Appendix A

Historic Cliff Crest Alignment Plans

Refer to the statement on the accuracy of the various cliff crest lines at the end of this appendix.

Legend
2020 Cliff Crest
2017 Cliff Crest
2013 Cliff Crest
1996 Cliff Crest
Land Parcels

0 10 20 30 40 50 m

Foreground imagery (May 2020, 0.05 m pixels) from WSP survey. Background imagery (2013, 0.3 m pixels) and land parcels sourced from LINZ Data Service, and licenced under Creative Commons Attribution 4.0 NZ. External data accuracy not guaranteed.

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CAPE PALLISER ROAD RESILIENCE
HISTORIC CLIFF CREST ALIGNMENTS

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N. Clarke	05/08/2020	5-C4072.00	01

Legend
2020 Cliff Crest
2017 Cliff Crest
2013 Cliff Crest
1996 Cliff Crest
Land Parcels

0 10 20 30 40 50 m

Foreground imagery (May 2020, 0.05 m pixels) from WSP survey. Background imagery (2013, 0.3 m pixels) and land parcels sourced from LINZ Data Service, and licenced under Creative Commons Attribution 4.0 NZ. External data accuracy not guaranteed.

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Legend
- 2020 Cliff Crest
- 2017 Cliff Crest
- 2013 Cliff Crest
- 1996 Cliff Crest
- Land Parcels

0 10 20 30 40 50 m

Foreground imagery (May 2020, 0.05 m pixels) from WSP survey. Background imagery (2013, 0.3 m pixels) and land parcels sourced from LINZ Data Service, and licenced under Creative Commons Attribution 4.0 NZ. External data accuracy not guaranteed.

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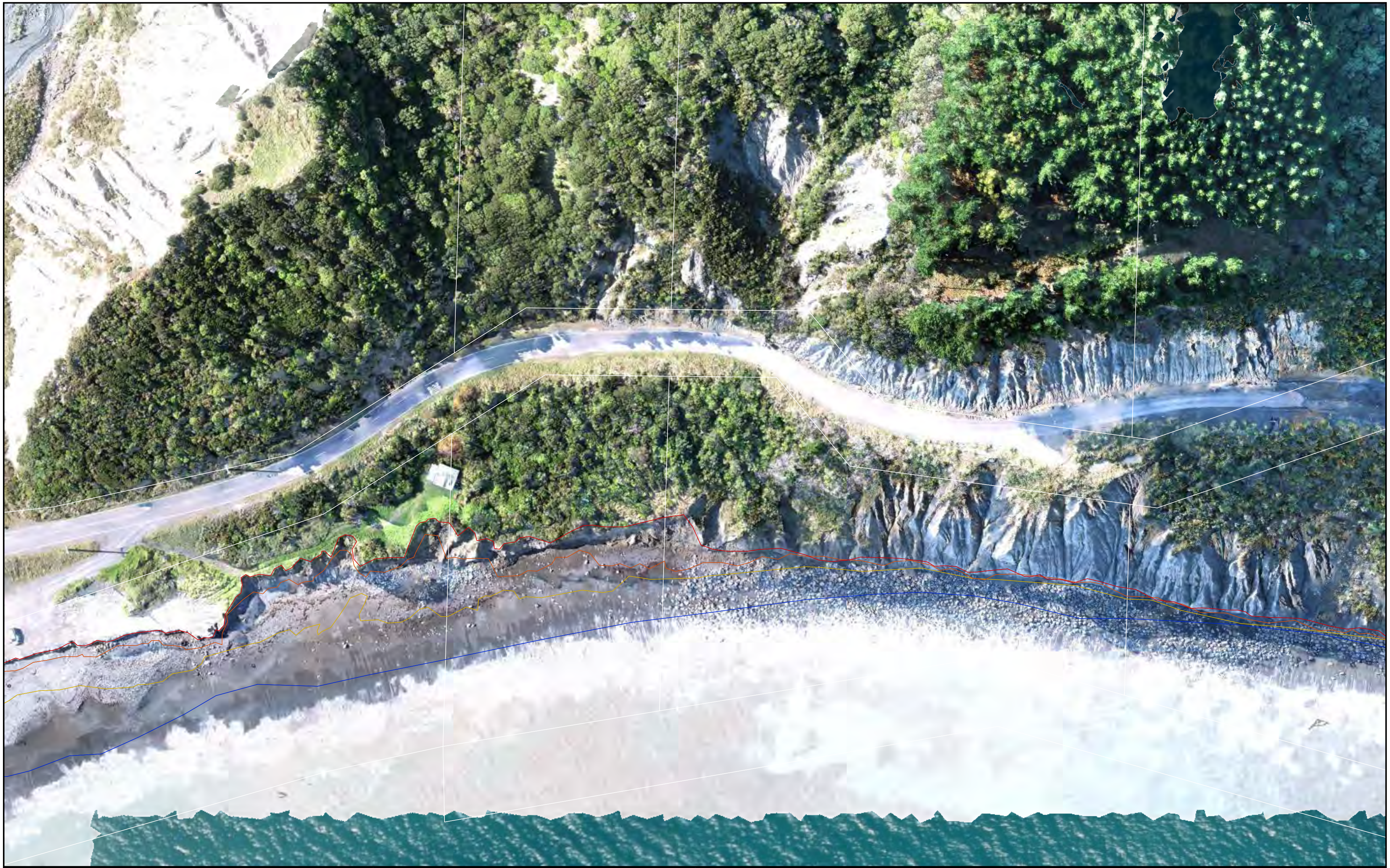

