WOODS

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*W-REF: P25-609*
*13 August 2026*

# STREAM EROSION ASSESSMENT

## Milldale North (Stage 14 – 17) Substantive Application

## 1. Introduction

This memorandum is prepared as part of the substantive application for Milldale North development (referred to as Stage 14-17) assessing Orewa River as it goes past the development site (Figure 1). Several existing tributaries located within the development extent and discharging to the stream (Figure 2) will be retained while one (named Stream 7 for this memo) will be realigned/reworked. Figure 3 indicates the proposed realignment of the streams. A small portion of the development is noted to discharge to the lower reaches of Waterloo Creek (Figure 4). Further to the east is an even smaller catchment contributing to a tributary of Waterloo Creek (the tributary discharges to Waterloo Creek at Wainui Bridge). It is noted that at the time of this reporting, there are active/ongoing developments in the upper catchment of Waterloo Creek which are more likely to drive the changes that the portion in this application. It is noted that the lower portion of Waterloo Creek is tidally influenced which is also more likely to drive erosional forces than the potential from this current proposal.

### 1.1. Background

As part of the Milldale North Plan Change application. 2024, Woods undertook a high-level stream erosion assessment (available upon request) which this assessment builds upon. As part of that exercise, a stream walkover was undertaken to identify areas of potential erosion and to note existing features along the streams. The report concluded that along Orewa River, some minor undercutting and slumping of banks were noted, however no extensive/active erosion was discovered except at the approach to upper Orewa Road bridge. Using the Healthy Waters erosion screening tool (EST), some cross sections were extracted along the stream which indicated the higher erosion risk closest to the bridge. The risk appeared to be driven more by increases in rainfall rather than the development.

It is noted that at the time of the plan change reporting, the assessment area included an area at the top of the catchment to Waterloo Creek. This is no longer the case as part of the current substantive application i.e.; the upstream development area has been excluded. However, the assessment undertaken then indicated that Waterloo Creek is already susceptible to erosion based on site observations. As mentioned in the preceding section, there is active development underway in the Waterloo Creek catchment. In reviewing results from the EST analysis of the lower Waterloo Creek, it was also concluded that rainfall was the bigger driver to erosion. Relative to the wider catchment development within Waterloo Creek, the proposal associated with Milldale North was of a much smaller footprint.

It should be noted that the assessment undertaken as part of the plan change only covered small sections of the stream hence the need for this expanded assessment that takes a holistic view of the streams rather than on specific cross sections.

## 1.2. Scope

The scope of the assessment includes evaluation of the existing erosion potential and how the proposal will affect/exacerbate it as well as the need for suitable mitigation measures.

A hydrodynamic flood model has been developed to undertake the assessment. As part of this, two model scenarios were developed.

- Pre-development model scenario representing existing conditions.
- Post-development model scenario representing development conditions.

This memorandum details the methodology adopted for the assessment, analysis of results, and conclusion/recommendations for erosion protection measures required for the streams (if any).

The assessment has been carried out for the 100-year ARI storm event with allowance for future 3.8°C temperature increase by 2110 under Maximum Probable Development (MPD) impervious coverage assumption. The 2-year and 10-year events will be presented as part of the detailed design once the pipe network model is completed and outlet locations are well known.

A geomorphic change detection analysis was also undertaken to quantify vertical changes in elevation over time and identify patterns of erosion and deposition within the stream corridor from two periods 2016 and 2024, using LiDAR.

