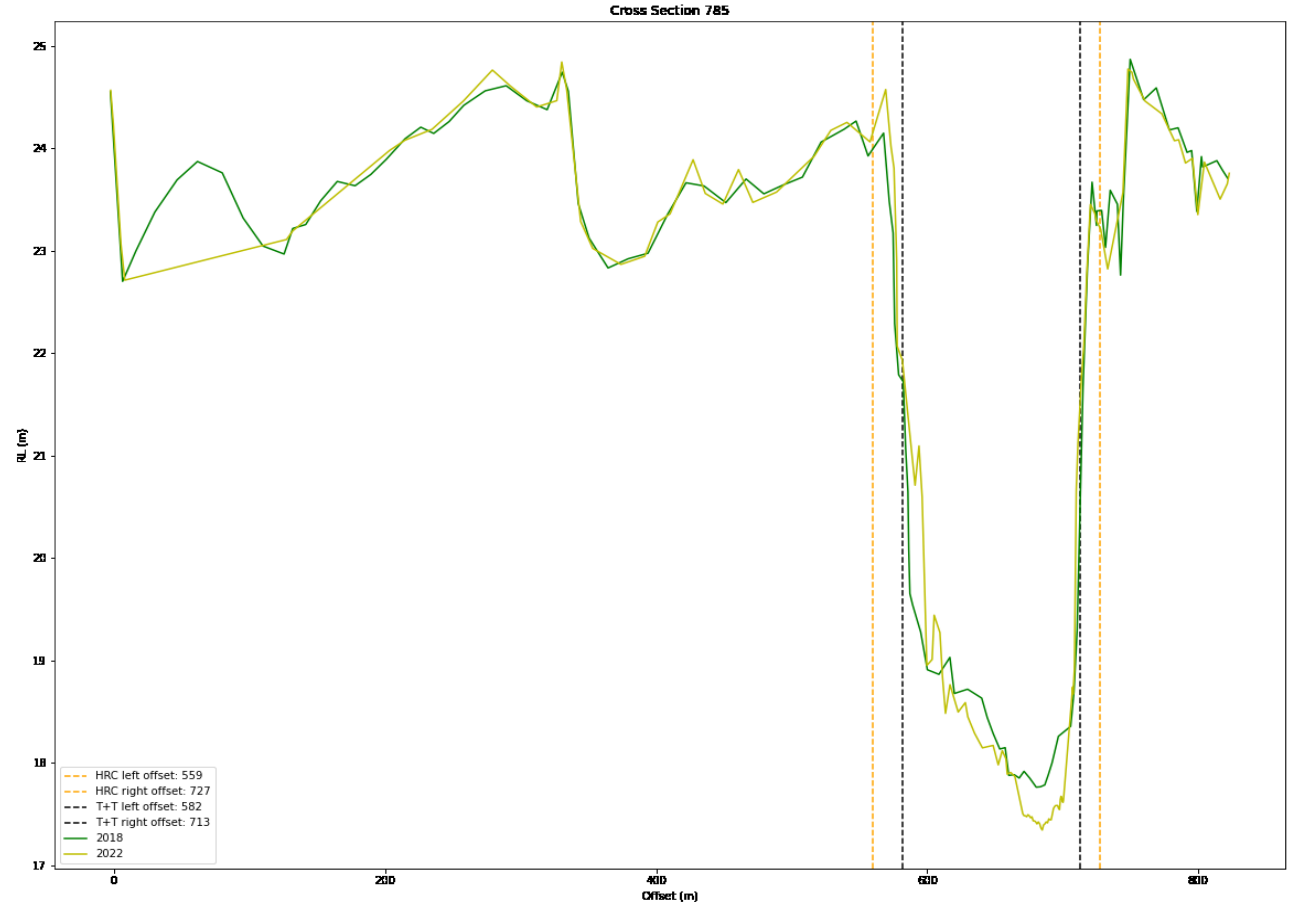

Cross Section 767
RL (m)
Offset (m)
HRC left offset: 523
HRC right offset: 656
T+T left offset: 559
T+T right offset: 661
2018
2022

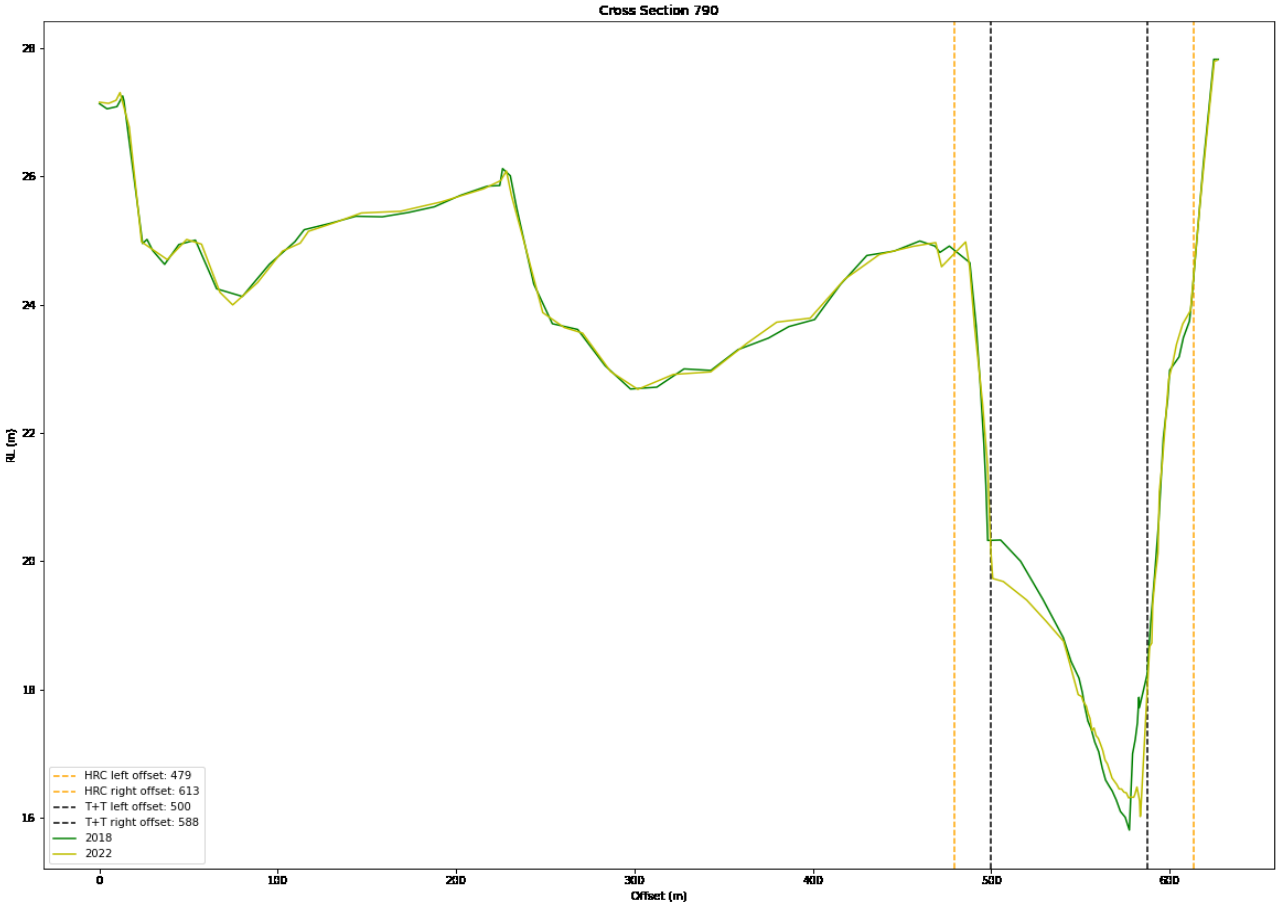

Cross Section 771
RL (m)
Offset (m)
HRC left offset: 300
HRC right offset: 600
T+T left offset: 320
T+T right offset: 576
2018
2022

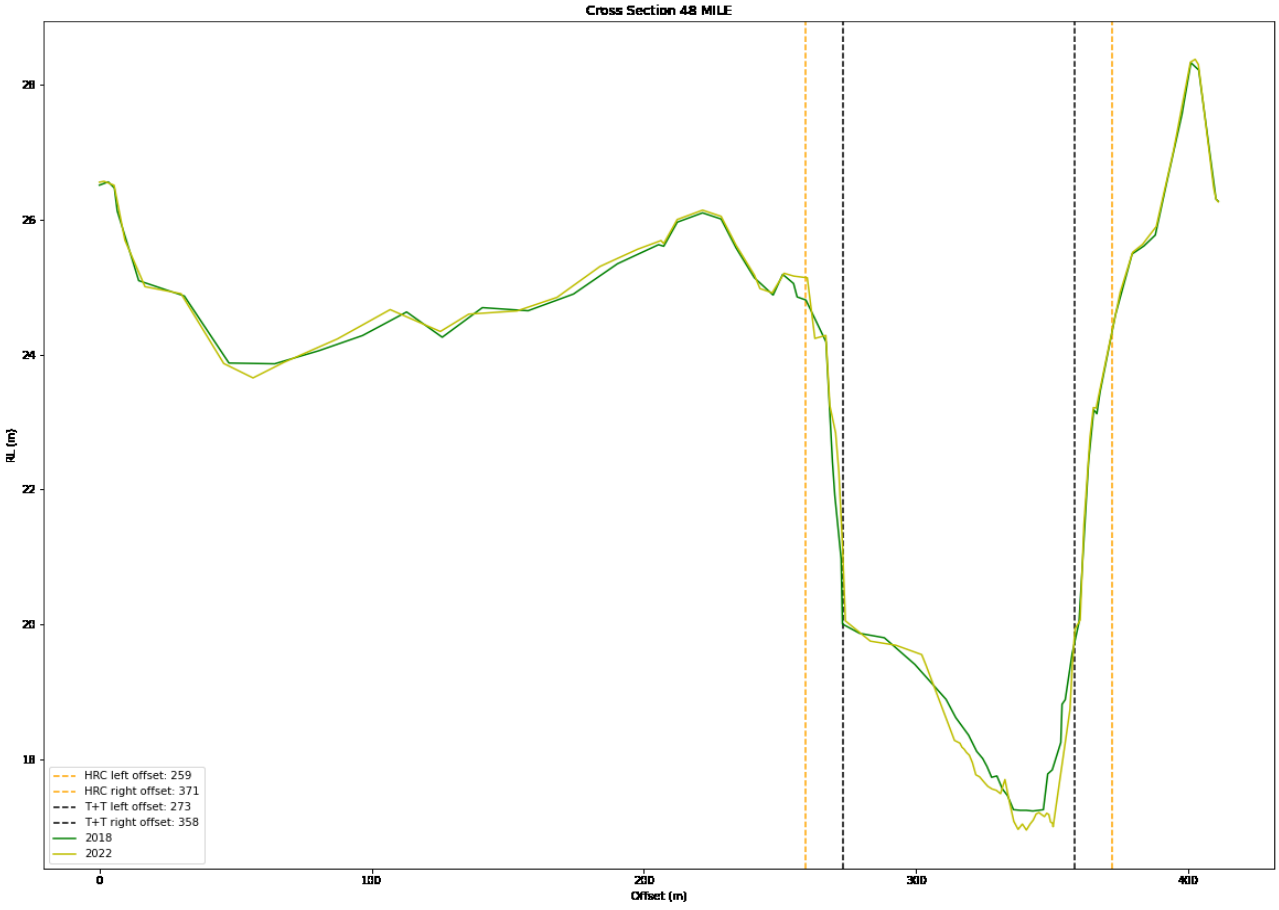

Cross Section 774
RL (m)
Offset (m)
HRC left offset: 197
HRC right offset: 426
T+T left offset: 208
T+T right offset: 409
2018
2022

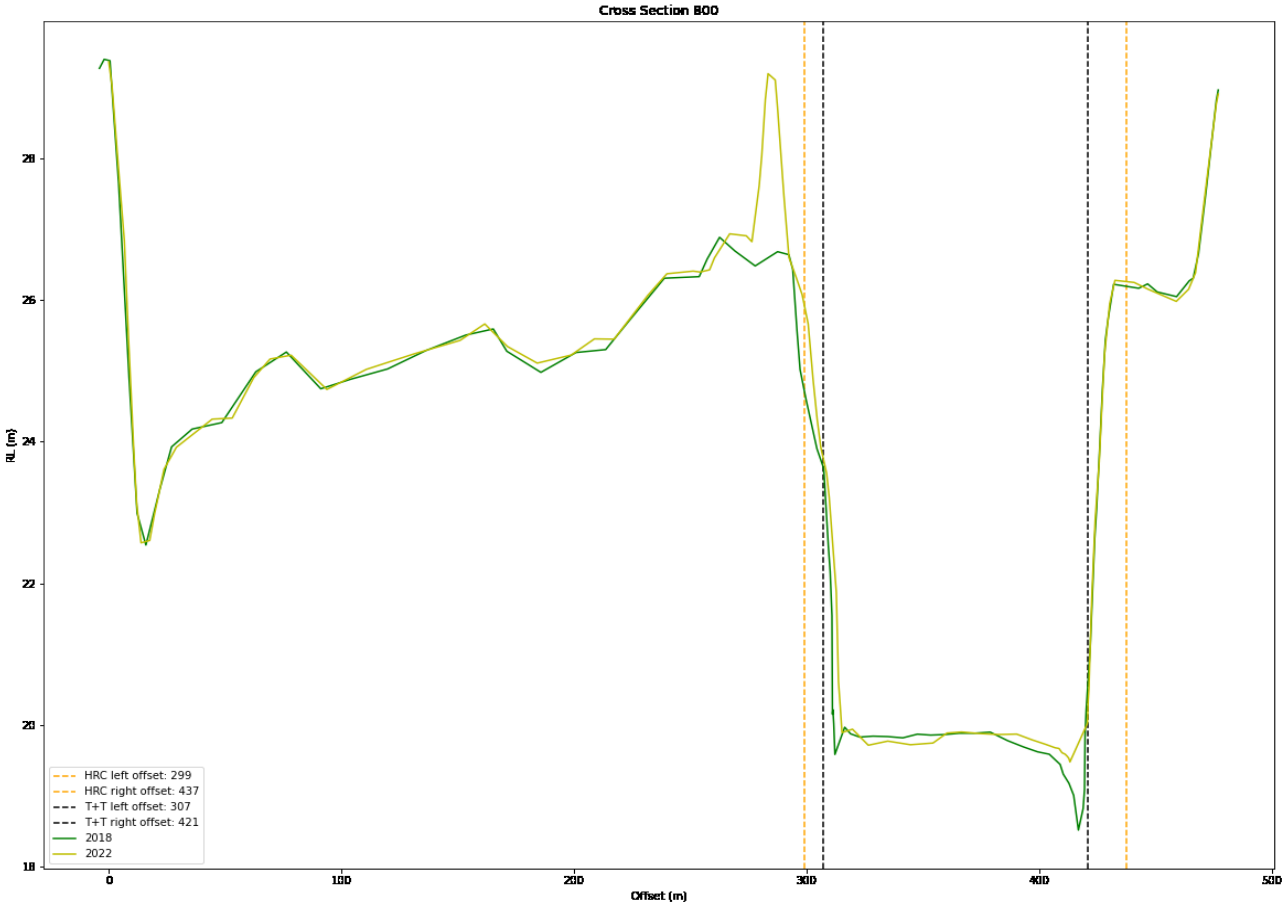

Cross Section 778
RL (m)
Offset (m)
HRC left offset: 91
HRC right offset: 238
T+T left offset: 100
T+T right offset: 238
2018
2022

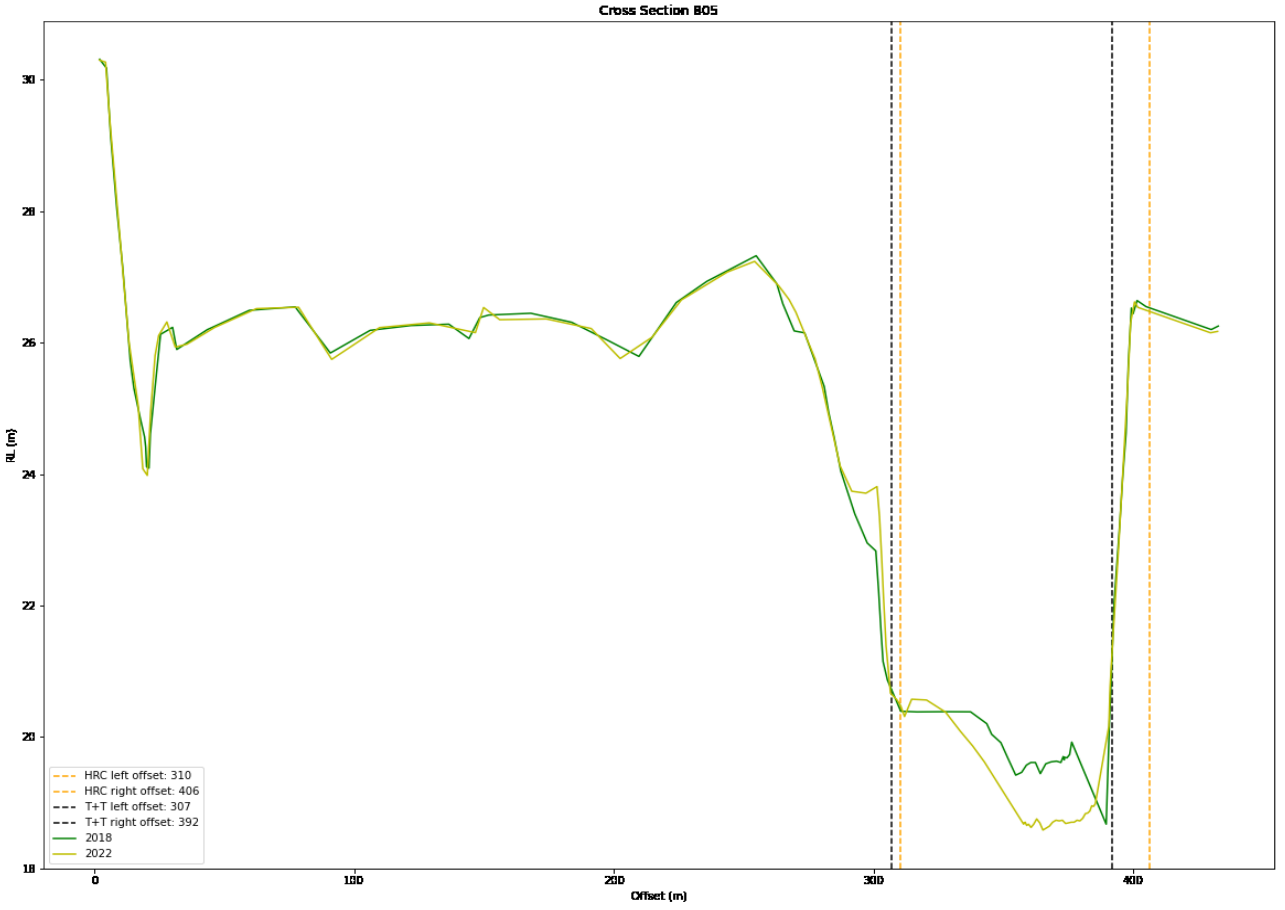

Cross Section 47 MILE
RL (m)
Offset (m)
HRC left offset: 2
HRC right offset: 131
T+T left offset: 1
T+T right offset: 10
2018
2022

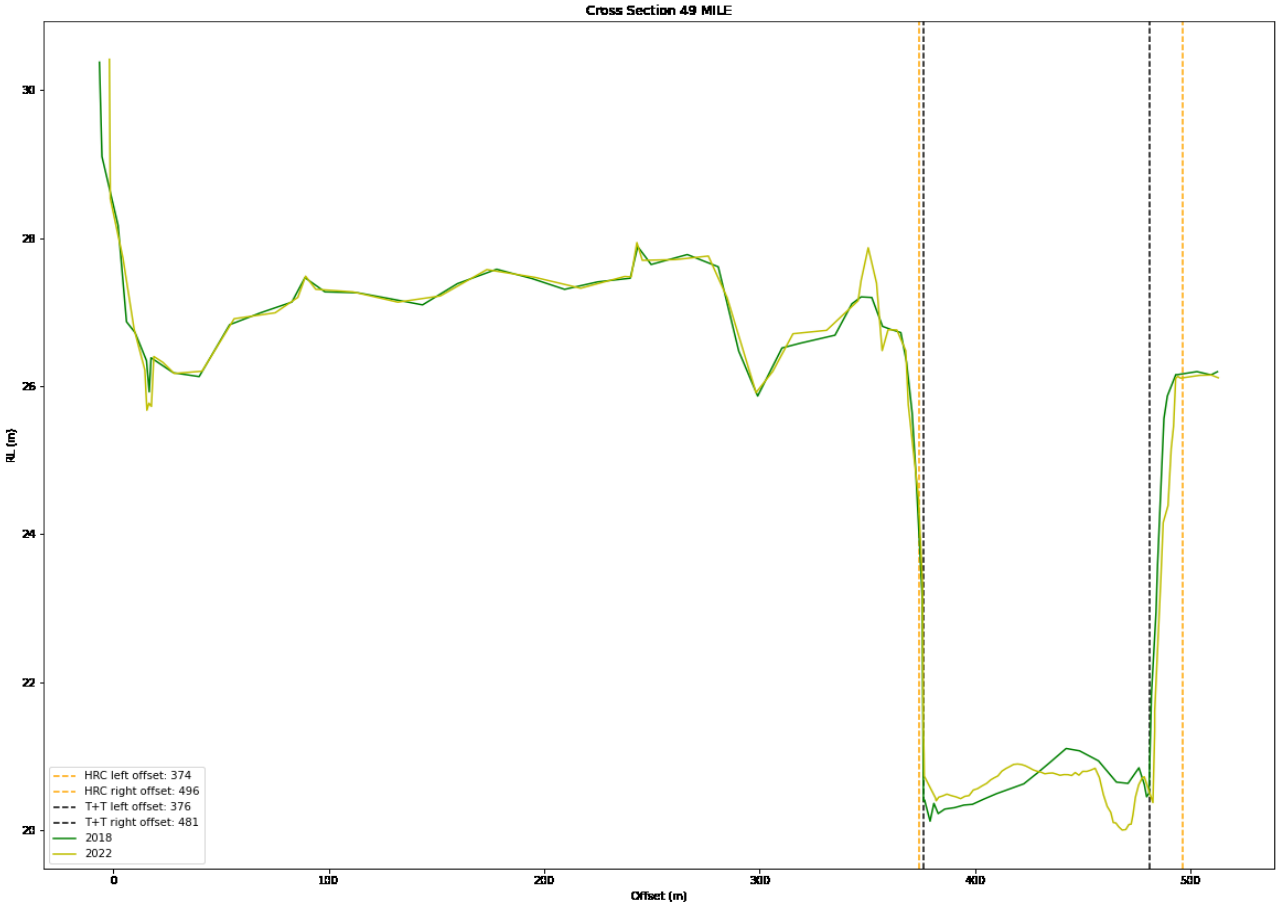

Cross Section 785
RL (m)
Offset (m)
HRC left offset: 559
HRC right offset: 727
T+T left offset: 582
T+T right offset: 713
2018
2022

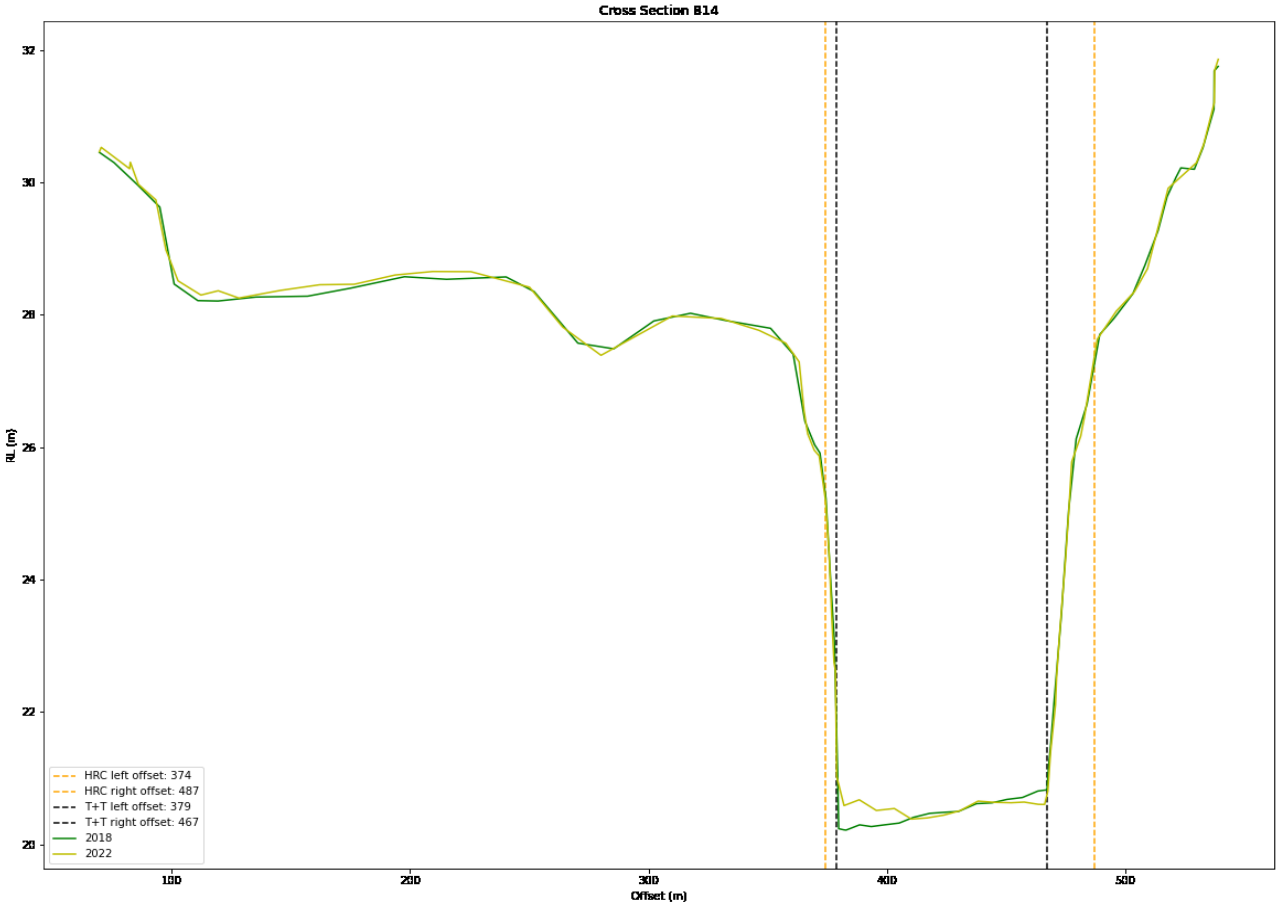

Cross Section 790
RL (m)
Offset (m)
HRC left offset: 479
HRC right offset: 613
T+T left offset: 500
T+T right offset: 588
2018
2022

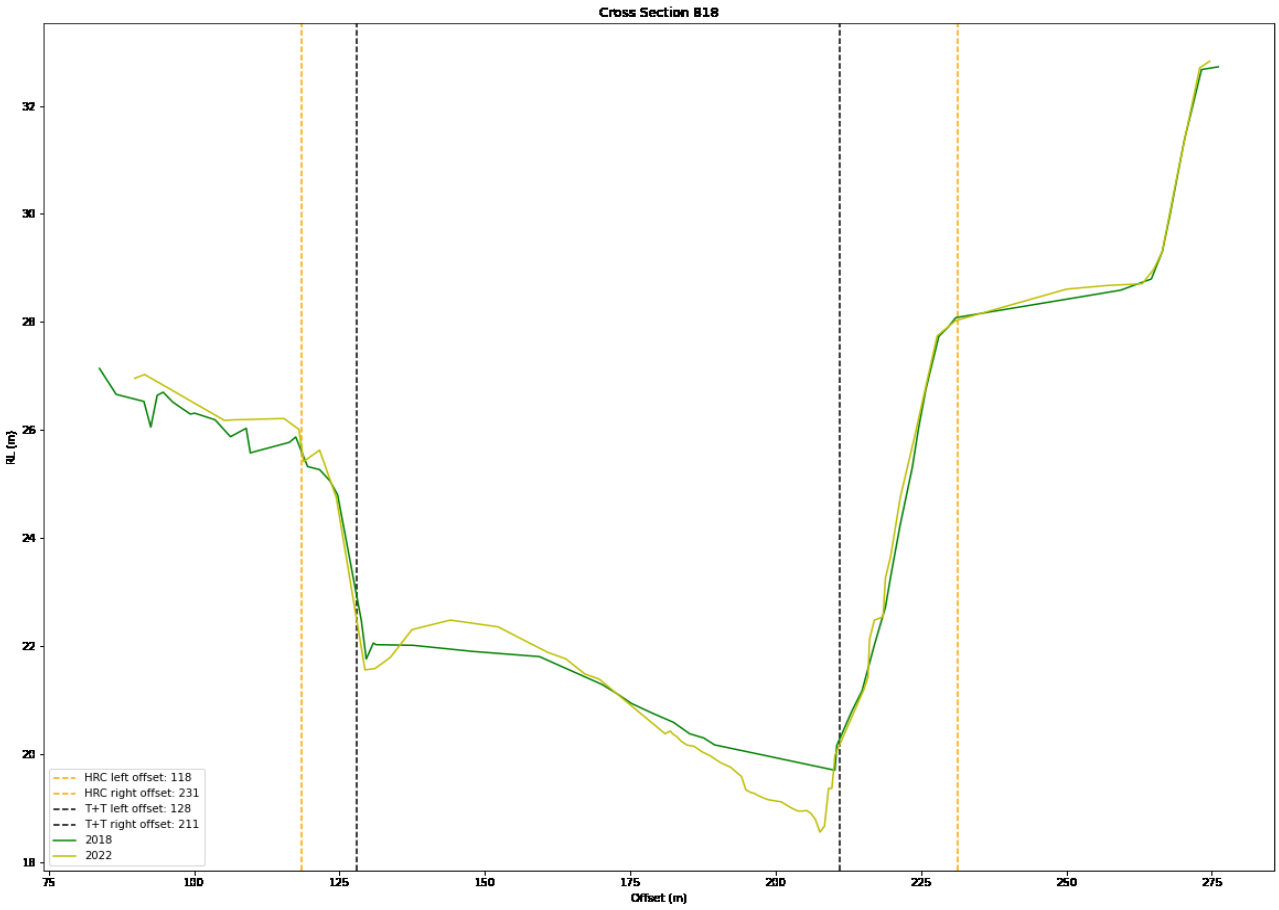

Cross Section 48 MILE
RL (m)
Offset (m)
HRC left offset: 259
HRC right offset: 371
T+T left offset: 273
T+T right offset: 358
2018
2022

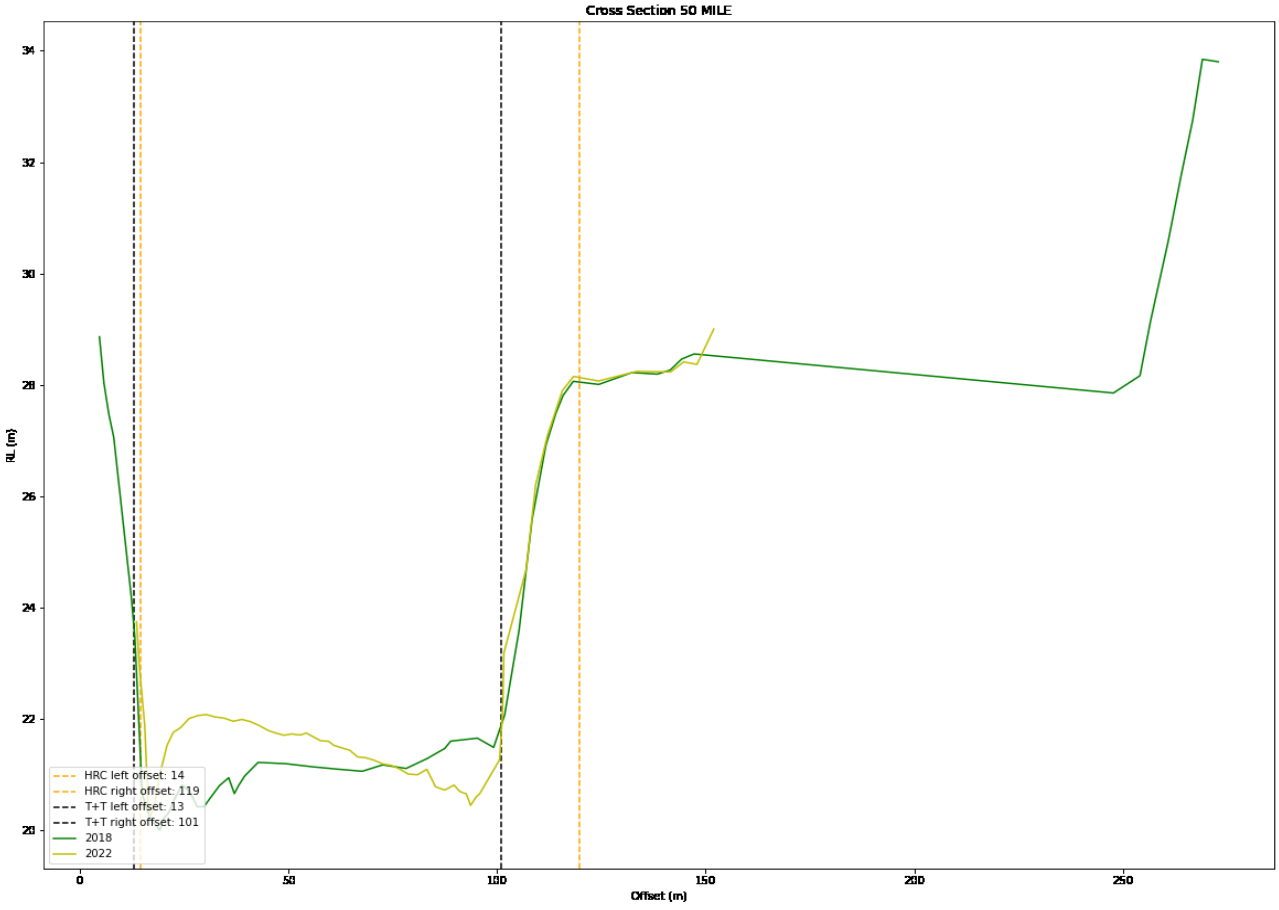

Cross Section 800
RL (m)
Offset (m)
HRC left offset: 299
HRC right offset: 437
T+T left offset: 307
T+T right offset: 421
2018
2022

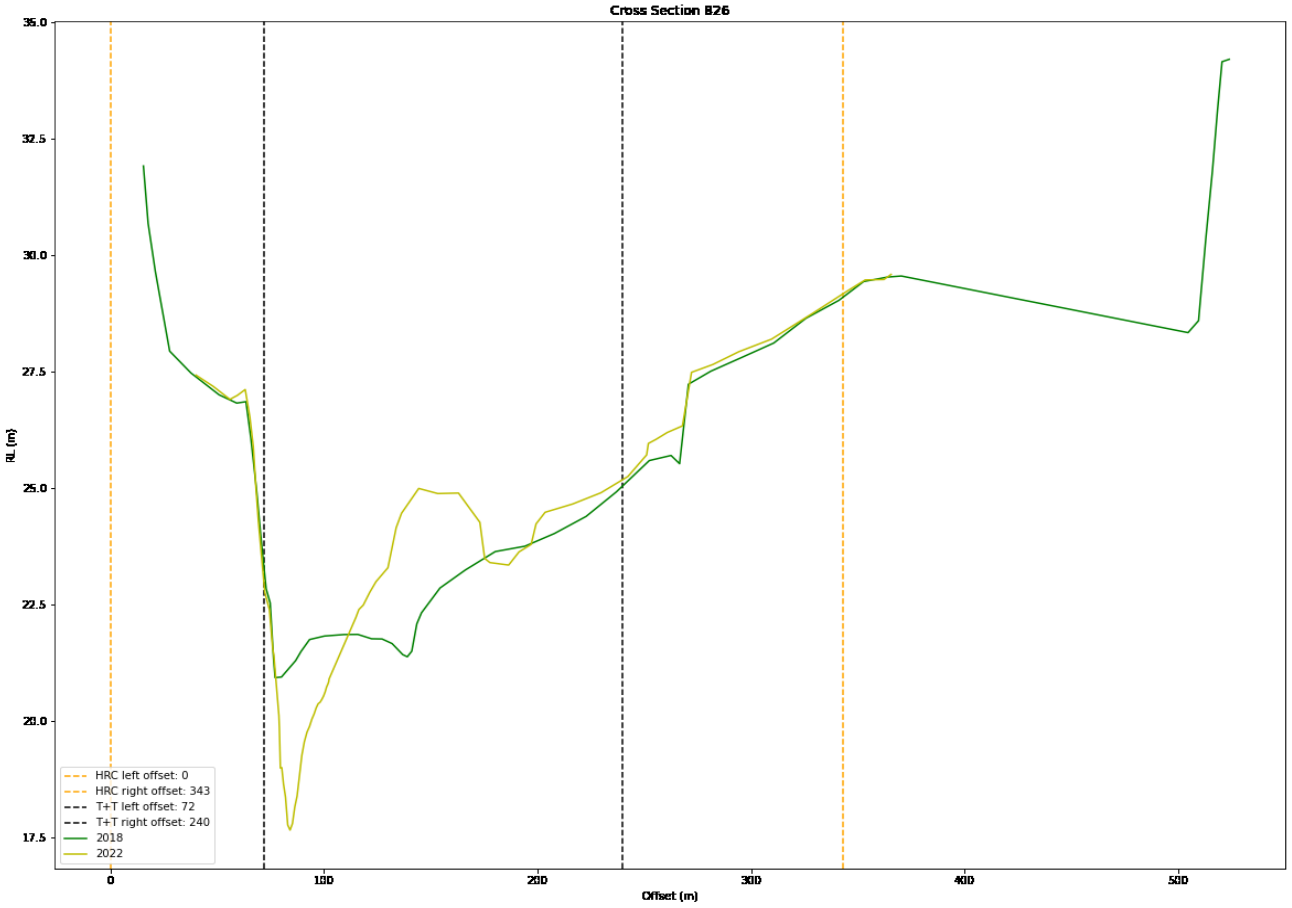

Cross Section 805
RL (m)
Offset (m)
HRC left offset: 310
HRC right offset: 406
T+T left offset: 307
T+T right offset: 392
2018
2022