Legend
- 2020 Cliff Crest
- 2017 Cliff Crest
- 2013 Cliff Crest
- 1996 Cliff Crest
- Land Parcels

0 10 20 30 40 50 m

Foreground imagery (May 2020, 0.05 m pixels) from WSP survey. Background imagery (2013, 0.3 m pixels) and land parcels sourced from LINZ Data Service, and licenced under Creative Commons Attribution 4.0 NZ. External data accuracy not guaranteed.

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Legend
- 2020 Cliff Crest
- 2017 Cliff Crest
- 2013 Cliff Crest
- 1996 Cliff Crest
- Land Parcels

0 10 20 30 40 50 m

Foreground imagery (May 2020, 0.05 m pixels) from WSP survey. Background imagery (2013, 0.3 m pixels) and land parcels sourced from LINZ Data Service, and licenced under Creative Commons Attribution 4.0 NZ. External data accuracy not guaranteed.

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Legend

- 2020 Cliff Crest
- 2017 Cliff Crest
- 2013 Cliff Crest
- 1996 Cliff Crest
- Land Parcels

0 10 20 30 40 50 m

Foreground imagery (May 2020, 0.05 m pixels) from WSP survey. Background imagery (2013, 0.3 m pixels) and land parcels sourced from LINZ Data Service, and licenced under Creative Commons Attribution 4.0 NZ. External data accuracy not guaranteed.

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Legend
- 2020 Cliff Crest
- 2017 Cliff Crest
- 2013 Cliff Crest
- 1996 Cliff Crest
- Land Parcels

0 10 20 30 40 50 m

Foreground imagery (May 2020, 0.05 m pixels) from WSP survey. Background imagery (2013, 0.3 m pixels) and land parcels sourced from LINZ Data Service, and licenced under Creative Commons Attribution 4.0 NZ. External data accuracy not guaranteed.

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Legend
- 2020 Cliff Crest
- 2017 Cliff Crest
- 2013 Cliff Crest
- 1996 Cliff Crest
- Land Parcels

0 10 20 30 40 50 m

Foreground imagery (May 2020, 0.05 m pixels) from WSP survey. Background imagery (2013, 0.3 m pixels) and land parcels sourced from LINZ Data Service, and licenced under Creative Commons Attribution 4.0 NZ. External data accuracy not guaranteed.

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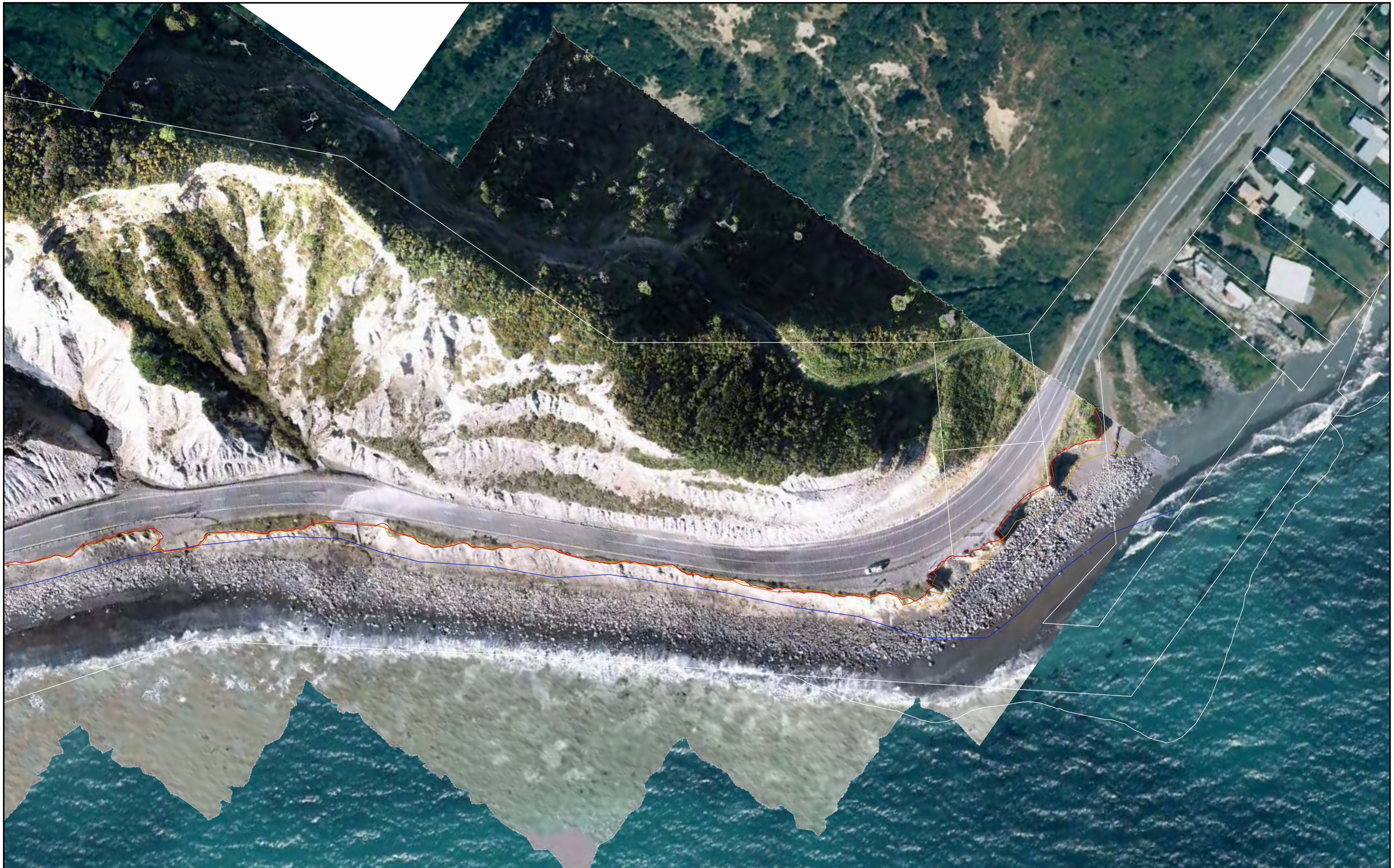