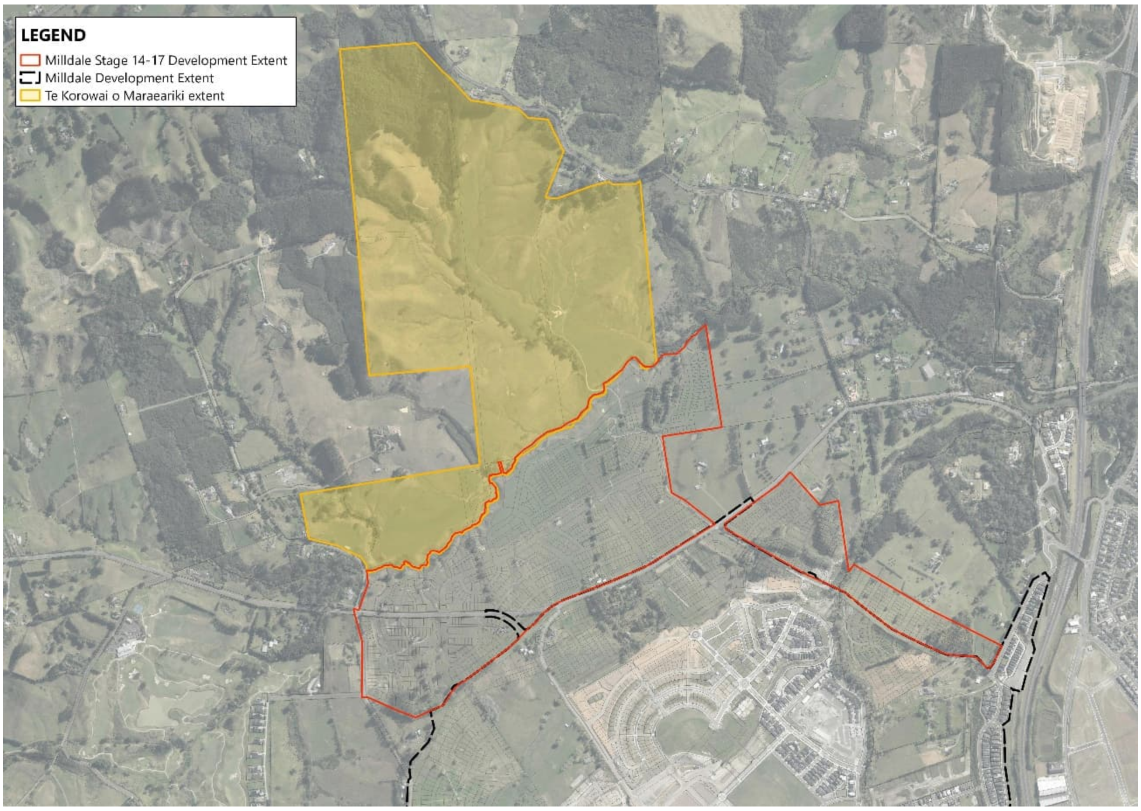



*Figure 1: Milldale North development*

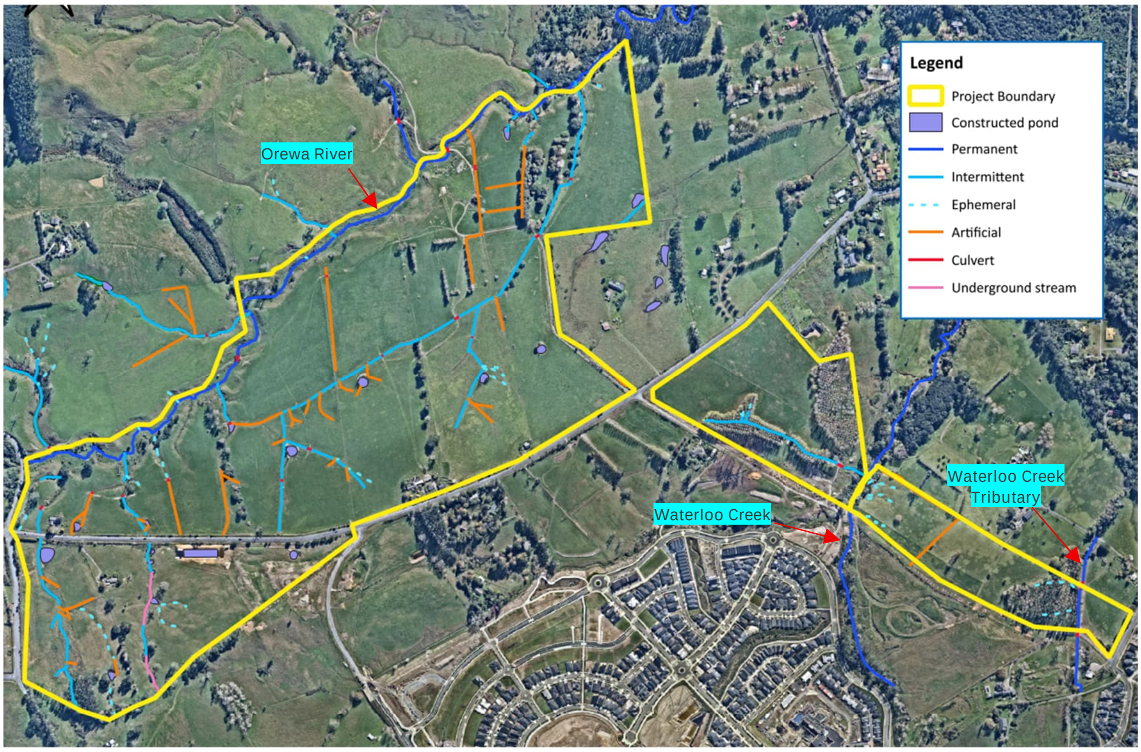



*Figure 2: Existing watercourses (Source: Virdis, March 2026)*

# 2. Stream network

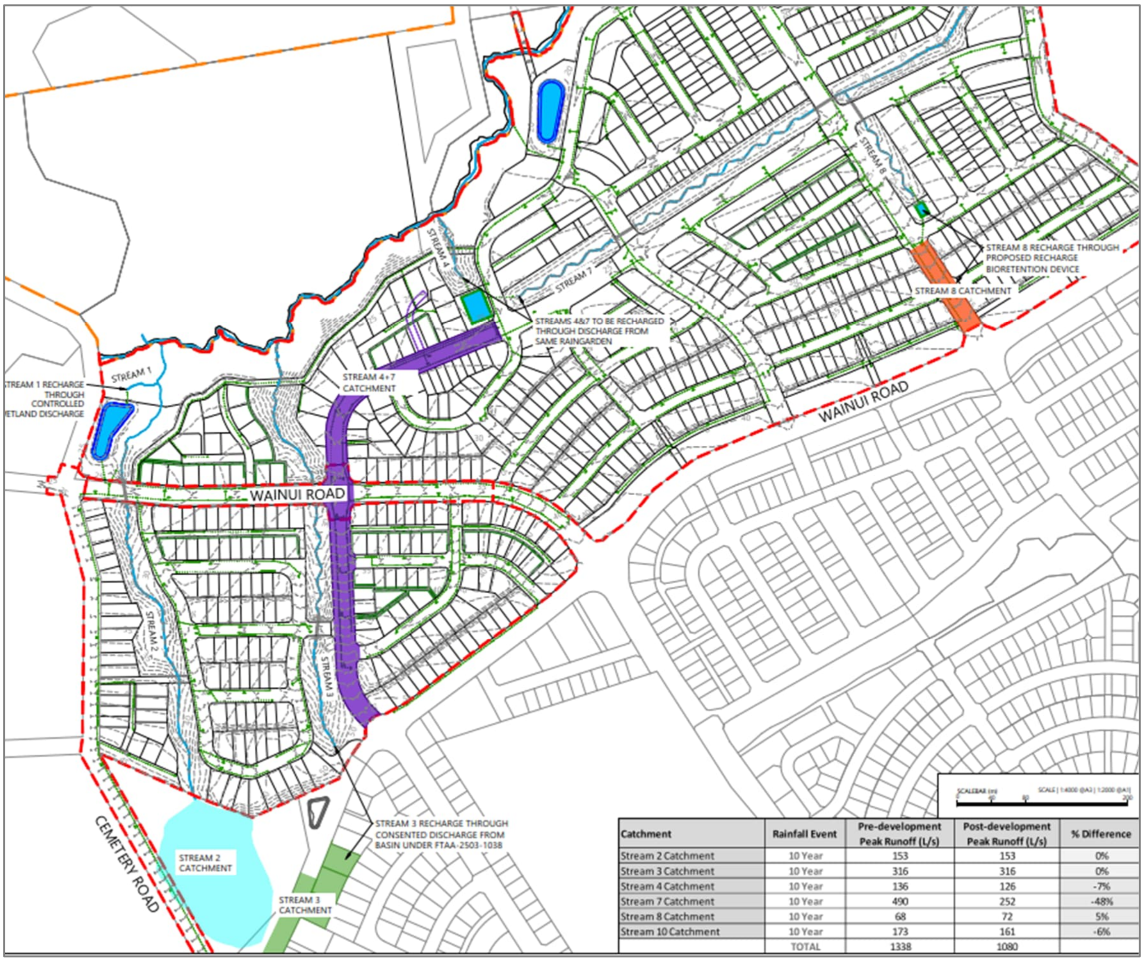
## 2.1. Orewa River Catchment

This catchment covers an area approximately 97ha along the south-eastern/true right bank side of Orewa River. The catchment comprises several tributaries into Orewa River with some of them having their own feeder streams. Table 1 summarises these tributaries based on the naming convention adopted for the reporting.

