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Geomorphological Assessment of the Waioeka inlet, Opotiki

A report prepared for Tonkin and Taylor Ltd on behalf of the Bay of Plenty Regional Council

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CONTENTS

1 INTRODUCTION

Tonkin and Taylor are carrying out an erosion hazard assessment for the Bay of Plenty Regional Council (BOPRC) between the Waiotahi and Waioeka Rivers (Figure 1). Tonkin and Taylor have commissioned Coastal Systems Ltd to prepare a "Geomorphological Assessment regarding the behaviour of the Waioeka Inlet, with particular focus on how far westward it might migrate before the spit is breached based on historical evidence. And/or how the inlets future behaviour could be incorporated within an erosion hazard assessment given that historic data shows the mouth migrating westward and speeding up".

The physical characteristics of the inlet and coast have been described by Dahm and Kench 2002, 2004 as follows. The catchment is some 1130 km^2 which is largely steep and forested hill country with two main tributaries, the Waioeka and Otara Rivers. The confluence is 1.5 km upstream of the throat (this straight reach forming the approach channel to the inlet throat). The annual mean flow in this reach is 43 m^3/s with combined spring tide discharge of 60 to 70 m^3/s, while the annual flood flow is about 1000 m3/y and combined spring tide discharge of 100 to 150 m3/s. River sediments are medium sand with increasing silt/clay on the margins and gravel within the main channel and western side of the inlet. The annual volume supplied to the inlet by the river is considered to be less than 15,000 m^3. Fine to medium sand occurs on the coast beyond the inlet. Net longshore drift is estimated to be in balance with a flux of some 10,000 m^3/y. The coast is backed by Holocene sand dunes and swamp. In addition, a relic sea cliff made of volcanic sediments lies some 1.75 km westward of the present Waioeka mouth (see Figure 1).