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A.1 Cliff Crestline Analysis – Limitations

Aerial images are overlaid by georeferencing, which requires that the chosen Ground Control Points (GCPs) are static through time. We ensure that this is the case by selecting structures such as bridges and buildings. Georeferencing quality is dependent on image resolution though, since low resolution can lead to poorer GCP selection accuracy. Variable look angle between the different images also introduces inaccuracies when georeferencing.

Cliff crestline selection is also dependent on image resolution. On lower resolution imagery, such as the 1996 aerial (1.565 m pixel resolution), the cliff crest is harder to identify, and poorer georeferencing quality compounds this issue. Imagery from 2013 and 2017 has 0.3 m resolution, and the 2020 UAV imagery has 0.05 m resolution. We therefore have a greater level of confidence in cliff crestline positions on the more recent imagery.

Error is introduced into the results due to the manual digitisation and measurement methods. This is exacerbated in places where the cliff crest position is hard to define, such as Johnson's Hill where there is a more gradual, gully-eroded slope between the road and the beach. We used the 3D site model produced from our UAV data to gain a better understanding of the cliff crestline position.

This methodology does not include error estimates, given the complex and inconsistent sources of uncertainty outlined above. Our analysis does not consider seasonal changes and specific storm events, which are inherently difficult to assess from infrequent aerial imagery. These factors, as well as varied storm intensity and frequency due to anticipated sea level rise and climate change, must be considered when using these erosion rates to forecast future cliff retreat. It may also be expected that cyclic variation in erosion rates will be observed in the future as it was in the past (Beca, 2000). It is difficult, however, to predict the timing and duration of such cycles.

Appendix B
Site History

Appendix B – Site History

Cape Palliser Road provides an important connection between small coastal communities that have developed in modern times. The settlements of Te Kopi, Whatarangi, Ngāwī and Mangatoetoe are located along the road. Of these, Te Kopi lies within Section 3 of the study area for this report, while the other settlements are south of the study area.

Historic photographs at Whatarangi Bluff, from 1931 and 1947, show an early iteration of Cape Palliser Road cut into coastal cliffs (Figure 9, Figure 10). The steep slopes below the road are still present today, and are vulnerable to wave erosion at the toe which leads to slumping.

Figure 9: Cape Palliser Road at Whatarangi Bluff in April 1931 (Stidolph, 1931).

Figure 10: Cape Palliser Road at Whatarangi Bluff in 1947 (O'Brien family, 1947).

Ongoing coastal erosion also affects the road elsewhere within the study area. By comparing a 1964 photo that overlooks the site (Figure 11) to an image from August 2020 (Figure 12), it can be seen that the width of the beach in Section 1 has been reduced significantly over the past half century. The 3D model produced from WSP's 2020 UAV imagery allows this perspective view of the study area to be seen in more detail (Figure 13).