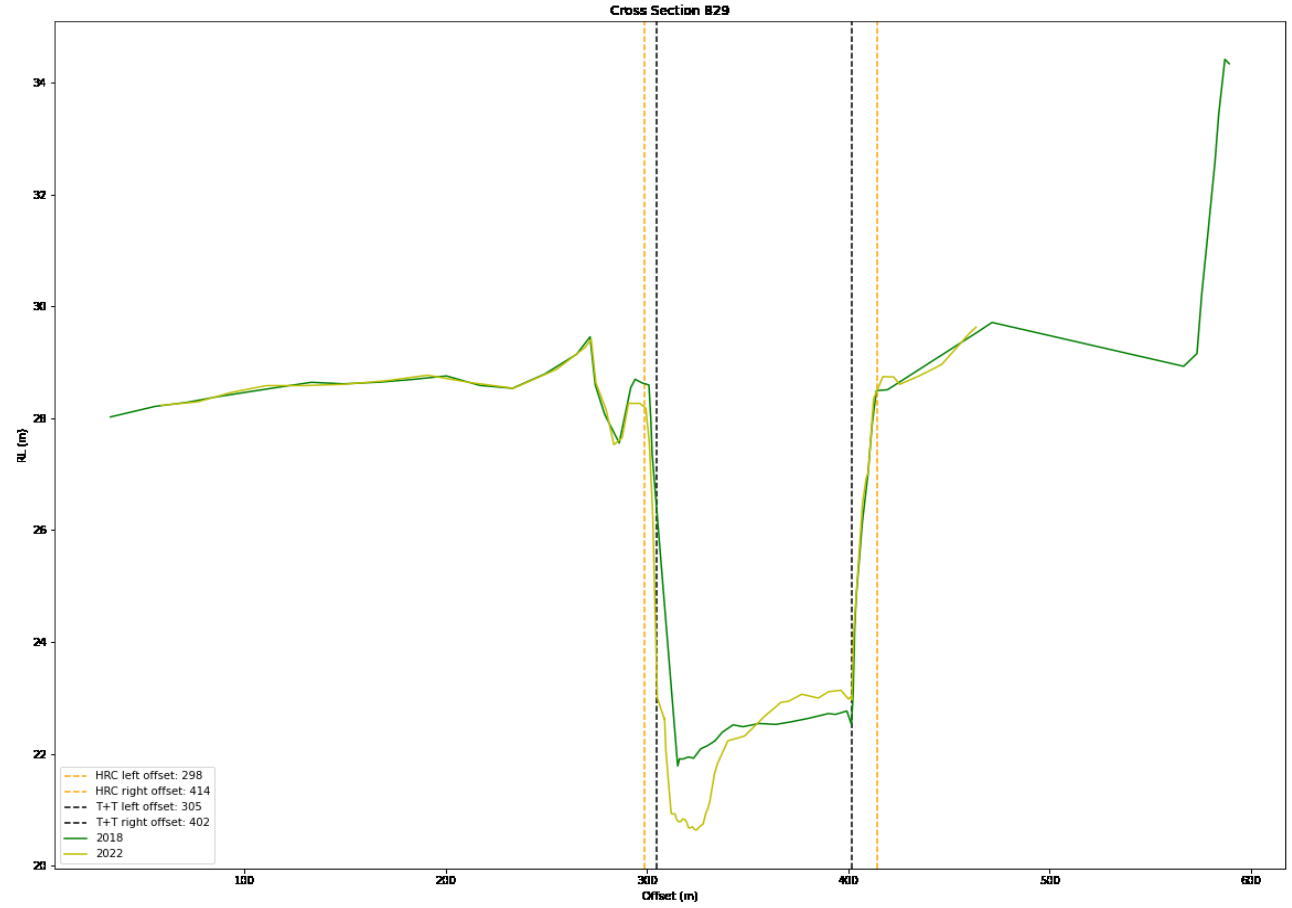

Cross Section 49 MILE
RL (m)
Offset (m)
HRC left offset: 374
HRC right offset: 496
T+T left offset: 376
T+T right offset: 481
2018
2022

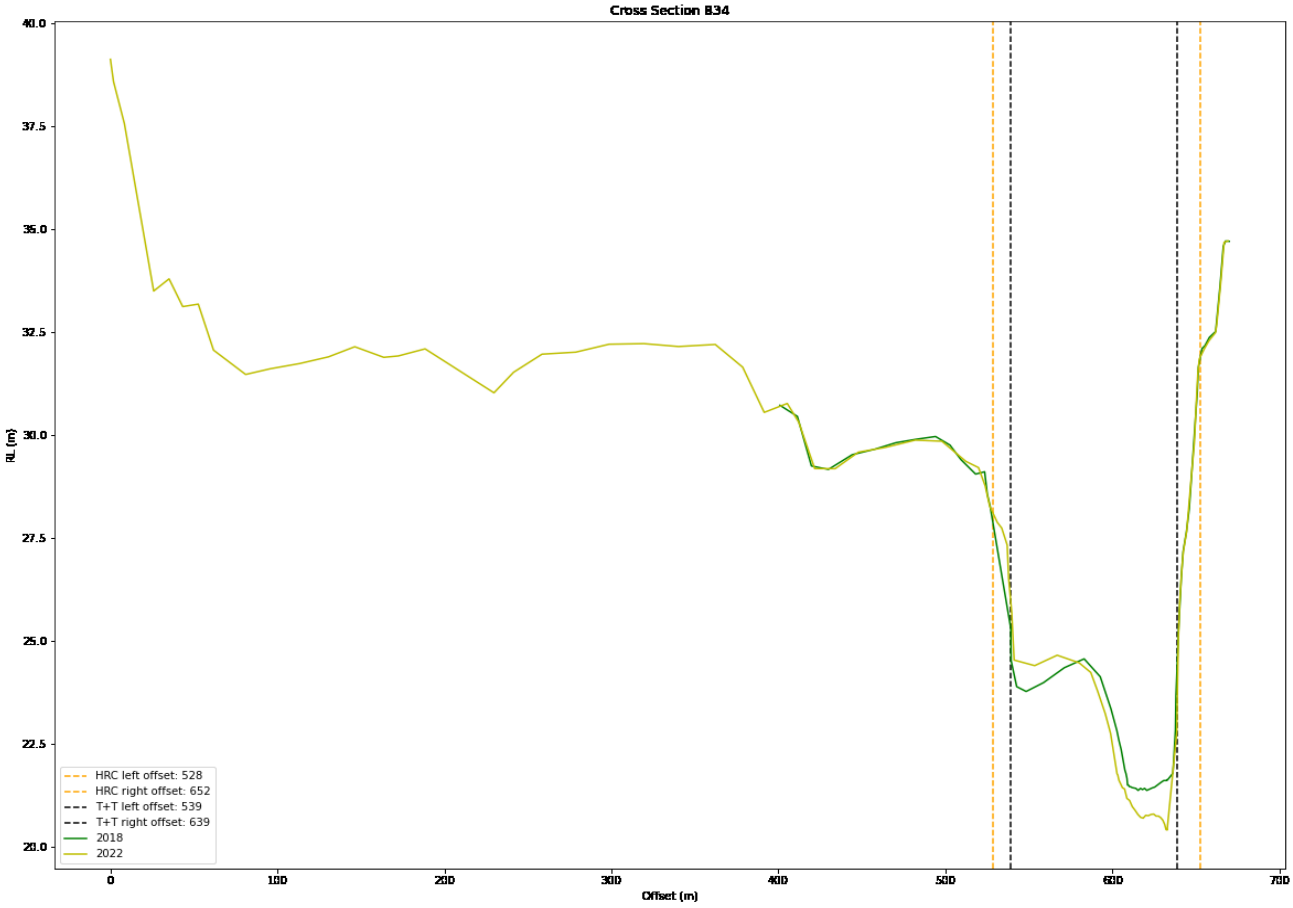

Cross Section B14
RL (m)
Offset (m)
HRC left offset: 374
HRC right offset: 487
T+T left offset: 379
T+T right offset: 467
2018
2022

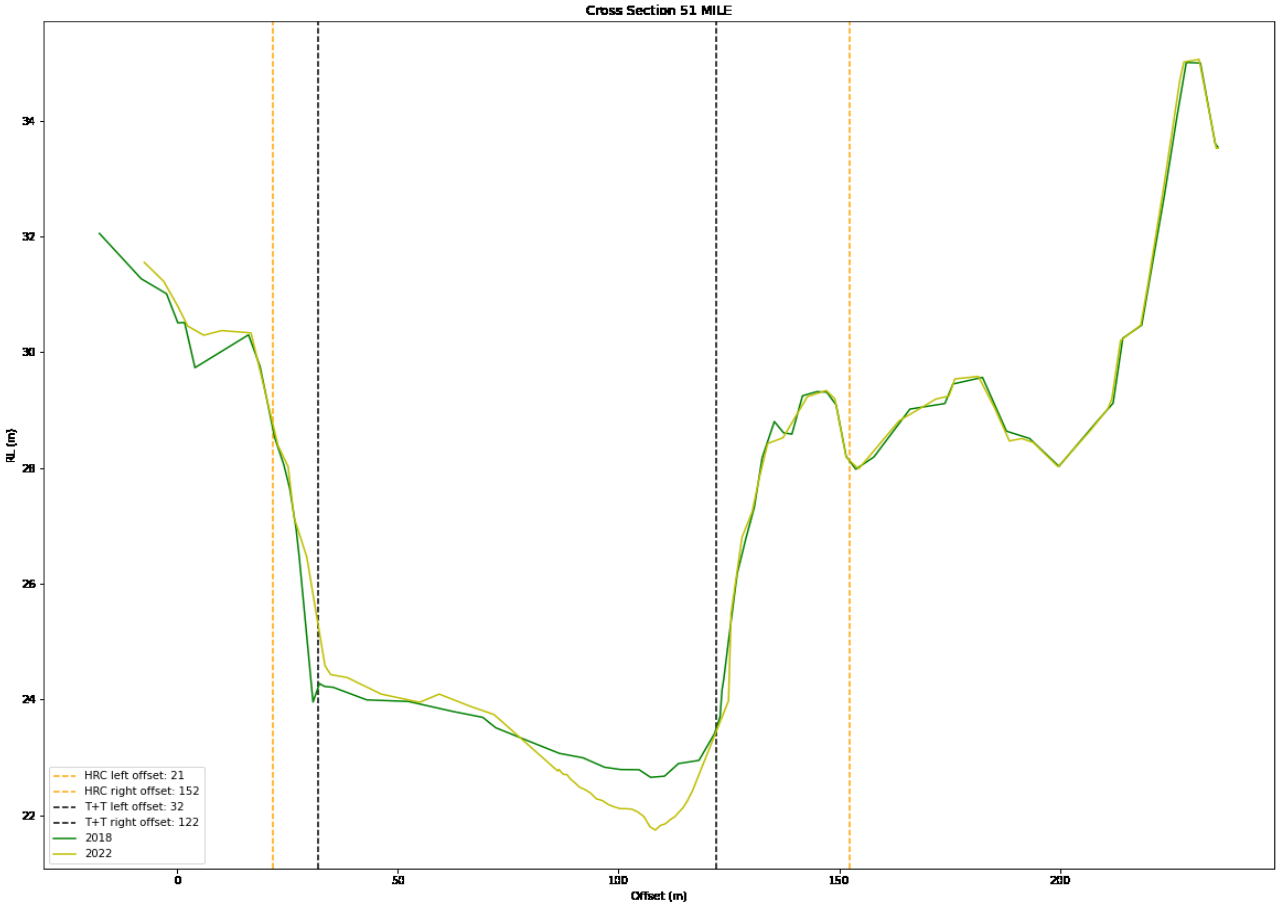

Cross Section 818
RL (m)
Offset (m)
HRC left offset: 118
HRC right offset: 231
T+T left offset: 128
T+T right offset: 211
2018
2022

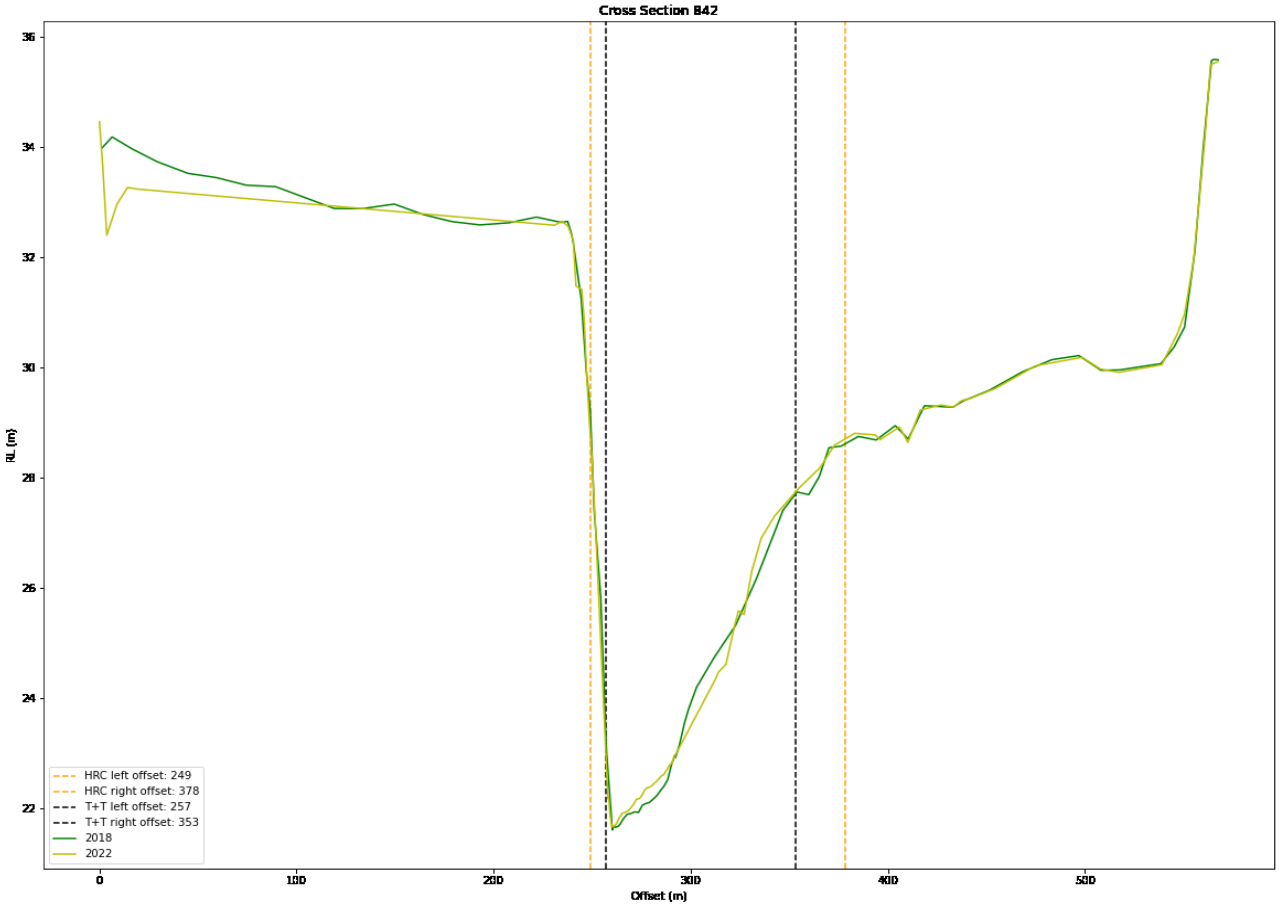

Cross Section 50 MILE
RL (m)
Offset (m)
HRC left offset: 14
HRC right offset: 119
T+T left offset: 13
T+T right offset: 101
2018
2022

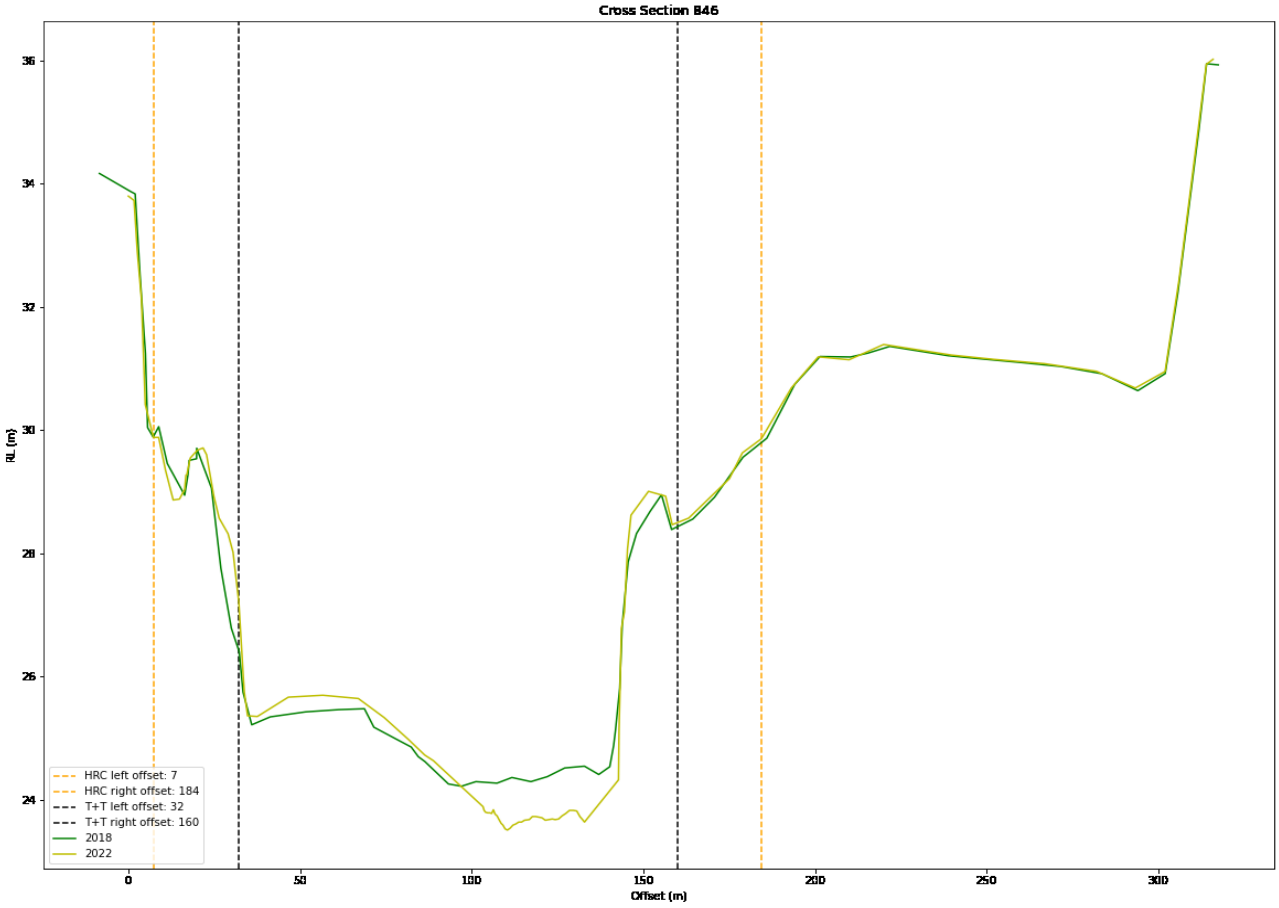

Cross Section 826
RL (m)
Offset (m)
HRC left offset: 0
HRC right offset: 343
T+T left offset: 72
T+T right offset: 240
2018
2022

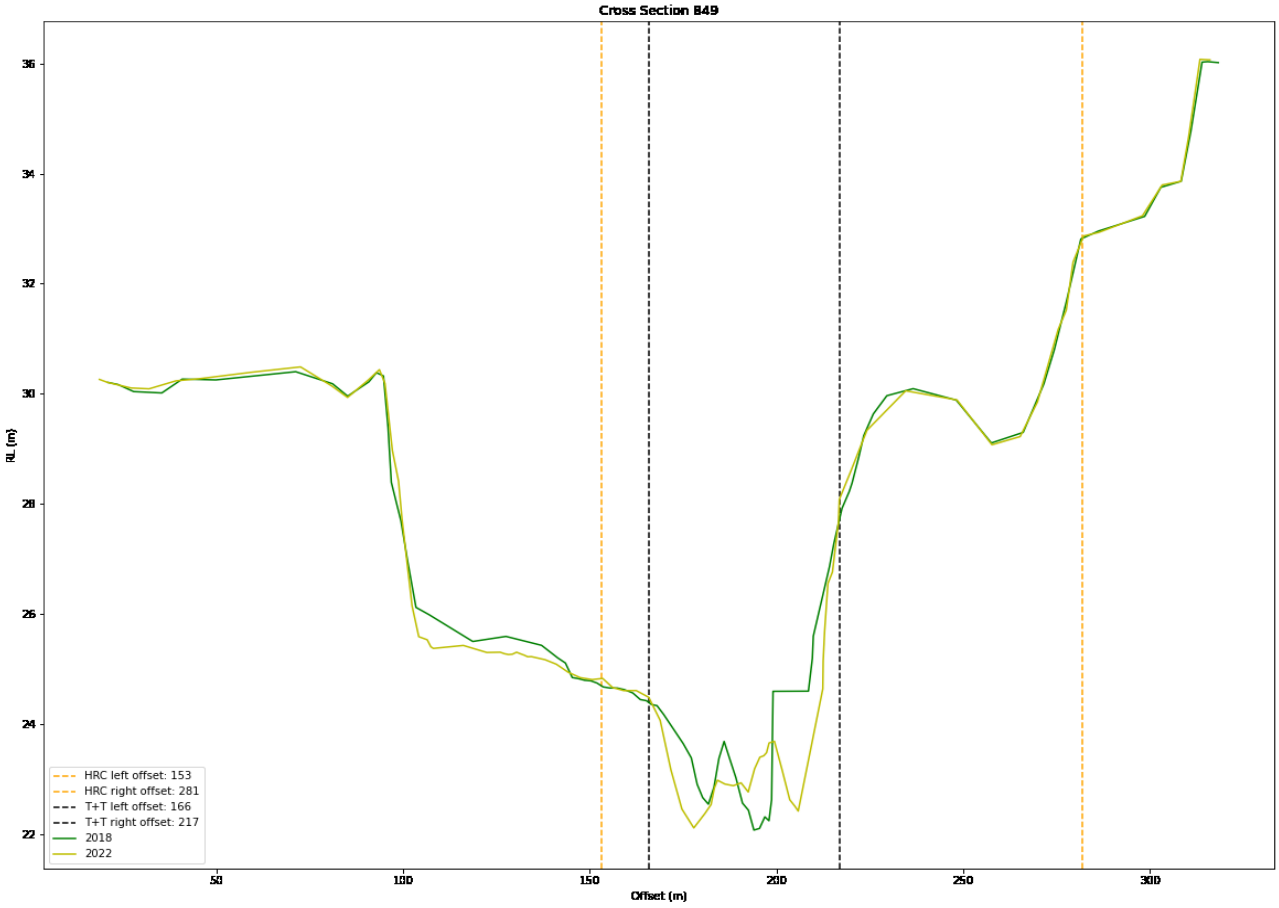

Cross Section 829
RL (m)
Offset (m)
HRC left offset: 298
HRC right offset: 414
T+T left offset: 305
T+T right offset: 402
2018
2022

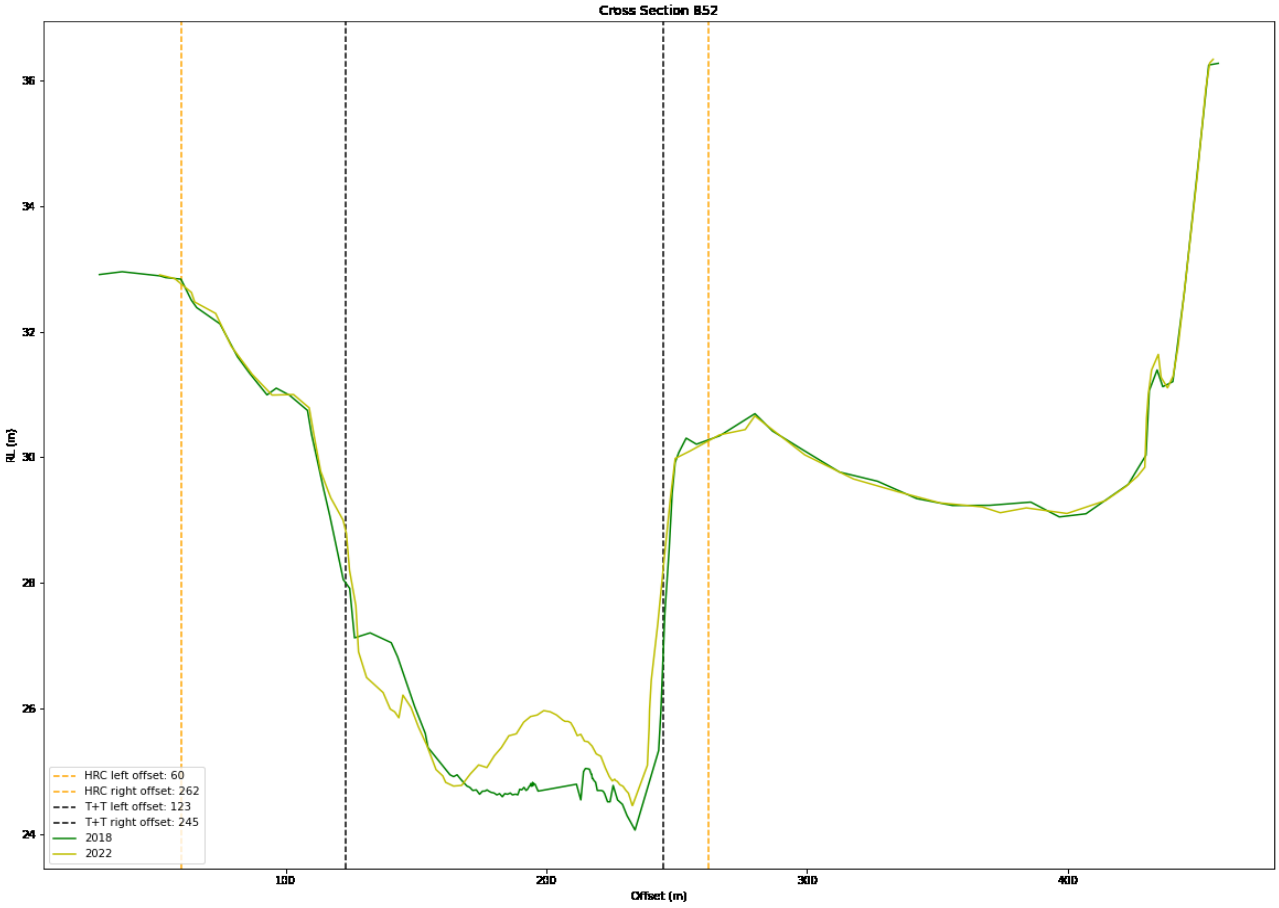

Cross Section 834
RL (m)
Offset (m)
HRC left offset: 528
HRC right offset: 652
T+T left offset: 539
T+T right offset: 639
2018
2022

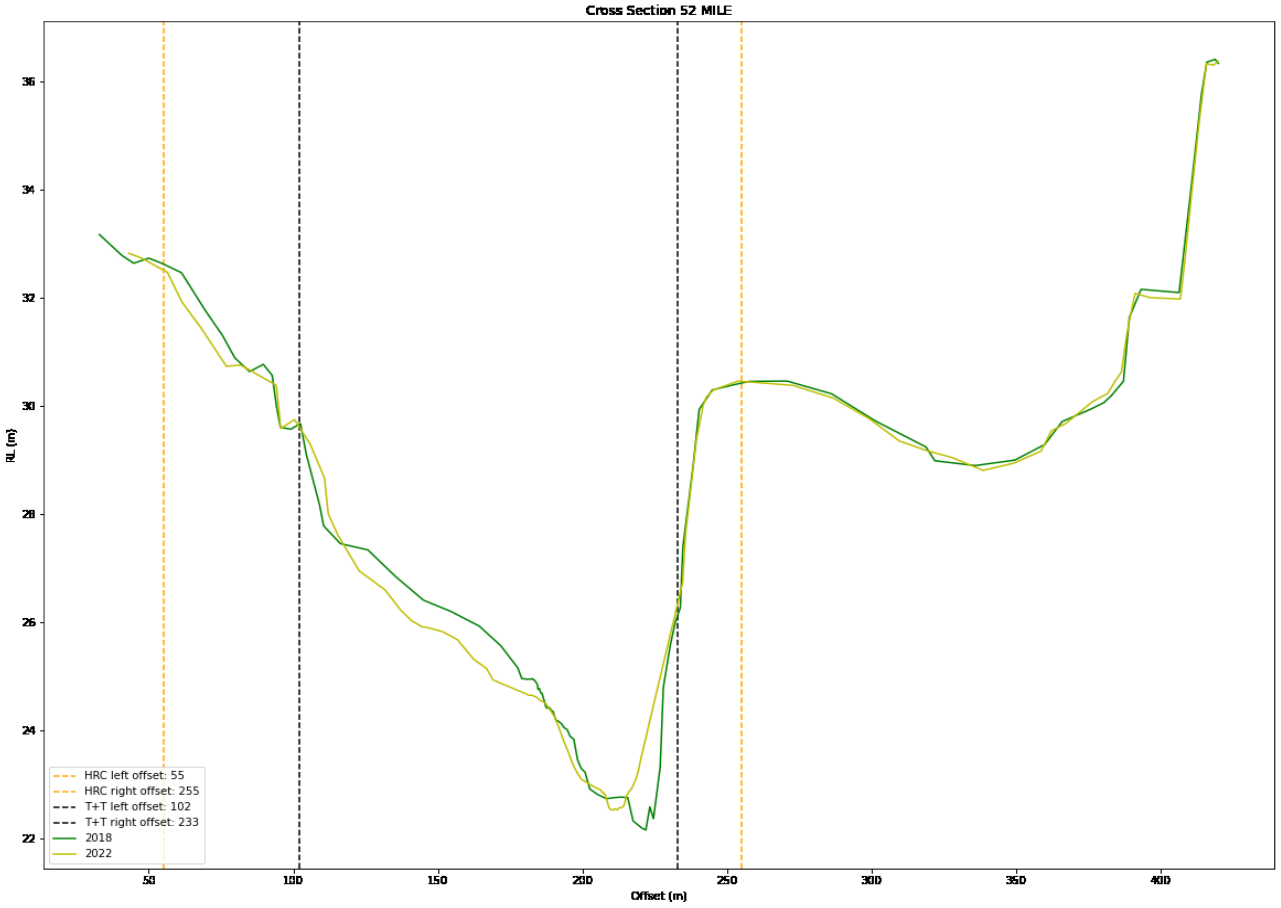

Cross Section 51 MILE
RL (m)
Offset (m)
HRC left offset: 21
HRC right offset: 152
T+T left offset: 32
T+T right offset: 122
2018
2022

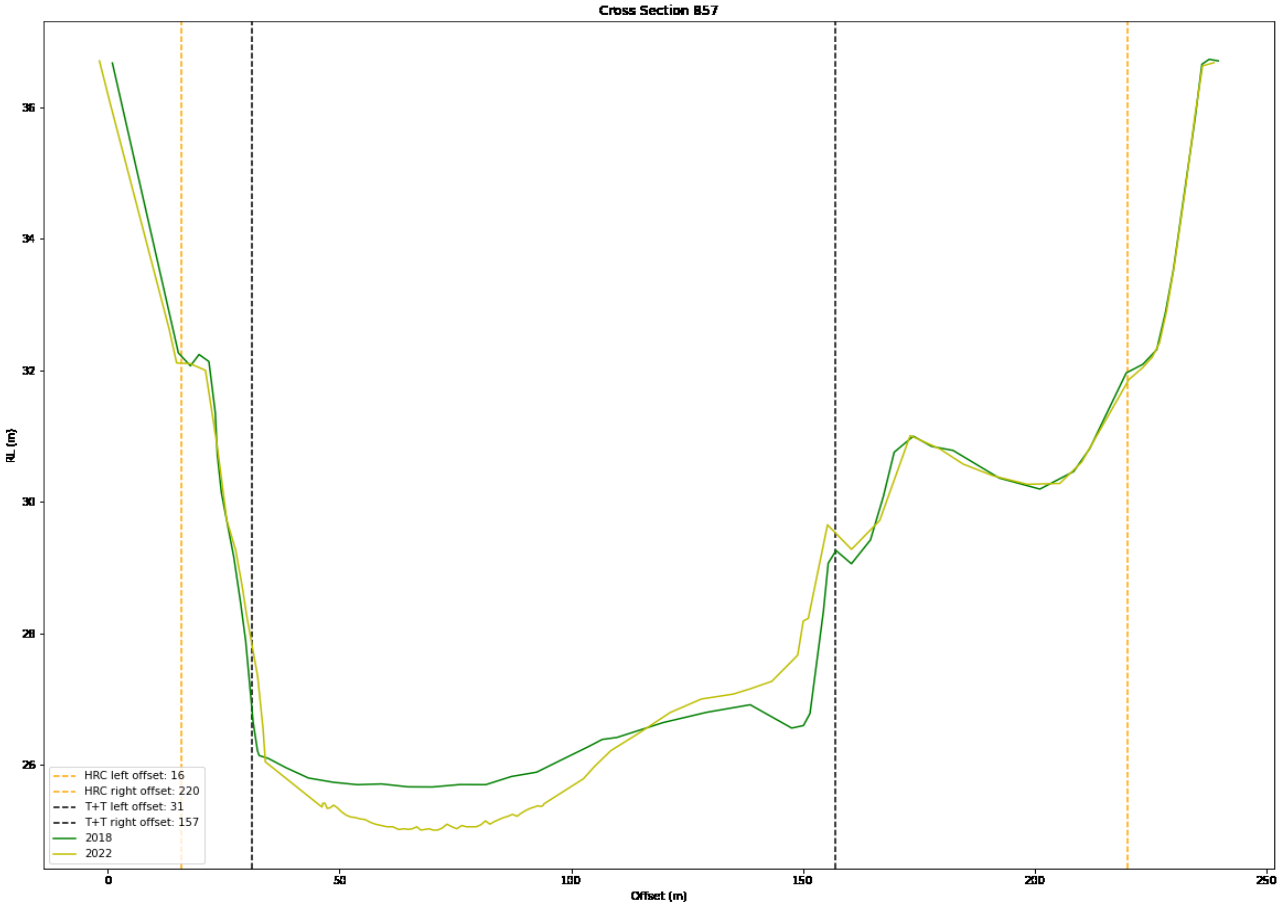

Cross Section 842
RL (m)
Offset (m)
HRC left offset: 249
HRC right offset: 378
T+T left offset: 257
T+T right offset: 353
2018
2022

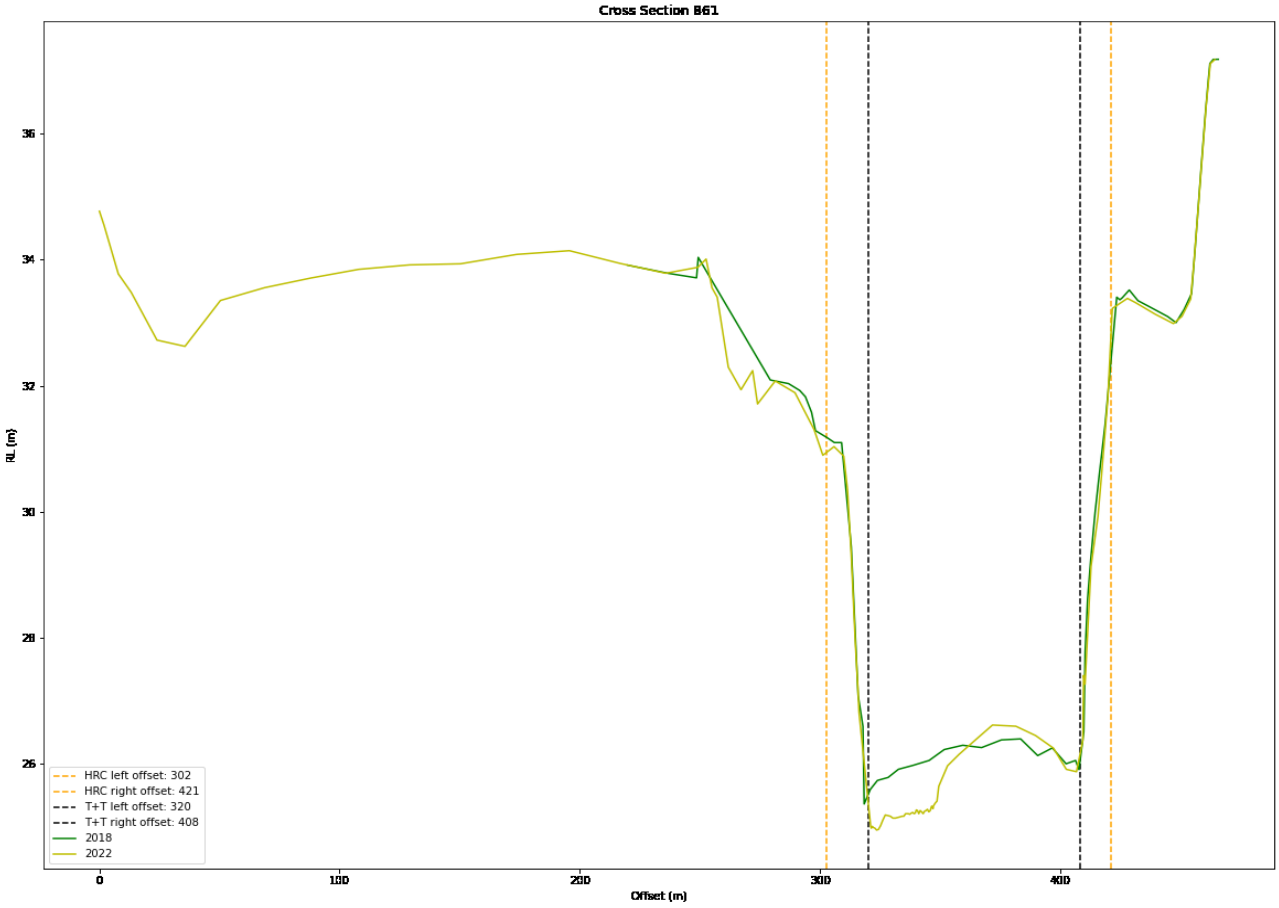

Cross Section 846
RL (m)
Offset (m)
HRC left offset: 7
HRC right offset: 184
T+T left offset: 32
T+T right offset: 160
2018
2022