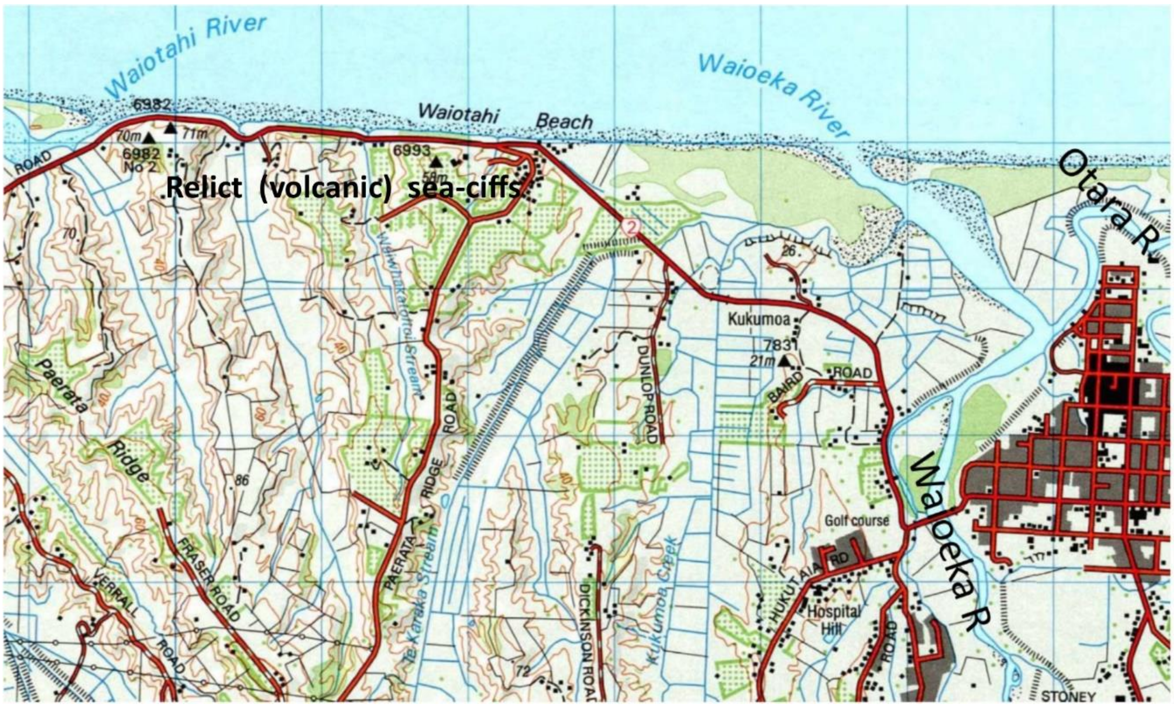

Figure 1 *Location diagram. Grid lines are 1 km apart*

Gibb (1994) found the open coast shoreline to be accreting to each side of the Waioeka Rivermouth: averaging 0.2 m/y to the east and 0.6 m/yr to the west. Dahm and Kench (2002, 2004) found the Waieoka entrance had migrated westward some 900 to 1100 m in the past 140 years (averaging 7.5 to 9.5 m/yr), but had slowed to 2.8 m/y between 1940 and 2000. BOPRC ground surveys of the western bank of the Waioeka River collected in 2017 and 2018, show an increased westward migration rate of 10 to 15 m/yr. These results demonstrate a net westward movement of the inlet, and indicate considerable shorter-term variation occurs with an episode of enhanced migration presently underway.

Three specific geomorphological aspects are investigated in the present study :

1. Longer-term behaviour of the river channel, banks, and the (inlet throat) approach channel;
2. The seaward basin shape in which earlier Holocene inlet behaviour may be preserved, and
3. Shorter-term entrance behaviour.

The present study analyses morphological data obtained from cadastral plans (1866, SO 2810, 1867, SO 2809), aerial photographs (1940, 1944, 1945, 1954, 1964, 1966, 1970, 1971, 1976, 1981, 1985, 1987, 2014-15), satellite imagery (2003, 2007, 2011, 2012, 2015, 2019), NWASCO coastal resource maps ec 3967 Sheets 3 and 4, and BOPRC ground survey data 1994, 2017, 2018). These data were abstracted after georeferencing to NZTM using LINZ spatial data and 2014-15 orthophotos downloaded from the LINZ web site https://www.linz.govt.nz/land/maps/aerial-imagery-and-orthophotography

2 LONGER-TERM (HISTORICAL) BEHAVIOUR

Channel orientation as it approaches the inlet throat can be a first order control of inlet configuration and behaviour where there are no structural (natural or artificial) controls and can over-ride net littoral drift direction (Shand and Shepherd, 2016). Consequently, a line was fitted to perturbations along the left bank of the approach channel for the 1867, 1945, and 2015 samples – these being approximately equally spaced and the western bank was chosen as it is evident in all images and is of particular interest to this study. The resulting alignments are depicted by straight lines in Figure 2 and define an average westward migration rate at the coast of 8.05 m per year with 8.2 m/yr for the 1867 to 1945 period and 7.9 m/y for the 1945 to 2015 period.

What is of initial interest is the increasing westerly offset of the approach channel as the associated ebb flow is a primary driver of morphological change. Indeed, this association suggests that continued westward migration of the entrance can be expected. However, to define a causal relationship, channel behaviour had to be investigated in more detail. In particular, river control structures were superimposed and riverbank change at 6 key locations were identified and vectorised (marked in Figure 2).