These perspective views across the study area show that land use around Cape Palliser Road comprises small settlements and farmland, plus areas of bush and forest. One notable change in land use has occurred at Johnson's Hill. There is a significant active slump in this area, which has been reactivated from old landslide material and is likely to have been moving slowly since the sea level reached its current position and began eroding the slope below the road (Perrin, 1995). Figure 11 shows that the land upslope of the road at Johnson's Hill was not forested in 1964, but has since been replanted with trees (Figure 12); this replanting was undertaken in the 1990s, to address the slope stability issues (Braaksma, 2020). Some of the replanted trees have been undermined by cuttings into the slope above the road (Figure 12), which were necessary to reinstate the road following landslide movement.

Figure 11: Cape Palliser Road in 1964, looking across the study area from Hurupi Stream to Whatarangi Bluff (Anderson, 1964).

Figure 12: Cape Palliser Road in August 2020, looking across the study area.

Figure 13: A perspective view across the study area at Cape Palliser Road, as seen in the 3D model produced from WSP's UAV survey imagery, captured in May 2020 for this study.

Road realignment has been necessary on several occasions in the past, throughout the study area, due to erosion and slumping of the coastal cliffs that undermines the pavement. At Whatarangi Bluff, abandoned sections of road can still be seen in recent imagery (Figure 14).

Figure 14: Cape Palliser Road at Whatarangi Bluff, showing abandoned road alignments (Stuff, 2016).

Appendix C
Site Hazards

Appendix C – Site Hazards

C.1 Coastal Hazards

Coastal hazards in eastern Palliser Bay are significant, with repeated previous occasions of undermining along Cape Palliser Road related to coastal erosion (Figure 15). These hazards have been considered in several past studies. Historic cliff retreat rates are presented by King (1930), and there have been more recent investigations at residential areas in Whatarangi (Tonkin + Taylor, 2018) and Te Kopi (Perrin, 1995).

Beca undertook coastal erosion assessments at Cape Palliser Road in the 1990s, mainly within our study area. Their investigations involved the analysis of historic aerial imagery since 1944, and their results are presented in a road realignment options report (Beca, 2000). Historic erosion rates given by the studies mentioned above are summarised in Section 5.1.

A subsequent Beca report (2009) also considered coastal erosion issues along Cape Palliser Road, including within our study area, and discussed risk mitigation options, and a landscape assessment by Stephen Brown Environments Ltd (2009), associated with the proposed coastal protection works, is included in the appendices of the 2009 Beca report.

The Wairarapa Coastal Strategy (developed as a joint initiative between the Masterton, Carterton and South Wairarapa District Councils, Rangitāne o Wairarapa and Ngāti Kahungunu ki Wairarapa iwi, and GWRC) featured a technical paper on coastal hazards in the Wairarapa (Barrow, 2002). This paper provided relevant data, photography and discussions about coastal erosion in Palliser Bay.

2013 LiDAR elevation data (LINZ, 2013) is available over the whole study area. This provides an accurate snapshot of the site topography as of 2013, including ground levels below vegetation on the upper slopes. This can be compared with our 2020 UAV imagery and elevation model, to gain an understanding topographic change and coastal retreat between 2013 and 2020. Historic aerial imagery is also available from LINZ Data Service, from which temporal landscape changes within the site, including coastal retreat, can be observed.

An analysis of coastal erosion rates, using historic aerial imagery, 2013 LiDAR data, and 2020 UAV data, is presented in Section 5.2. A discussion on coastal protection options is given in Section 0.

Figure 15: Road damage at the southern end of Whatarangi Bluff, due to a coastal drop out following erosion during a storm (Stuff, 2015).

C.2 Johnson's Hill Landslide

Technical assessment of the landslide was carried out by Nick Perrin of GNS in the 1990's. Information from GNS's work on this landslide is included in the Beca (2000) realignment option report and other memos.

Description of the landslide

C.2.1 Extent and level of activity

A summary of information from Perrin (1995) *and Perrin* (2002) *is as follows:*

- An upslope dormant large landslide, 1100 m in width and 300 m long.
- Further down(slope) an active section is 400 m by 300 m and up to 40m deep.
- Actively moving (section was) about 150 m by 100 m by 10 to 20 m deep. The lower area was noted as more complex with slumping, flowing etc.
- Inferred to be an old deep-seated bedding-controlled failure mechanism.
- The upper extent of the active portion is not well defined.
- In the 1990s reactivation of part of the slide mass was occurring as a result of wave erosion at the toe and road cutting.
- The slide was actively creeping, and a tension crack periodically opens up along the side scarp(s).
- The slip became active after a particularly wet winter in 1995. The affected area was a reactivation of part of a larger ancient slide. There were cracks in the road at the time.
- Further slipping was reported at this site in the winter of 2002, and a school bus driver refused to take children over the slip area.
- Incipient rotational failure of the slide debris under the outside edge of the road as a result of wave erosion.
- Monitoring pins have been used at different times to monitor the areas of the slide that are moving. Perrin (1995) noted that ~10 pipes/pegs were surveyed and provided information on movement trends.
- Implementation of slope monitoring was proposed to gain an idea of degrees of success of remediation activities.
- Planting of the slope above the road with trees was recommended by GWRC and carried out in the 1990s/2000s as a stabilisation measure.