*Table 1: Orewa River stream network summary*

| Stream name | Comments |
|---|---|
| Stream 1 | Existing minor tributary to Stream 2 |
| Stream 2 | Existing tributary to OR, originating south of Wainui Road. To remain largely unchanged but culvert upgrade proposed at Wainui Road. Minor farm track culverts to be removed |
| Stream 3 | Existing tributary to OR, originating south of Wainui Road. To remain largely unchanged but culvert upgrade proposed at Wainui Road. Minor farm track culverts to be removed |
| Stream 4 | Existing tributary to OR, originating north of Wainui Road. Upper reach of the stream to be filled in. |
| Stream 7 | Existing tributary to OR, originating north of Wainui Road. The stream is to be realigned with multiple culverts to be installed. |
| Stream 8 | New tributary to Stream 7 |

Several outlets will be created from the multiple pipe networks and overflows from associated devices (wetlands and recharge devices) to discharge into Orewa River for primary events. The behaviour of flows and interfacing of the outlet structures will be assessed as part of the detailed design as previously mentioned. There are well defined methodologies for preventing scour at outlet structures and these will be incorporated into the outlet design.




| Catchment | Rainfall Event | Pre-development Peak Runoff (L/s) | Post-development Peak Runoff (L/s) | % Difference |
|---|---|---|---|---|
| Stream 2 Catchment | 10 Year | 153 | 153 | 0% |
| Stream 3 Catchment | 10 Year | 316 | 316 | 0% |
| Stream 4 Catchment | 10 Year | 136 | 126 | -7% |
| Stream 7 Catchment | 10 Year | 490 | 252 | -48% |
| Stream 8 Catchment | 10 Year | 68 | 72 | 5% |
| Stream 10 Catchment | 10 Year | 173 | 161 | -6% |
| | TOTAL | 1338 | 1080 | |

*Figure 3: Proposed realignments or Orewa River tributaries*

## 2.2. Waterloo Creek Catchment

Adjacent to the development site, Waterloo Creek only has one tributary, Stream 10 on the true left bank. This is an existing stream that is to remain unchanged but will be culverted. At the eastern portion of the development, Waterloo Creek tributary will also remain unchanged. Outlets from the pipe networks and devices will be installed and discharge to the streams.

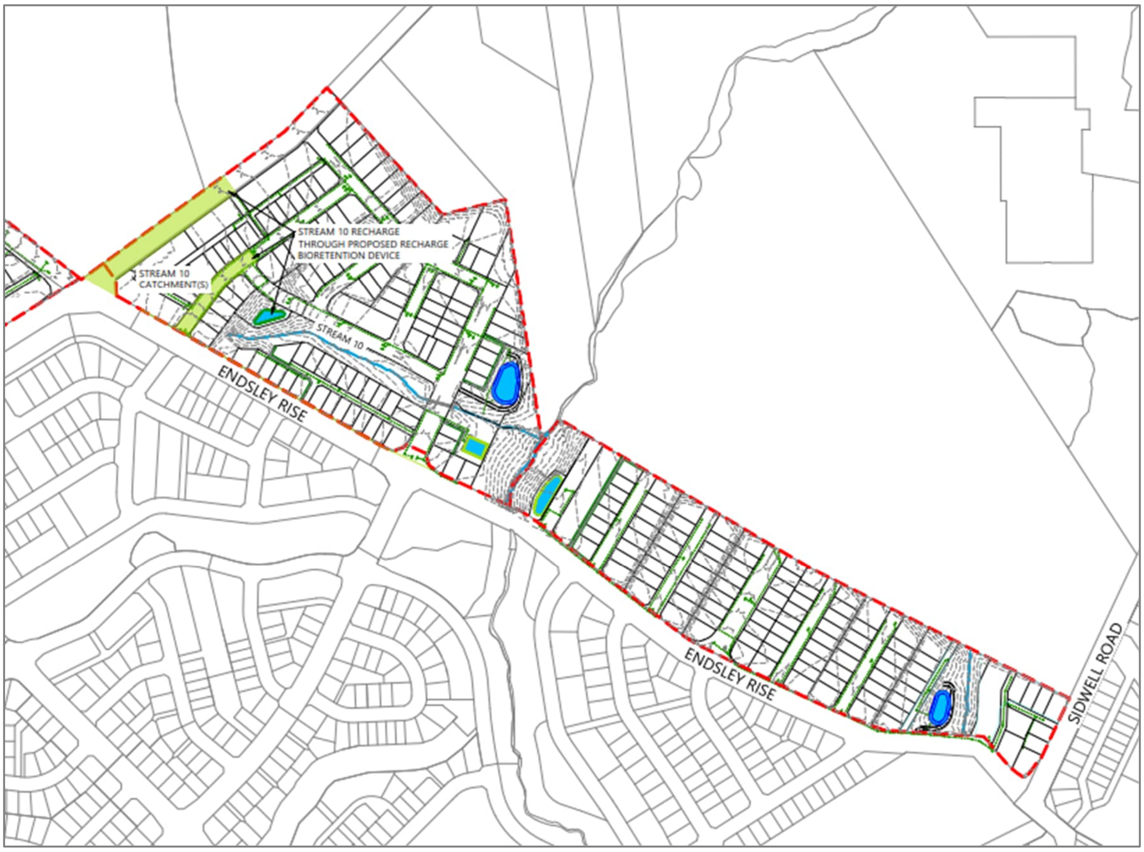



*Figure 4: Waterloo Creek catchment*

# 3. Flood model

## 3.1. Model setup

The assessment utilised a cutdown model that focuses mainly on the streams. The overall flood modelling for the development was prepared on XP-Storm (model build available upon request) however for the stream assessment, a HEC-RAS 1D/2D model was selected to provide/capture finer details along the streams. The hydraulic model was divided into two areas, Orewa River Catchment and Waterloo Stream Catchment. Hydrographs for the various events were extracted for the numerous subcatchments and used as input to the HEC-RAS hydraulic model.

A summary of the hydraulic model set-up is provided in Appendix 2.

## 3.2. Model scenarios

As discussed previously, pre-development and post-development model scenarios have been modelled.

1. Pre-development scenario

The pre-development model scenario has been developed to evaluate the potential of erosion on Orewa River in the existing state. The model scenario helps establish a baseline to compare if the proposed development will exacerbate erosion along the stream.

2. Post development scenario

The post development scenario has been developed to assess potential erosion risk for streams within the proposed development. The results of the model scenario have been compared with the pre-development scenario to assess if the potential erosion risk to the stream has been exacerbated because of the proposed development.

# 4. Assessment

## 4.1. Methodology

This section outlines the methodology adopted to undertake the assessment.

Healthy Water's Auckland Council has provided Woods with Erosion Screening Tool (EST) which provides a methodology to estimate potential erosion risk in streams. The profiles for excess shear as provided in EST have been used to carry out the assessment.