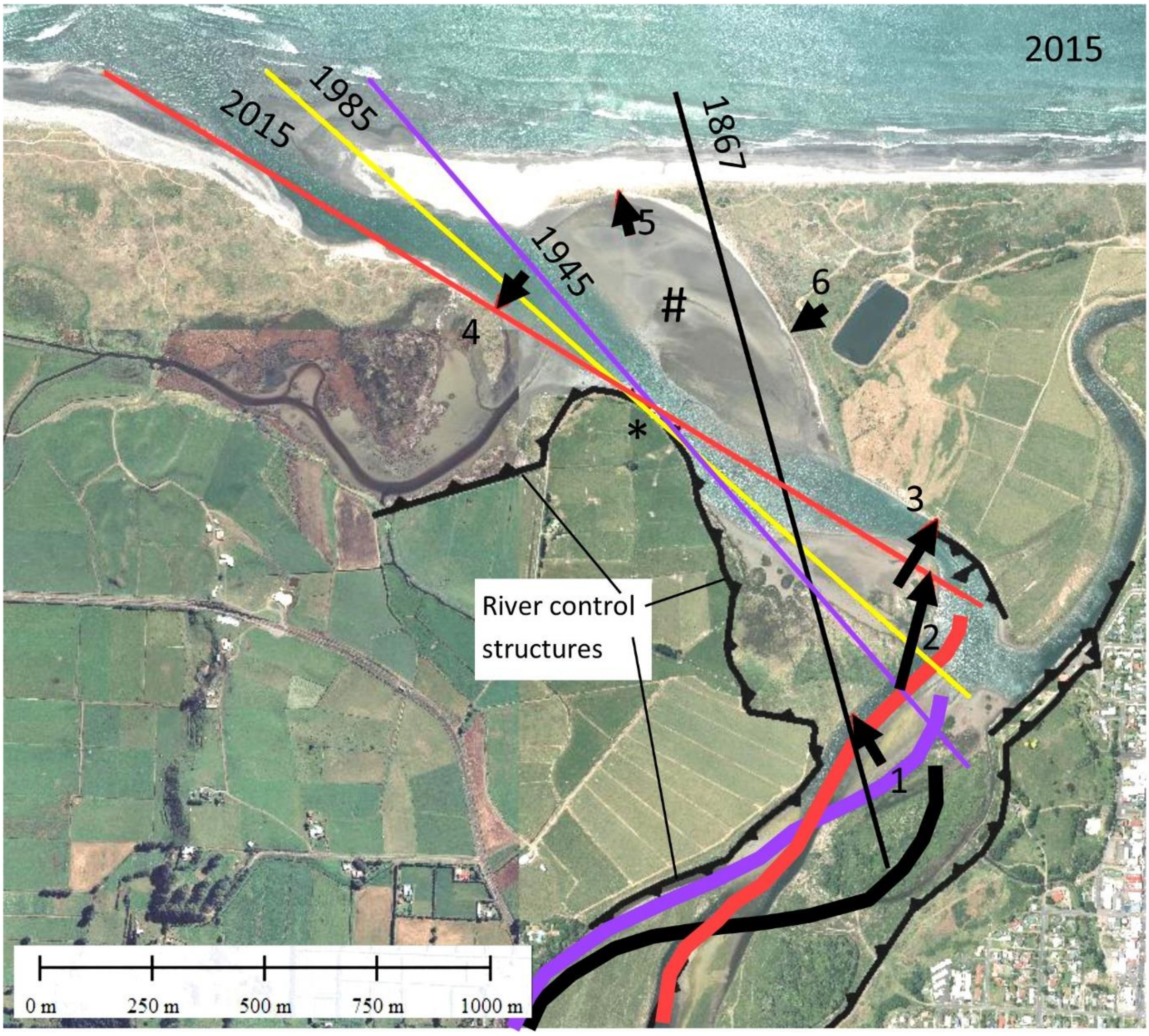

Figure 2 *Inlet approach channel alignments (straight lines) for 1867, 1945, 1985 and 2015. Upstream river channels (bold curved lines at base of image) for 1867, 1945 and 2015 are also shown. Shoreline change vectors (1945 to 2015) are depicted for key sites, and river control structures (stop banks and riprap protection works) are also marked.*

The first result is the control apparently exerted by the left bank control structure mid way along the approach channel (marked by the asterisk in Figure 2), a location where the 1942, 1985 and 2015 alignments all intersect and pivot anti-clockwise. This (1960s?) structure appears to have arrested what had been westward bank migration since 1878.

Now considering the vectorised locations of bank change beginning at the upstream end. The main river channel immediately upstream of Vector 1 has changed from a west to east orientation (see 1867 channel marked by the thick black line) to the current more south to north orientation (2015 bold red line). This has resulted in the bank at Vector 1, which is immediately downstream of the control structure, eroding some 120 m and the depositing sediment in the vicinity of Vector 2 where a point bar some 260 m long has formed since

1945. This point bar has subsequently directed flow against the right bank in the vicinity of Vector 3 where the back has retreated some 165 m since 1945. The BOPRC placed protective rock rip rap at this location in 2013 but according to council staff little of this structure remains after recent flood events. These channel and bank behaviours would result in the alignment axes rotating around the mid approach channel structure (marked by the *) and thence drive the approach channel against the western bank in the vicinity of Vector 4 which has sustained 90 m of erosion since 1945. These mechanisms have thus caused the historical westward migration of the inlet mouth and this behaviour could continue into the future - all things being equal.