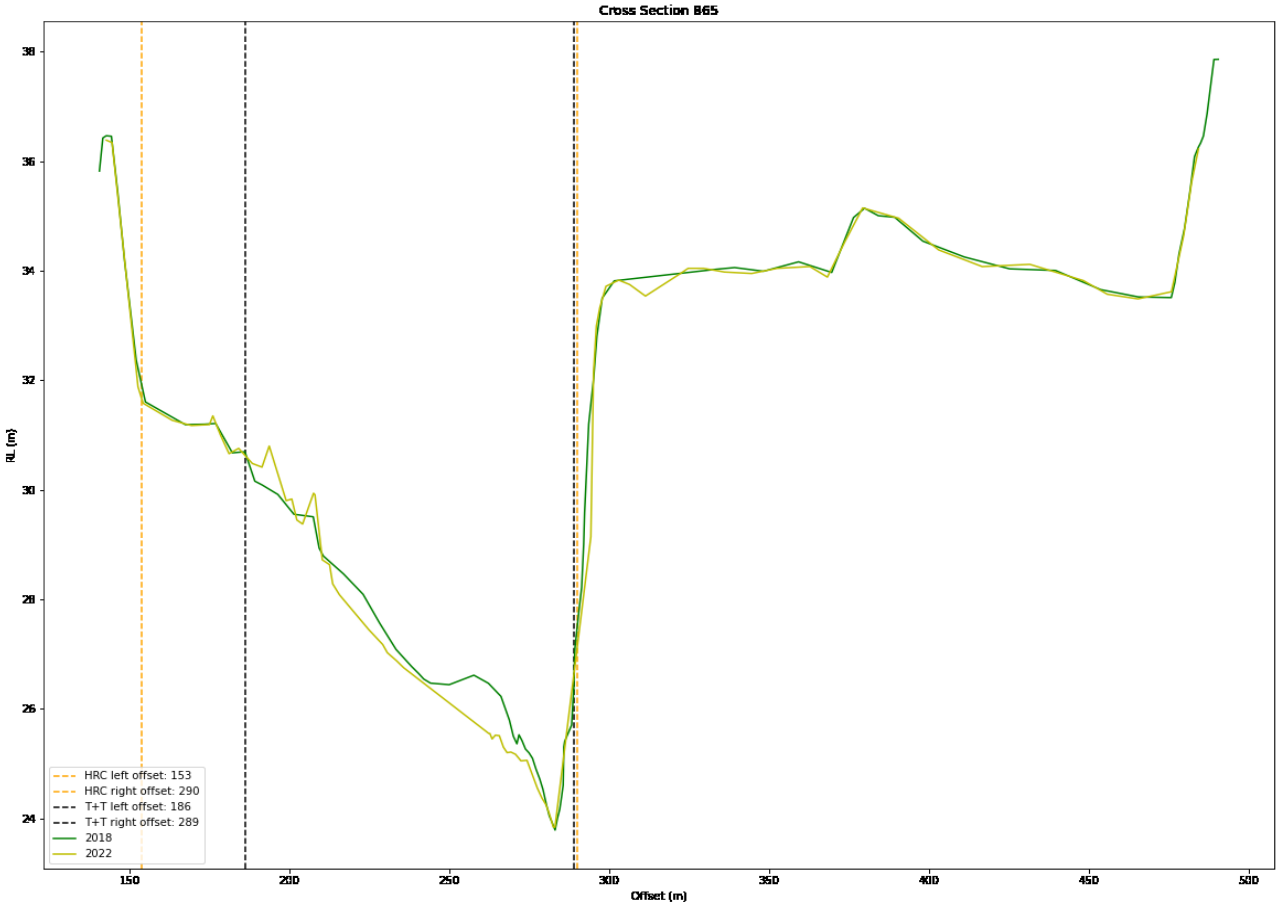

Cross Section 849
RL (m)
Offset (m)
HRC left offset: 153
HRC right offset: 281
T+T left offset: 166
T+T right offset: 217
2018
2022

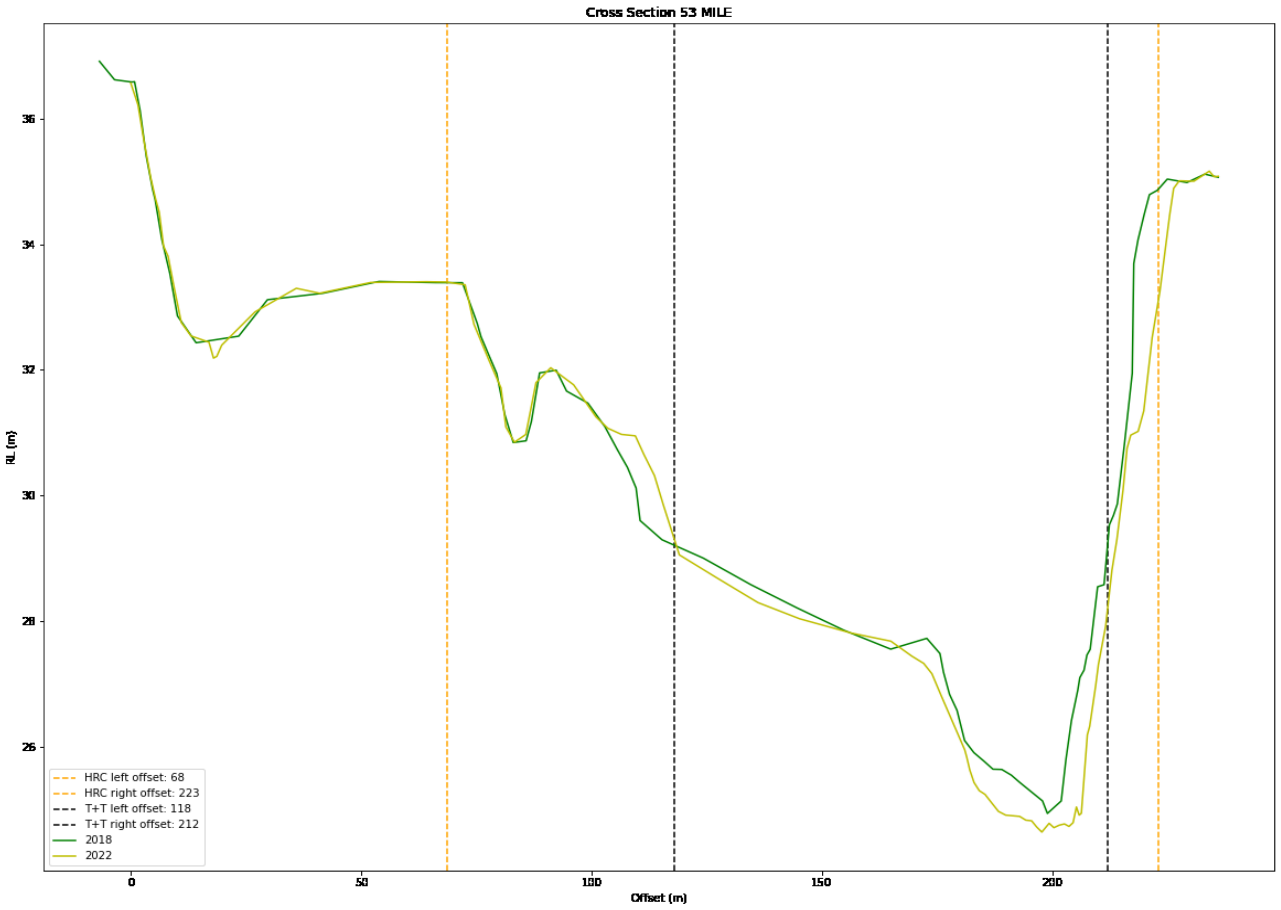

Cross Section 852
RL (m)
Offset (m)
HRC left offset: 60
HRC right offset: 262
T+T left offset: 123
T+T right offset: 245
2018
2022

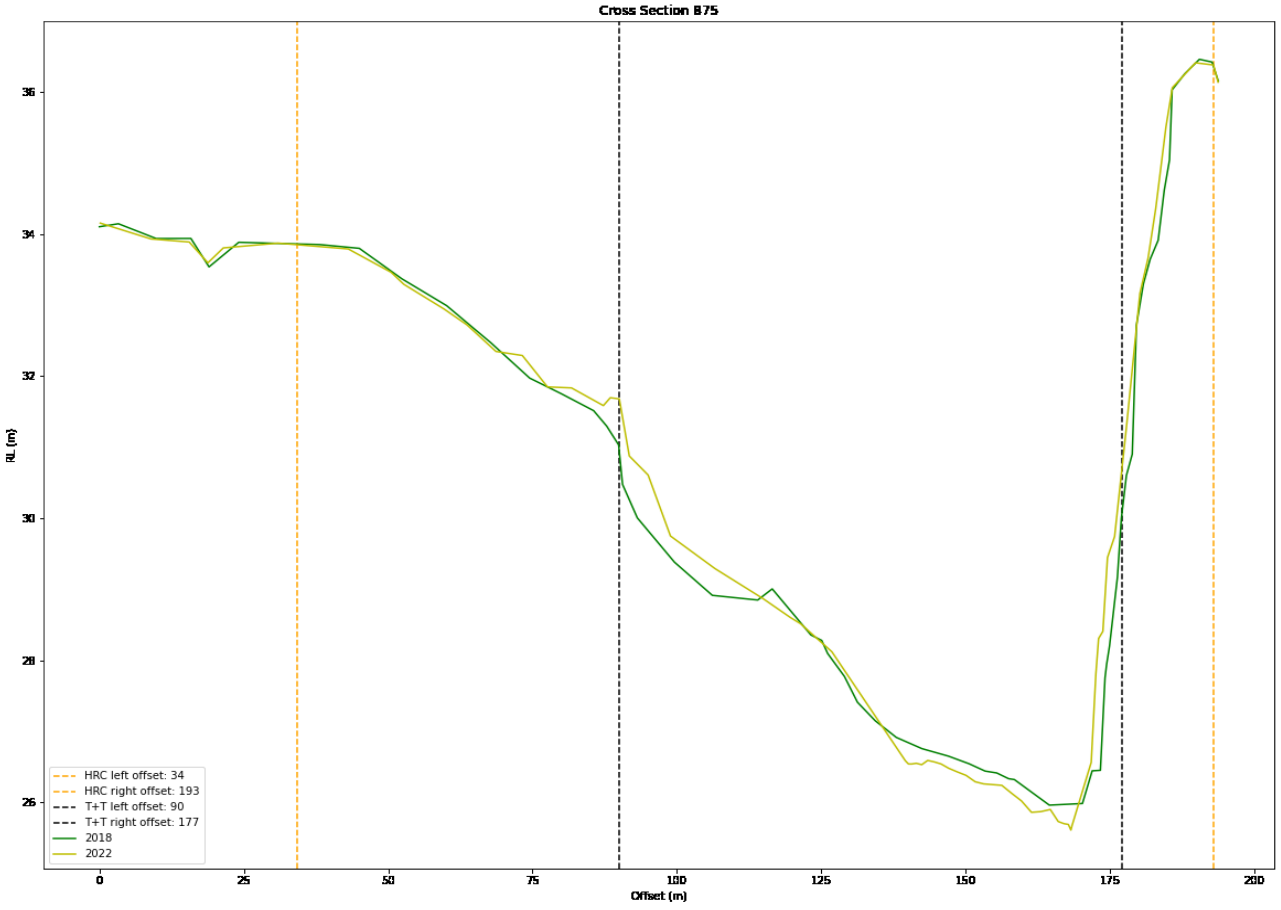

Cross Section 52 MILE
RL (m)
Offset (m)
HRC left offset: 55
HRC right offset: 255
T+T left offset: 102
T+T right offset: 233
2018
2022

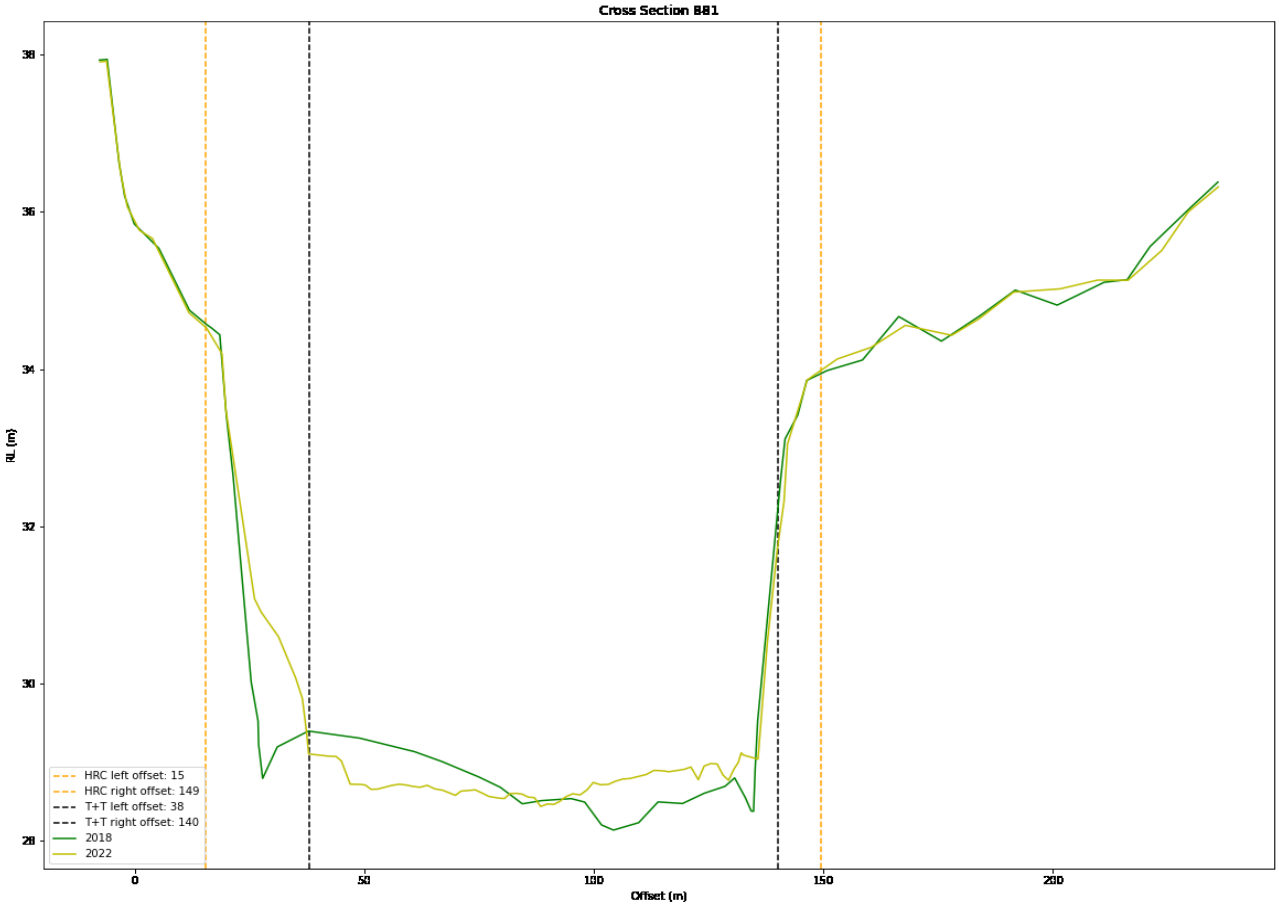

Cross Section 857
RL (m)
Offset (m)
HRC left offset: 16
HRC right offset: 220
T+T left offset: 31
T+T right offset: 157
2018
2022

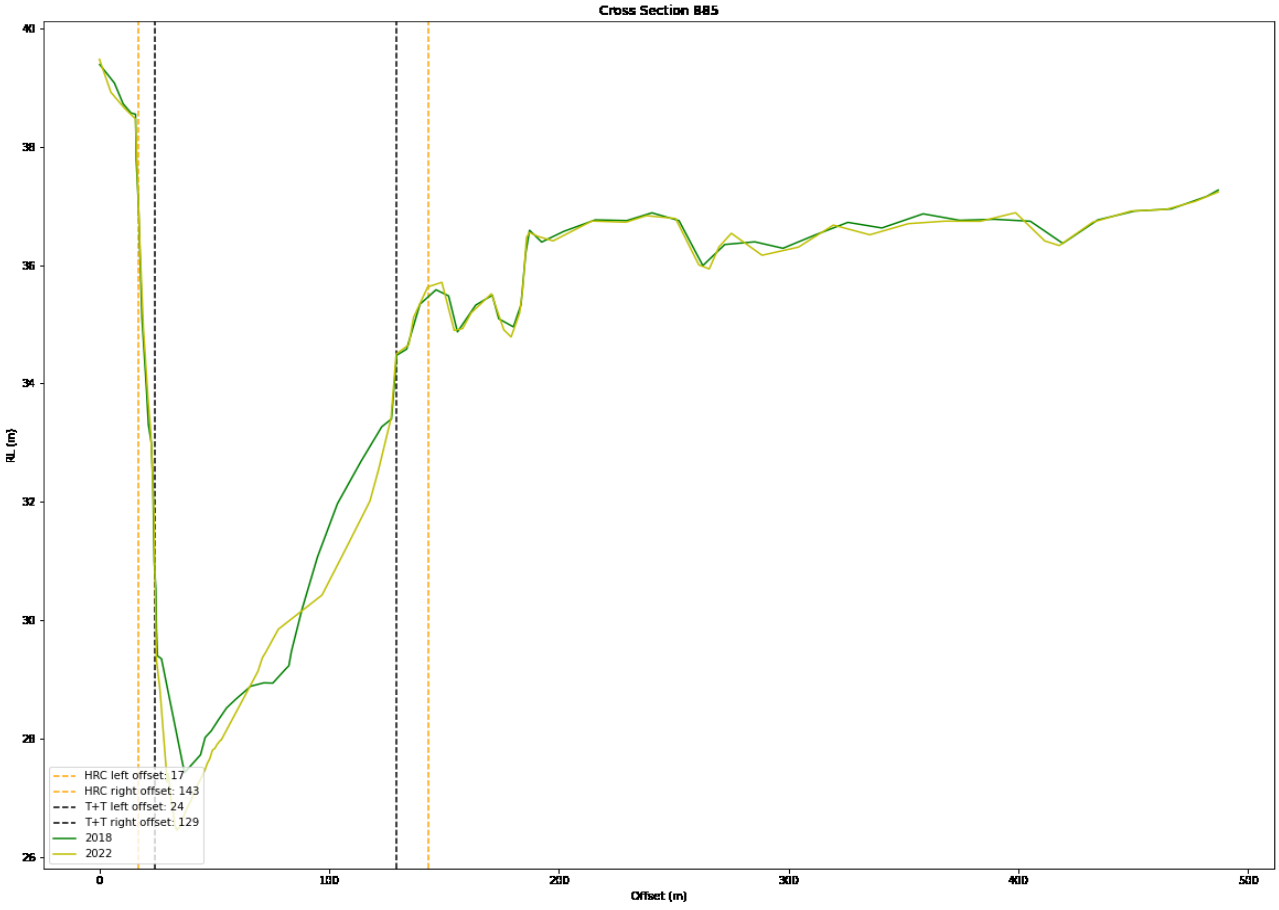

Cross Section 861
RL (m)
Offset (m)
HRC left offset: 302
HRC right offset: 421
T+T left offset: 320
T+T right offset: 408
2018
2022

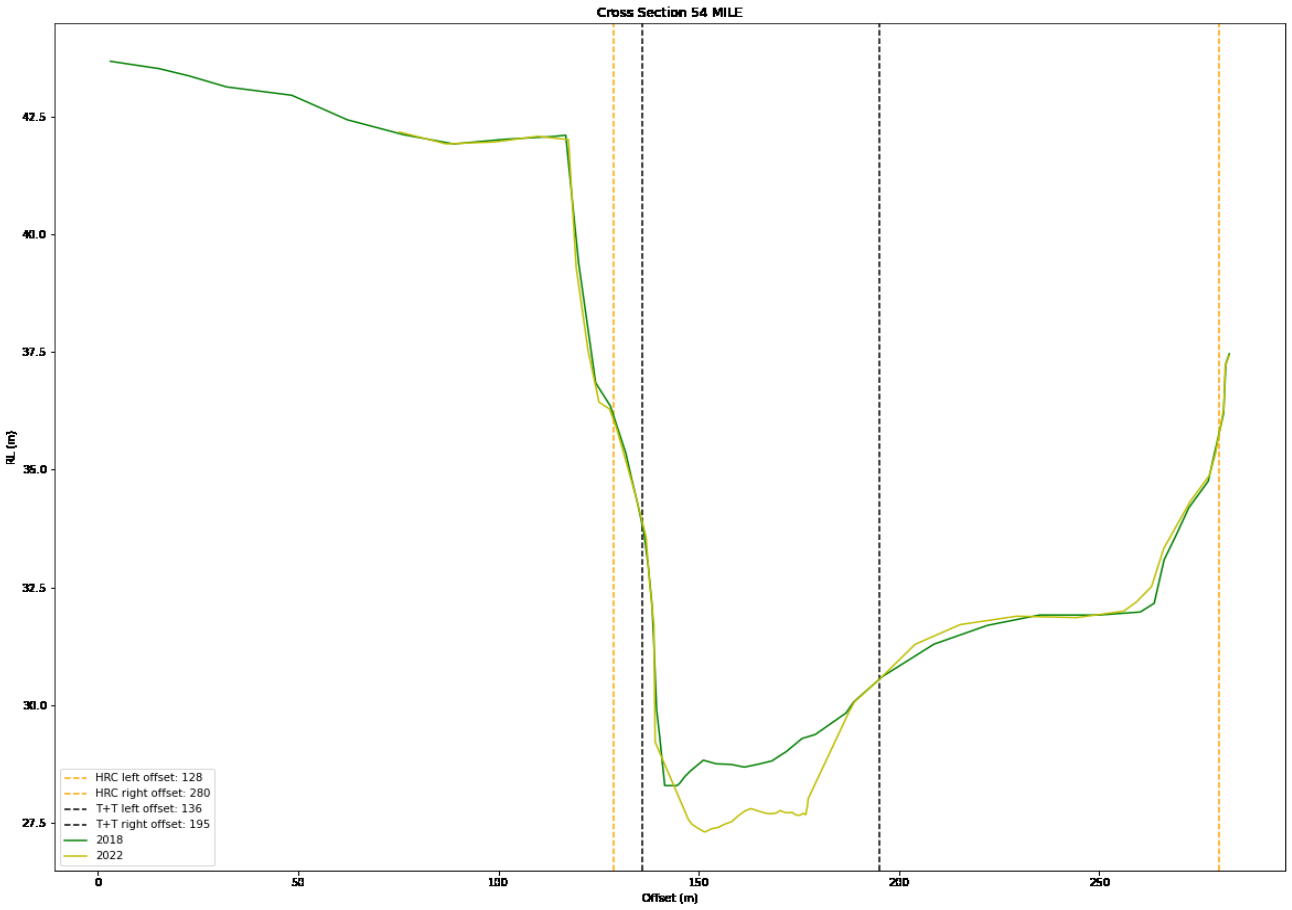

Cross Section 865
RL (m)
Offset (m)
HRC left offset: 153
HRC right offset: 290
T+T left offset: 186
T+T right offset: 289
2018
2022

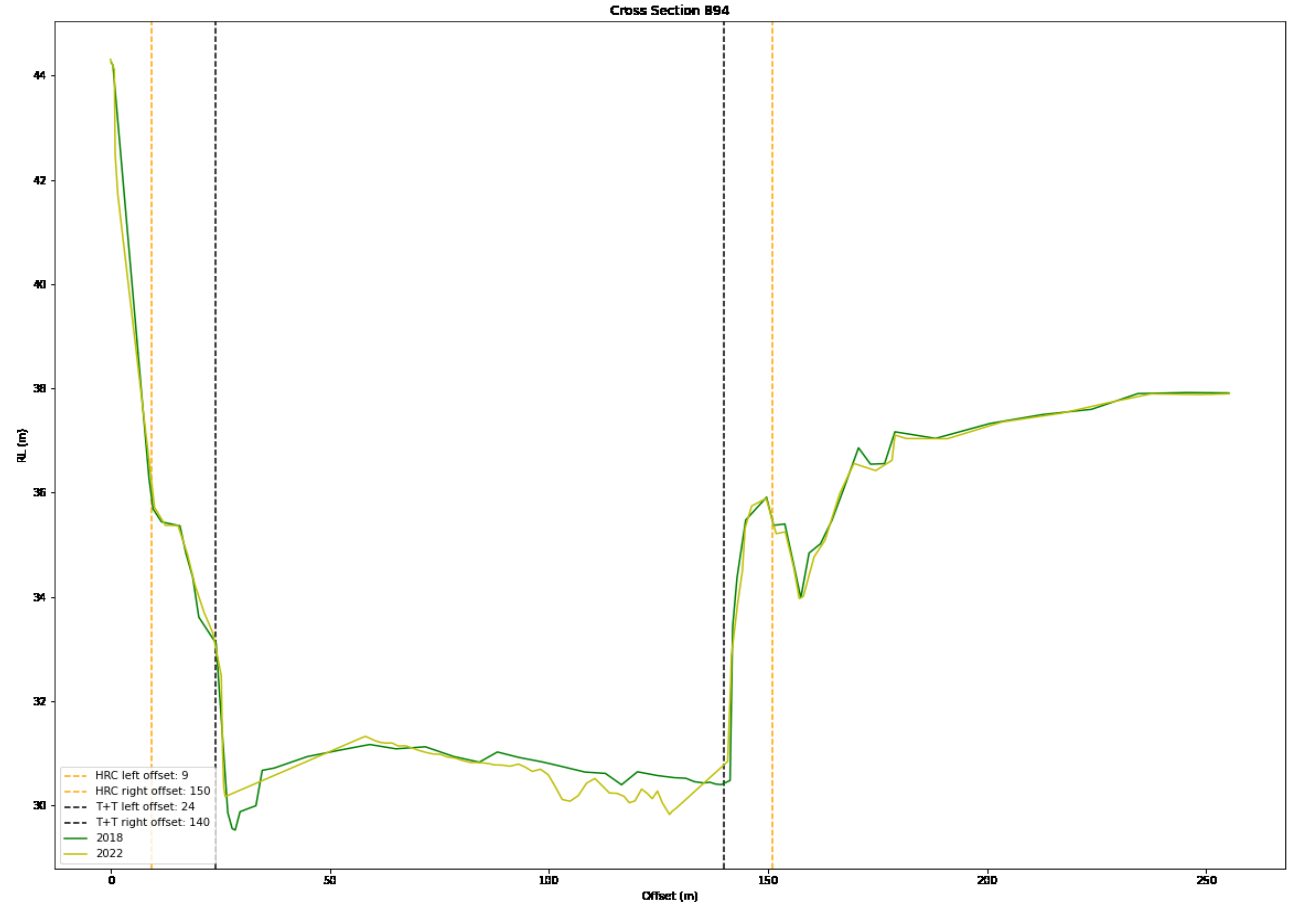

Cross Section 53 MILE
RL (m)
Offset (m)
HRC left offset: 68
HRC right offset: 223
T+T left offset: 118
T+T right offset: 212
2018
2022

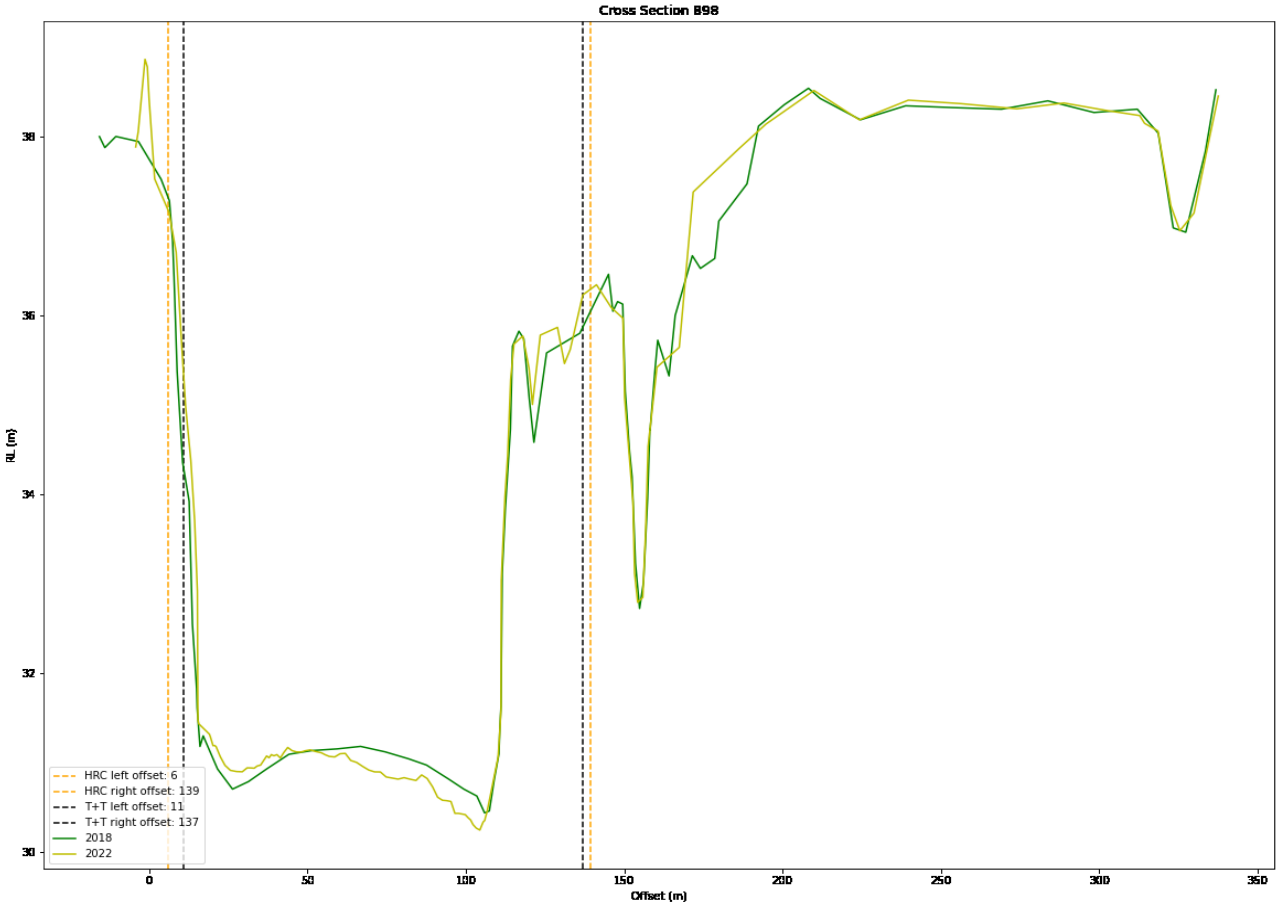

Cross Section 875
RL (m)
Offset (m)
HRC left offset: 34
HRC right offset: 193
T+T left offset: 90
T+T right offset: 177
2018
2022

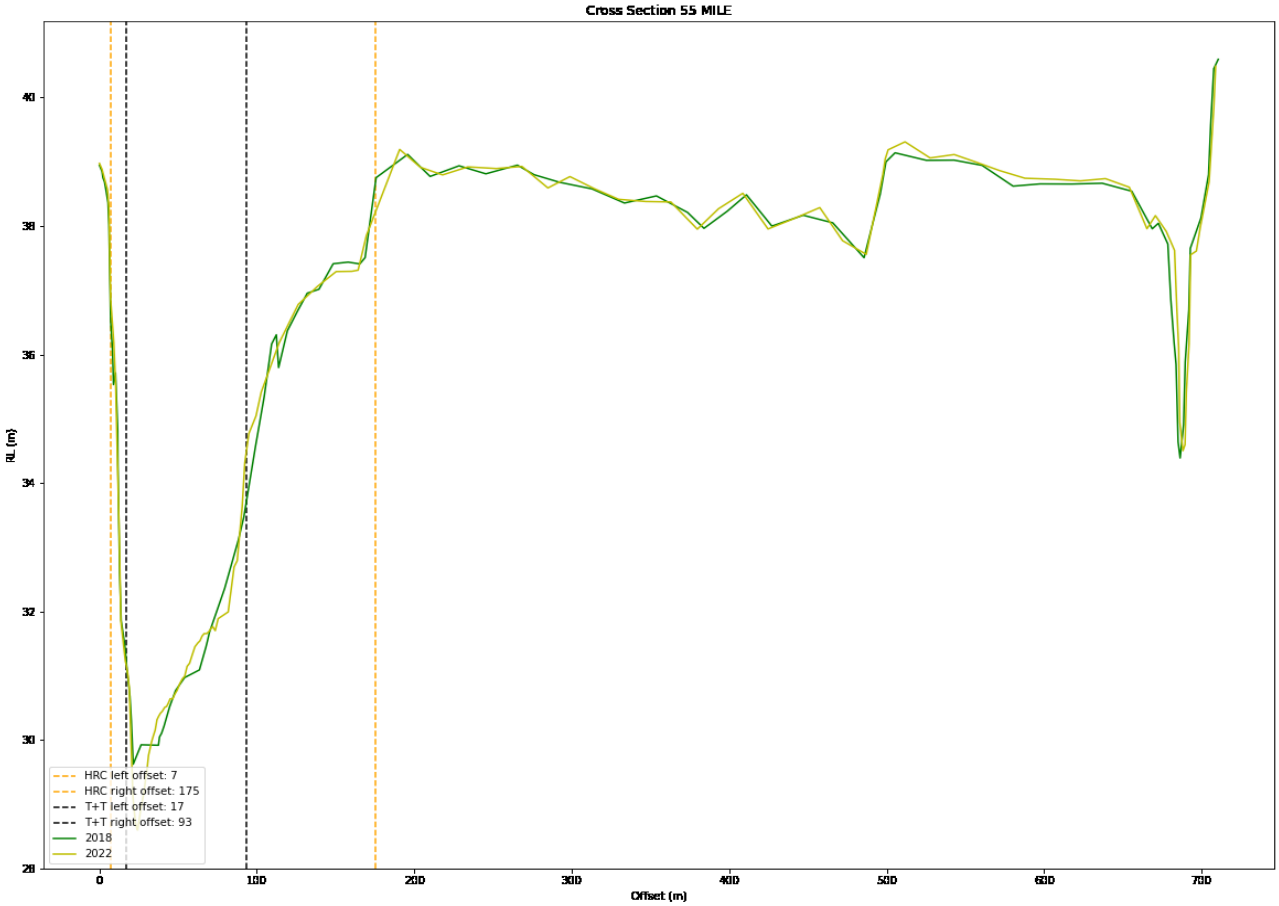

Cross Section 881
RL (m)
Offset (m)
HRC left offset: 15
HRC right offset: 149
T+T left offset: 38
T+T right offset: 140
2018
2022

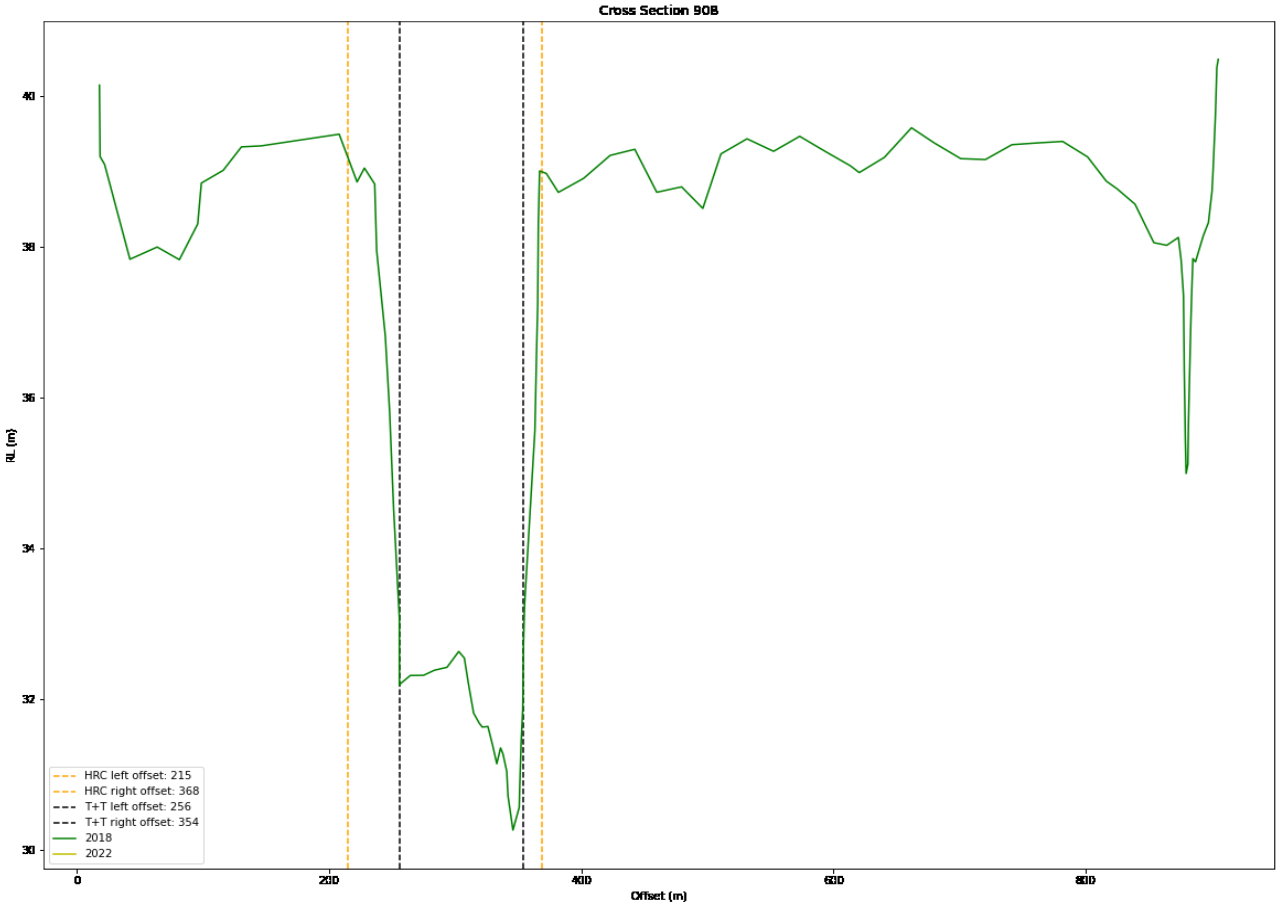

Cross Section 885
RL (m)
Offset (m)
HRC left offset: 17
HRC right offset: 143
T+T left offset: 24
T+T right offset: 129
2018
2022