The maximum excess shear stress results have been extracted for all simulated scenarios, which have been analysed to find erosional hotspots. The bed shear stress results were converted into excess shear stress results and categorised based on the risk thresholds as stated in the EST. The resultant output which was used to draw conclusions included percentage exceedances.

Table 2 provides the Auckland Council erosion risk profiles as stated in the EST.

*Table 2: EST erosion risk profile*

| Threshold | Excess Shear | Description |
|---|---|---|
| Green | < 1.0 | Indicates no erosion predicted to occur *(no erosion)* |
| Yellow | > 1.0 < 2.0 | Indicates the potential for some erosion of the channel *(minimal erosion)* |
| Orange | > 2.0 < 10.0 | Indicates the potential for channel to be mobile, *(active erosion)* |
| Red | > 10.0 | Indicates potential rapid rates of erosion and incision of channel *(rapid erosion)* |

### 4.1.1. Critical shear

In the absence of site-specific geotechnical parameters, the 50th percentile median critical shear stress (32.6 Pa) was adopted from Auckland-specific data compiled by Cardno for Auckland Council. This is supported by recommendations in Auckland Council Technical Report 038 / 2009 Erosion Parameters for Cohesive Sediment in Auckland Streams which suggests "using the median critical shear stress (approximately 33 Pa)" if specific parameters are not developed for a stream.

## 4.2. Assessment

This section presents model results and compares the two scenarios: pre-development and post-development. Maximum excess shear stress outputs were extracted to identify erosional hotspots and assess whether the proposed development introduces new areas of concern.

As previously noted, for this substantive application, the modelling focused on the 100-year ARI event while smaller events will be reviewed as part of the detailed design given that the smaller events are more relevant with respect to design of outlet structures (generally designed for up to 10-year ARI events).

The assessment indicated that under the 100-year predevelopment condition, Orewa River will be subject to varying degrees of active erosion mainly along the stream centre with small pockets of rapid erosion at some isolated locations along reach (Figure 5). The most prominent rapid erosion hotspot is noted at the Upper Orewa Road bridge (downstream of the development area) which is consistent with site observations.

In the post development scenario (Figure 7 to Figure 11), it has been observed that the modelled excess shear remains within the same band as the existing situation which implies that the proposed development does not exacerbate erosion within Orewa River. Relative to the overall Upper Orewa River catchment, the proposed development accounts for small contributions into stream i.e., less than 5%, which does not create detectable changes in depth which in turn does not affect/drive up erosion potential. It has been observed that some erosion is likely along the downstream portion of modified

Stream 7 (Figure 10 – focus area 3). Suitable erosion mitigation measures will be provided at this location, designed in accordance with Auckland Council TR2013/018 or other relevant design standards such as HEC14. A suite of potential devices/measures is provided in Appendix 3.

With respect to the preliminary pipe network outlets along Orewa River, the proposed locations have been noted to be areas/spots of low erosion potential (Figure 7 to Figure 10). At the time of detailed design, the pipe network will be modelled which will provide velocity and erosion potential data which will be utilised to design site specific erosion mitigation measures in accordance with Auckland Council TR2013/018 or other relevant design standards e.g., HEC14. Generally, for pipe outlets, either wing walls or stilling basins/scruffy domes with riprap aprons are to be utilised.

For Waterloo Creek (main reach), under predevelopment conditions (Figure 7 and Figure 11), the modelling indicates active erosion along the stream adjacent to the development area and extending approximately 250m downstream. Some zones of rapid erosion have also been identified. As part of the development, the portion of Waterloo Creek between Stages 16 and 17 will be modified, where the banks will be reshaped. This results in some slight increases in the erosion potential along this section of the creek in the post development scenario. While this is the case, as part of the construction of these banks, armouring will be provided which will reduce the potential for erosion.

Along the Waterloo Creek tributary to the east, active erosion is observed in both the pre and post development scenarios. Similar to the proposed works along the main reach, the banks of the tributary adjacent to the development site will also be modified and as part of the modification earthworks, armouring will be provided. For all the outlets to Waterloo Creek and its tributary (Figure 11), erosion protection measures (designed in accordance with TR2013/018 or HEC14) will be installed and design details will be provided as part of the detailed design stage.

It should be noted that as part of the stormwater management strategy as described in the preceding section, 95th percentile events for both catchment discharging directly to Orewa River (and its tributaries) and Waterloo Creek (and its tributary) will be managed onsite or by communal devices. This strategy ensures that frequent events, which would otherwise be likely to drive most of the erosion, will be controlled via slow release to the receiving environment and are therefore mitigated.

Overall, the screening assessment concludes that the proposed development does not materially increase erosion potential in the Upper Orewa River, where the development contributes less than 5% of catchment flow and modelled excess shear is comparable to existing conditions. Localised increases are predicted along the reshaped banks of Waterloo Creek between Stages 16 and 17 and along the downstream portion of modified Stream 7. In both cases bank armouring and outlet erosion protection designed in accordance with TR2013/018 or HEC14 will be provided, and the proposed riparian setbacks are sufficient to accommodate the predicted erosion behaviour. Residual erosion risk is therefore assessed as low, with the specific measures identified in the toolbox (Appendix 3) to be confirmed at detailed design.