It is noted that should the rock control at point * not have existed then the bank would have likely continued to erode at this location and an anti-clockwise meander develop which would have returned the channel to a more shore-normal orientation. Indeed, the Holocene morphology considered in the following section suggests that the present approach channel may has a more extreme westward offset than occurred previously.

However, our bank analysis at Vector 5 shows that the inside of the spit has migrated (eroded) seaward some 95 m since the 1940s. By contrast the spit's seaward shoreline has been relatively stable so the spit is narrowing - from about 75 m in 1985 to 20 m in 2014-15 or (1.8 m/yr), with the rate increasing to over 2.2 m/yr since 2003. The reason for this narrowing appears to be related the eastern (right) bank adjacent to the inter-tidal flat (# in Figure 2) migrating westward (up to 80 m at Vector 6 since the 1940s) and then focusing and deflecting flow westward along the spit (at Vector 5) toward the mouth. If this erosion (at Vector 5) continues, the spit could breach in about 10 years time. However, given that the breach will be the result of a constrained floodway rather than driven by erosion induced by the main approach channel, the persistence of such a breech and its impact on the western shoreline, the problematic area of interest for the present study, is uncertain.

3 HOLOCENCE MORPHOLOGY

Figure 3 provides a 3D view as State Highway 2 approaches Waiotahi Beach. The Waioeka Rivermouth lies approximately 1 km downcoast. The road can be seen to run along the base of the relict (Holocene) seacliff. The orientation of the sea-cliff is interpreted as the westernmost margin of the Waioeka River and preserves an extreme orientation. Also marked in Figure 3 are yellow and red straight lines – these being parallel to the 1985 river alignment and the 2015 river alignments respectively as depicted earlier in Figure 2. The 1985 alignment is approximately parallel to the road (base of relict sea-cliff), while the red 2015 alignment has a greater westward offset than the relict cliff-line. These orientations at least suggest the present offset is greater than that experienced by this river in the past. However, as discussed in Section 2, the present offset may be unduly influenced by river control structures, while the Holocence orientation would relate to a natural system. This evidence and argument are therefore perhaps more of interest than assistance in answering the question relating to westward migration potential of the inlet system.

Figure 3 *State Highway 2 approaching Waiotahi Beach with old sea-cliff on the left (inland) side of the road. The Waioeku Rivermouth is to lower right off photo (1 km distant). The red line is parallel to the present channel approach alignment (red line in Figure 2), while the yellow line is parallel to the 1985 approach channel alignment in Figure 2. See text for discussion.*

4 SHORTER-TERM BEHAVIOUR

The more recent imagery and survey data show the erosion of the (vegetation-defined) western shoreline in the vicinity of the throat has increased. This raises the issues of if, and if so then how, such change should be incorporated when calculating the longer-term migration rate for an erosion hazard assessment.

Shorter-term inlet behaviour is a product of several variables and inter-related processes which invariably result in sediment moving from one side of the inlet throat to the other (inlet bypassing). A primary mechanism (evident in the Waioeka historical imagery) involves growth of the tip of the spit (by marine and fluvial processes during periods of lower energy) followed by "trimming" or shortening of the spit tip during higher energy – especially extreme river flood events. Sediment swept seaward is subsequently returned, typically as a coherent sand-body, through the surfzone to weld onto the western (in the Waioeka situation) inter-tidal beach or platform. This material can prograde the shoreline with a portion being transported inland through the throat and form recurved spits (for example see the western shoreline immediately landward of Vector 4 in Figure 2).

In situations where the spit has a longer low-lying end section, flood flows may "cut" through the spit with the truncated portion welding onto the previously offset side of the inlet. Artificial cutting is often used as part of inlet management regimes.