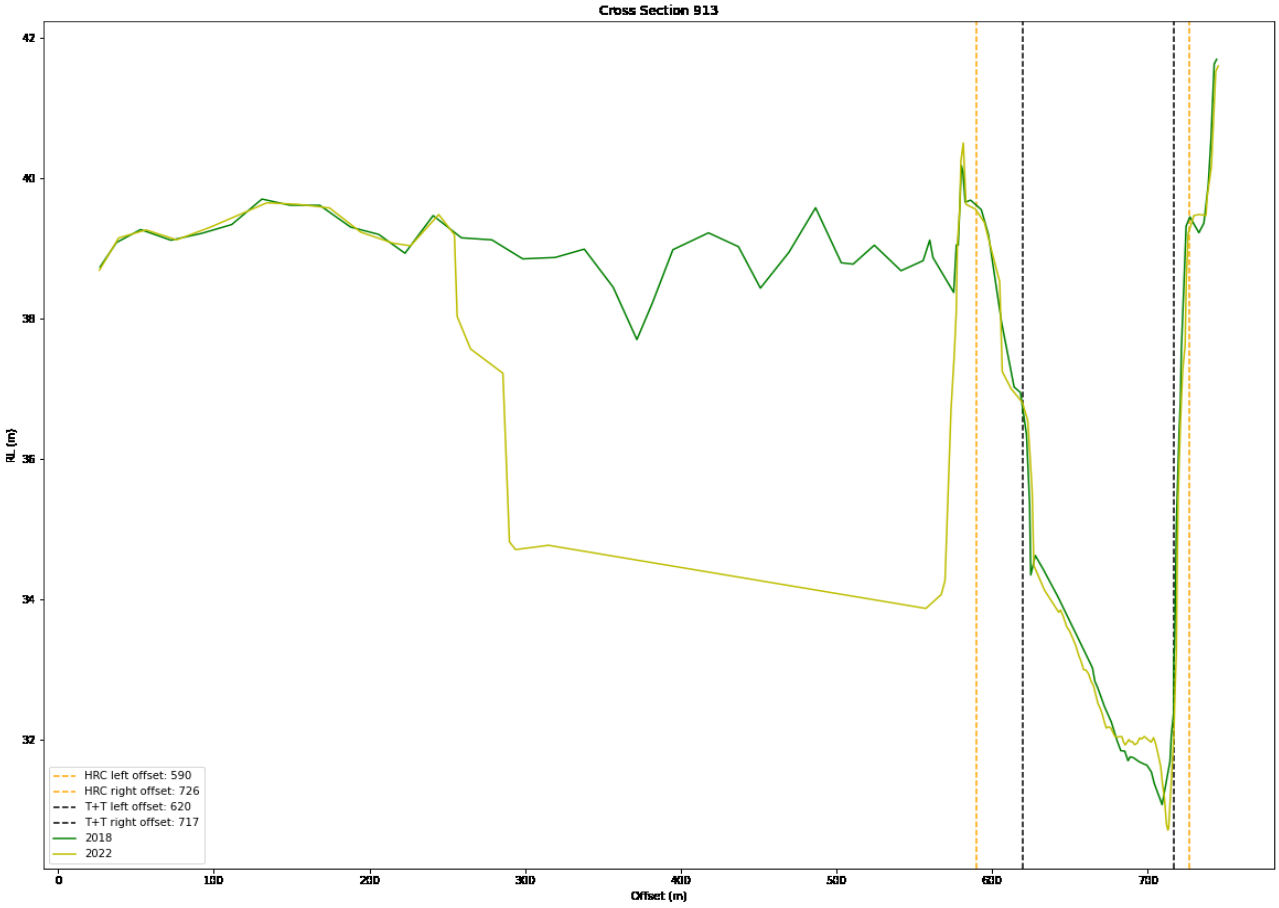

Cross Section 54 MILE
RL (m)
Offset (m)
HRC left offset: 128
HRC right offset: 280
T+T left offset: 136
T+T right offset: 195
2018
2022

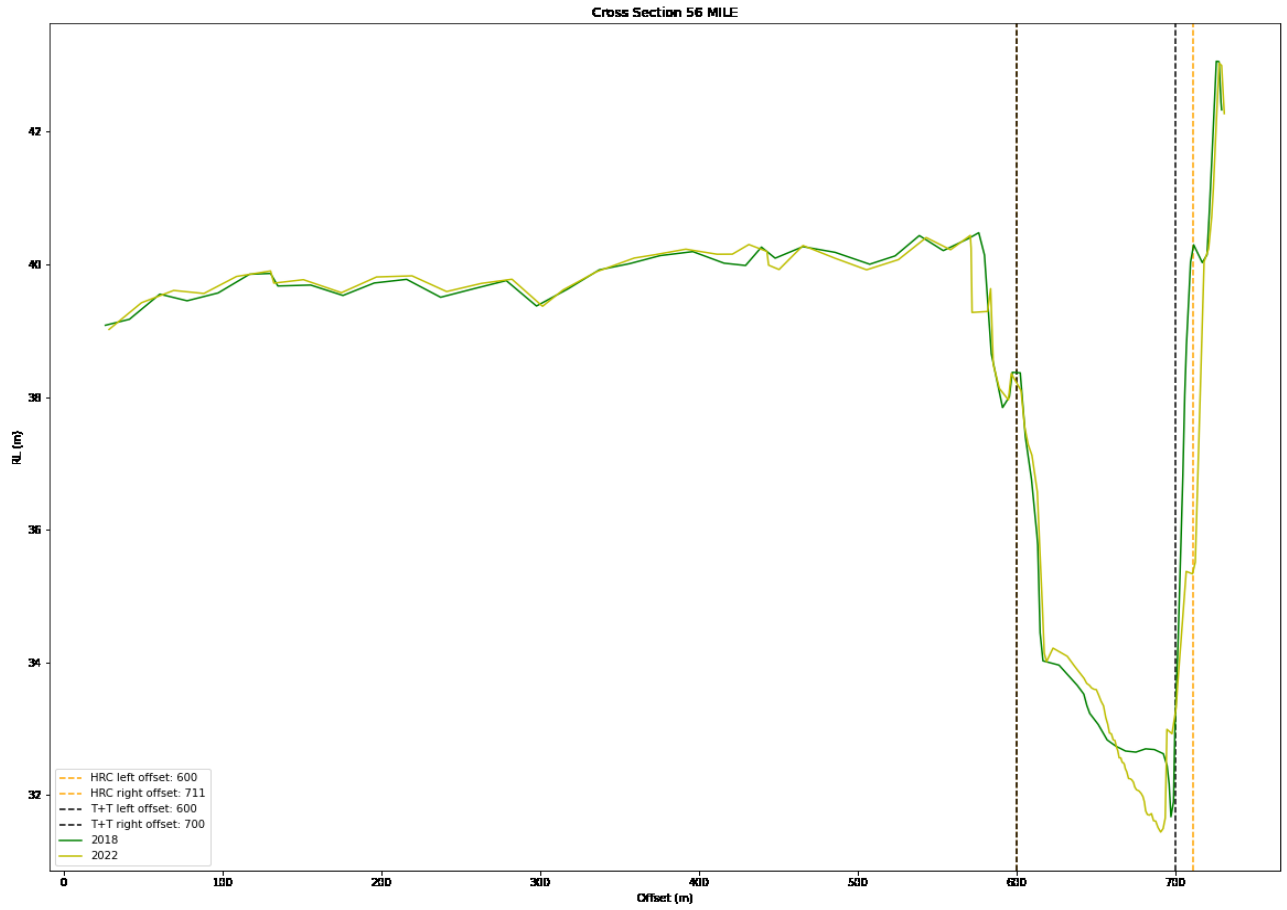

Cross Section 894
RL (m)
Offset (m)
HRC left offset: 9
HRC right offset: 150
T+T left offset: 24
T+T right offset: 140
2018
2022

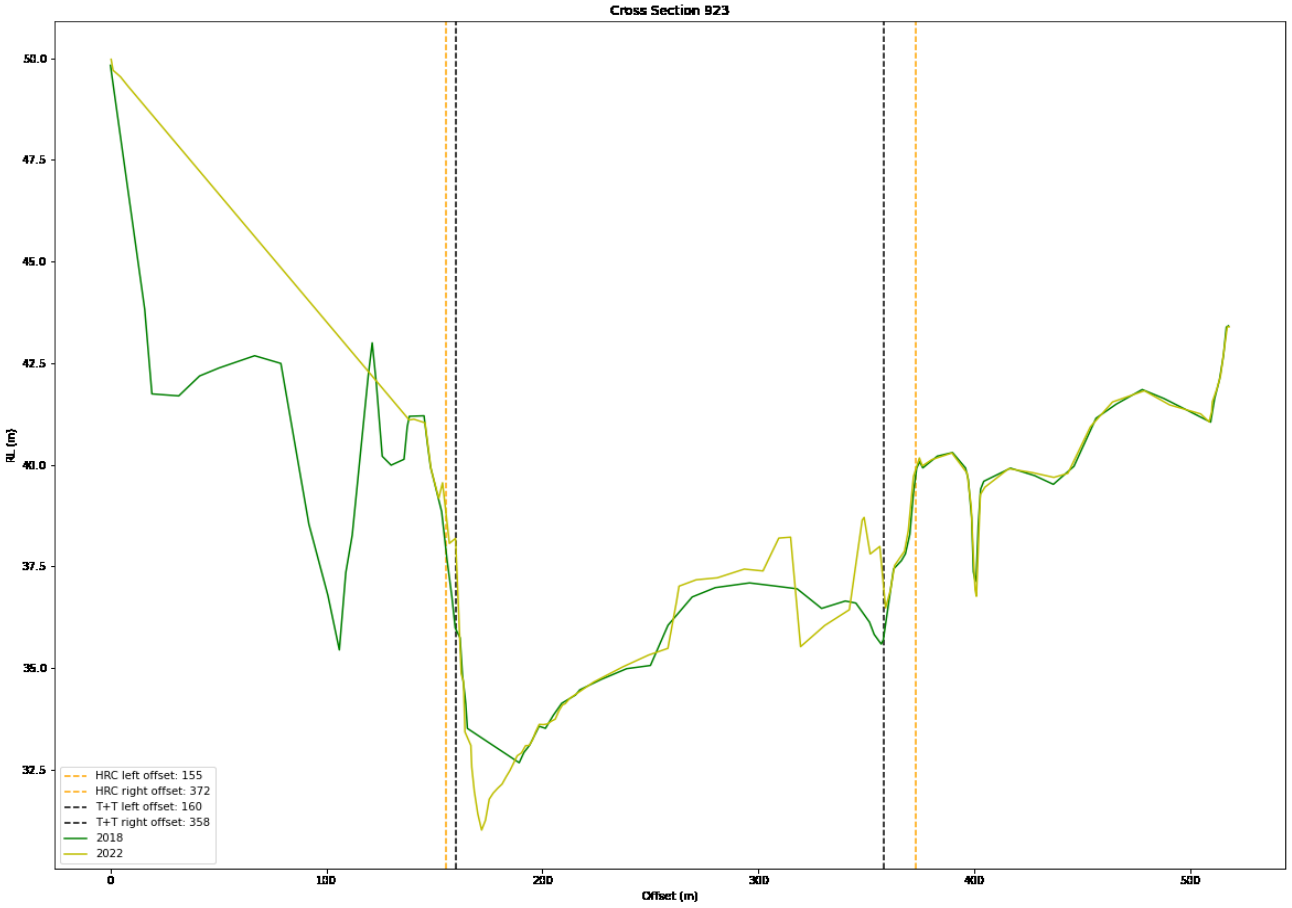

Cross Section 898
RL (m)
Offset (m)
HRC left offset: 6
HRC right offset: 139
T+T left offset: 11
T+T right offset: 137
2018
2022

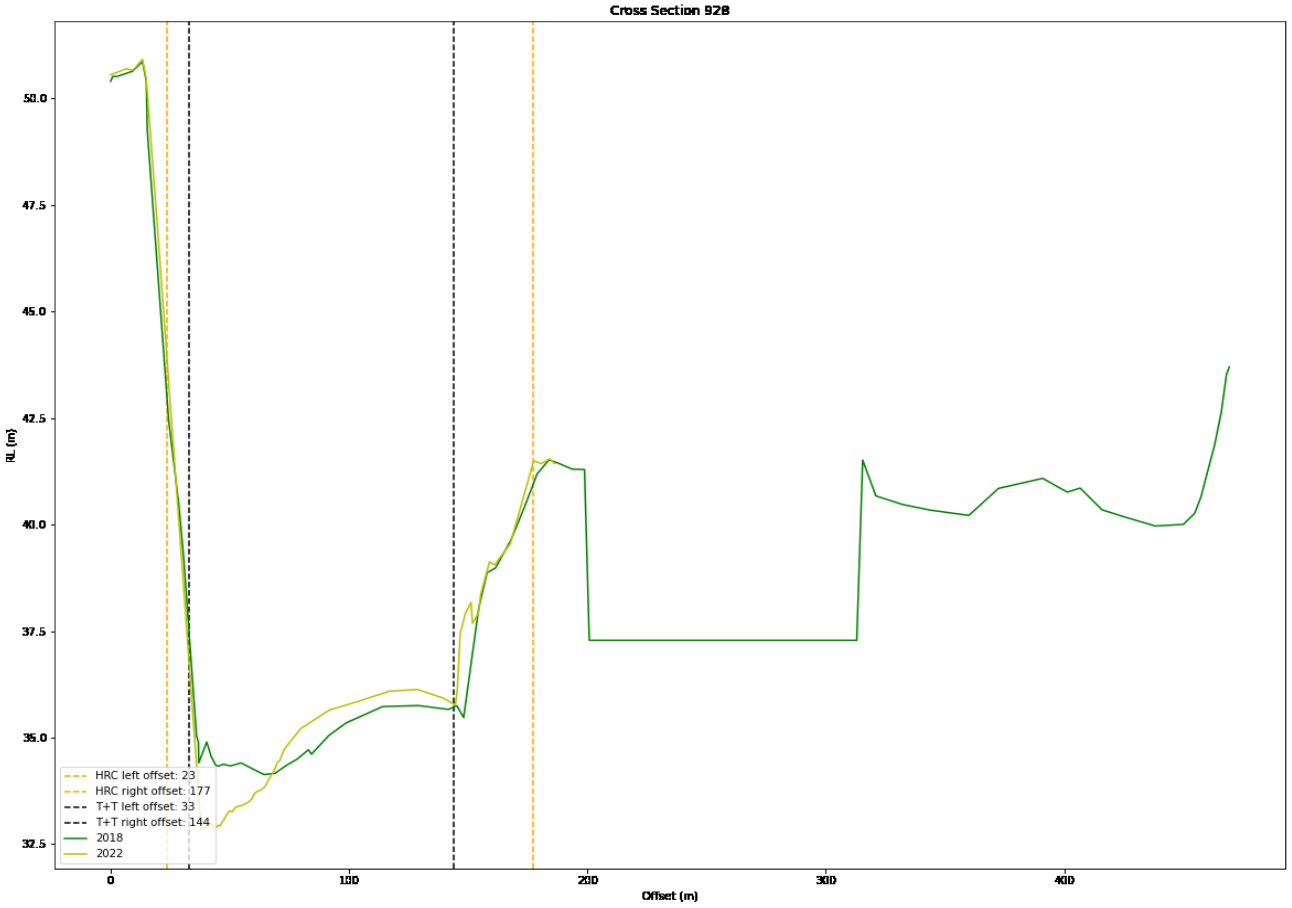

Cross Section 55 MILE
RL (m)
Offset (m)
HRC left offset: 7
HRC right offset: 175
T+T left offset: 17
T+T right offset: 93
2018
2022

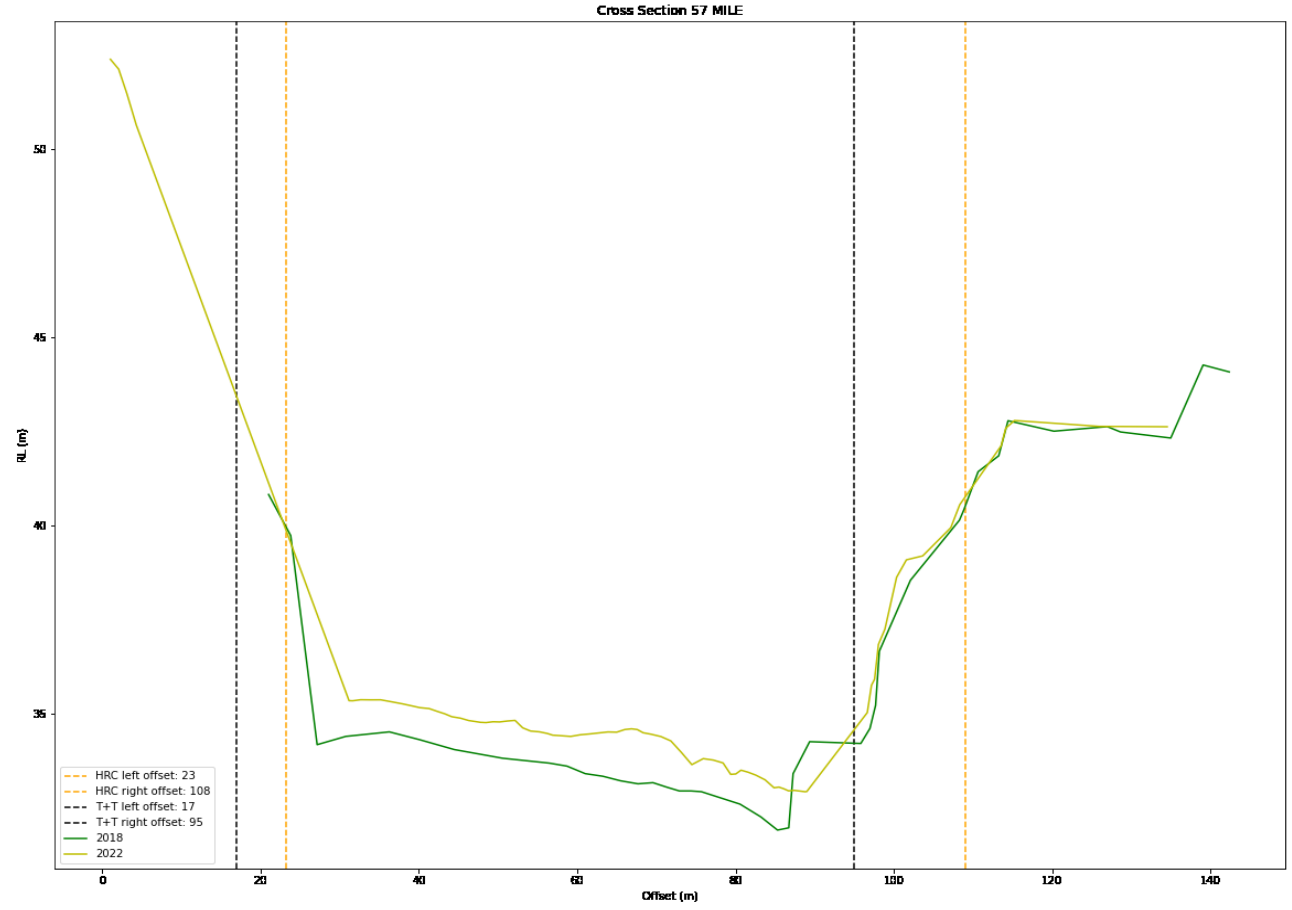

Cross Section 908
RL (m)
Offset (m)
HRC left offset: 215
HRC right offset: 368
T+T left offset: 256
T+T right offset: 354
2018
2022

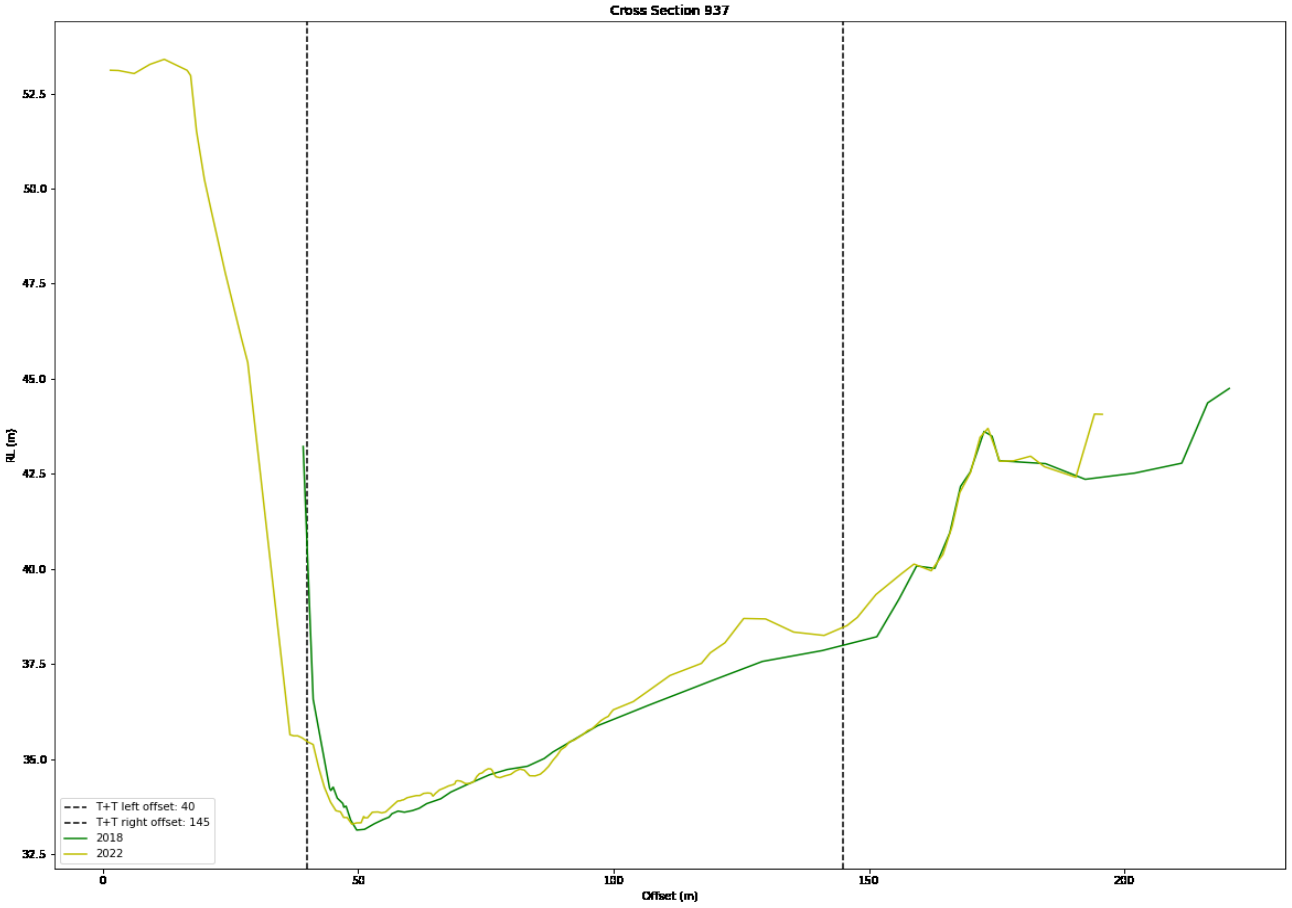

Cross Section 913
RL (m)
Offset (m)
HRC left offset: 590
HRC right offset: 726
T+T left offset: 620
T+T right offset: 717
2018
2022

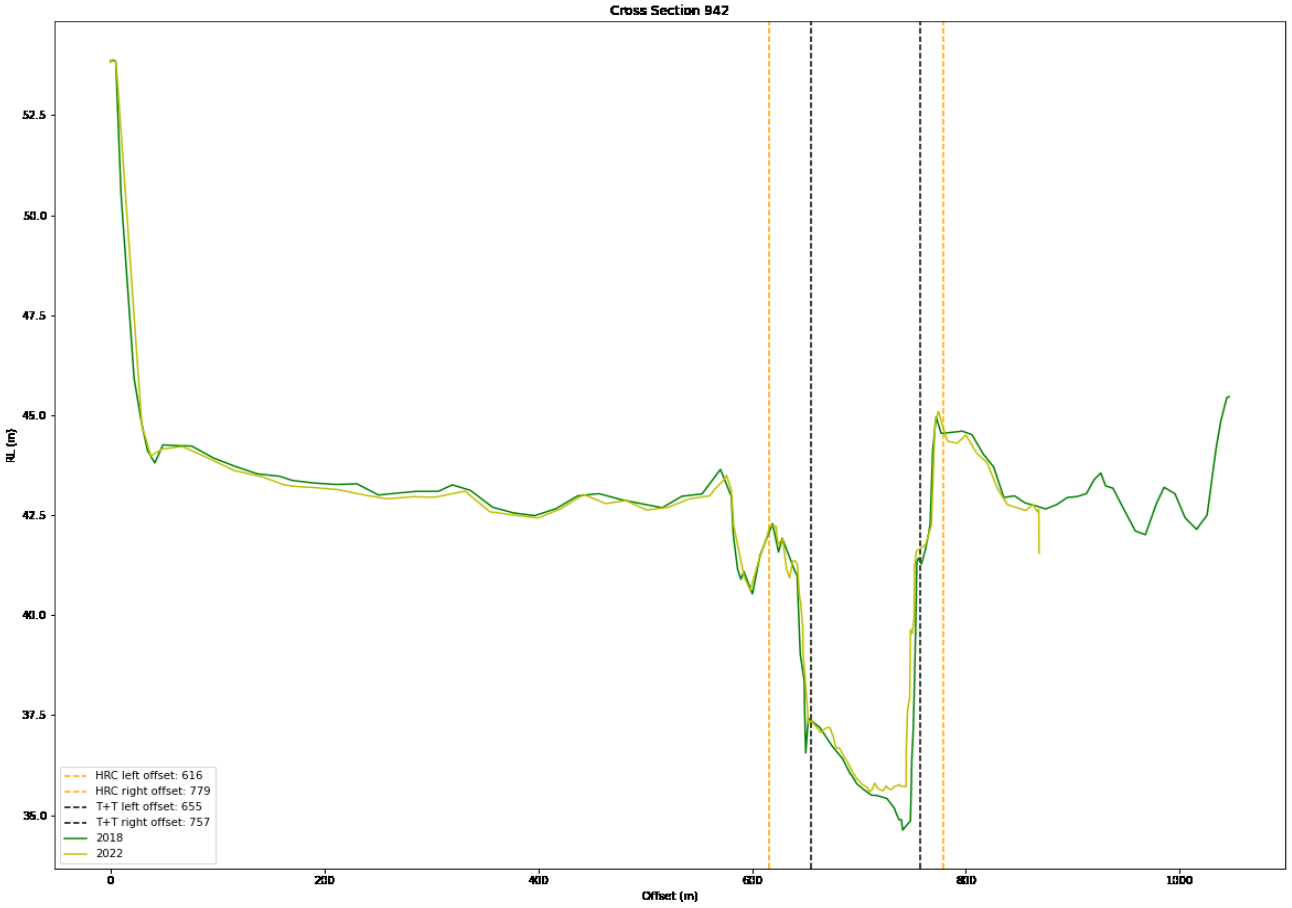

Cross Section 56 MILE
RL (m)
Offset (m)
HRC left offset: 600
HRC right offset: 711
T+T left offset: 600
T+T right offset: 700
2018
2022

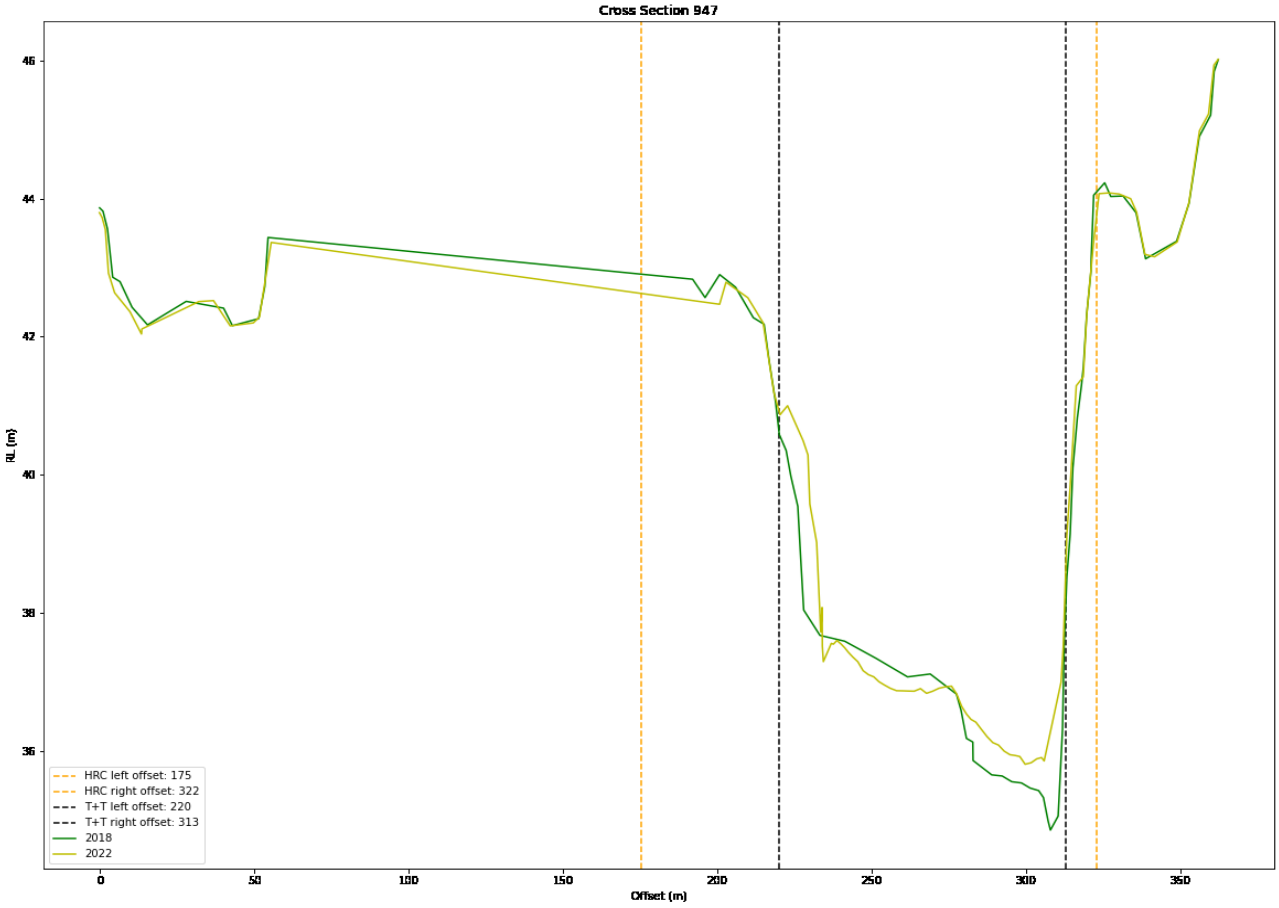

Cross Section 923
RL (m)
Offset (m)
HRC left offset: 155
HRC right offset: 372
T+T left offset: 160
T+T right offset: 358
2018
2022

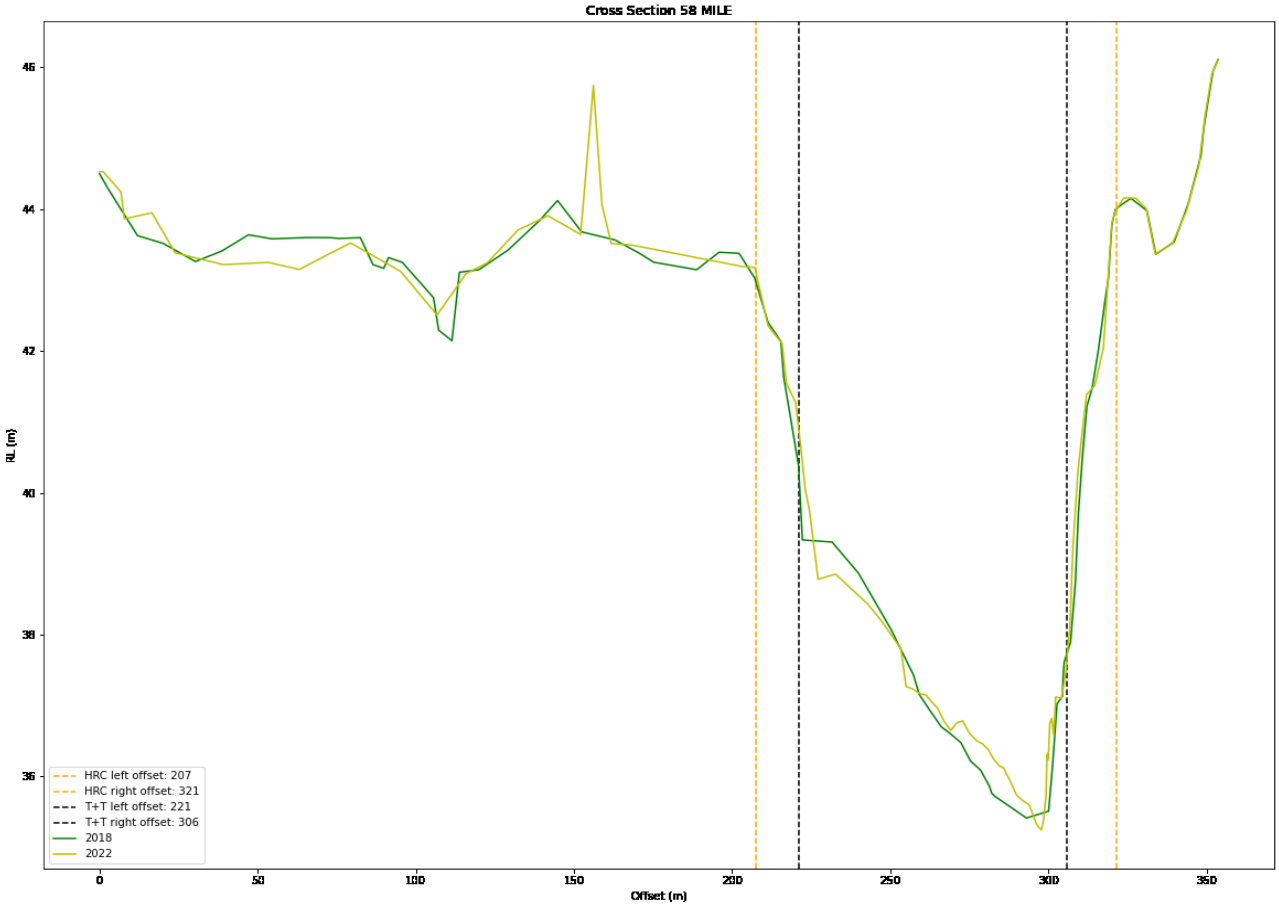

Cross Section 928
RL (m)
Offset (m)
HRC left offset: 23
HRC right offset: 177
T+T left offset: 33
T+T right offset: 144
2018
2022

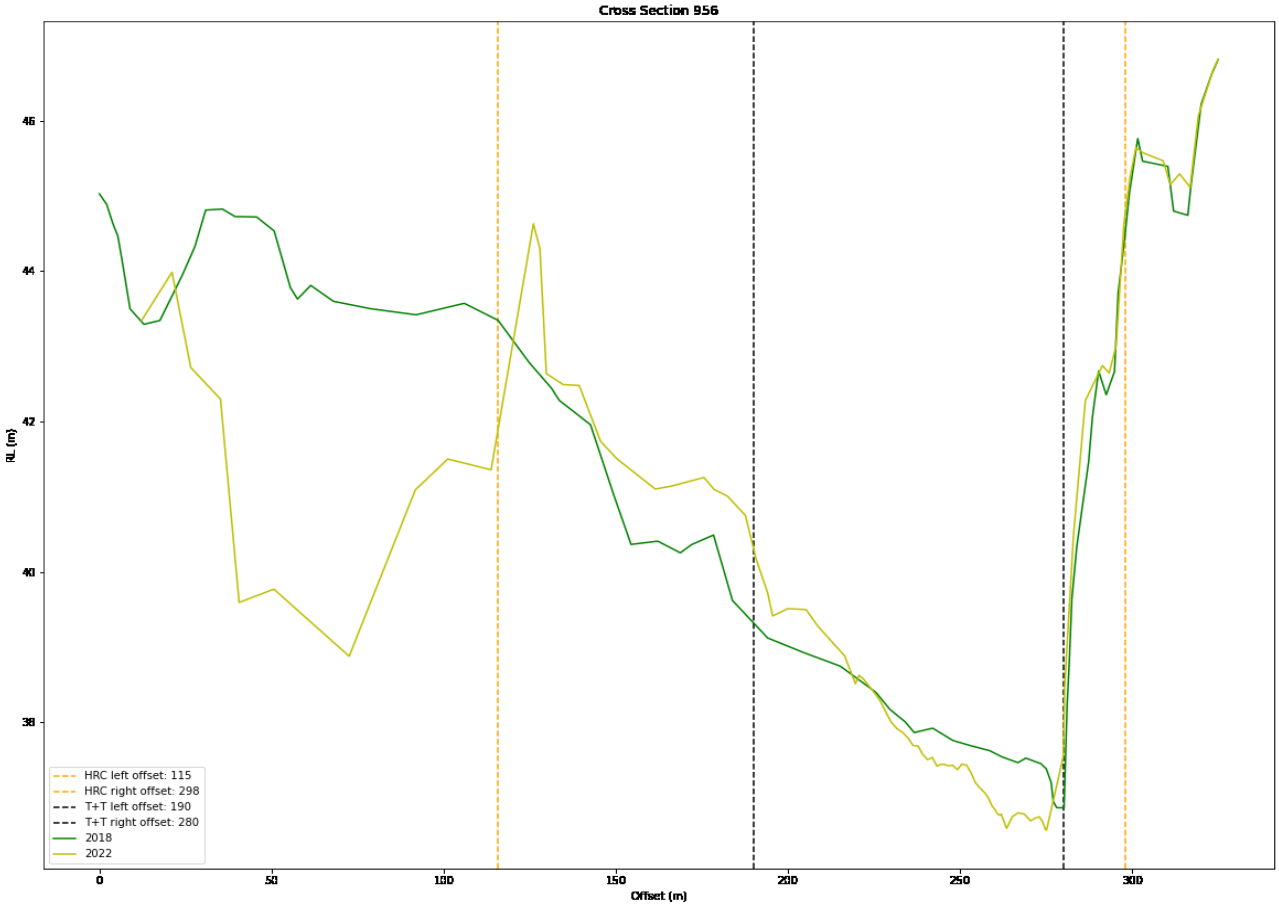

Cross Section 57 MILE
RL (m)
Offset (m)
HRC left offset: 23
HRC right offset: 108
T+T left offset: 17
T+T right offset: 95
2018
2022