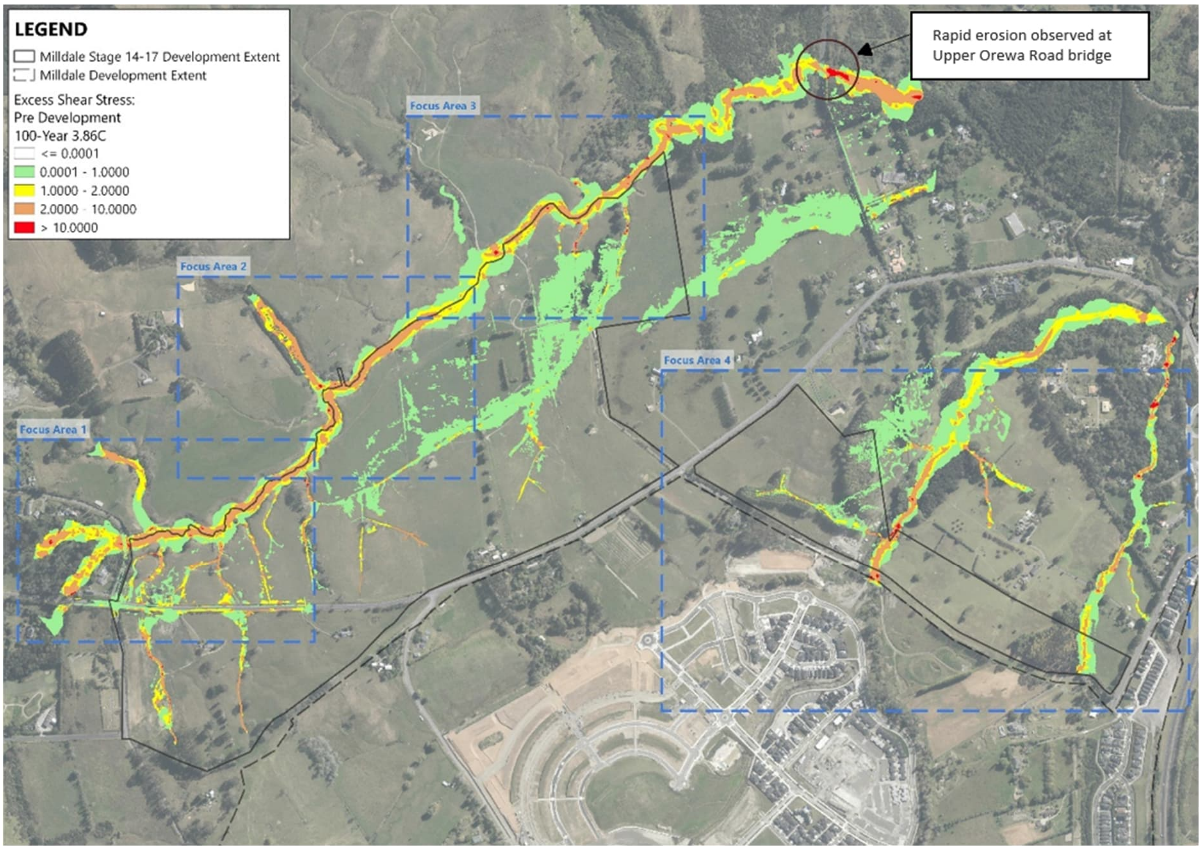


*Figure 5: Maximum excess shear stress results for pre-development model scenarios (100-year ARI)*