Where this process involves a greater length of spit (typically wider and higher), the process is referred to as spit “breeching” and this tends to occur over a longer time period. This latter process is what may occur at Vector 5 during the next decade or so.

Trimming processes are evident in the Waioeka image series as occurring every few years. However, the most recent episode appears to involve a longer section of spit with more significant morphological impacts. Key images which summarise this process between 2011 and 2019 are depicted in Figure 4.

The 2011 image shows the inlet with a strong westerly asymmetry and well-defined spit. The spit outline has been superimposed upon the 2012 image and his shows a recently shortened (flood trimmed) subaerial spit along with a more shore-normal channel orientation across the ebb delta , and a coherent sand body or “slug” (marked by the asterisk) on the western inlet platform – presumably composed of the truncated spit sediment.

The November 2015 image, which has the 2012 high and low water lines superimposed, shows the subaerial spit has extended westward some 450 metres which is substantially greater than for any other inter-survey period in the historical record back to 1940. On the offset (western) side of the inlet, the 2012 slug appears to have migrated onshore and the high tide shoreline has subsequently prograded seaward some 50 m adjacent and seaward of the throat. Inside the throat the high tide shoreline had eroded by a similar amount. Such erosion is commonly observed when waves and or current cross a sand body/area of deposition. Also of note, the channel approaching the throat in the 2015 image has a more westward orientation (see the white arrow in Figure 4) than in any earlier image.

The 2019 image, which has 2015 features superimposed, shows a slightly shortened spit and a slug in the western surf zone – both indicative of a previous flood event trimming the spit tip, followed by some recovery. Of particular significance, however, is erosion to the western high water shoreline adjacent to the throat and even greater erosion (marked by the #) of the accompanying vegetation front defining the dune-line. This dune erosion is consistent with the channel’s antecedent (2015) westward approach direction forcing flow into the western side of the throat. The BOPRC vegetation-front surveys from June 2017 and May 2018 (the latter co-incides with the 2019 image vegetation line), show 80% of this erosion had occurred prior to the 2017 survey. And a comparison of the 2015 HWM superimposed upon the 2019 image shows this shoreline has recovered some 70 %.

This type of more extreme short-term inlet behaviour appears to have not occurred before and may result either from random processes or as a product of the increasing westerly offset of the approach channel in which case such behaviour can be expected to occur again and perhaps dominate in the future. While substantial HWM recovery has occurred (which leads vegetation/dune recovery) perhaps indicating a random process, this may be premature as the 2019 image shows persistence of the westerly channel approach immediately upstream of the throat (see the white approach arrow on the 2019 image in Figure 4).