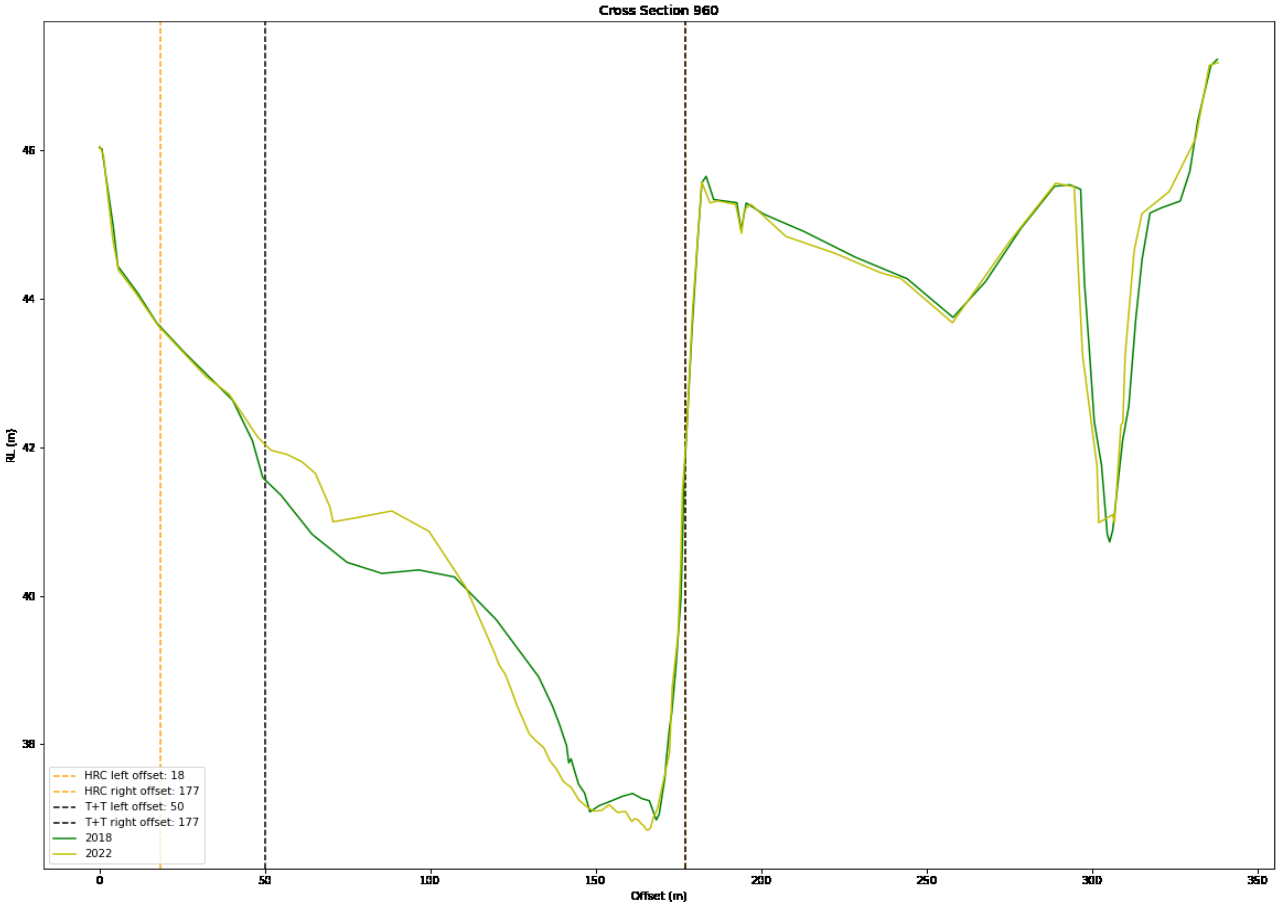

Cross Section 937
RL (m)
Offset (m)
T+T left offset: 40
T+T right offset: 145
2018
2022

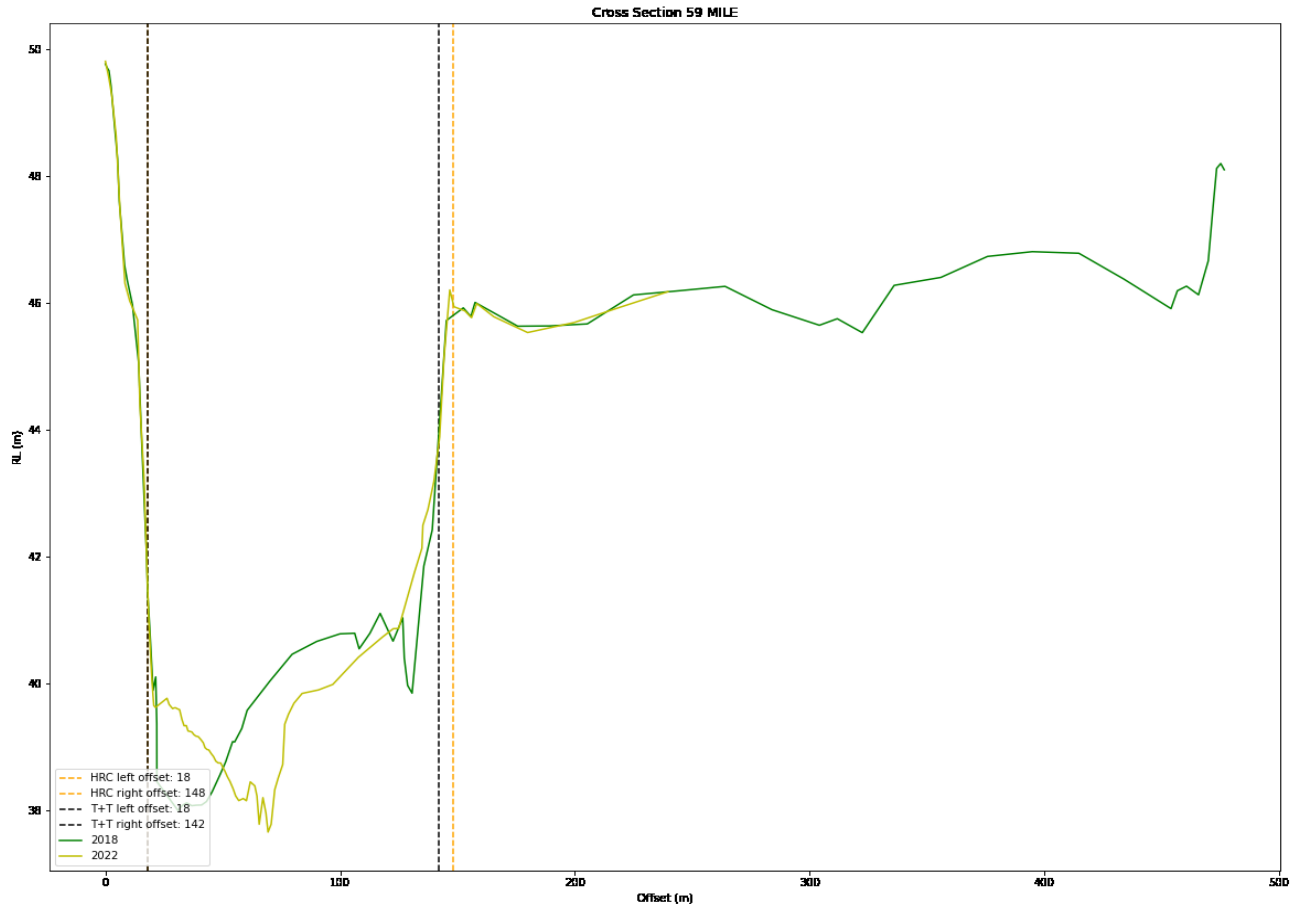

Cross Section 942
RL (m)
Offset (m)
HRC left offset: 616
HRC right offset: 779
T+T left offset: 655
T+T right offset: 757
2018
2022

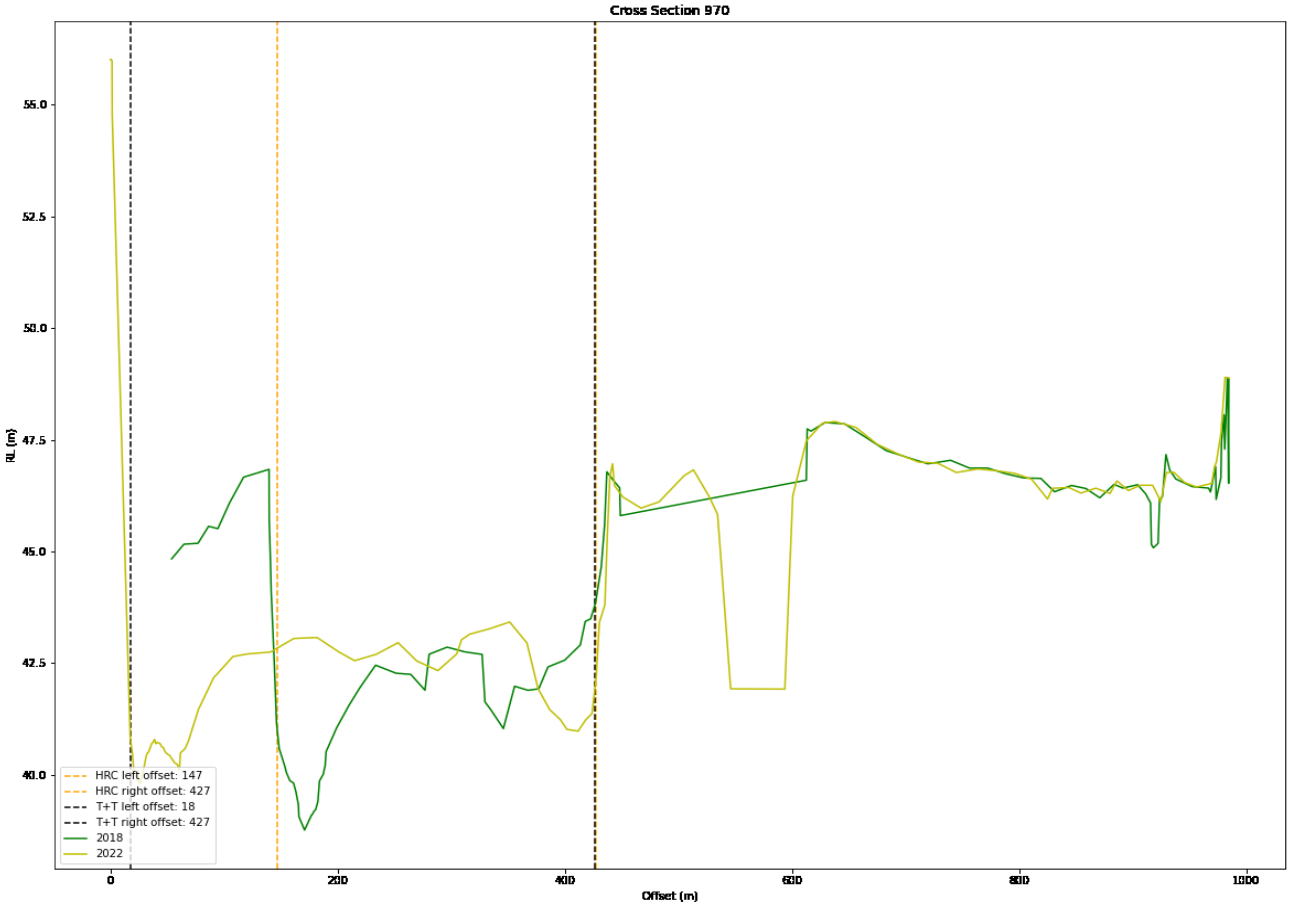

Cross Section 947
RL (m)
Offset (m)
HRC left offset: 175
HRC right offset: 322
T+T left offset: 220
T+T right offset: 313
2018
2022

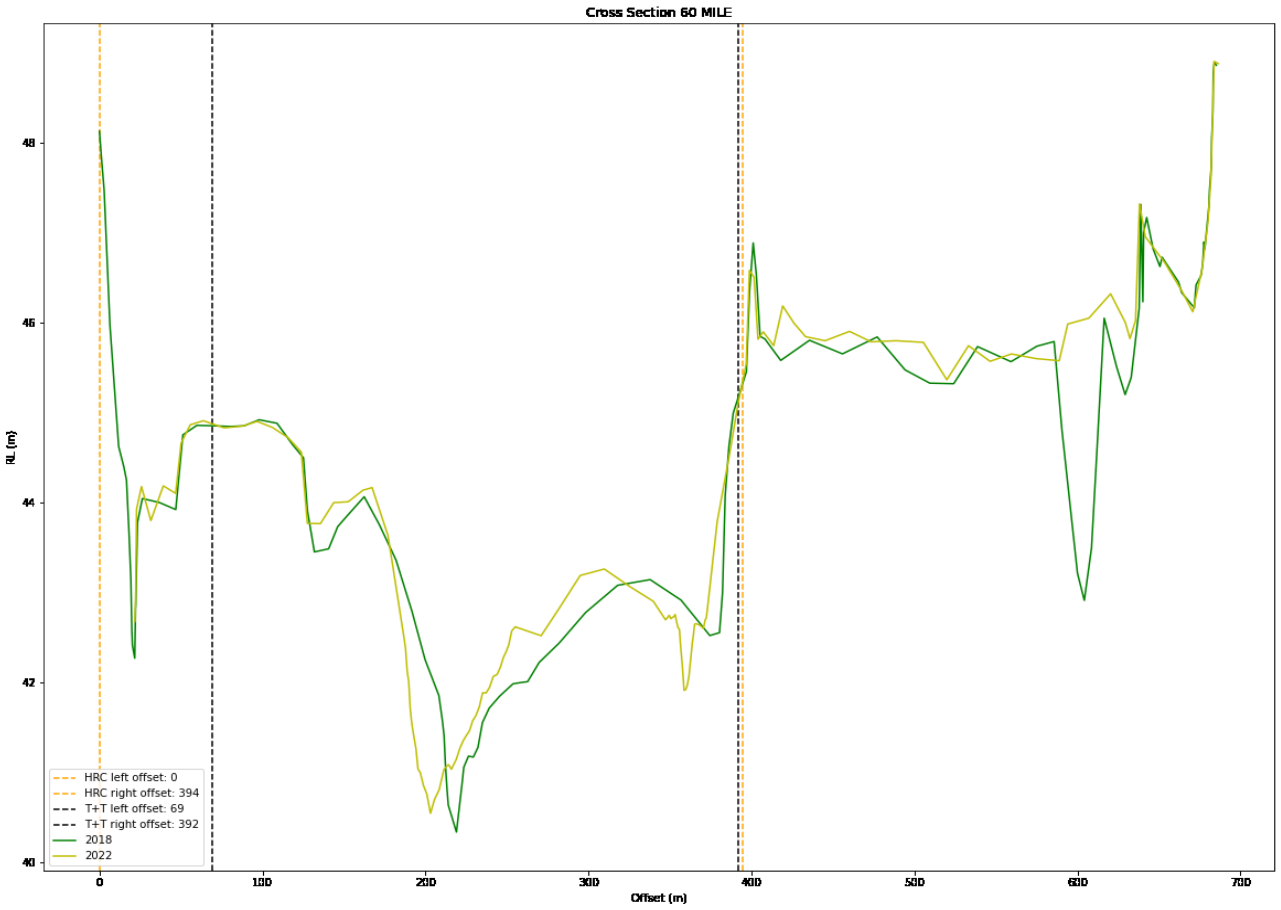

Cross Section 58 MILE
RL (m)
Offset (m)
HRC left offset: 207
HRC right offset: 321
T+T left offset: 221
T+T right offset: 306
2018
2022

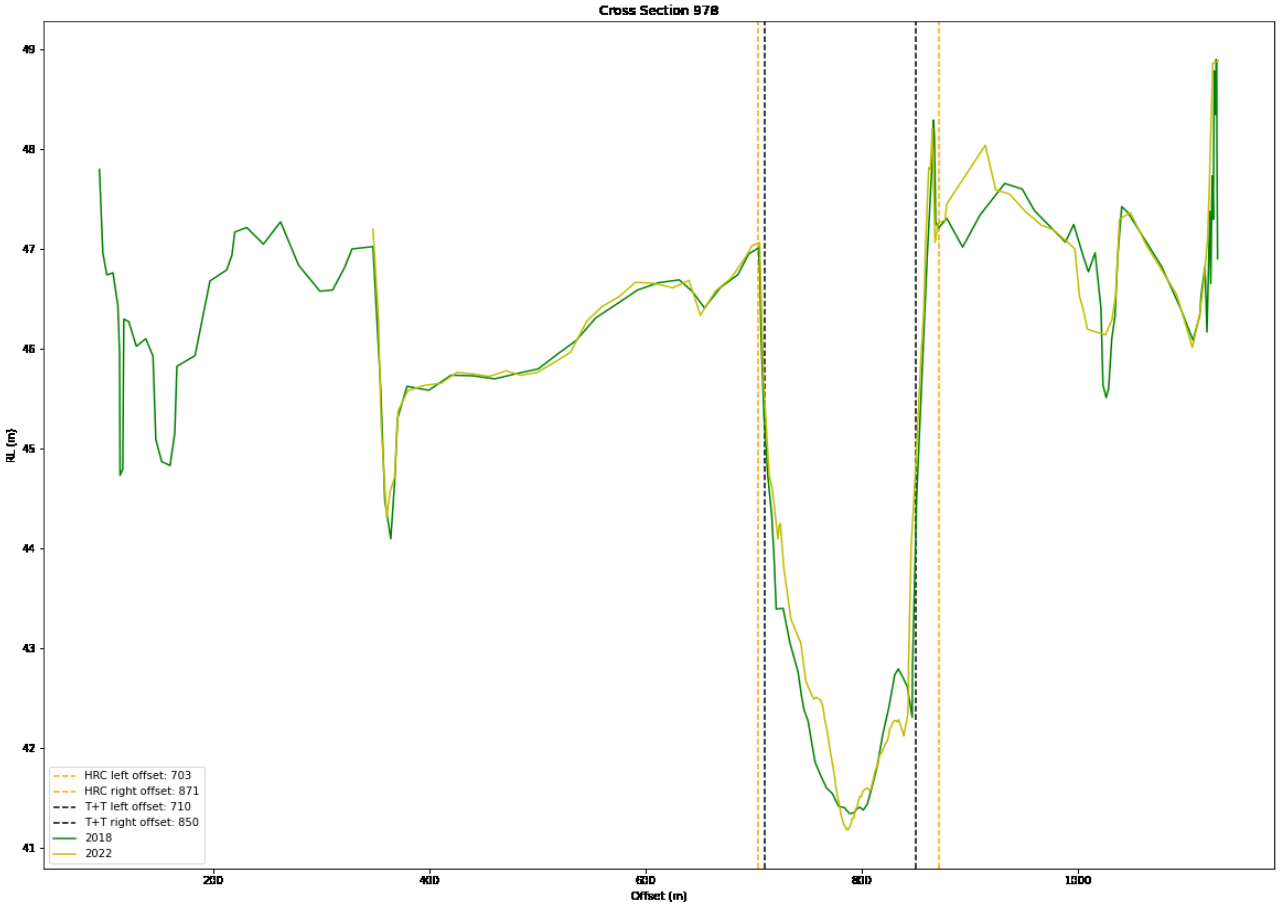

Cross Section 956
RL (m)
Offset (m)
HRC left offset: 115
HRC right offset: 298
T+T left offset: 190
T+T right offset: 280
2018
2022

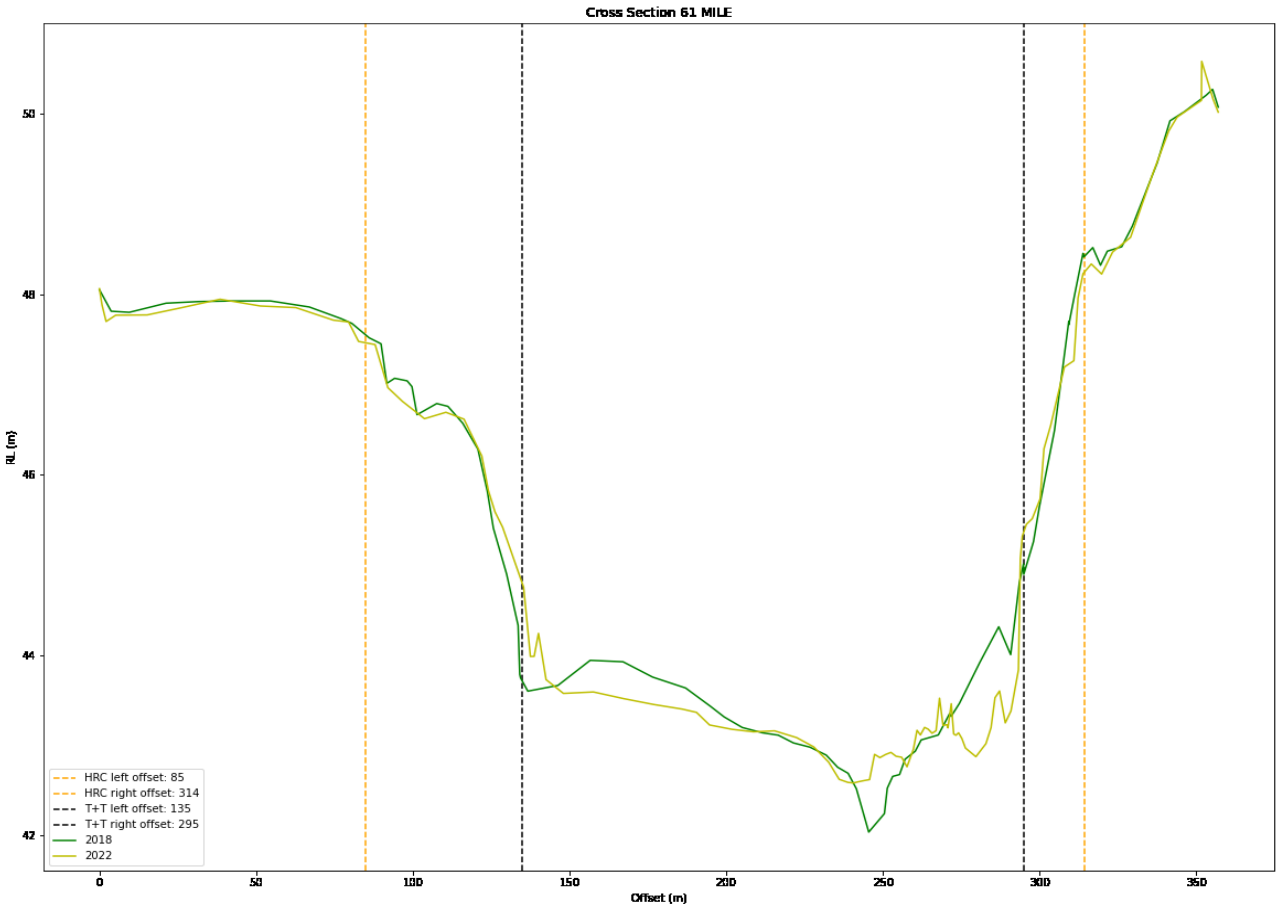

Cross Section 960
RL (m)
Offset (m)
HRC left offset: 18
HRC right offset: 177
T+T left offset: 50
T+T right offset: 177
2018
2022

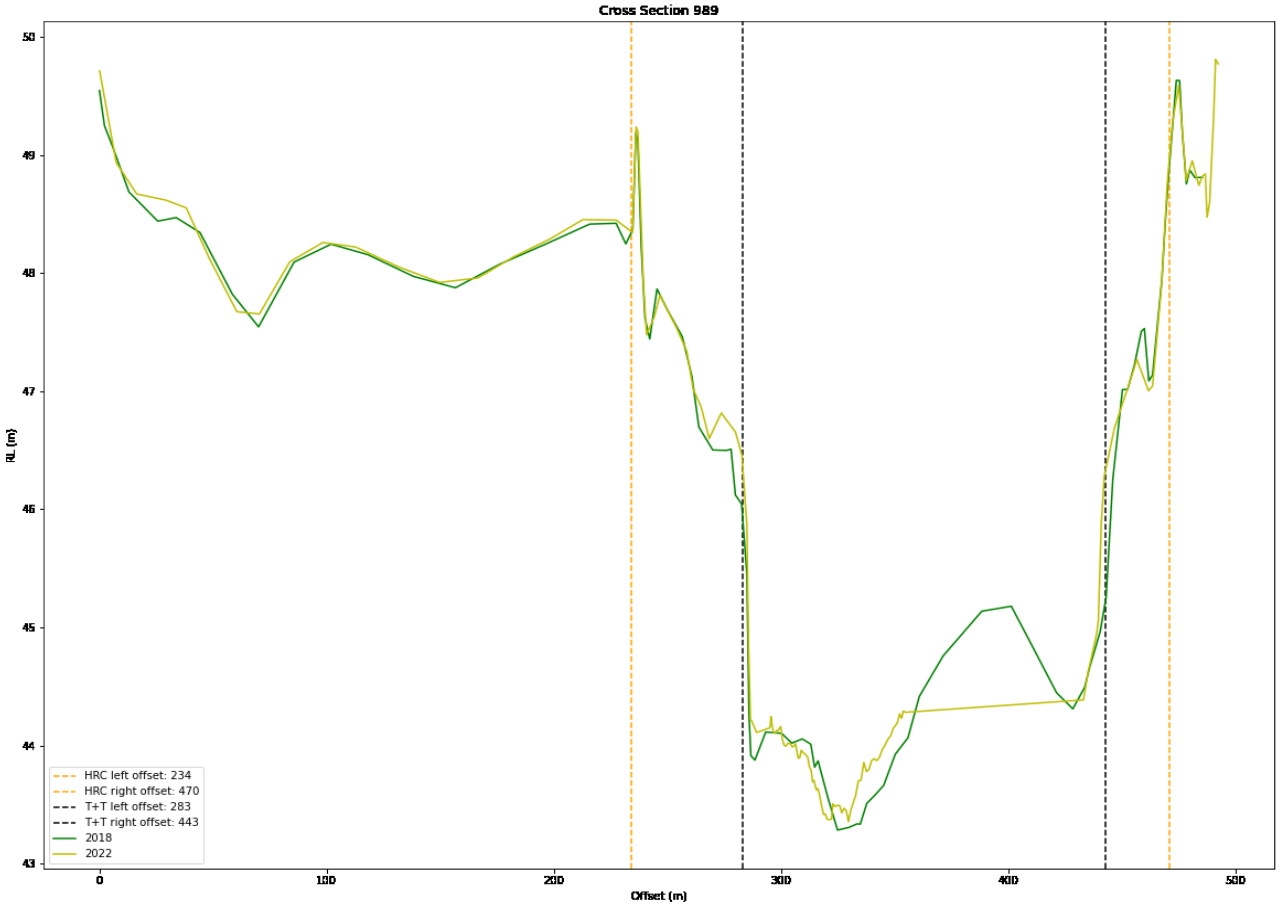

Cross Section 59 MILE
RL (m)
Offset (m)
HRC left offset: 18
HRC right offset: 148
T+T left offset: 18
T+T right offset: 142
2018
2022

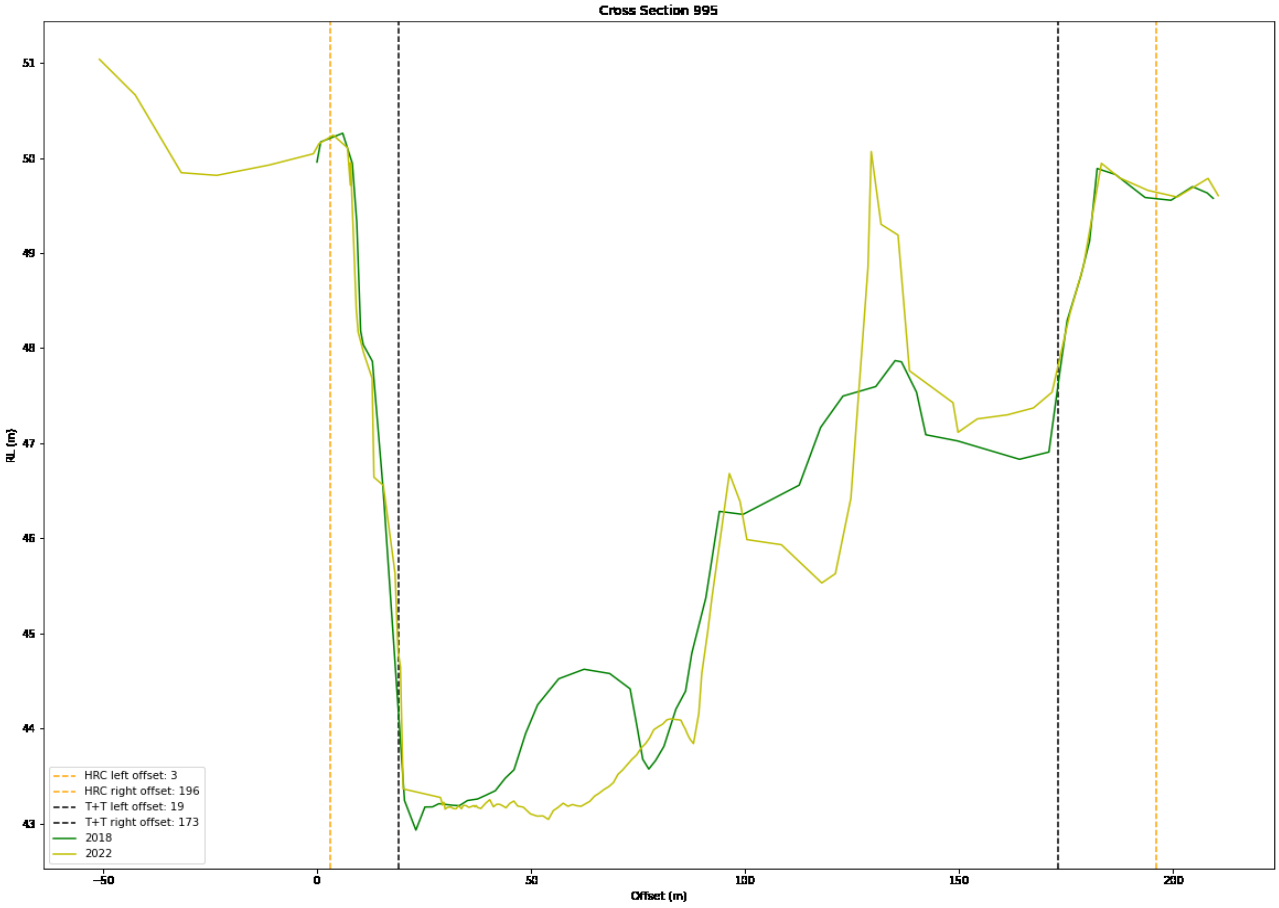

Cross Section 970
RL (m)
Offset (m)
HRC left offset: 147
HRC right offset: 427
T+T left offset: 18
T+T right offset: 427
2018
2022

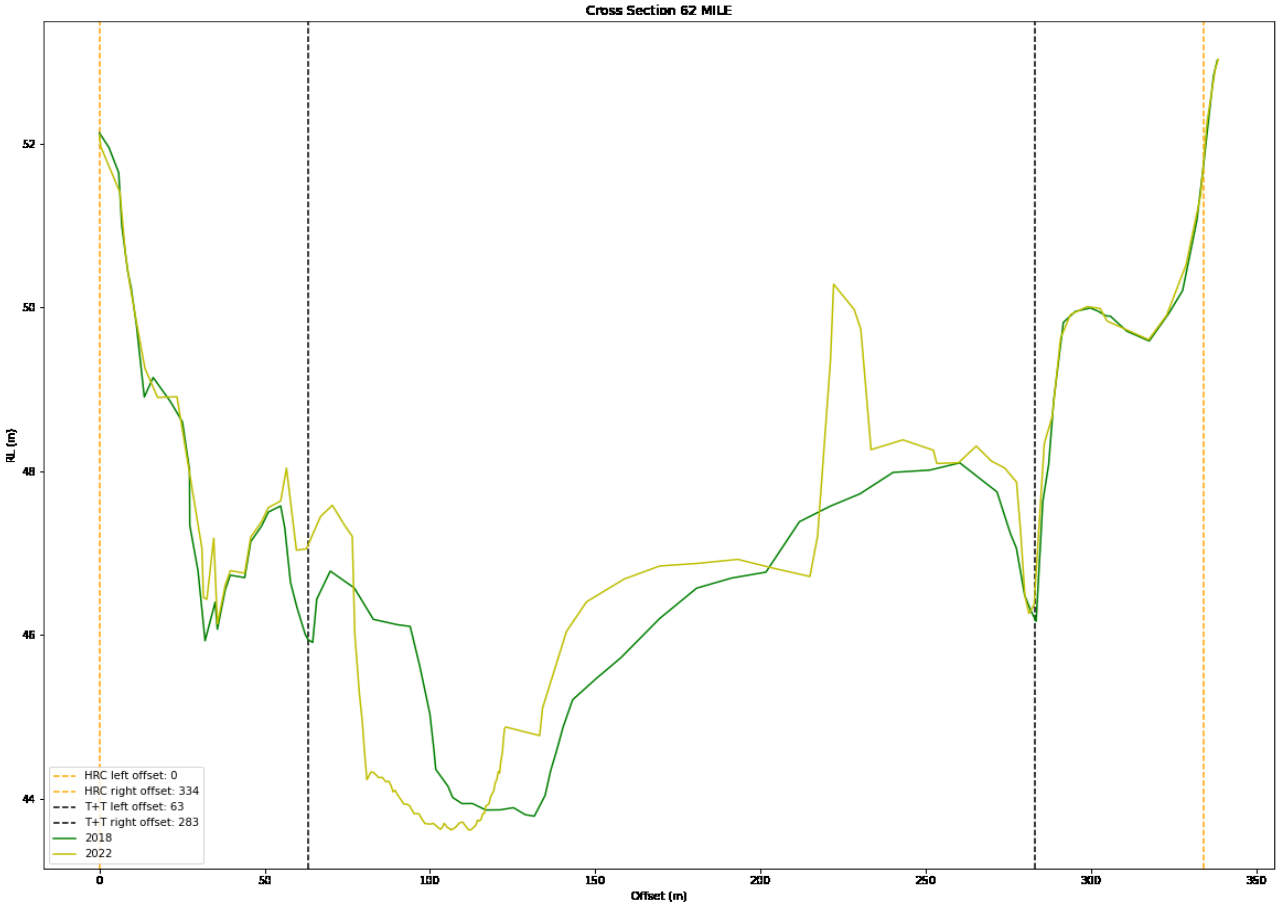

Cross Section 60 MILE
RL (m)
Offset (m)
HRC left offset: 0
HRC right offset: 394
T+T left offset: 69
T+T right offset: 392
2018
2022

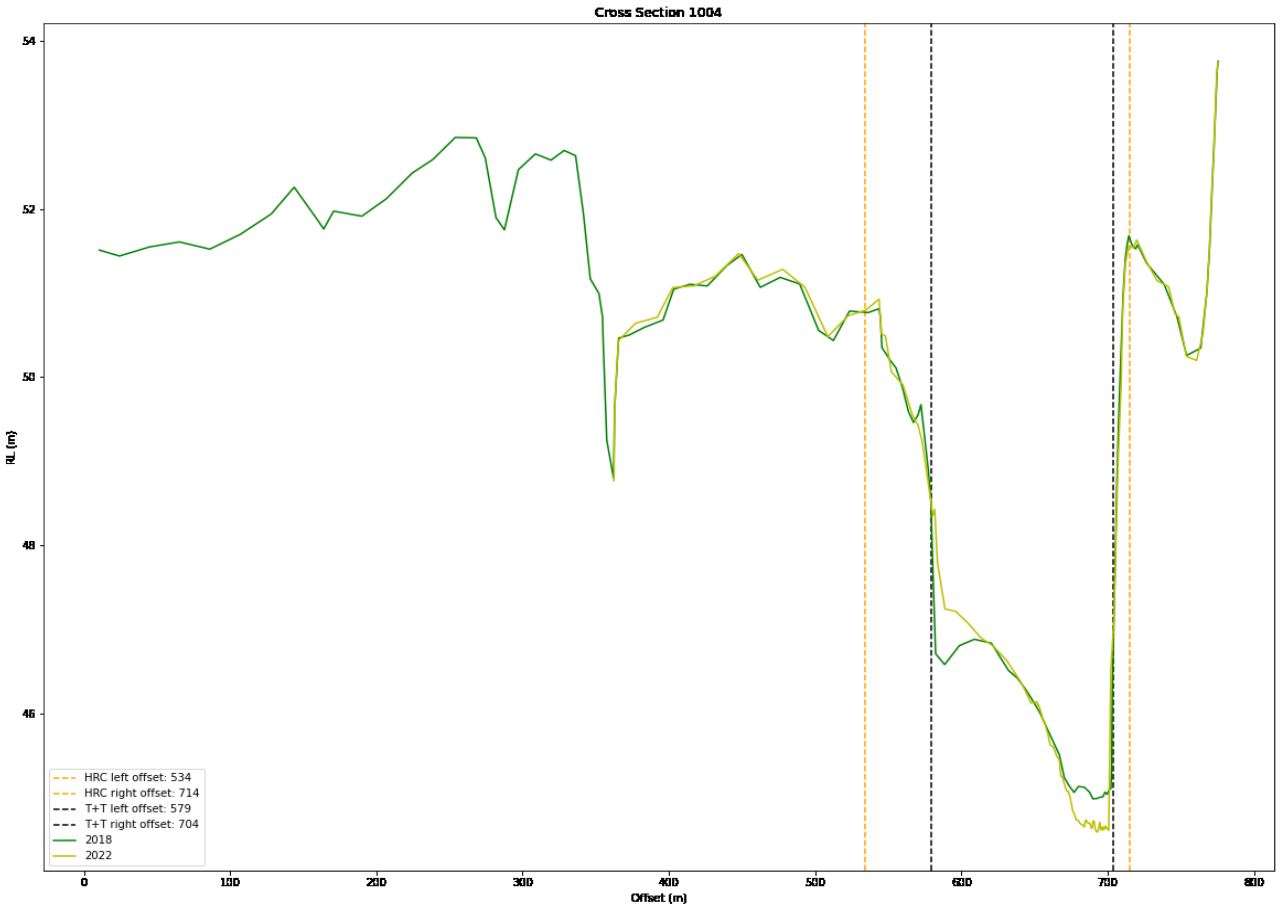

Cross Section 978
RL (m)
Offset (m)
HRC left offset: 703
HRC right offset: 871
T+T left offset: 710
T+T right offset: 850
2018
2022