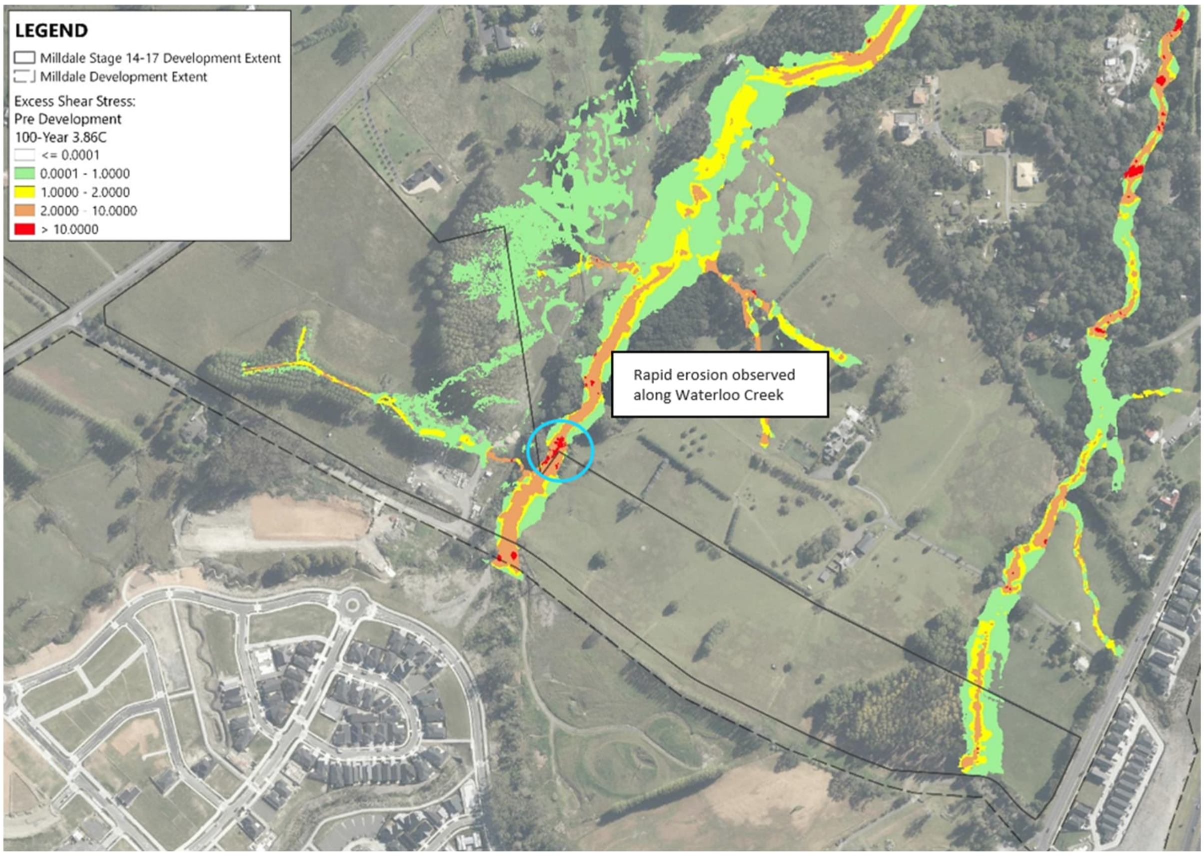


*Figure 6: 100-year ARI predevelopment excess shear Focus Area 4*

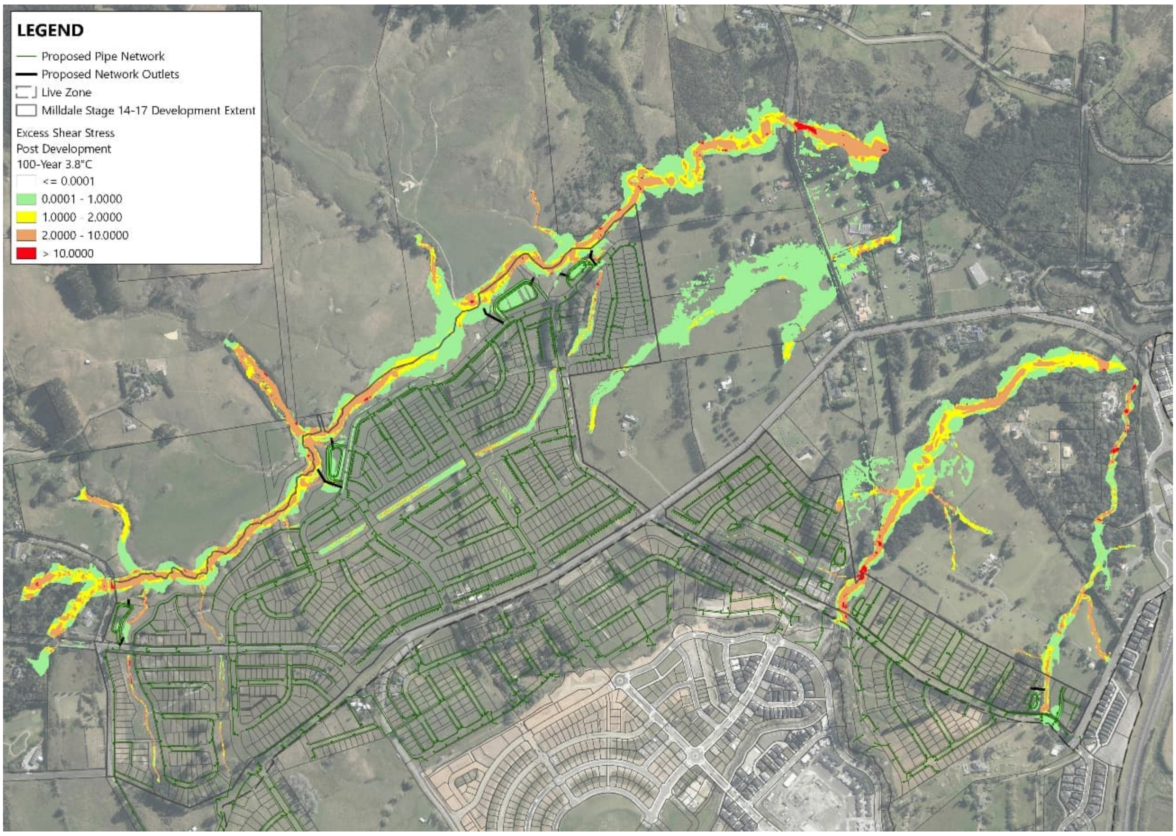



*Figure 7: Maximum excess shear stress results for post-development model scenarios (100-year ARI)*