More recently SWDC (TL pers comm) have noted:

- That survey marks (presumably installed within the last 18 years) were monitored every 18 months but are not now.
- After a period when movement had stopped, the main Johnson's Hill landslide has been moving since the Kaikoura earthquake.
- Currently the active portion of the landslide is about 300m wide.

C.2.2 Water / seepages

- Water seepages as shown in Figure 16 are apparent immediately above the road. SWDC arranged subsoil trench installation in May 2020 and found significant seepage flows at shallow depth.
- There were *no* signs of seepages on the slope above the road in an (extensive) walkover in the 1990s (Stan Braaksma, pers comm).

C.2.3 Geological Factors

- The underlying geology is s*oft blue-grey fine sandy siltstone to silty sandstone* – of Bells Creek Formation.
- The maps of bates (1969) shows bedding of the mudstone dipping at 20 and 30 degrees to WNW ie dip / dip direction of 20-30° / 300°, this is consistent with observations on site.

- The slope angle is about 20 to 30deg to the northwest which is about the same orientation as the bedding in the siltstone.
- Steep fault zones related to the Dry River Fault may well be affecting the groundwater and strength of the base of the slope where the landslide daylights ground level – inferred to be just below sea level.

C.2.4 Comments on stabilisation of the landslide

- Cutting into a slope of saturated actively-sliding debris and very weak sandy siltstone without making extensive provision for drainage above the road will cause further problems (Perrin, 1995).
- Cutting into the slope to move the road away from the sea would cause further instability issues; this was noted to undermine the Cypress trees planted above the road to help stabilise it (Braaksma, 2020).
- Tectonic uplift could improve the situation as the shoreline would re-establish further out from the slope toe; but such uplift would only happen in connection with a major earthquake (such as occurred at Kaikōura), which would trigger more landslides (Perrin, 2002).
- An option was considered to look at an alternative inland route between Te Kopi and Washpool. This would avoid the active coastal erosion on the present route, but will be difficult to establish because of slope instability. Likewise, the existing route cannot be improved by cutting into the cliffs, as this would probably cause more large-scale landsliding (Perrin, 2002). Comments from Stan Braaksma (2020) indicate that the realignment would have to be situated on Greywacke bedrock, well back in the hinterland.
- Johnson's Hill is likely to remain an on-going problem, but there is room there to realign the road as required, and stabilisation measures (mainly drainage) should help (Perrin, 2002).

C.2.5 Drainage measures

- Surface drainage *on the slope above the road will act to prevent infiltration of rainwater* (Perrin, 1995).
- Numerous drilled drains have been installed in the past (>10 years ago) – only one of these is still visible and is not flowing (Figure 17).
- Installation of a 'French drain' was carried out in May 2020 to intercept the spring discovered just upslope of the road (Figure 16), with no movement noticed on the road since (Tim Langley, personal communication).
- At least one culvert / subsoil outlet pipe discharges to the slope below the road (introducing water into the unstable lower slope).
- Previous drainage socks and pipes have been left behind below the road (Figure 18) – while none of these were noted to be flowing when we carried our June 2020 drone flight.

Figure 16: Snapshots from a video of a groundwater spring encountered by Fulton Hogan on 7 May 2020, during excavation for a subsoil trench associated with roadworks.

Figure 17: Erodible cut face near the northern edge of Johnson's Hill Landslide. An indicative position of the edge of the landslide is shown. The contact between brown sandstone (left) and grey mudstone is evident. June 2020 photo.

Figure 18: Drainage at Johnson's Hill landslide. Drainage outlets below the road (green), French drain location on the upper side of the road (blue), and redundant green culvert extension socks (red).

Appendix D
Site Geology

Appendix D – Site Geology

D.1 Geological Setting

Based on the GNS regional geology maps of Wellington (Begg & Johnston, 2000), the geology of the site is variable. A geology map from Bates (1969) shows bedding orientation angles and fault locations as inferred in 1969 (Figure 19). As indicated in Figure 20, geological units encountered across the study area include:

- Alluvial fan, scree and colluvial deposits consisting of poorly sorted gravels (Q1a).
- Beach deposits consisting of marine gravel with sand, mud and beach ridges (Q1b).
- Beach deposits consisting of marine gravel with sand, commonly underlying loess and fan deposits (Q5b).
- **Bells Creek Mudstone**, upper Mangaoranga Formation, Hurupi Formation and Clay Creek Limestone. Massive blue grey calcareous mudstone with sparse fossils and discontinuous limestone lenses and sparse tuff beds (Msb).
- Kupe's Sail Beds, Sunnyside and **Pūtangirua Conglomerate**, basal sandstone, and sandy siltstone, with minor grit; moderately to well bedded sandstone and calcareous sandstone with minor poorly sorted conglomerate **(Msp).**
- Whatarangi Formation, grey graded sandstone and siltstone, minor siltstone and conglomeratic interbeds (Kg).