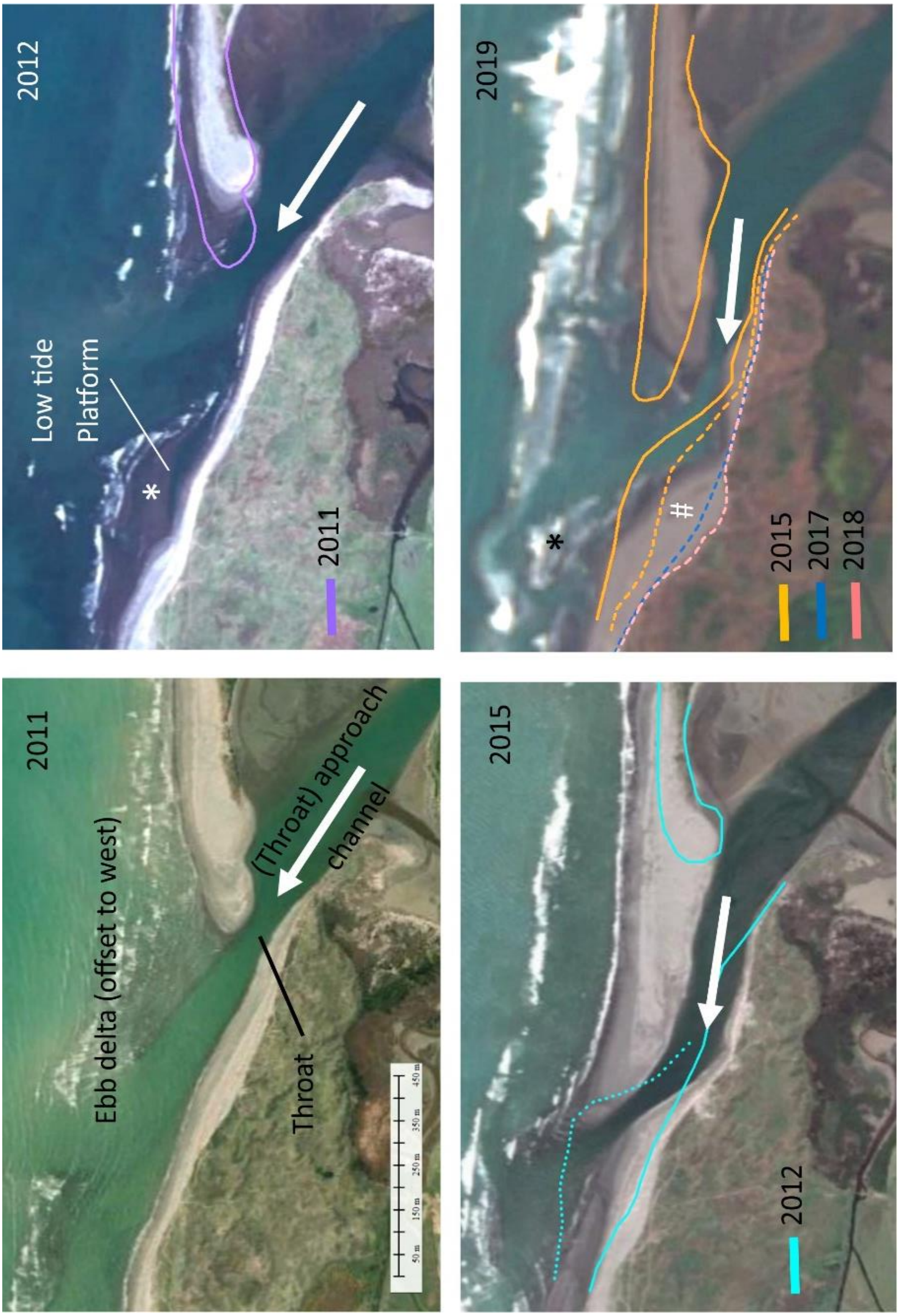

Figure 4 *Recent inlet configuration changes. Dotted line marks low tide platform, solid lines denote high water mark (HWM) and the dashed lines denote vegetation front/dune toe, all from the previous image. The 2017 and 2018 shorelines are BOPRC dune vegetation surveys. White arrows depict the inlet throat approach channel, asterisks mark recent sediment accumulations (slugs) and the hash marks recent erosion/recovery.*

5 SUMMARY/CONCLUSIONS

This somewhat high-level geomorphological assessment of the Waioeka Inlet found that the inlet throat has systematically migrated westward between 1867 and 2015 at an average rate of about 8 m/yr with this rate substantially increasing more recently.

This migrational process is related to changes in the upstream channel configuration – changes which have been affected by both natural river processes and also influenced by river control structures. Such upriver changes will potentially continue their effect inlet morphology.

However, continues extrapolation is potentially problematic for the following reasons:

1) The approach channel's (high-end) westerly offset captured during the Holocene by western cliff alignment is less than the present offset;
2) Upriver processes have also been narrowing the spit several hundred metres east of the typical throat location and breeching within the next 10 years appears to be plausible, and
3) Recent accelerated erosion is associated with a unique short-term behaviour that may result from a random process, i.e. it is unlikely to be repeated.

Each of the above reasons have caveats; however, because of their potential validity and the excessive high-end predictors derived from analysis and extrapolation the full data set with its recent extreme values , I suggest that an erosion hazard assessment for this area could be based on a long-term erosion component determined by regression analysis which excludes the more recent extreme period of erosion (i.e. use 1940 to 2012 data). In addition, a short-term component should be included to account for the more recent increase in erosion. This approach should provide adequate protection until future inlet behaviour becomes more certain.

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