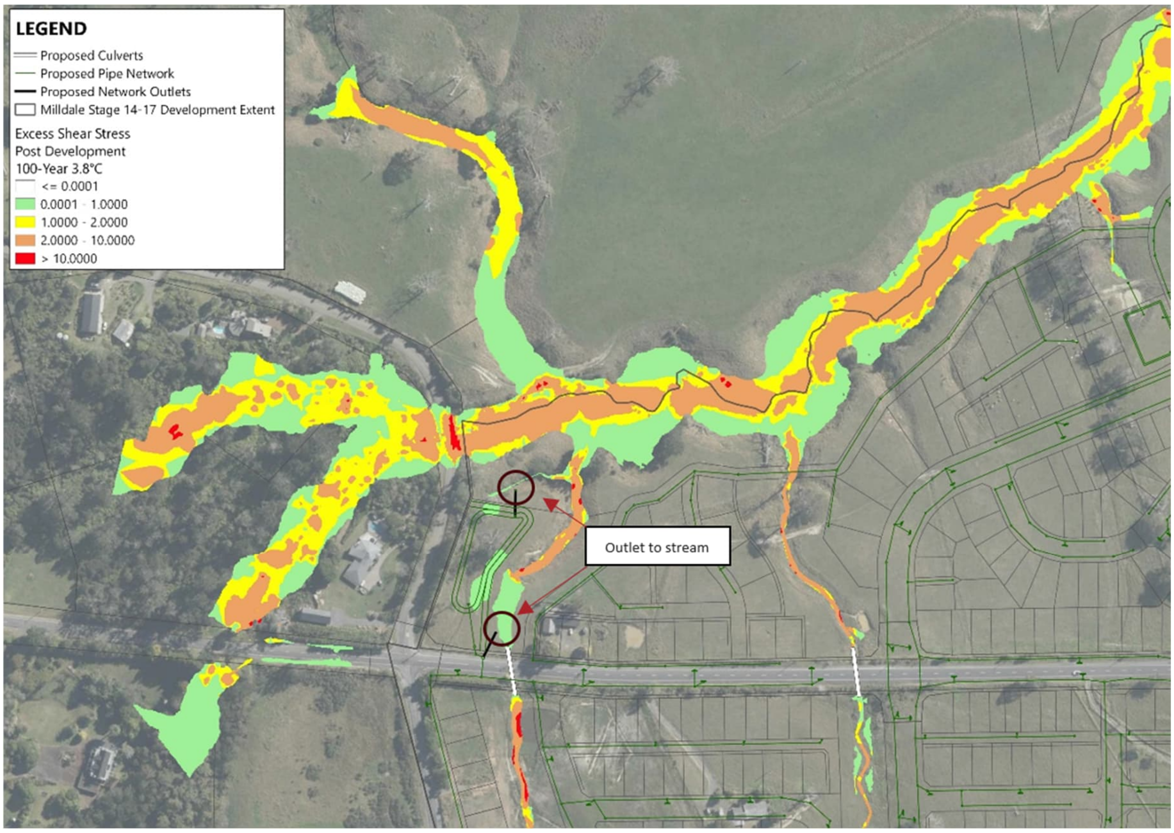



*Figure 8: 100-year ARI post development excess shear Focus Area 1*

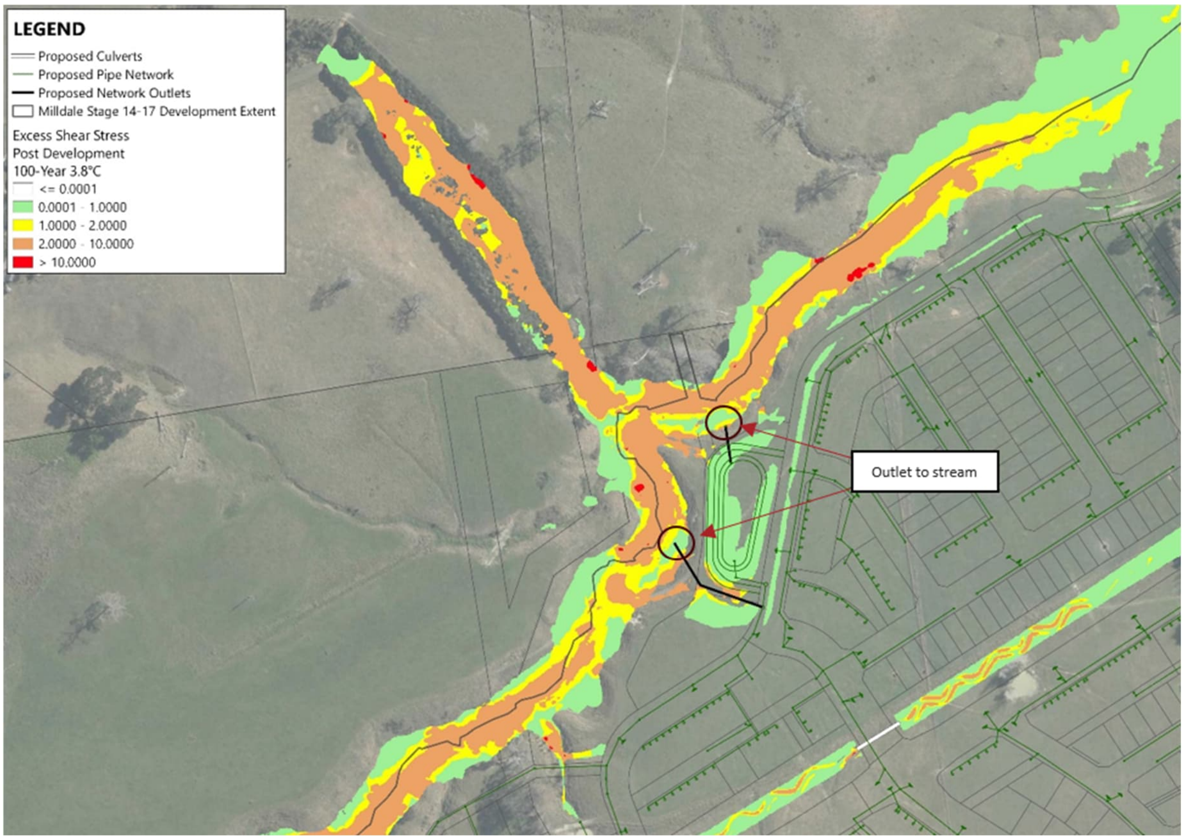



*Figure 9: 100-year ARI post development excess shear Focus Area 2*

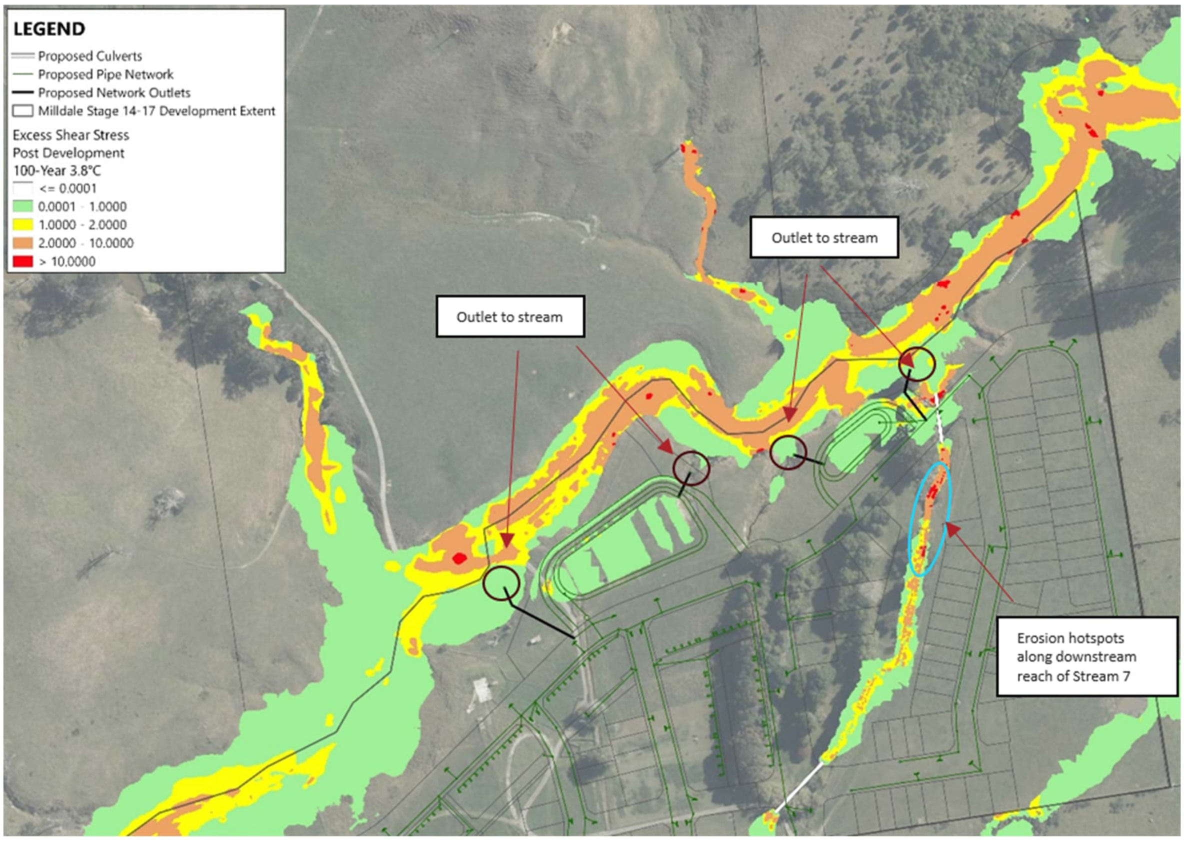



*Figure 10: 100-year ARI post development excess shear Focus Area 3*

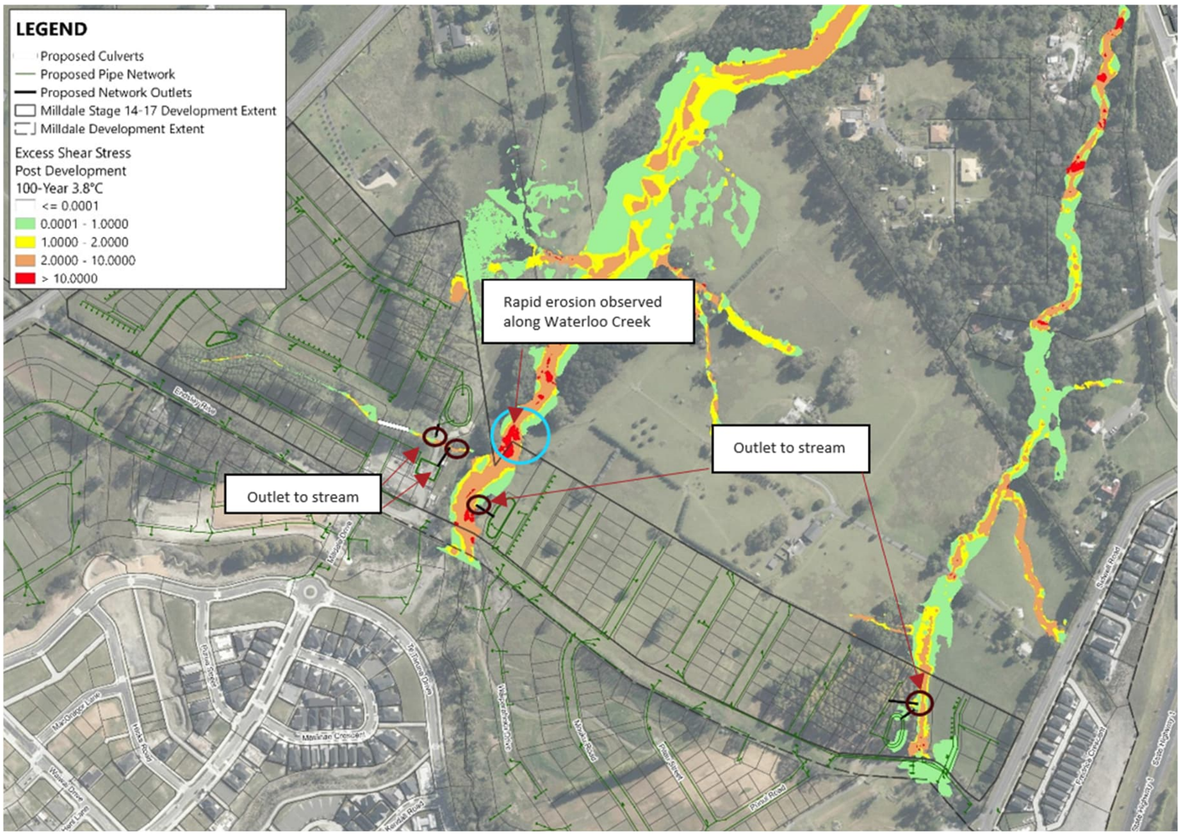



*Figure 11: 100-year ARI post development excess shear Focus Area 4*

## 5. Geomorphologic change detection (GCD) analysis

A geomorphic change detection analysis has undertaken (for Orewa River) to assess the vertical change in elevations and identify patterns of erosion and deposition within the stream corridor (Appendix 1). The reporting concluded that:

- The Orewa River, within the assessed extent, is a cohesive-clay, passively meandering system that has remained planform-stable over an 80+ year historical record, consistent with the erosion-resistant nature of the fine-grained bank material identified along the corridor
- Active geomorphic adjustment is not occurring at a system-wide scale; rather, it is concentrated at a small number of discrete locations:
    - An erosion hotspot at a large outer meander in Segment 1
    - A pair of knickpoints downstream of the Tributary 2 confluence in Segment 3
    - Localised bank slumping on Tributary 2 approaching its confluence with the Orewa River
- Geomorphic Change Detection (GCD) results corroborate the Tributary 2 slumping as a genuine instability signal
- The broader corridor-wide GCD signal is attributed to LiDAR-related artefacts rather than genuine aggradation
- These findings should be considered alongside future design and modelling work for the site, with the identified instability locations warranting particular attention should any works be proposed in their vicinity

# 6. Conclusion

Woods has undertaken a Stream Erosion Risk Assessment as part of the substantive application for the Milldale North development (Stages 14–17). The scope of the assessment covers the Orewa River as it passes the development site, along with portions of Waterloo Creek and its tributary within the development footprint. Several existing tributaries will be retained, while Stream 7 is proposed to be realigned and reworked.

The assessment was undertaken using a HEC-RAS 1D/2D hydraulic model for the 100-year ARI event under Maximum Probable Development (MPD) conditions with an allowance for future climate change (3.8°C), applying the Auckland Council EST methodology to compare pre-development and post-development excess shear stress conditions. Geomorphic Change Detection (GCD) analysis was also utilized to review historical stability.

The assessment concludes that:

- The proposed development does not materially increase erosion potential within the Orewa River. The development's contribution to the Upper Orewa River catchment is less than 5% of overall flow and modelled excess shear stress in the post-development scenario remains within the same risk band as existing conditions.
- GCD analysis confirms that the Orewa River is a cohesive-clay, planform-stable system over its 80+ year historical record, with active adjustment confined to discrete locations—namely the outer meander in Segment 1, knickpoints downstream of the Tributary 2 confluence, and bank slumping on Tributary 2 near its confluence with the Orewa River.