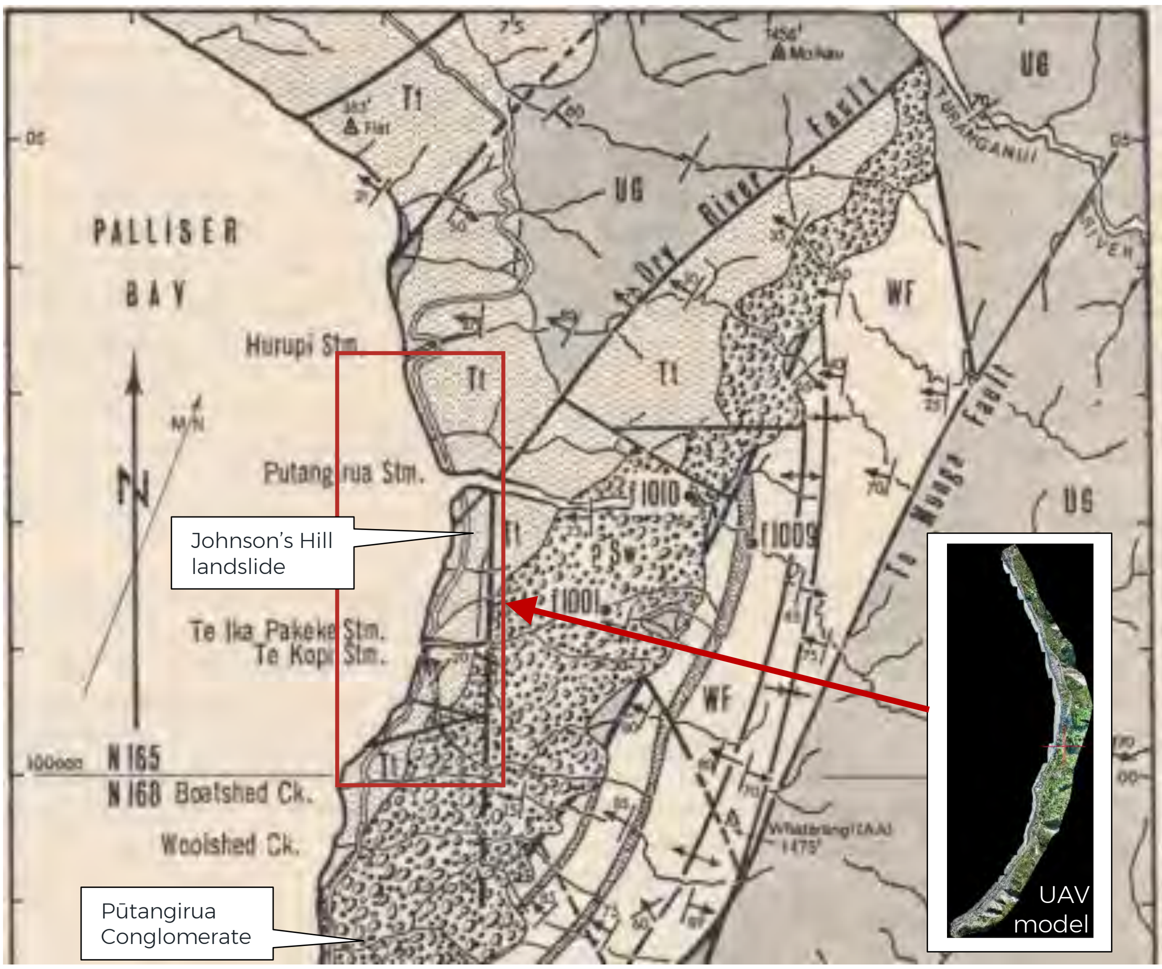

Figure 19: Geological map of eastern Palliser Bay from Bates (1969), showing bedding orientation angles within the Bells Creek Mudstone (Tt) and inferred faults.