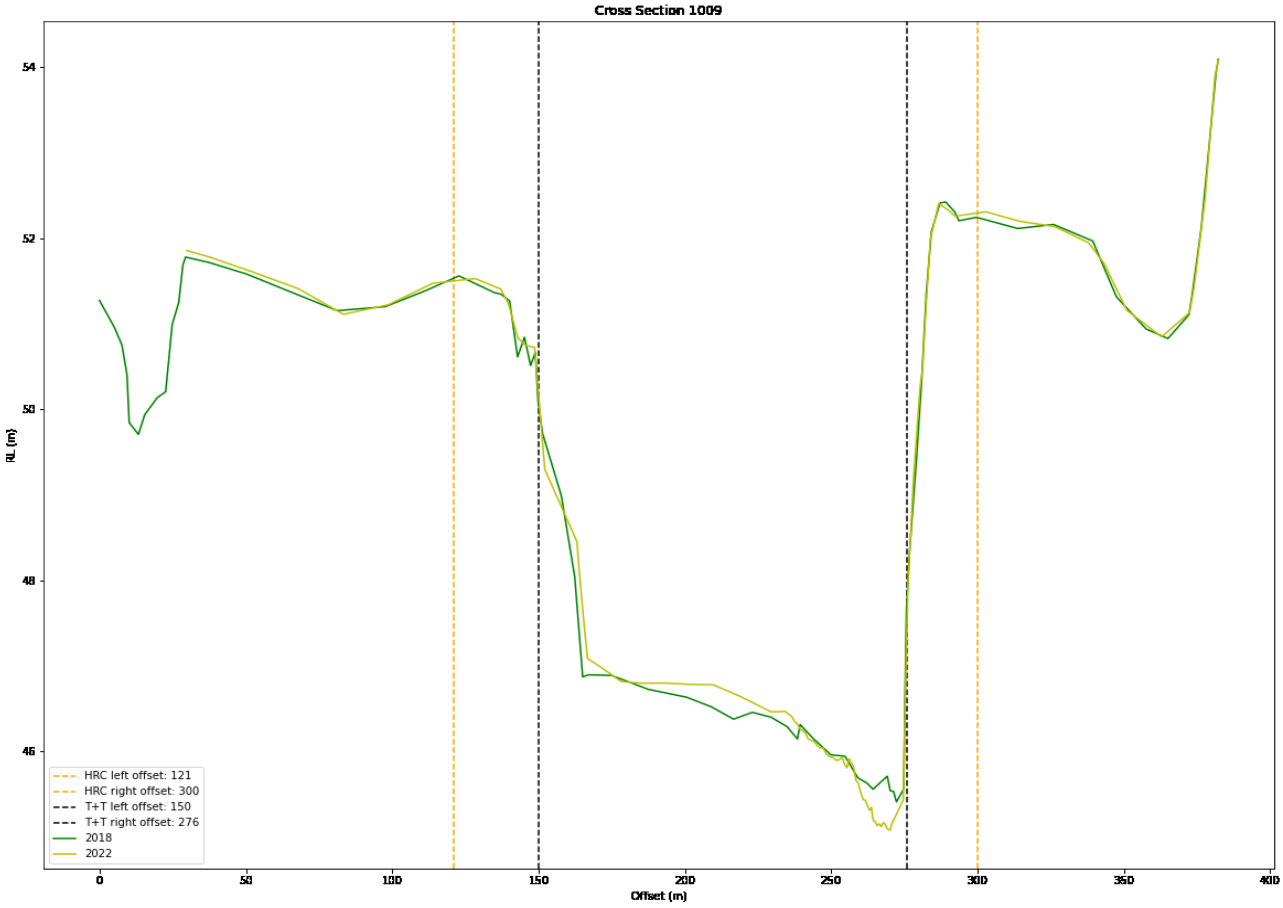

Cross Section 61 MILE
RL (m)
Offset (m)
HRC left offset: 85
HRC right offset: 314
T+T left offset: 135
T+T right offset: 295
2018
2022

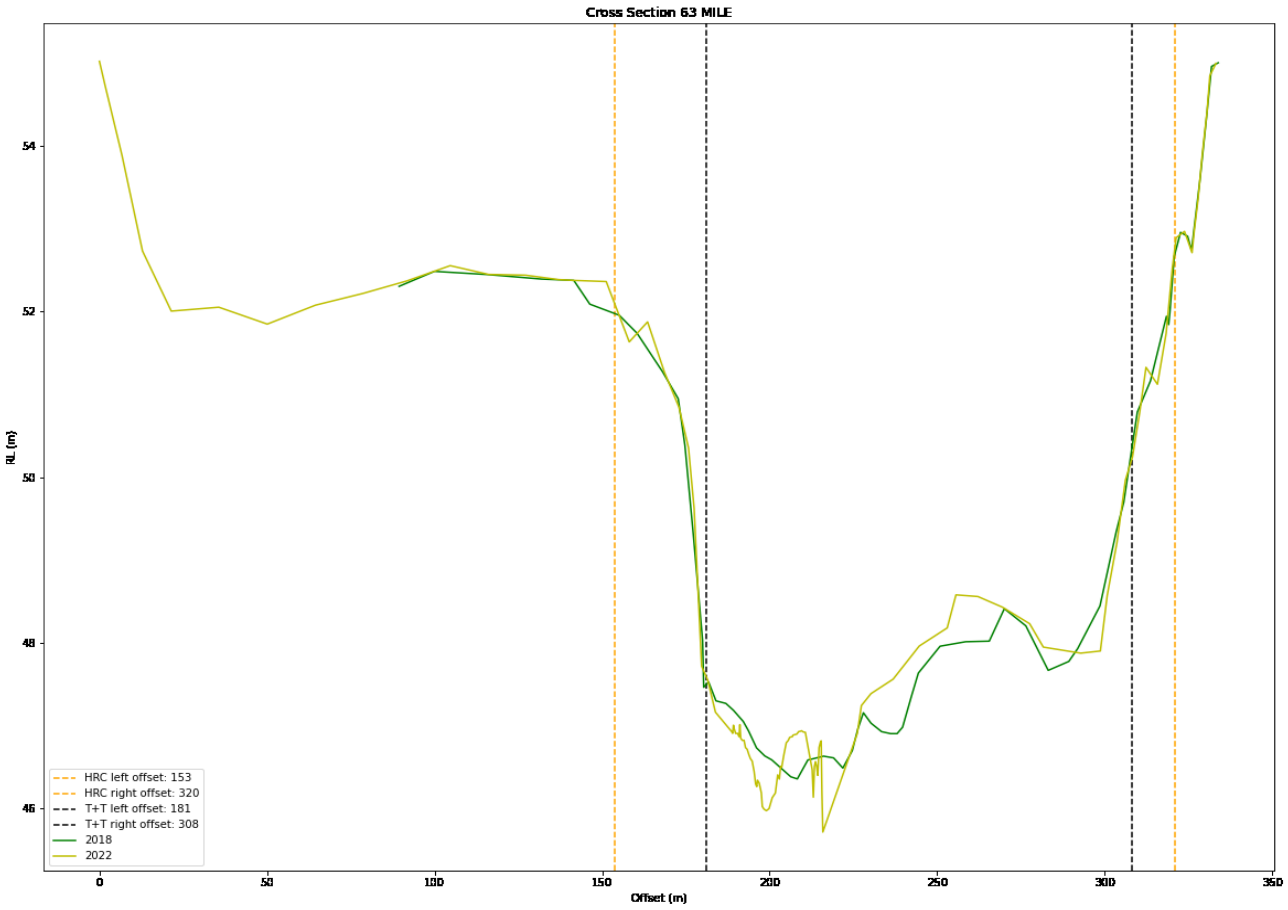

Cross Section 989
RL (m)
Offset (m)
HRC left offset: 234
HRC right offset: 470
T+T left offset: 283
T+T right offset: 443
2018
2022


Cross Section 995
RL (m)
Offset (m)
HRC left offset: 3
HRC right offset: 196
T+T left offset: 19
T+T right offset: 173
2018
2022


Cross Section 62 MILE
RL (m)
Offset (m)
HRC left offset: 0
HRC right offset: 334
T+T left offset: 63
T+T right offset: 283
2018
2022


Cross Section 1004
RL (m)
Offset (m)
HRC left offset: 534
HRC right offset: 714
T+T left offset: 579
T+T right offset: 704
2018
2022

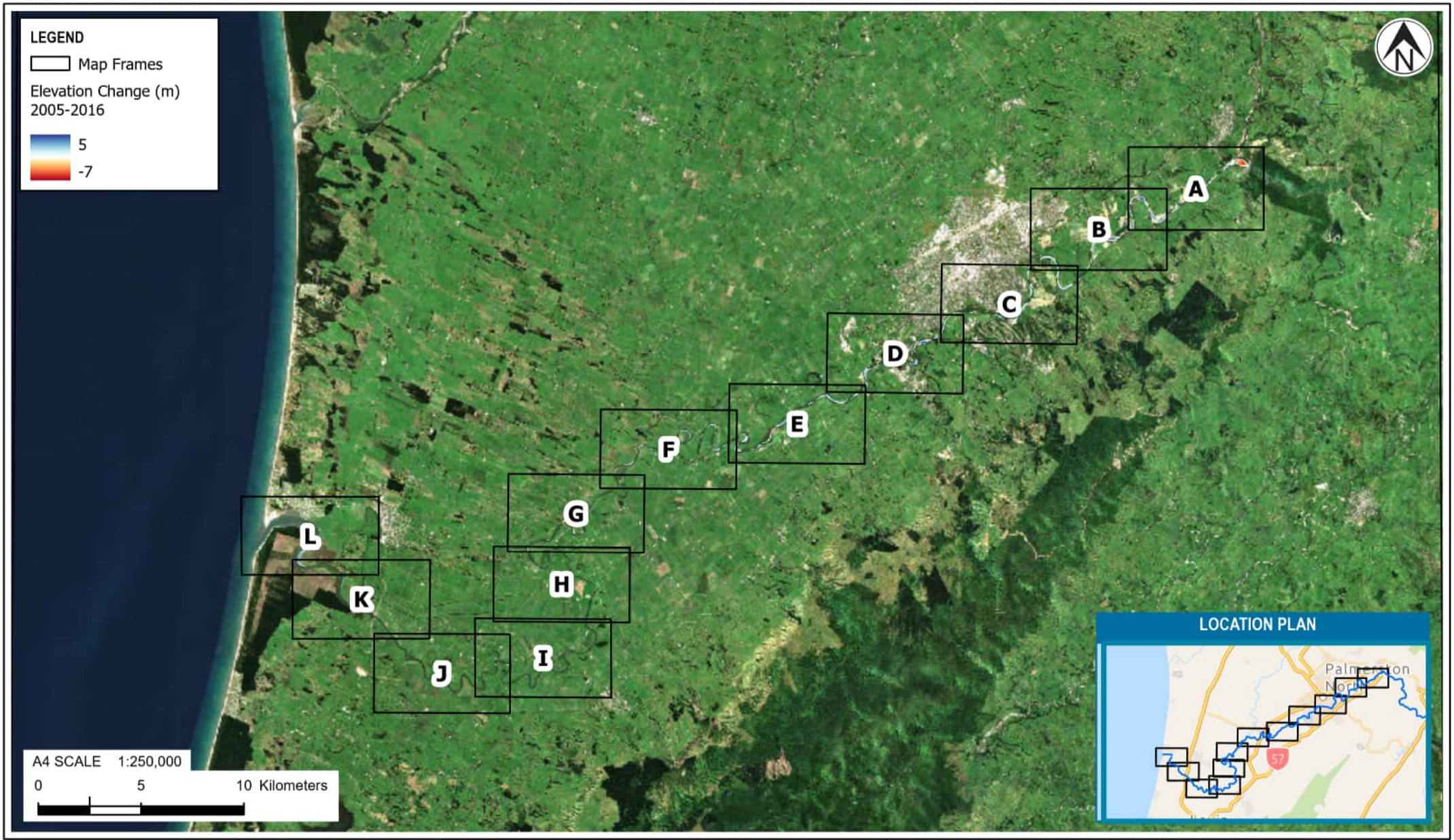

Cross Section 1009
RL (m)
Offset (m)
HRC left offset: 121
HRC right offset: 300
T+T left offset: 150
T+T right offset: 276
2018
2022


Cross Section 63 MILE
RL (m)
Offset (m)
HRC left offset: 153
HRC right offset: 320
T+T left offset: 181
T+T right offset: 308
2018
2022