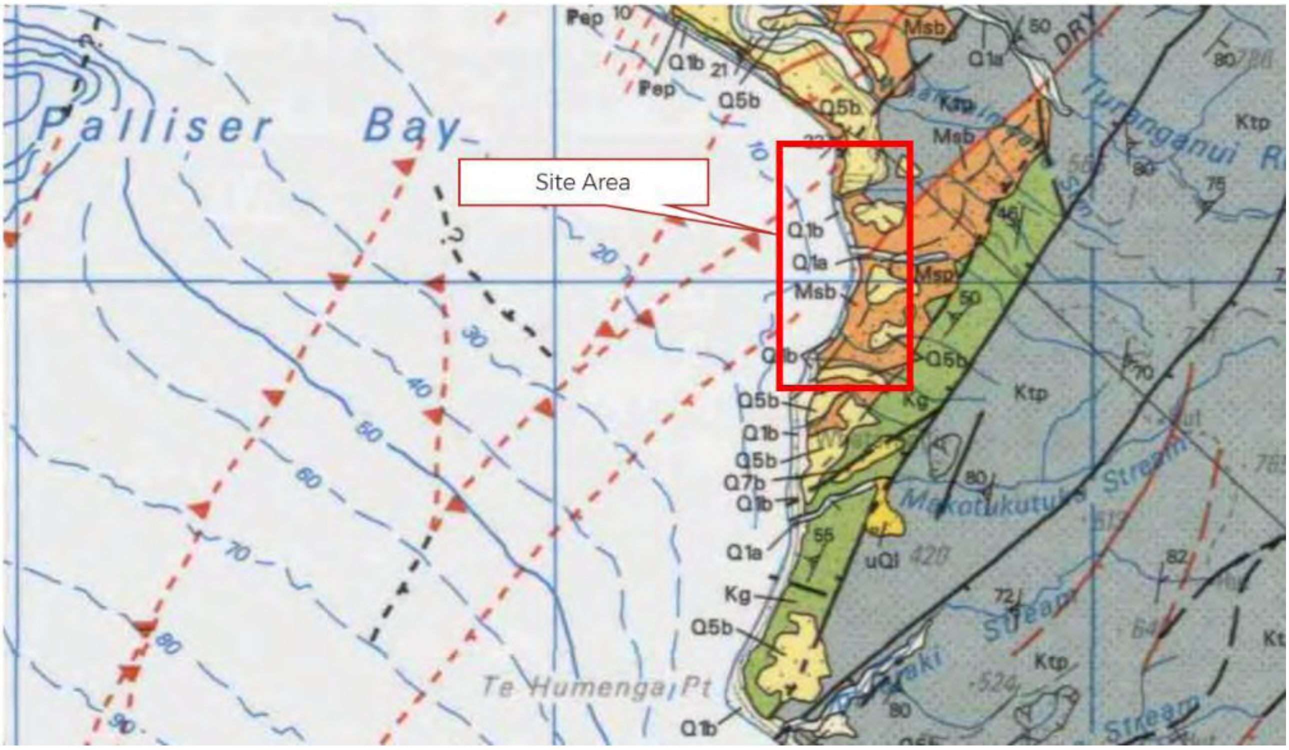

Figure 20: Geological map of eastern Palliser Bay from GNS (Begg & Johnston, 2000)

Active faults in the wider region include the Dry River, Waihora, and Arakihi Faults (Table 5) plus many unnamed faults. The GNS active faults database (http://data.gns.cri.nz/af, accessed June 2020) indicates that the Dry River Fault, a steep (50 to 80°) northeast-dipping reverse fault, runs through the centre of the study area close to Johnson's Hill, with a recurrence interval of 5000 years.

Table 5: Summary of active faults near the study area

Fault	Recurrence Interval	Magnitude	Slip Rate	Proximity
Dry River	5000	7.3	0.3 – 1.2 mm/yr	Within site
Waihora	Unknown	Unknown	Unknown	~1.5km NW
Arakihi	Unknown	Unknown	Unknown	~11km SE

D.2 Field Observations

Throughout the study area, alluvial fan and beach deposits were observed on the coastal side of the road (Q1a and Q1b). In road cuttings on the inland side of the road, mudstone (Msb) plus siltstone and sandstone (Msp) are exposed, with thicknesses of up to ~150m when observed from the road. Bedding in the Bells Creek Mudstone (Msb) is visible in a gully just north of Te Kopi settlement (Figure 21). Above the siltstone and sandstone lithologies are alluvial and beach deposits of gravel with sand.

Geological contacts were observed in several locations throughout the study area (Figure 22). In a gully at Whatarangi Bluff, a contact between Bells Creek Mudstone deposits and overlying alluvial gravels was observed. At Johnson's Hill, a contact between sandy siltstone deposits (Msp) and Bells Creek Mudstone is visible in cut slopes above the road. In the beach cliff at Te Kopi, the boundary between Bells Creek Mudstone and overlying beach deposits is exposed.

Figure 21: Dipping beds in an outcrop of Bells Creek Mudstone (Msb), with horizontally-bedded brown conglomerate unconformably overlying.

At Whatarangi Bluff, water seepage was observed at the contact between Bells Creek Mudstone and overlying alluvial gravels (Figure 22). Multiple localised water seepages were also seen throughout the Bells Creek Mudstone in cut slopes at Johnson's Hill, with channels formed by surface water run-off indicating that this rock is easily erodible.

Slope angles at Whatarangi Bluff are highly variable, ranging from 45° to 90°. The typical measured slope angle for the sandstone and siltstone materials ranged from 50° to 60°. Water seepages were noted by Tim Langley of SWDC to influence the stability of the steep slopes, including at the 2015 dropout section at the southern end of Whatarangi Bluff.

Figure 22: Geological contacts observed within the study area, at [a] Whatarangi Bluff, [b] Johnson's Hill, and [c] Te Kopi.