# Appendix D Geomorphic Change Detection raw results

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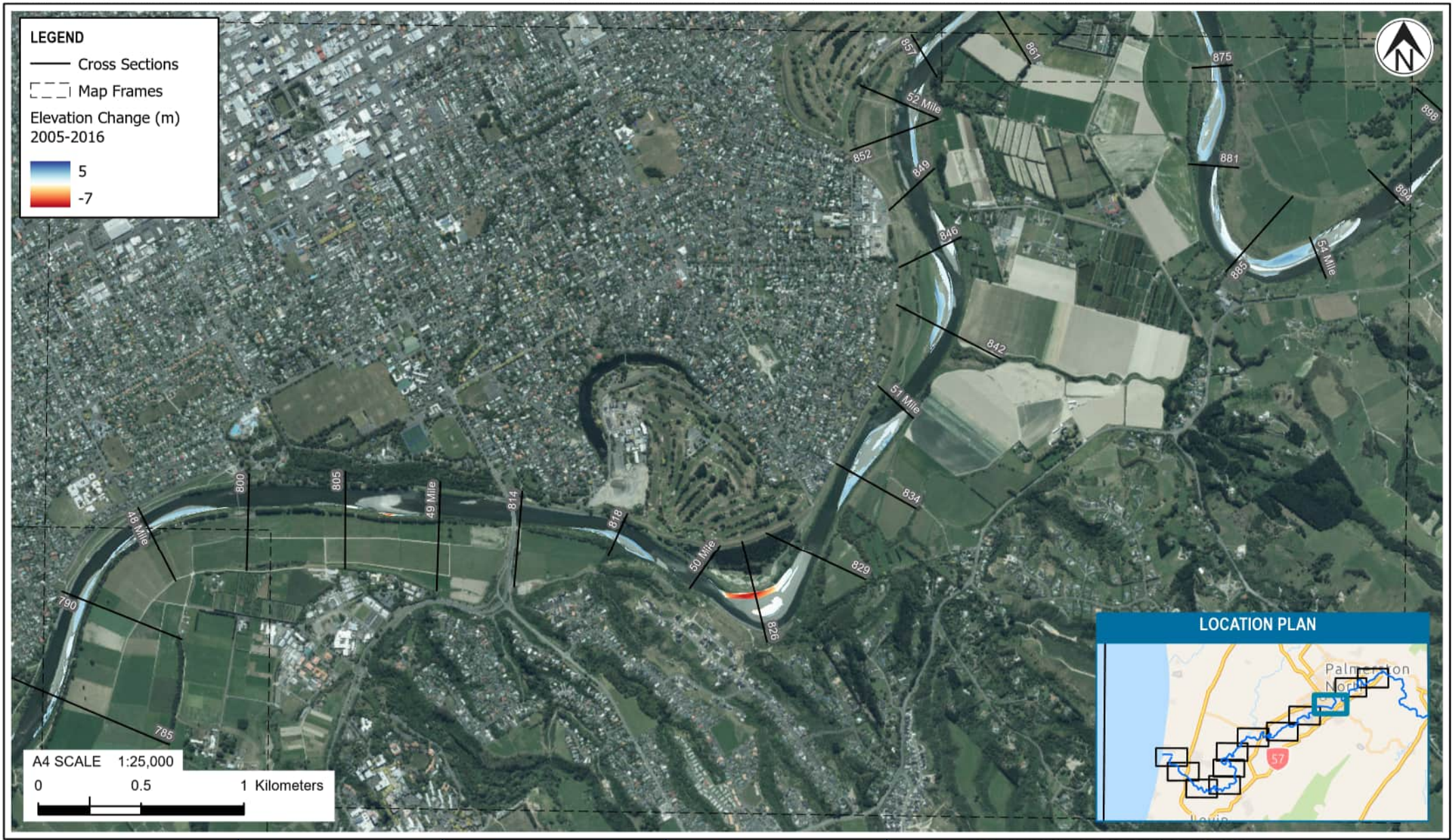
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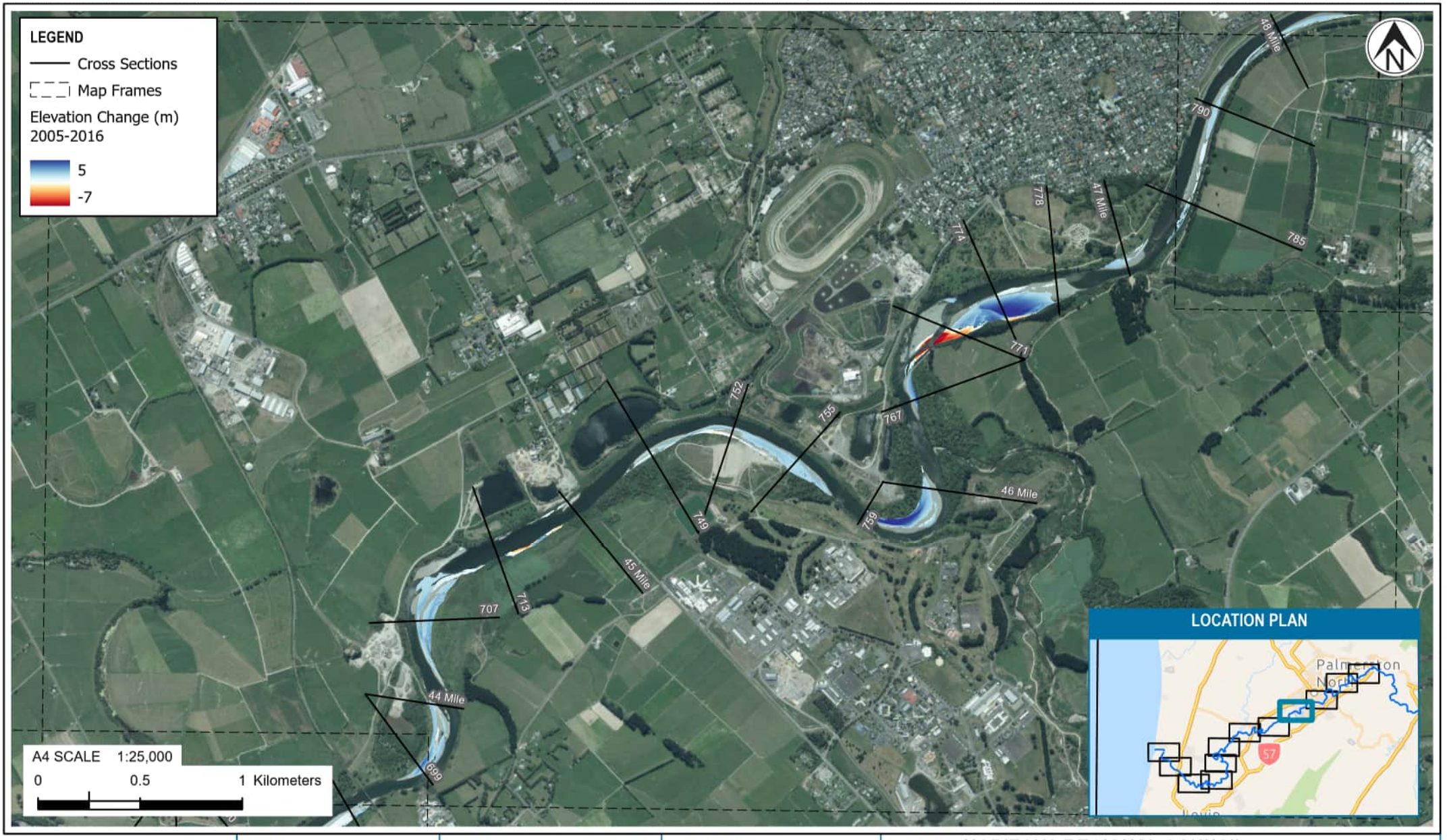
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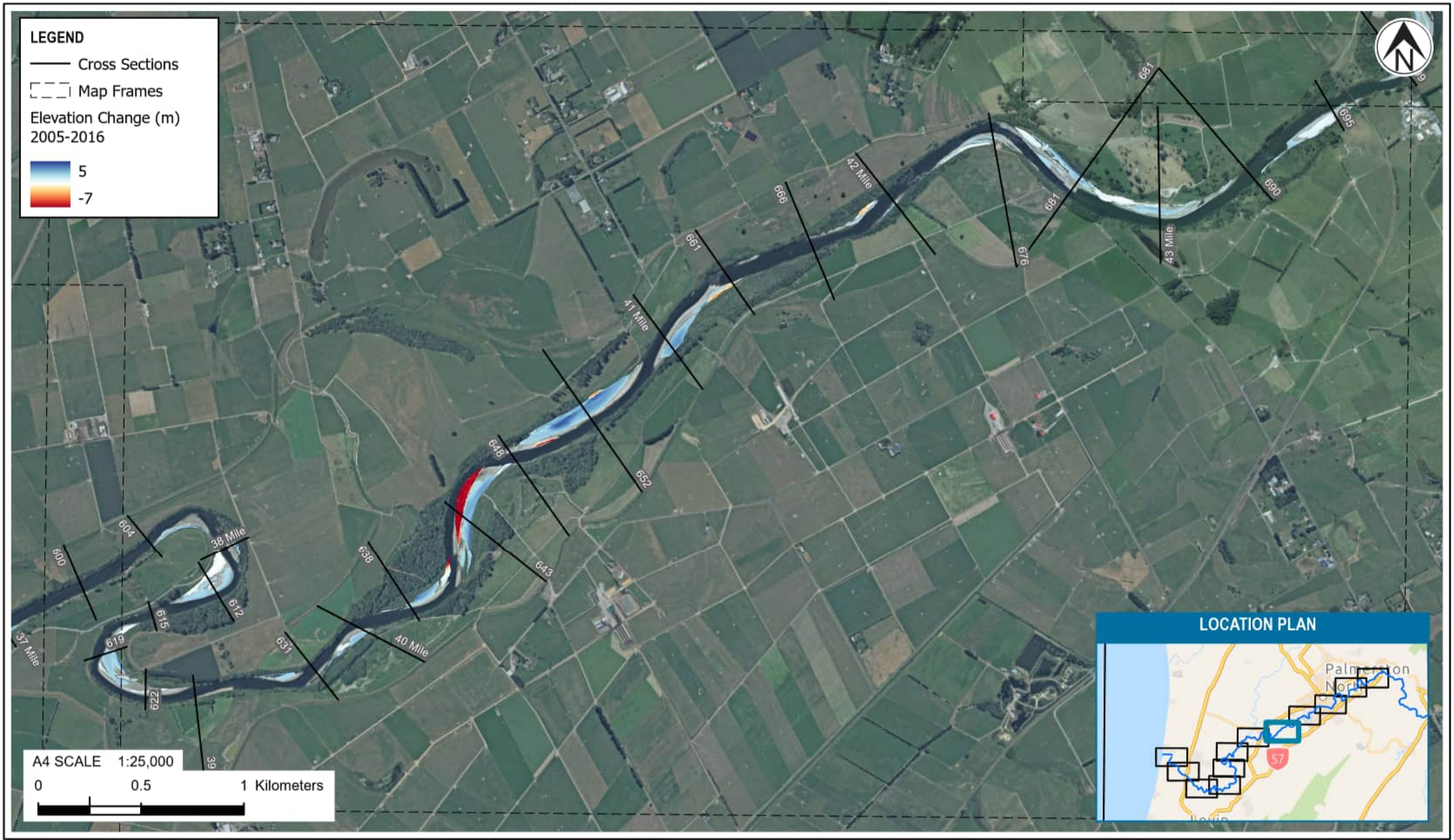
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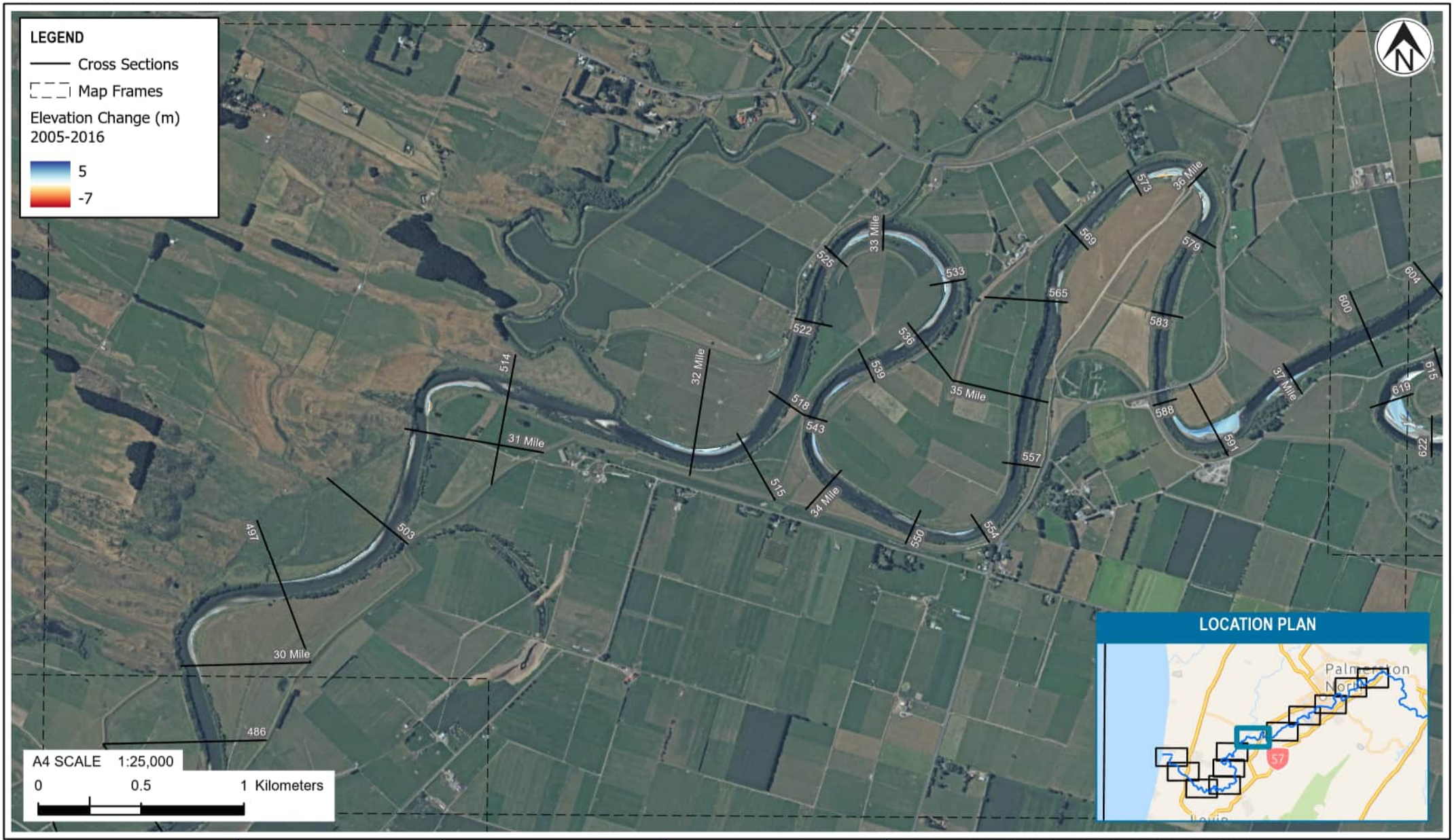
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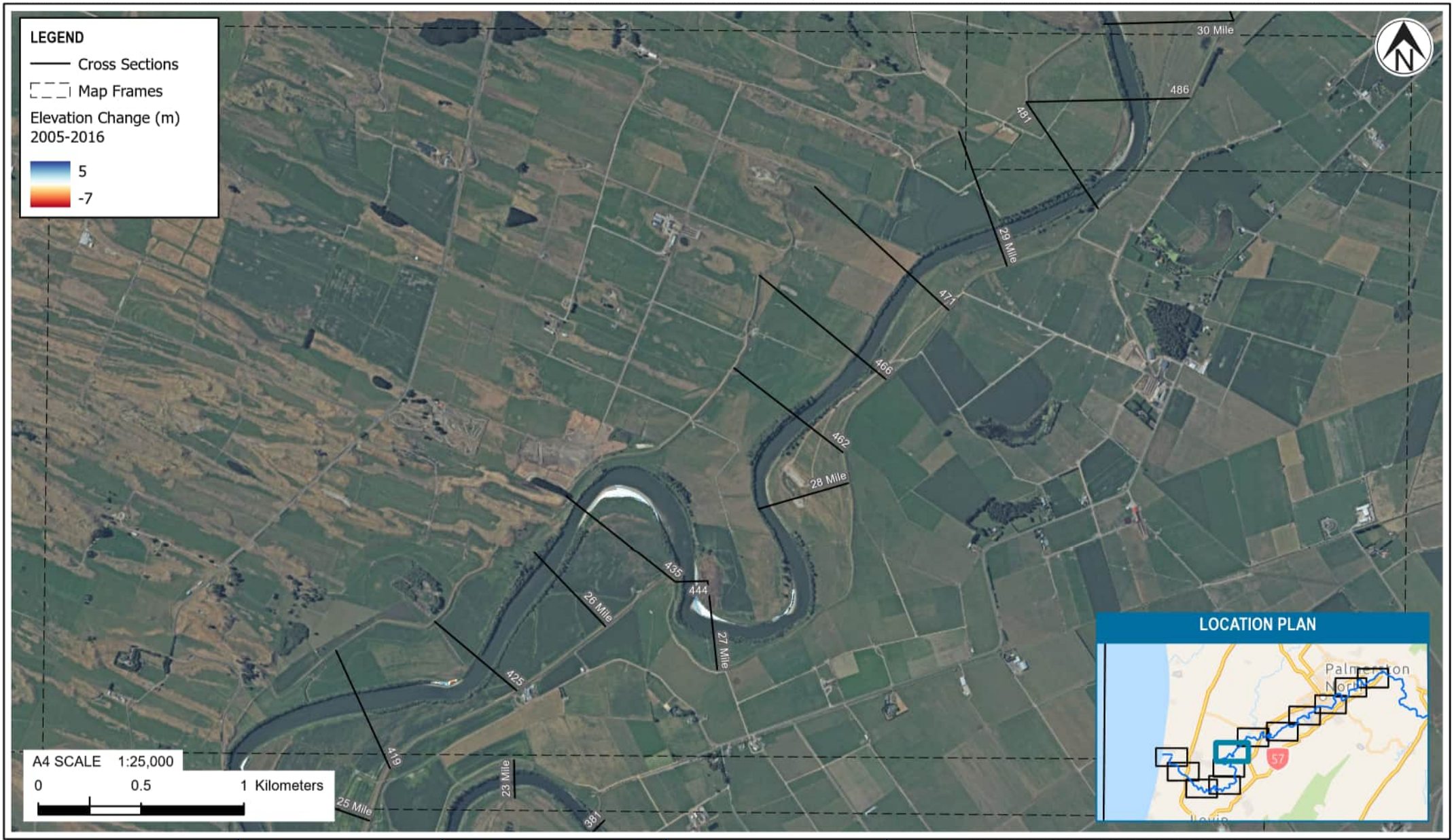
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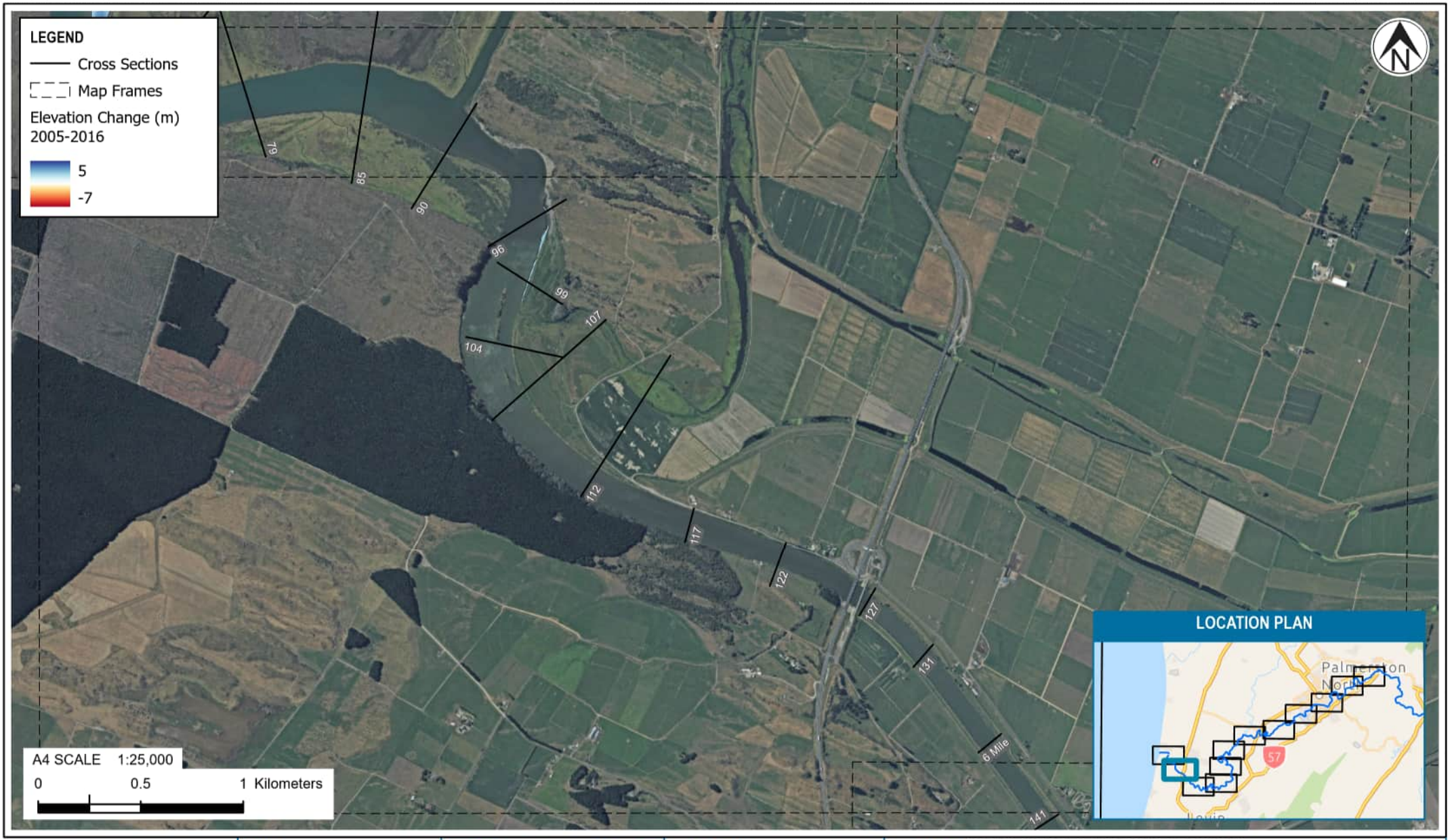
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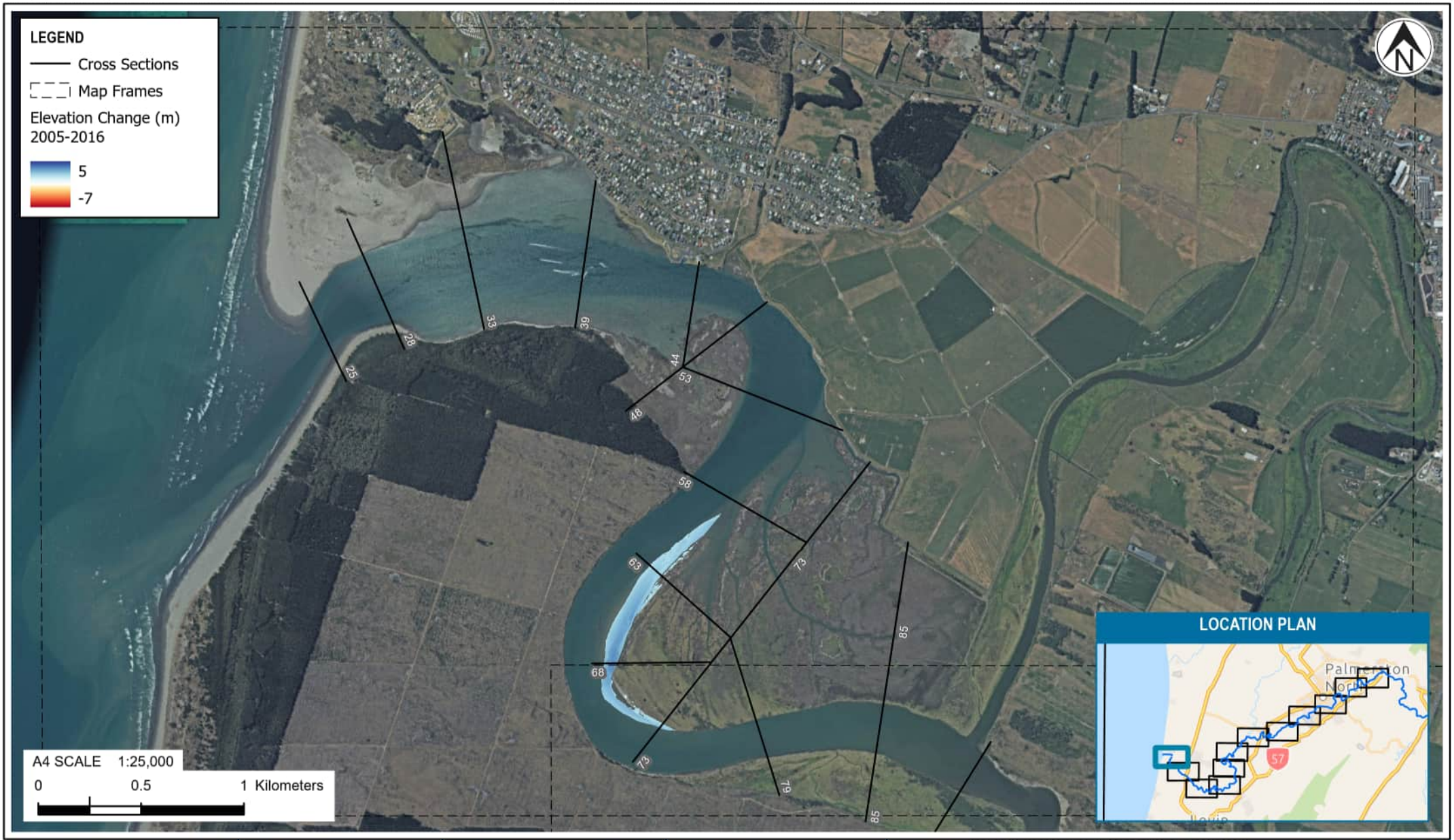
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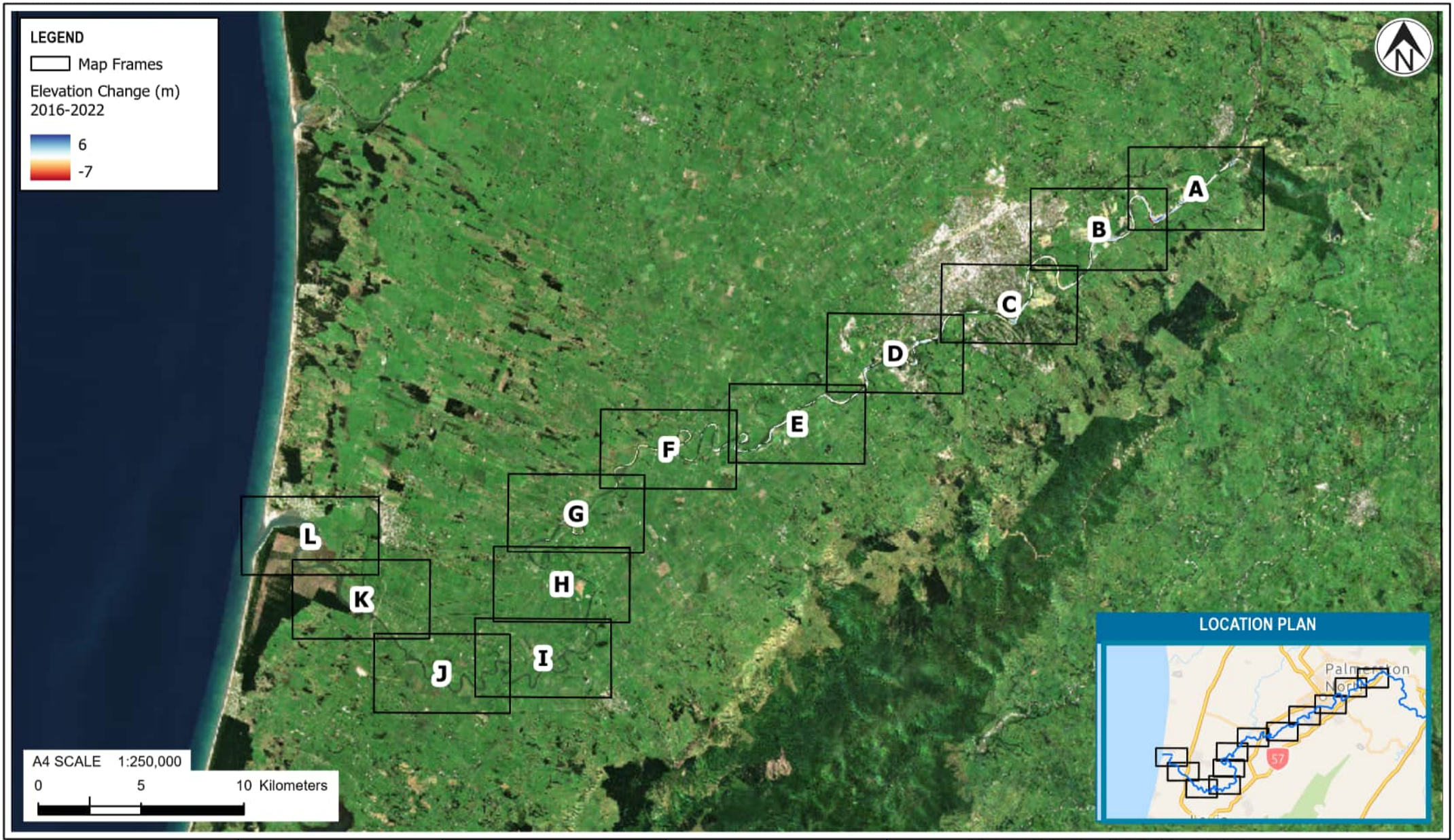
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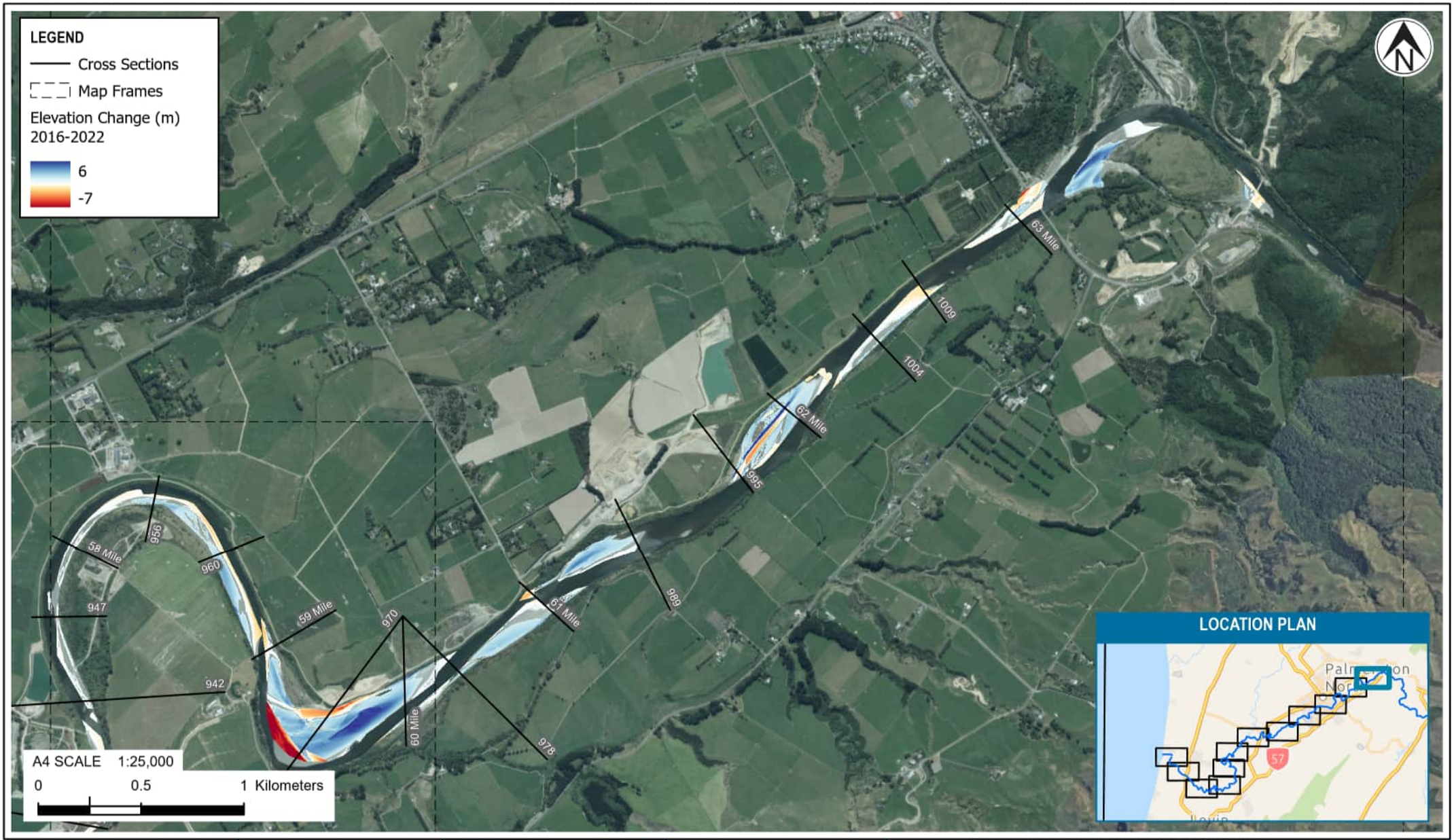
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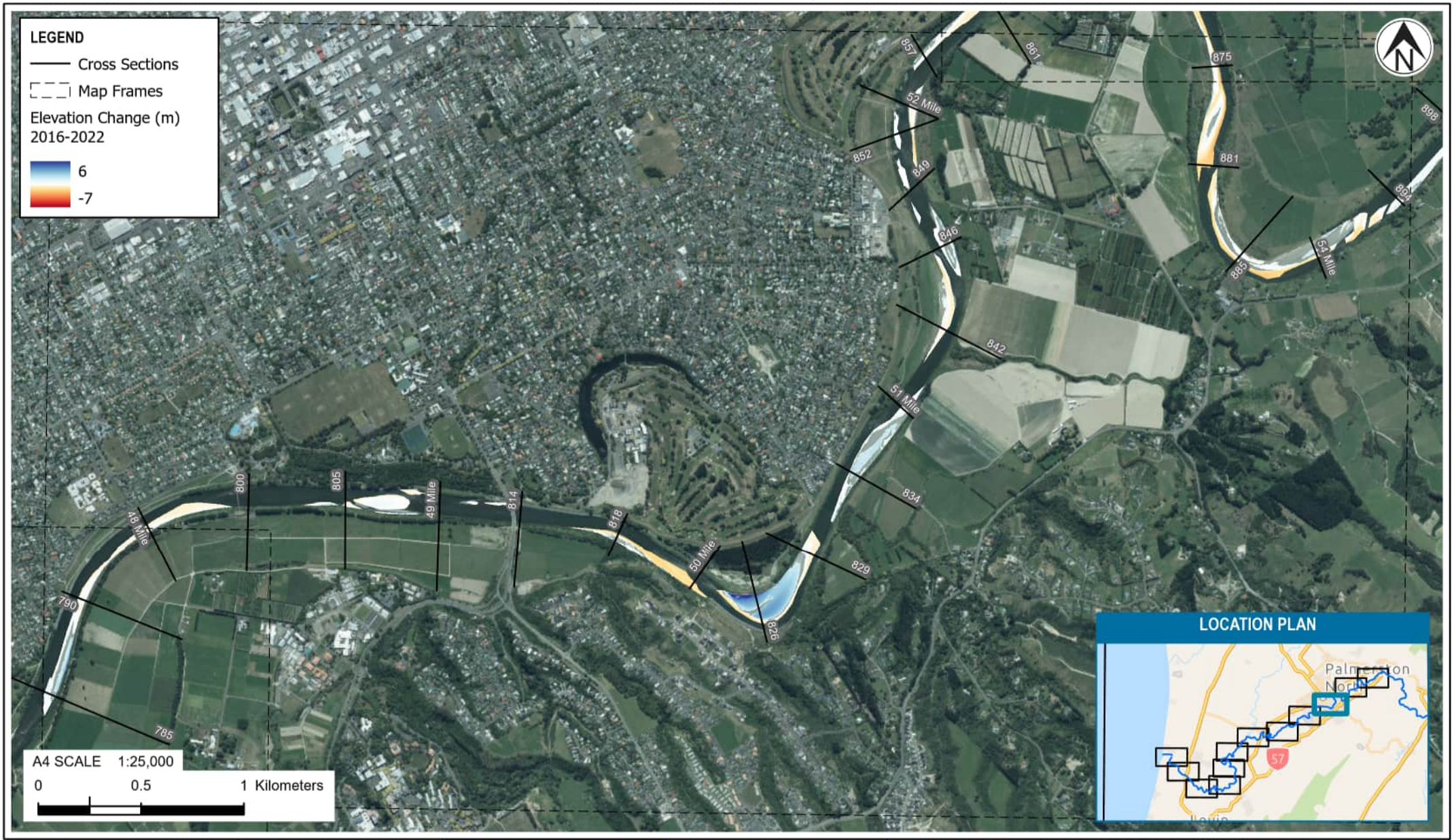
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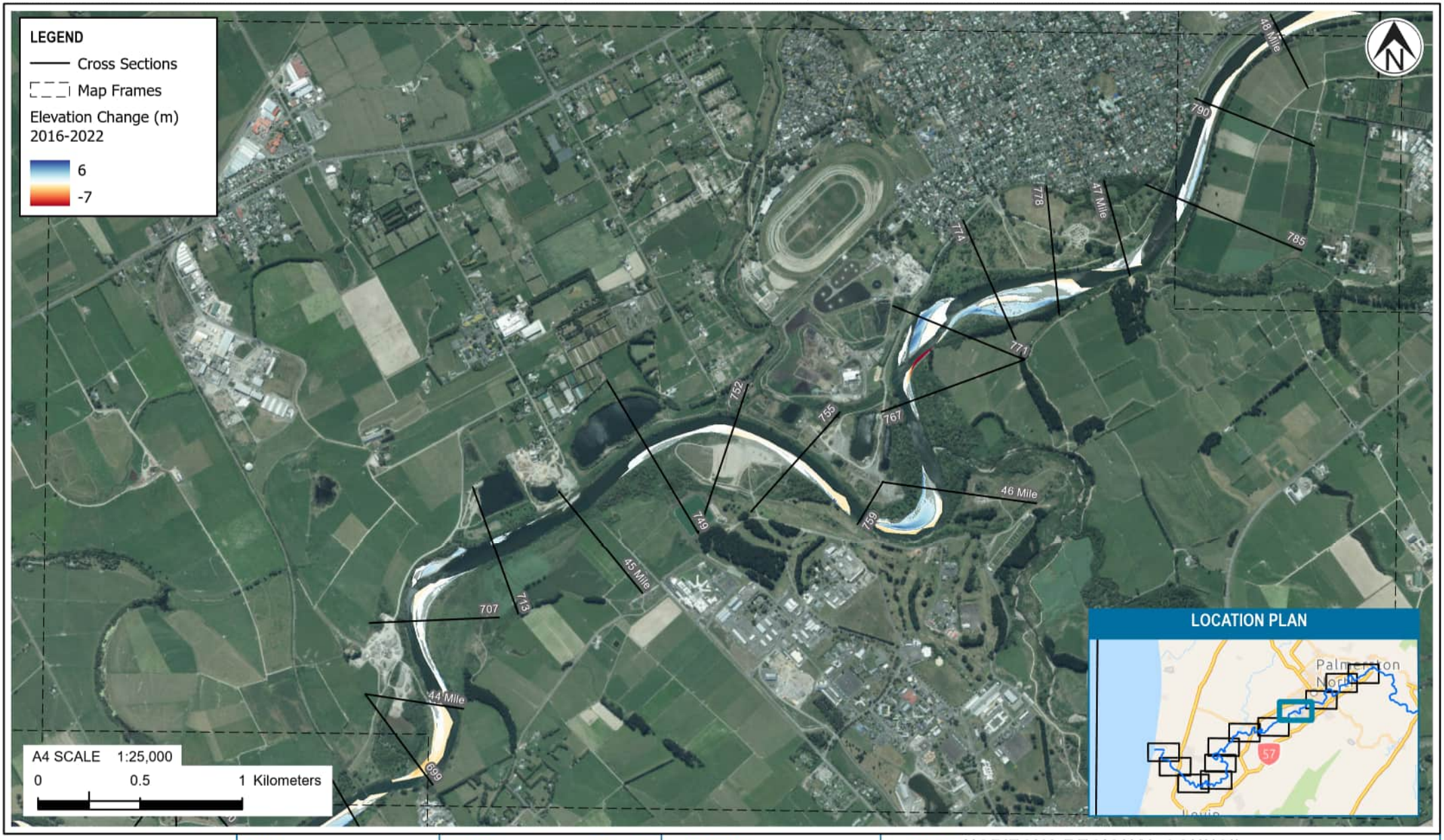
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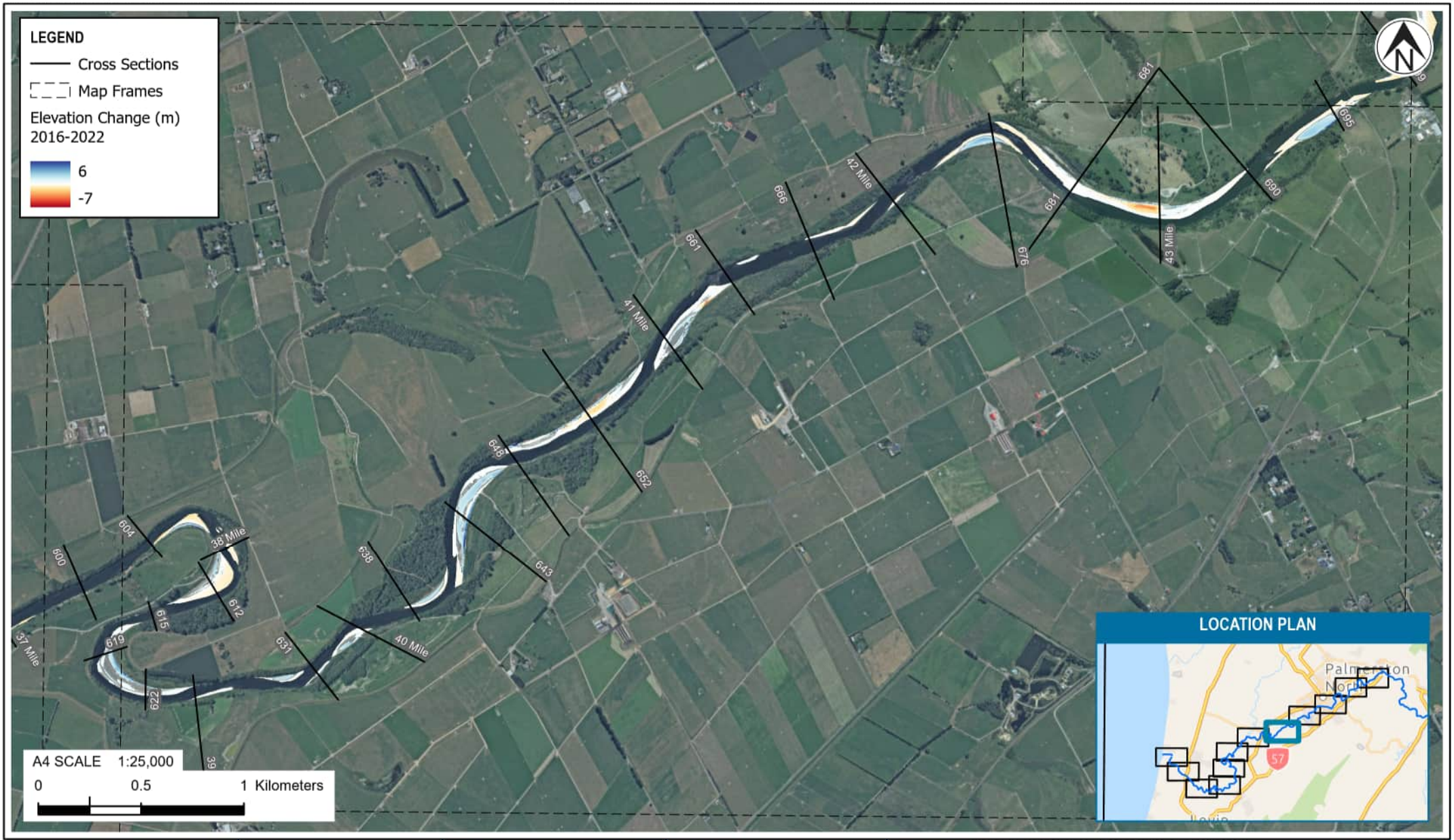
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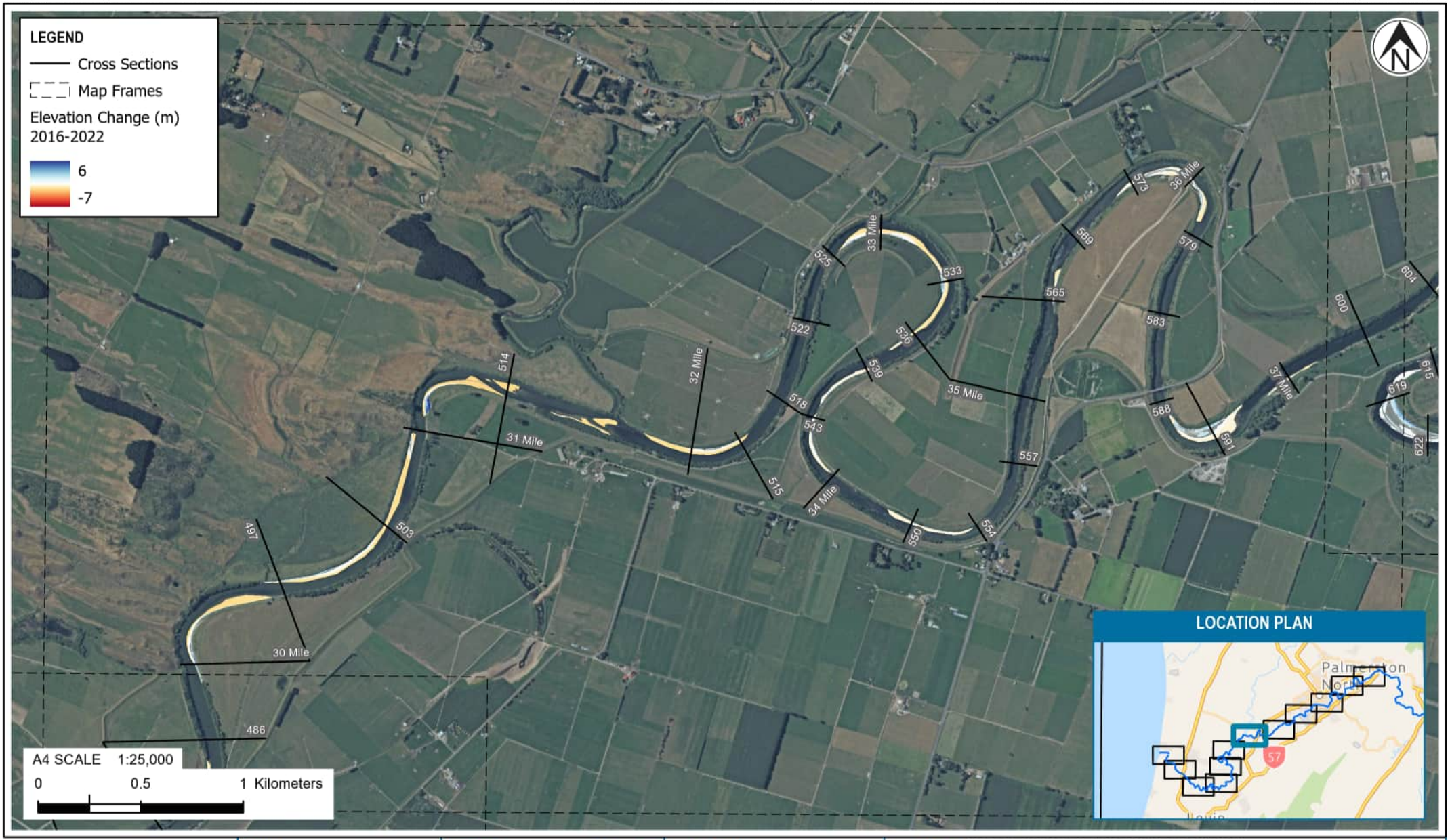
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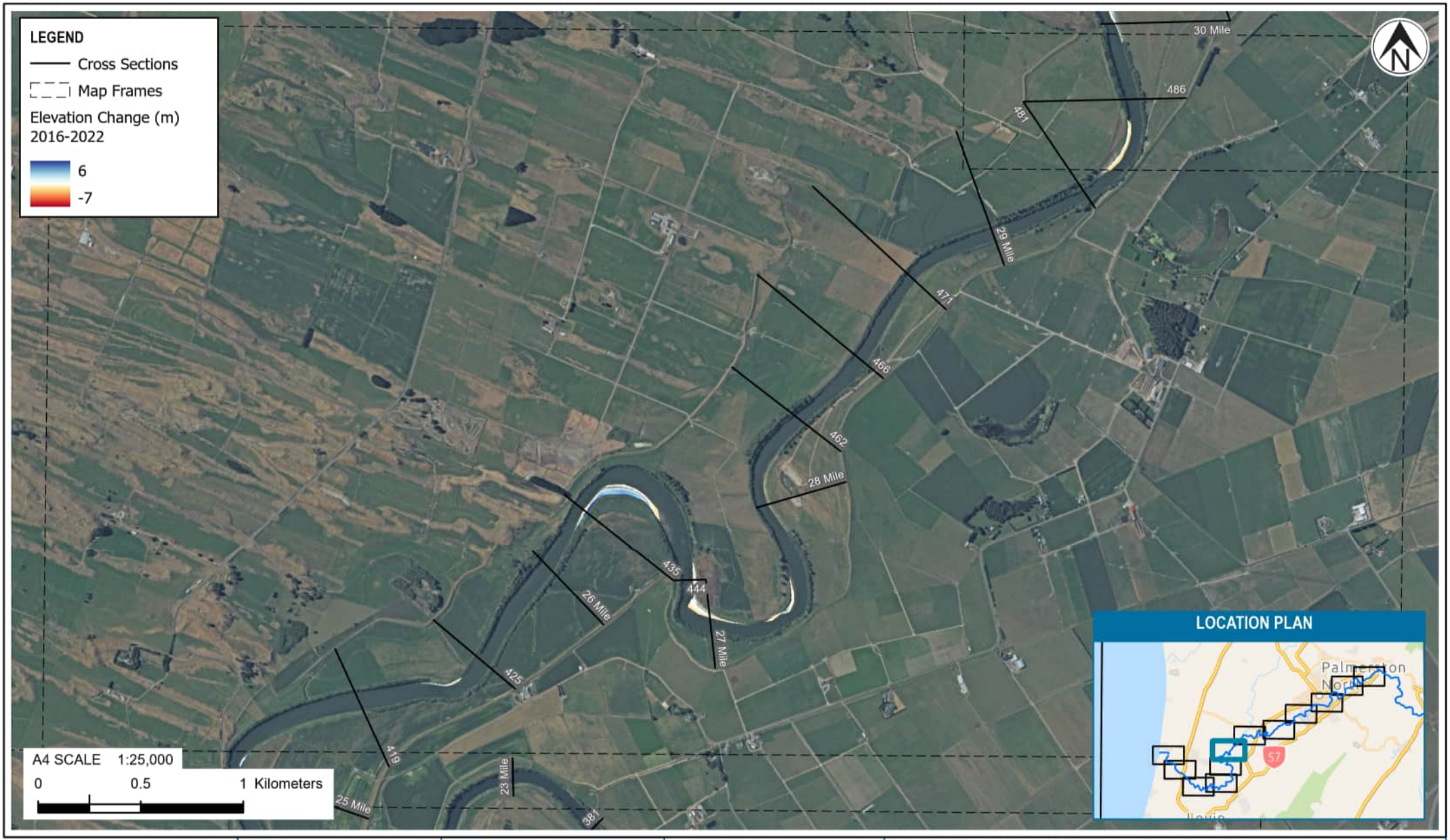
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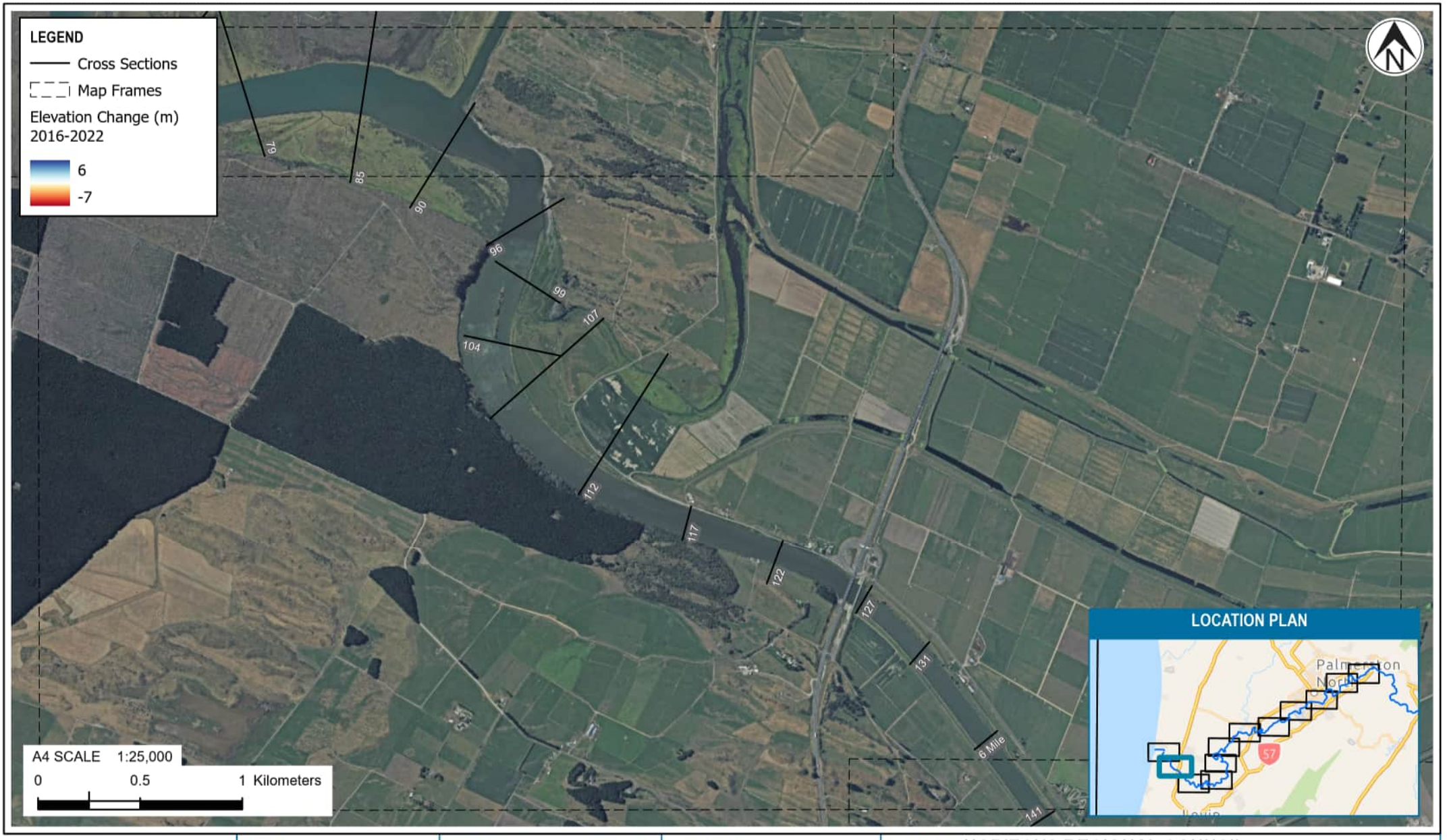
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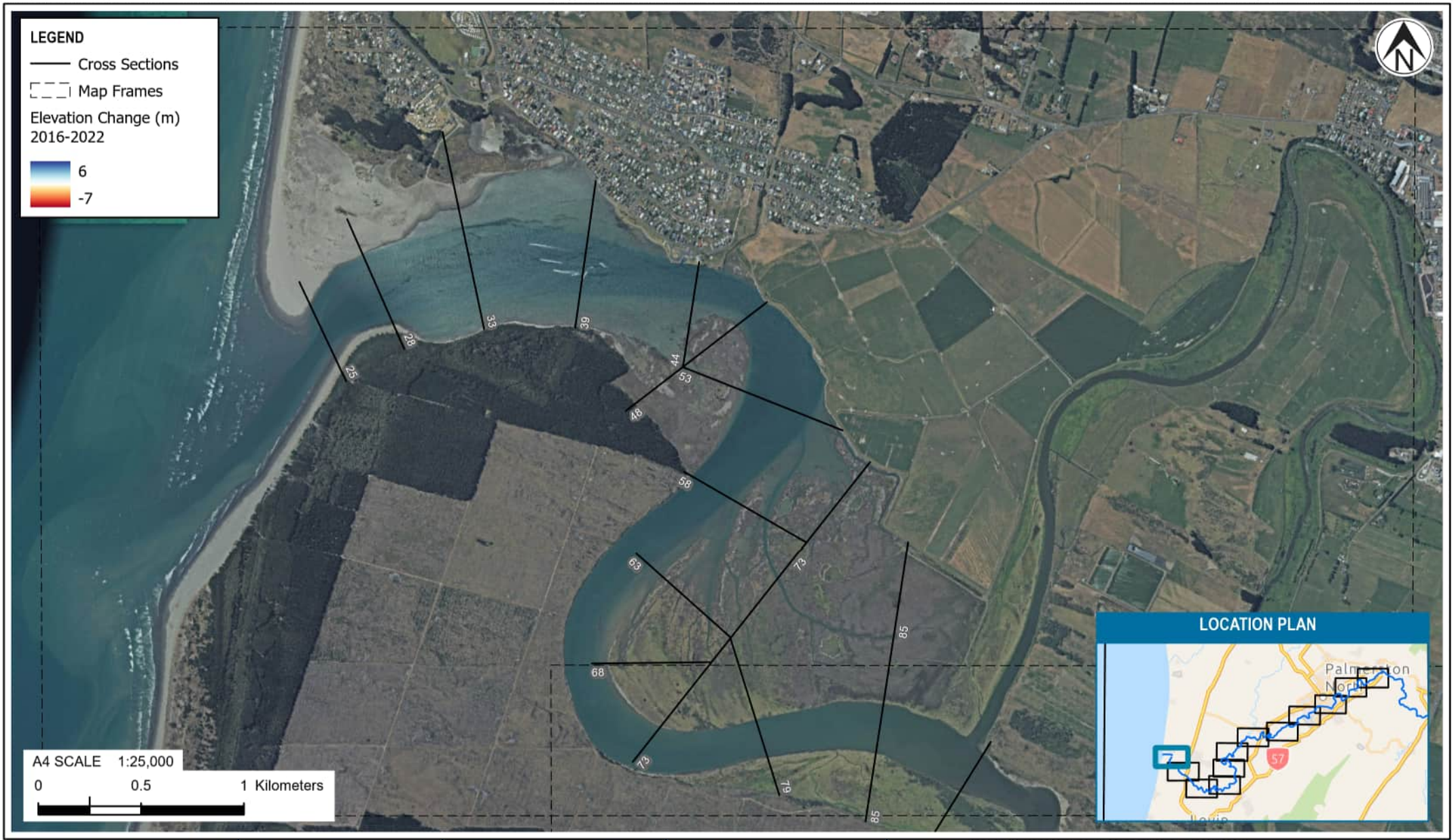
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DOD 2016-2022

SCALE (A4) 1:25,000 FIG No. APPENDIX D, FIGURE 2L REV 1

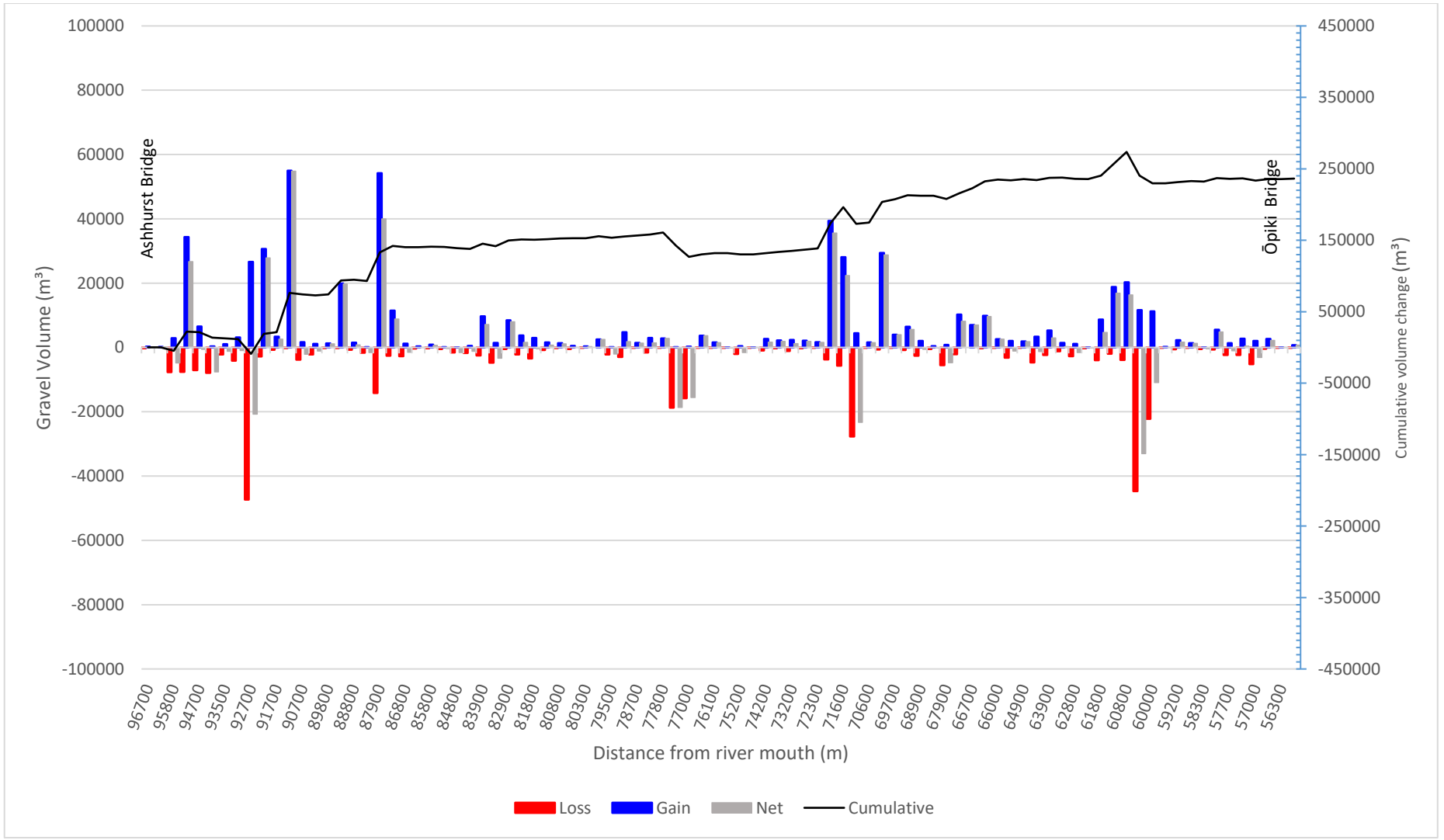



*Figure Appendix D.1: Change in gravel volume from Ashhurst Bridge to Ōpiki Bridge between 2005 and 2016 using GCD analysis using expanded vertical scale. Note: GCD is only feasible from consecutively dry surfaces between 2005 and 2016.*

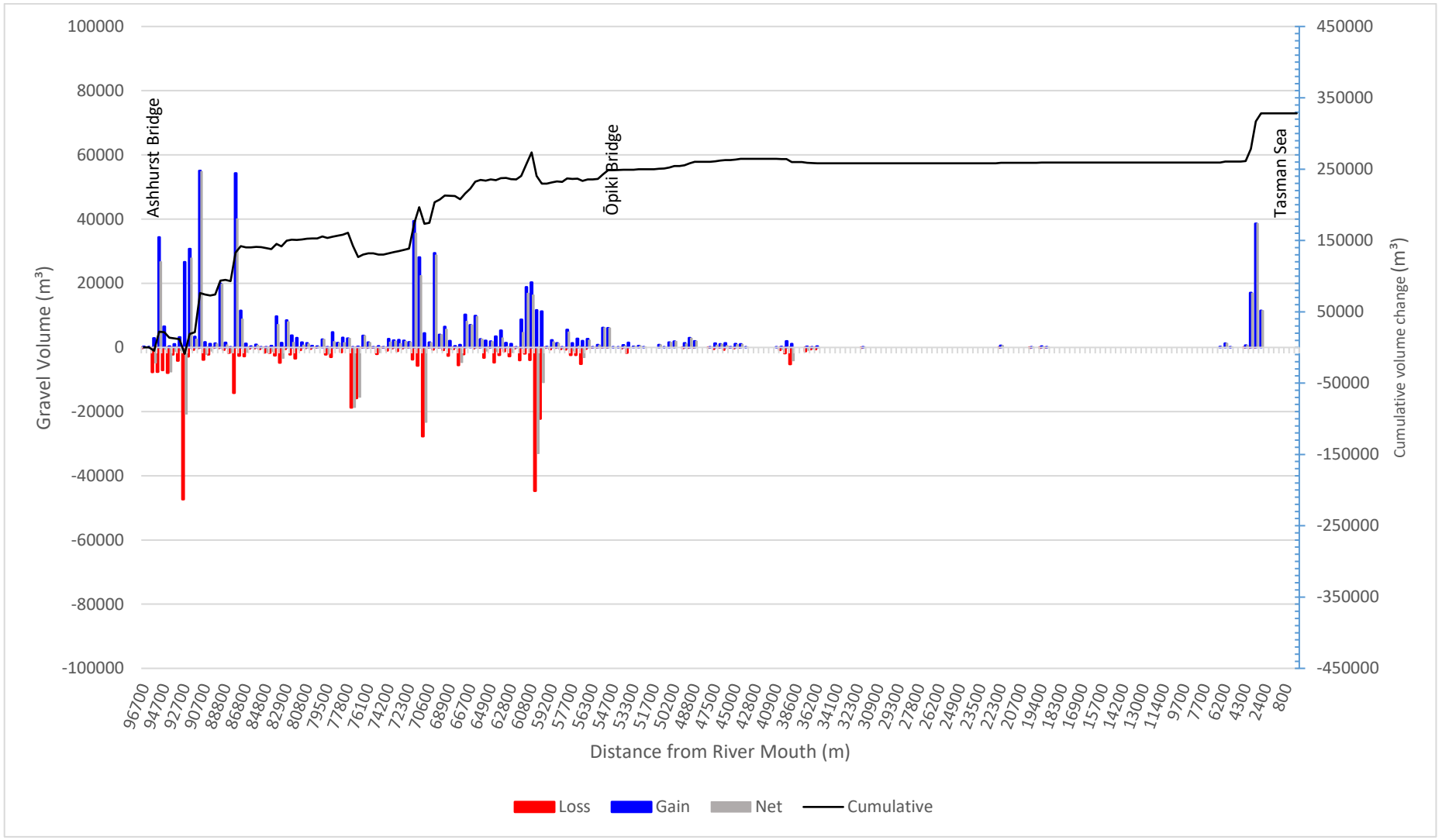



*Figure Appendix D.2: Change in sediment volume from Ashhurts Bridge to Tasman Sea between 2005 and 2016 using GCD analysis using an expanded vertical scale. Note: GCD is only feasible from consecutively dry surfaces between 2005 and 2016.*

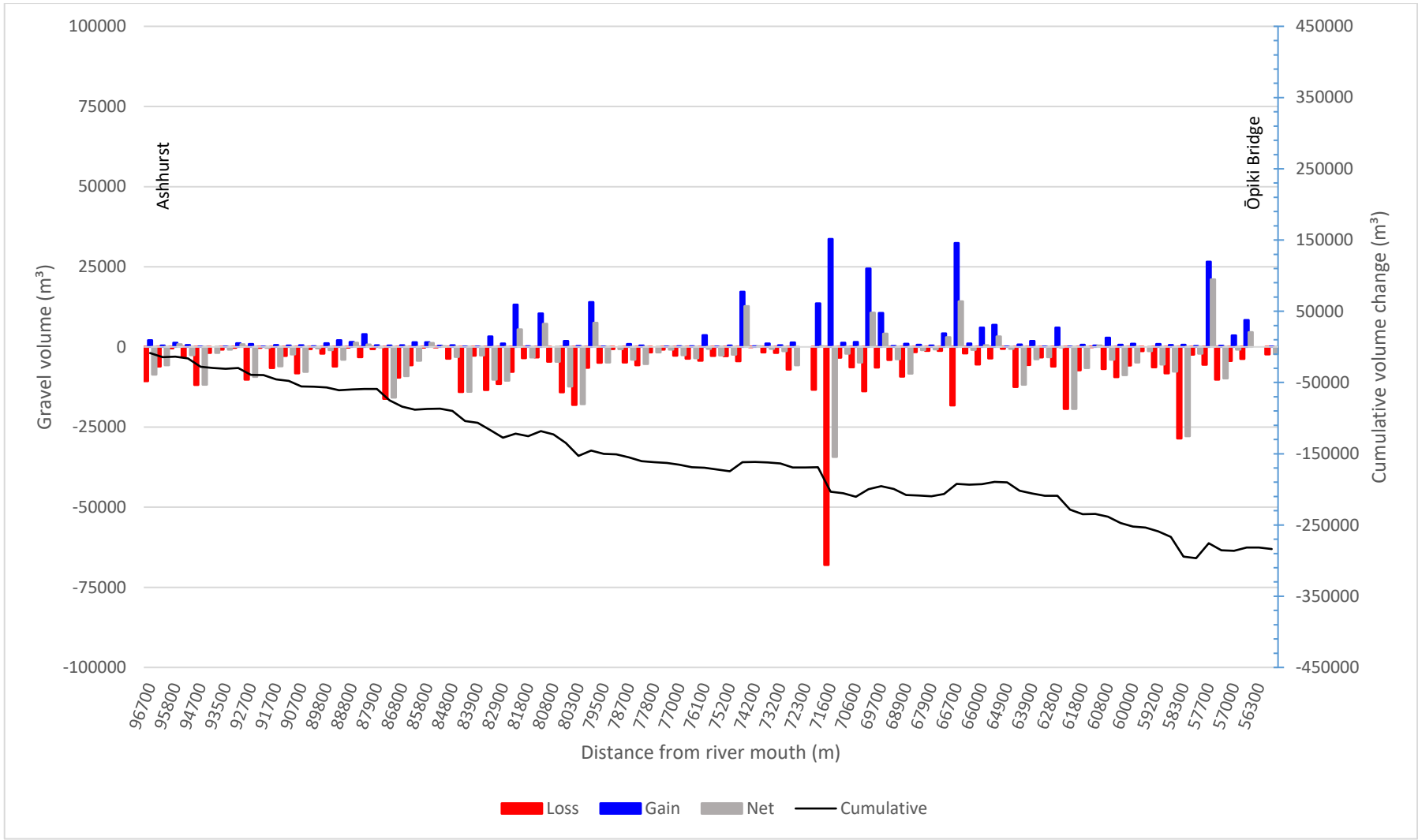



*Figure Appendix D.3: Change in gravel volume from Ashhurst Bridge to Ōpiki Bridge between 2016 and 2022 using GCD analysis using expanded vertical scale. Note: GCD is only feasible from consecutively dry surfaces between 2016 and 2022.*

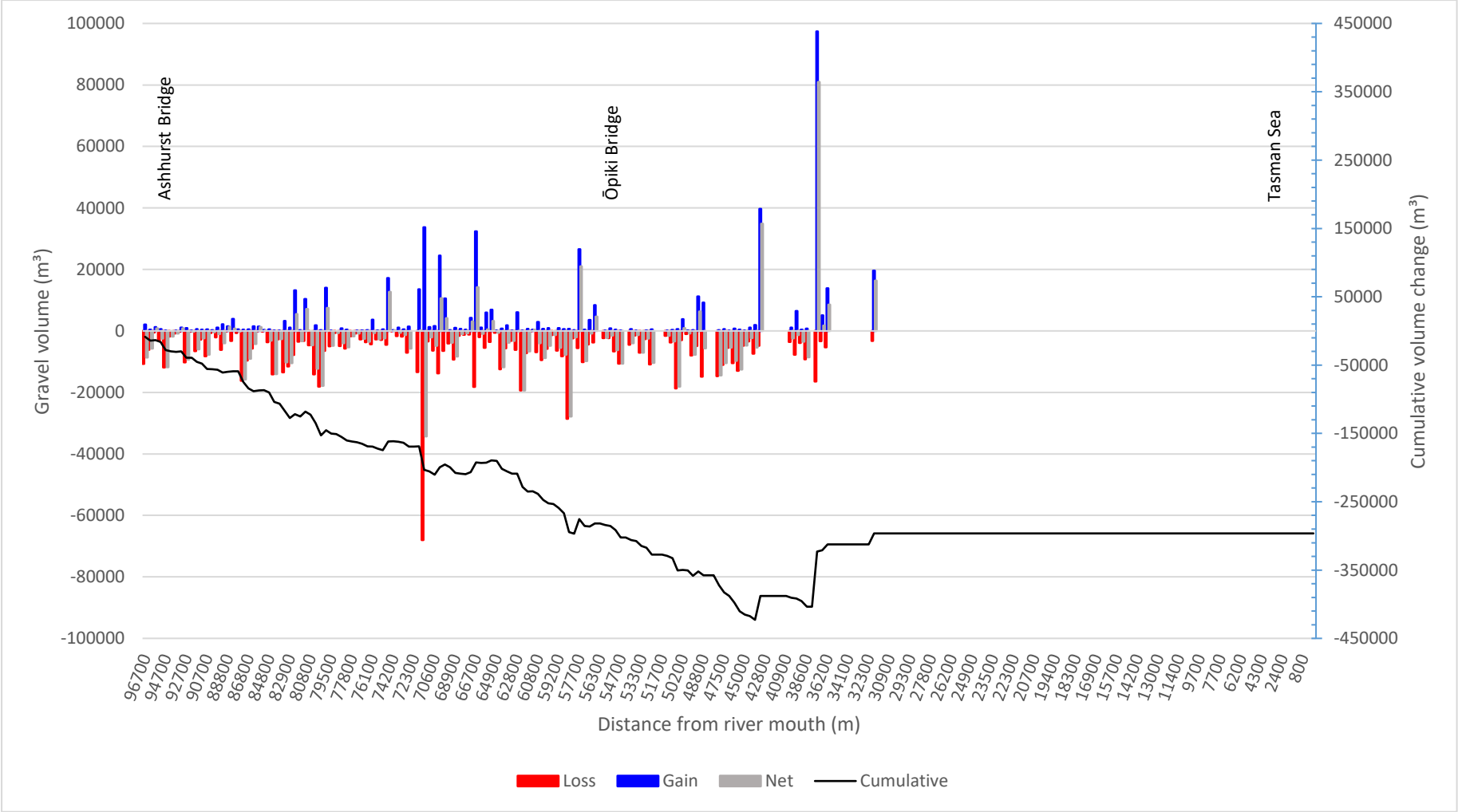



*Figure Appendix D.4: Change in sediment volume from Ashhurst Bridge to Tasman Sea between 2016 and 2022 using GCD analysis, using expanded vertical scale. Note: GCD is only feasible from consecutively dry surfaces between 2016 and 2022.*

# Appendix E Summary of selected morphological budget research articles

| Paper and brief description | Methods used | Data and tools used | Results | Limitations and assumptions |
|---|---|---|---|---|
| Whale (2019)<br>Lower Manawatū Gravel Resource Study – Horizons Regional Council<br><br>• Assessment of change in gravel resource for the lower Manawatū River 2011 to 2018. | • Lower Manawatū River separated into gravel phase and silt phase.<br>Gravel reach - below Ashhurst Bridge (63 Mile benchmark) to above Ōpiki Bridge (37 Mile benchmark).<br>The silt phase, Ōpiki Bridge to mouth is separated into five reaches.<br>• Calculation of the area beneath channel cross-sections, defined by the wetted perimeter in the gravel reach and between the right and left stopbanks in the silt reach.<br>• Sediment volume change between two cross-sections integrated throughout the reach. | • Cross-sectional survey data: gravel reach 2011, 2017/8; silt reach 1990s, 2011, and 2017/18.<br>• Area beneath active channel of each cross-section calculated using HILLTOP Hydro software.<br>• Areas integrated between cross-sections.<br>• Volume = XS area * distance between cross-sections<br>• Cross-sections analysed using over plot function in Manager to ascertain mean bed level in HILLTOP Hydro software.<br>• Aerial photography used to trouble shoot unexpected results, by confirming the active geomorphological process acting in a reach. | Gravel Phase:<br>• Overall aggradation of 890,000 $m^3$ gravel, with a general increase in mean bed level of 0.2 0.4 m.<br>• More than 10,000 $m^3$ gravel deposition estimated between 63 Mile mark to BM 947, as well as the 56 Mile mark to BM 834, and the 50 Mile mark to BM 707.<br>• Between BM 942 and BM 923 around Higgins Aggregates on Te Matai Road, BM 829 and BM 826 around ANZAC Cliffs, as well as BM 699 to 695, which are located above and below the Longburn Railway Line, and BM 615 to 612 located below Hamilton's Line low gravel losses were noted.<br>Silt (Sand) Reach:<br>• Rates of sedimentation throughout the sand reach vary significantly.<br>• Channel shape tending toward narrowing and deepening.<br>• Reach 1 (Mile 37 to 32) overall increase in sediment volume of 94,387 $m^3$ (2011-2017/8) – decrease in bed elevation with associated channel narrowing.<br>• Reach 2 (Mile 32 to 24) overall increase in sediment volume of 162,065 $m^3$ (1993-2017/8).<br>• Reach 3 (Mile 24 to 19) overall reduction in sediment volume of -105,213 $m^3$ (1994-2017/8). | • Some surveys were located across accreted gravel bars and data extrapolated between cross-sections, causing overestimation of deposition in the reach. These errors were rectified through visual interpretation of aerial photography.<br>• Provides no context for behavioural change, only suggestions as to reasons for changes in sediment volume can be made.<br>• Lower river areas may have tidal influence which could affect sediment volume change.<br>• Cross-sectional surveys were represented for different periods of time over the course of the river. Direct comparisons of annually averaged sediment volume change cannot be made between the reaches as significant events may have occurred during different time periods. |

| Paper and brief description | Methods used | Data and tools used | Results | Limitations and assumptions |
|---|---|---|---|---|
| | | | • Reach 4 (Mile 24 to BM 127) overall reduction in sediment volume of -957,232 $m^3$ (1995-2017/8).<br>• Reach 5 (BM 127 to BM 25) overall reduction in sediment volume of -1,081,530 $m^3$ (1997-2017/8). | |
| Bell (2012)<br>Lower Manawatū Scheme Gravel Resource Study. Horizons Regional Council.<br><br>• Examination of lower Manawatū River gravel resource and gravel extraction records 1997 – 2011.<br>• Reach location: 63 Mile benchmark, just downstream of Ashhurst Bridge, to the 37 Mile benchmark, just upstream of the Ōpiki Bridge | • Cross-sectional survey data used to calculate gravel volume under assumed 0 m datum for both bed and channel.<br>• Trapezoidal method and Hilltop calculations compared for validation.<br>• Gravel extraction volumes added to calculated values to examine river behaviour in lieu of extraction. | • 115 cross-sections surveyed 19 times throughout 1991-2011.<br>• Hilltop software used to calculate change in the active channel mean bed level which was multiplied by assumed channel width to provide area below an assumed datum of 0 m. The same process was applied to channel cross-sectional data as a whole.<br>• Data was integrated and compared between cross-sections to calculate sediment volume change.<br>• Data was summed to provide a cumulative volume for the reach. | • Relatively constant rates of sediment volume when gravel extraction is considered in calculations.<br>• A greater proportion of eroded sediment originated on the channel bed, rather than through bank erosion.<br>• Deposition favours channel edge rather than the bed, which appears to be lowering.<br>• Significant degradation occurred between Mile 63 and 48.<br>• 320,000 $m^3$ gravel transported 1997-2003 between Mile 63 and 53.<br>• Channel edge deposition seen between Mile 43 and 37.<br>• 250,000 $m^3$ gravel deposited between Mile 42 and 40.<br>• A larger portion of gravel was transported following three significant flood events (February 2004, August 2004, September 2010), than during the period 1997-2003. | • Not a continuous data set - missing survey data overcome by amalgamating different years and different cross-section extents.<br>• Not all cross-sections were perpendicular to flow, therefore a cosine correction was applied to calculated cross-sectional areas.<br>• Assumed a gravel active channel bed.<br>• Assumed active channel is found within the extent of the riverbed.<br>• Assumes linear variability in channel profile between cross-sections.<br>• Assumed gravel extraction effects only realised in reach from which it was extracted.<br>• It is noted that some gravel was lost to attrition. |
| Brewer and Passmore (2002)<br>Sediment budgeting techniques in gravel-bed rivers.<br><br>• Comparison of sediment budget calculation | • Two-dimensional planform budget used to calculate net sediment change from paired planform surveys, as derived from field-based surveys, topographic maps, and aerial photography. | • Planform maps: 1:10 metric resolution. Minimum four tic-marks used to align maps. Displacement errors < 1 m<br>• Aerial photography: 1:10 000 scale. Displacement errors < 1 m | • Net gain/loss volume for studied reach using the planform, cross-profile and morphological budget methods over four time periods compared. | • Neither within reach sediment transfers, nor throughputs, are represented by the morphological budget, only gross/net changes between survey dates, resulting in |

| Paper and brief description | Methods used | Data and tools used | Results | Limitations and assumptions |
|---|---|---|---|---|
| methodologies for a reach of the River Severn, U.K. | • Channel profile budget used both planform and channel cross-section repeat surveys in a three-dimensional space to calculate sediment gain/loss volumes.<br>• The morphological budget combines planform and channel cross-section data to sum sediment change (volume of gain/loss) for individual morphological units in a reach. | • Surveyed planform maps 1:2000 resolution displacement error < 0.1 m.<br>• River channel cross-sectional surveys<br>• ArcGIS | • Morphological budget methodology deemed to be the most useful tool., providing more accurate budget estimates and shown to be less sensitive to cross-section location and spacing. | underestimation of sediment transport rates.<br>• Morphological budget considers fine- and coarse-grained sediment collectively. |
| Fuller et al. (2002)<br>Annual sediment budgets in an unstable gravel-bed river: the River Coquet, northern England<br><br>• A three-dimensional morphological sediment budget technique was used along a 1 km gravel-bed reach of the River Coquet, U.K. to estimate sediment output volumes. | The morphological budget approach utilised in this study combines planform and cross-profile data to create estimates of sediment volume change for each morphological unit within sub-reaches.<br>ArcGIS was used to calculate elevation change and standardise to net sediment gain/loss values per $m^2$. This was transcribed to volumetric change by multiplying by corresponding planform areas for each morphological unit within the sub-reach.<br>A comparison of cross-sections created from planform survey data using a DEM and field surveyed data was undertaken. | • Annual channel planform surveys were conducted, using theodolite-EDM (electromagnetic distance measuring) ground survey with a total station at low-flow stage and digitised using ArcGIS.<br>• Repeat channel cross-sections were surveyed less than 75 m apart.<br>• Channel cross-sections were surveyed using theodolite electronic distance measurement (EDM) from monumented pegs. | The difference in elevations between field surveyed cross-sectional data and those obtained from planform data was smaller than the $D_{84}$ for the study reach.<br><br>Sediment volumes represented for each sub-reach in a bar chart format and described within the text in terms of sediment erosion, transport and deposition, the dominant process operating between geomorphic units. | • Vertical changes in topography that can occur between cross-sections are not represented through morphological budgeting.<br>• It is assumed that channel cross-sections capture morphological units present within each reach.<br>• Changes to morphological units between survey time frames are not captured through the morphological budget methodology.<br>• Morphological budgeting focuses on the gravel component of the bed-load material, considered to have the greatest impact on channel morphology.<br>• Sediment throughputs are not represented within the morphological change budget. |
| Christensen (2013)<br>Te Kauru Upper Ruamāhanga Floodplain Management Plan<br>Greater Wellington Regional Council | Mean bed level across the active channel width was analysed to determine dominant geomorphological processes (aggradation/degradation).<br><br>A morphological gravel budget was created through a combination of planform and | • Mean bed level was determined from field cross-sectional surveys and change calculated from repeat surveys 1995-2011.<br>• Bedload transport rates were estimated as a percentage of suspended-sediment yield. Percentages of bedload fraction | • Gravel input from bank erosion was found to be greater than due to bed degradation and contributions from upper tributaries and hillslope processes.<br>• A flow chart showing calculated values for each parameter of the gravel budget equation for the rivers | • Extrapolation of cross-sectional data separated by several hundred meters is noted as a limitation to the study.<br>• Data inputs were compiled on different time scales and periods.<br>• Assumed that cross-sections represent changes at the reach scale. |

| Paper and brief description | Methods used | Data and tools used | Results | Limitations and assumptions |
|---|---|---|---|---|
| • Assessment of dominant geomorphological processes acting within the Upper Ruamāhanga in terms of floodplain management planning. | channel profile methods to calculate volumetric gravel change. This was then summed and averaged annually to produce a gravel yield for the Upper Ruamāhanga River System. | estimates (20-40% for mountainous regions) given by Turowski et al. (2010). Suspended-sediment load values derived from NIWA's Water Resources Explorer NZ.<br>• Bank erosion gravel contributions were established from digitised historic aerial photographs using a DEM to determine channel width and planform area change, which was multiplied by bank height to estimate volumes.<br>• Gravel extraction was accounted for in the morphological budget in terms of an annual value.<br>• A Torlesse sandstone abrasion coefficient of 0.003 $km^{-1}$ was used as per the Soil Conservation and Rivers Control Council (1959). | in the Upper Ruamāhanga River System and a net gravel output of 252 000 $m^3$/year for the catchment given. | • Accuracy of the surveyed cross-sectional data is noted as a limitation to the calculation of change in sediment storage.<br>• Definition of the active channel from channel cross-sections is considered a potential source of error in sediment budget calculation. |
| Fuller et al. (2003)<br>Reach-scale sediment transfers: an evaluation of two morphological budgeting approaches<br><br>• Comparison of cross-section and DEM derived sediment budgeting techniques, using a 1 km gravel-bed reach of the River Coquet, U.K.. | Sediment budgets were created using field surveyed cross-sectional and planform data (March 1999, and 2000) and derived DEMs. Cross-sections were chosen to represent in-channel morphological units within the reach, i.e. Each bar was crossed at least once.<br>Used methods given by Fuller et al., (2002) and Brewer and Passmore (2002).<br>Different grid size DEMs (5 m, 1 m, 0.5 m, and 0.25 m) were used to undertake an error analysis based on spatial scale. Coarse grids may provide insufficient representation of slope changes (Brasington et al. 2000), however fine grids may create 'noise' (Brasington and Richards, 1998) and require longer processing times. | • Field surveyed channel cross-section and planform data using a Total Station.<br>• Surfer spatial analysis software was used to create the DEM, from which vertical changes were calculated and multiplied by morphological unit area within the planform to give volumetric change.<br>• High resolution sampling was undertaken within the active channel to capture topography more accurately and a surface DEM created using Surfer.<br>• Ordinary Kriging used to calculate error estimates.<br>• DEM differencing used to calculate net gains/losses in sediment between 1999 and 2000 surfaces. | • Cost-benefit ratios showed that 1 m grid size DEMs adequately represent the model area.<br>• Differences between cross-sections surveyed elevations and those generated from the DEM were close to the $D_{84}$ of the surface sediment, thus an acceptable substitution.<br>• Channel morphology changes (erosion/deposition) identified using DEM differencing and volumetric change estimated.<br>• Comparison of cross-section and DEM derived sediment losses show underestimation using cross-sections likely due to morphological changes between cross-sections that are not represented through this method. | Morphological changes in channel features not represented by discrete cross-sections – localised scour/fill may be occurring between cross-sections. |

| Paper and brief description | Methods used | Data and tools used | Results | Limitations and assumptions |
|---|---|---|---|---|
| | | | • The paper concludes that DEMs provide better surface representation and more accurate topographic definition from which to calculate morphological budgets and is therefore a superior methodology than using field measured cross-sectional data.<br>• Data output visualised as a sediment volume ($m^3$) net gain/loss bar chart. | |
| Carson and Griffiths (1989)<br>Gravel transport in the braided Waimakariri River: mechanisms, measurement and predictions<br>• Gravel bed yields were calculated over different timescales using two different methodologies for the lower Waimakariri River, NZ. | Bedload yields were calculated using the Meyer-Peter and Muller (MPM) equation and estimated using a morphological budget derived from digitisation of aerial photographs.<br>Analysis was undertaken at different time scales; for individual flood events, and over short, medium and long term (1967-1983) time periods. | • Vertical aerial photographs of a 5 km reach were taken at six-time intervals (after each significant flow event) over a 15-month period during low flow conditions.<br>• Areas of erosion/deposition were digitised, and a volume determined by using an estimated depth of scour multiplier.<br>• Known extracted gravel volumes added to calculated sediment volumes to account for removed sediment.<br>• Discharge data used as an input to the MPM formula. Specific equation inputs provided in paper.<br>• Stadia cross-sectional surveys at the downstream portion of the reach used to calculate sediment accretion as a validation of results. Cross-sections survey every 5 years at a distance oof v800 m. | • Estimates of sediment volume accumulation and deposition given separately.<br>• Estimates of bed load yields were comparatively similar for the two methods used over short-term (before and after individual flood events) and long-term time frames (due to averaging of fluctuations).<br>• Bed material size data is important for short-term yield predictions.<br>• Changes in sediment yield over the medium-term time frame was less well represented using the morphological approach due to the highly dynamic nature of bed condition flux.<br>• Conclusions drawn about movement of individual geomorphological units (such as in-channel bars). | • Gravel extraction practices occur in the lower portions of the reach.<br>• Sediment yield estimates calculated using morphological approach will be “lower bound” estimates.<br>• Frequent aerial photography should be used to assess changes in morphological units as these changes may occur in rapid succession and not be recorded by annual photographs.<br>• Assumptions regarding inputs to the MPM equation provided in paper. |
| Church (2006)<br>Bed material transport and the morphology of alluvial river channels | DEMs can be created from topographic surveys to calculate changes in sediment volume. | Sediment transport regimes examined based on the Shields number. | Not applicable | • Distance between cross-sectional surveys and point density within surveys affect precision of morphological budgets created using said input data. |

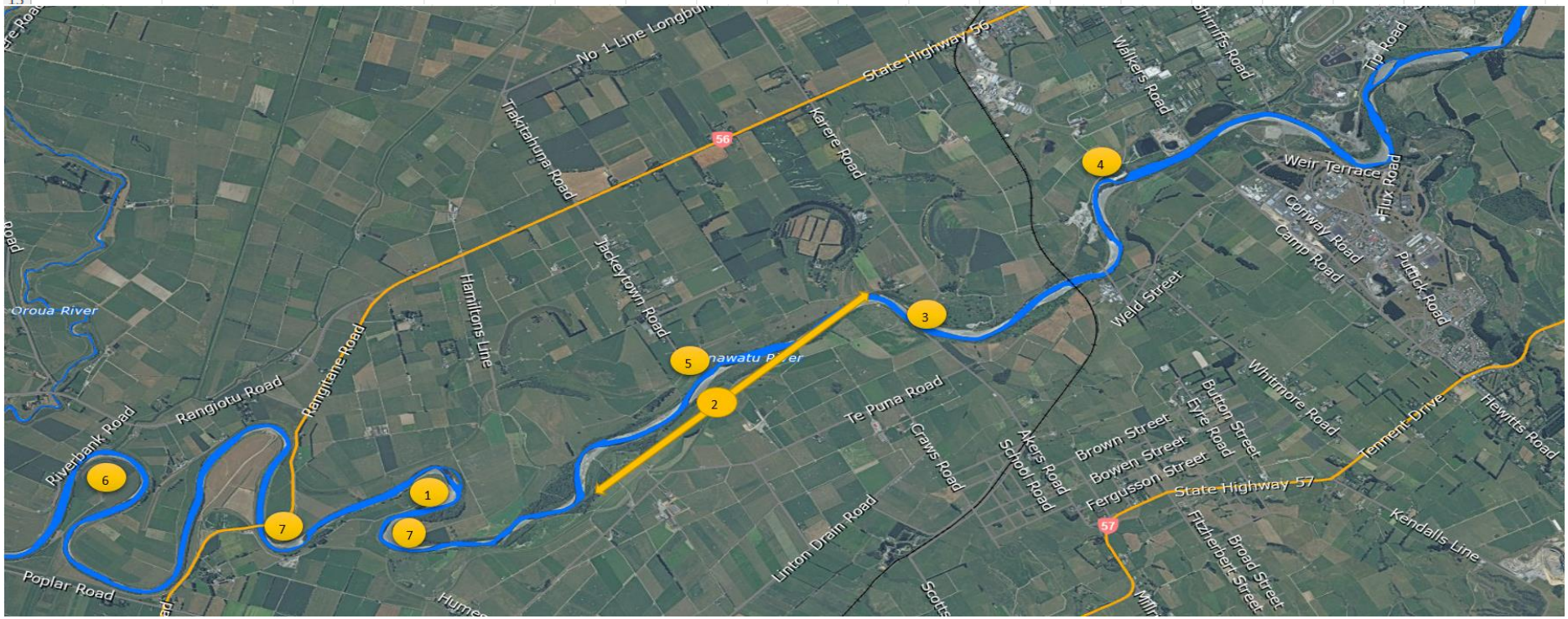
| Paper and brief description | Methods used | Data and tools used | Results | Limitations and assumptions |
|---|---|---|---|---|
| • Review of transport regimes and a brief description of methodologies used to quantify them.<br>• "Alluvial river channel [morphology] is the consequence of sediment transport and deposition by the river". | | | | • Morphological change calculated using DEMs provides "lower-bound estimates" as between survey scour/fill is not accounted for.<br>• Surveys should be timed to represent individual channel forming events to provide more accurate morphological change estimates. |
| Tunnicliffe and Baucke (2021)<br>Bedload transport and gravel supply in the Waiapu Catchment<br>• Summary of recreational, environmental, and commercial importance of bedload transport and its effect on rivers in the Waiapu Catchment. Mass balance formula solved for bedload which is used to inform gravel extraction recommendations for consents. | • A mass balance framework is used to solve for transfer of material into the reach in relation to material leaving the reach, providing volumetric change in material stores.<br>• Topographic surveys from different time periods are derived from LiDAR and drone imagery. These are overlayed and estimates of volumetric change provided. | • DEMs of Difference (DOD) were created from LiDAR and drone-based photogrammetry for 2020 and 2021 and storage changes calculated.<br>• Mass balance inputs:<br>Cross-sectional area<br>Reach storage volume<br>Bed elevation<br>Bed Width<br>Downstream coordinate of reach boundaries<br>Time interval between surveys<br>Deposit porosity<br>Gravel removed through Extraction. | • To account for natural variability in gravel yield with time, this report advises gravel consents are tied to bedload yield as a proxy for annual flood intensity and duration.<br>• It is suggested that monitoring is necessary to facilitate adaptive management of rivers under gravel extraction; site surveys, grain-size surveys, biota census.<br>• Outputs of DEM presented as maps and bar charts for individual reaches. Cumulative storage changes in a downstream direction presented as a bar chart. | • Mean bed elevation changes (erosion/deposition) can occur over time frames not represented by cross-sectional survey data, therefore transport rates determined from surveys represent a minimum change.<br>• Suspended sediment and washload materials are not considered in the budget calculations of this report as they are assumed to have little effect on channel morphology changes.<br>• More flood events occurred during the second year of sampling: therefore, a larger gravel volume change was estimated. |
| Fuller and Vale (2009)<br>Morphological budgeting in the Motueka River: analysis of technique<br>• Comparison of two different data inputs used to create a morphological budgets for the Motueka River: field survey cross-sections and DEMs. | Field surveyed cross-sections and DEMs derived from topographic surveys were used to create a morphological budget and data outputs compared. Different cross-section spacings were also investigated from the DEM. | • DEMs were created using Surfer® from data collected during typically low flow conditions (autumn) for successive years (2008-9) via Trimble® GPS receiver base station and Rover units.<br>• Greater point density representation was implemented within the active channel than open flat areas.<br>• Cross-sections were extracted from the DEM at different, but equal, spatial extents. Some DEMs were visually | • Results provided as a DOD channel map showing elevation changes and a net volume change value for the reach.<br>• Volume change calculations for the different methods provided as a table and as a bar-chart, summed for the study reach.<br>• DEM derived cross-sectional spacing 90 m or less produced volumetric change calculations more in-line with true DEM values, which was | • Cross-sectional approach had a "smoothing effect on the morphological units of the reach".<br>• Positioning of cross-sections to accurately represent geomorphic units is a key consideration during analysis. Cross-sections should be located to represent geomorphological unit, such as gravel bars.<br>• Distance between cross-sections is an important factor as calculated rates |

| Paper and brief description | Methods used | Data and tools used | Results | Limitations and assumptions |
|---|---|---|---|---|
| • Short history of DEM use for morphological budgeting and its superior accuracy and ease of data acquisition noted. | | adjusted to better represent bend planform.<br>• Volume change was derived from the difference between 2009-2008.<br>• Mean bed level changes (2009-2008) were used to calculate volume changes for each cross-section and applied to an equal distance between cross-sections. | considered the most accurate method, and may represent a "critical distance" for cross-section placement.<br>• True DEM inputs yielded a more thorough methodology than both methods of cross-section derivation for mean bed level change analysis. However, it is acknowledged that true DEM scale data resolution is cost and time prohibitive for large reaches. | of sediment change are extrapolated for the reach allocated between cross-sections, which may include many geomorphological units if the distance is great.<br>• Aggradation/degradation occurring between cross-section is not accounted for. |

# Appendix F Gravel extraction data

- Spreadsheet and map supplied in email from Bernadette Pancho to Ian Fuller 12 June 2024. Note: map refers to two sites as ‘7’ with location of site ‘8’ not mapped.

| | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P | Q | R |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | **ATH-2008011972.00** | | | | | | | | | | | | | | | | | |
| 2 | **Gravel Extraction** | | | | | | | | | | FY | | | | | | | |
| 3 | Contractor | Northing | Easting | Ref Map | 22-23 | 21-22 | 20-21 | 19-20 | 18-19 | 17-18 | 16-17 | 15-16 | 14-15 | 13-14 | 12-13 | 11-12 | 10-11 | Total |
| 4 | Mangataweka | 1811003.41 | 5521544.45 | 1 | 0 | 0 | 0 | 1223 | 11210 | 6901 | 8196 | 3497 | 8350 | 5794 | 6941 | 6500 | un | 58612 |
| 5 | Whitelock | 1813277.41 | 5522499.91 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 15000 | 497 | 1113 | 3320 | 2237 | 1963 | un | 24130 |
| 6 | Callesen | 1815264.78 | 5523216.51 | 3 | 1200 | 6000 | 5332 | 5250 | 0 | 2840 | 2668 | 460 | 1995 | 5648 | 2500 | 5000 | un | 38893 |
| 7 | Longburn Shingle | 1816965.50 | 5524840.79 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 600 | 0 | 0 | 0 | 0 | un | 600 |
| 8 | Tocker | 1813411.18 | 5522776.99 | 5 | 0 | 0 | 0 | 0 | 3308 | 3172 | 815 | 7892 | 1631 | 0 | 0 | 3000 | un | 19818 |
| 9 | Ray Reid | 1808194.35 | 5521706.87 | 6 | 0 | 0 | 0 | 2922 | 0 | 2300 | 0 | 0 | 1500 | 0 | 0 | 0 | un | 6722 |
| 10 | Hopkins | 1809512.89 | 5520780.08 | 7 | 0 | 4000 | 0 | 2400 | 5500 | 0 | 800 | 120 | 0 | 0 | 0 | 0 | un | 12820 |
| 11 | HRC | un | un | 8 | 0 | 0 | 6300 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | un | 6300 |
| 12 | Hifarm/hirock | un | un | 9 | 0 | 3580 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | un | 3580 |
| 13 | Barber | un | un | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1000 | 0 | un | 1000 |
| 14 | | | | Total | 1200 | 13580 | 11632 | 11795 | 20018 | 15213 | 27479 | 13066 | 14589 | 14762 | 12678 | 16463 | 29500 | 201975 |
| 15 | | | | | | | | | | | | | | | | | | |



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