Appendix E

Coastal Processes

Appendix E – Coastal Processes

E.1 Coastal Classification

Strike-slip and Dip-slip faults are characteristic of the Wairarapa area, both onshore and offshore (Barrow, 2002). A coast with these features is often denominated as a collision or leading-edge coast, which Inman (1994) describes as a coast characterised as follows:

- Narrow continental shelves bordered by deep basins and ocean trenches;
- Submarine canyons cut across the narrow shelves;
- Earthquake and, sometimes, volcanic activity; and
- Rugged shores backed by sea-cliffs and coastal mountain ranges.

The study site certainly presents the characteristics of a collision coast.

Figure 23 shows the bathymetry of the Cook Strait, offshore Palliser Bay, where the Cook Strait canyon is easily identifiable. Barrow (2002) highlighted that eastern Palliser Bay, where the study site is located, is an area where cliff recession rates are particularly high due to the rapid marine erosion of soft mudstone and sandstone cliffs. He observed “the more resistant rocks retreat more slowly and remain as headlands while weaker formations are cut back to form embayments”.

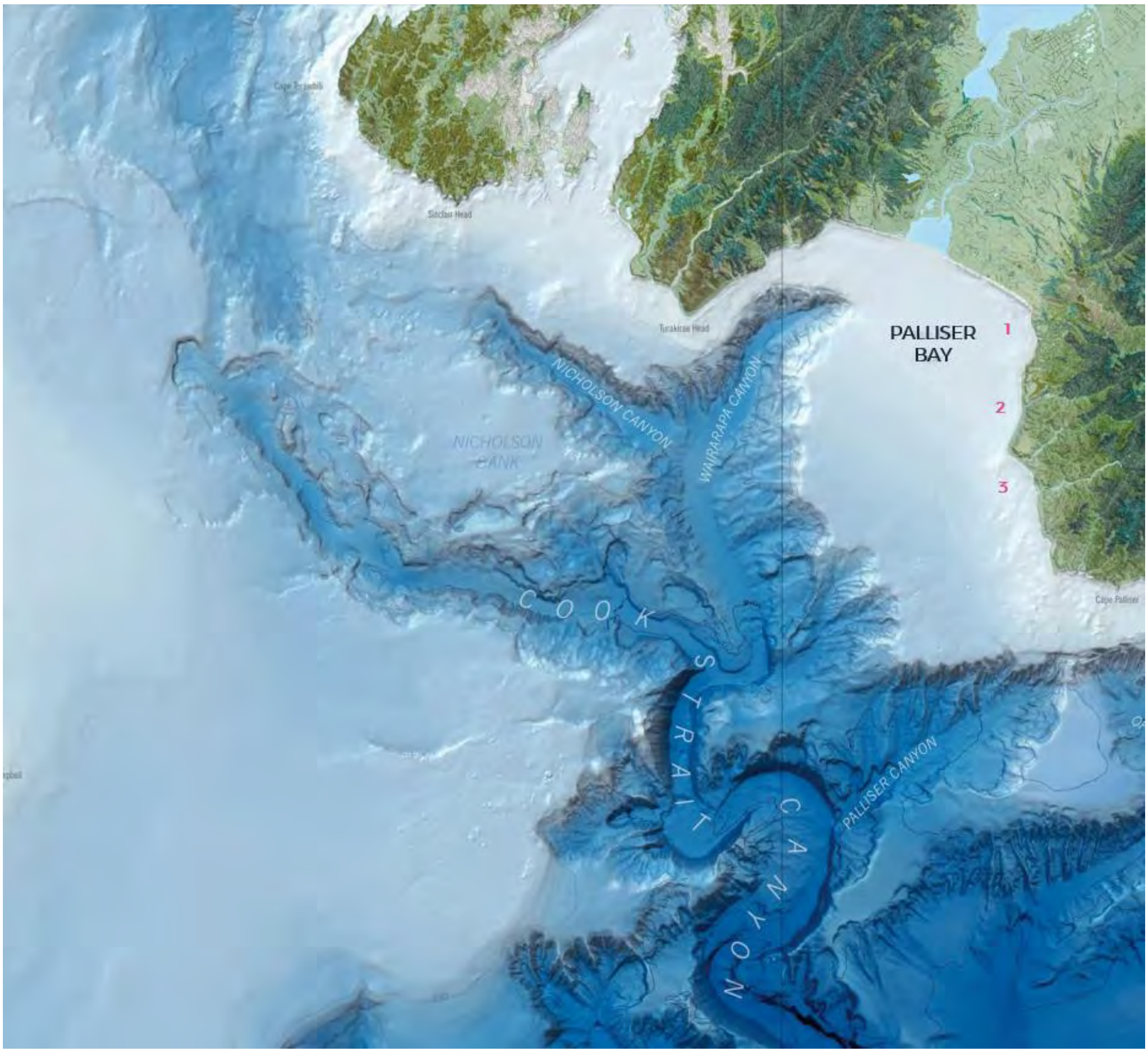

Figure 23. Poster showing the bathymetry of the Cook Strait Canyon, offshore of Palliser Bay (NIWA, 2009). The Palliser Bay label and the magenta numbers have been added later. The magenta numbers refer to an approximate location of data points for wave heights.