- The most prominent existing erosion hotspot, located at the Upper Orewa Road bridge, is consistent between pre- and post-development conditions and site observations, and is understood to be driven predominantly by rainfall rather than by the proposed development.
- Localised increases in erosion potential have been identified along the downstream portion of the realigned Stream 7 and the reshaped banks of Waterloo Creek between Stages 16 and 17. Both areas will incorporate bank armouring and/or outlet erosion protection designed in accordance with Auckland Council TR2013/018 and/or HEC14, to be finalised at the detailed design stage using the toolbox of measures provided in Appendix 3.
- All pipe and device outlets discharging to the Orewa River, Waterloo Creek, and their tributaries will require site-specific erosion protection, with detailed design and modelling of the pipe network confirming final velocities, erosion potential, and appropriate protection measures at each location.

The proposed erosion mitigation measures, combined with the stormwater management strategy managing 95th percentile events onsite or via communal devices, are considered sufficient to manage residual erosion risk to a low level. The development will not cause unacceptable erosional effects to the surrounding stream network.

# Appendix 1 – Geomorphic Assessment

**To**
Auckland Council

**From**
*Danny Baucke – Fluvial Geomorphologist*

*W-REF: P25-609*
*12 August 2026*
*Reviewer: Boniface Kinnear – Principal Engineer*

# Geomorphic Assessment

## 1. Introduction

This memo presents the findings of a geomorphic assessment of the Orewa River undertaken by Wood & Partners Consultants Limited (Woods), covering between the Gervin Road culvert crossing (upstream) and the Upper Orewa Road bridge crossing (downstream), a total assessed length of approximately 3,025 m. The assessment also considers two farm-drain tributaries entering the Orewa River within this extent, Tributary 1 (280 m) and Tributary 2 (870 m).

The assessment combines desktop review, field observation, and Geomorphic Change Detection (GCD) analysis to characterise the current geomorphic condition of the assessed extent, identify locations of active or potential instability, and provide context for downstream engineering and planning purposes. Field assessment was undertaken over two site visits, on 20 March 2026 and 1 April 2026.

## 2. Study Area

The assessment covers the Orewa River within the Milldale North development area, Rodney Local Board area, Auckland Region, extending from the upstream extent at a road culvert crossing on Gervin Road, downstream to the bridge crossing at Upper Orewa Road, a total length of approximately 3,025 m. For the purposes of this assessment, this extent is divided into three broad segments based on riparian vegetation cover.

**Segment 1** - Gervin Road culvert to the Tributary 1 confluence (0-490 m).

**Segment 2** - Tributary 1 confluence to the start of the riparian corridor (490-1,865 m).

**Segment 3** - riparian corridor start through to the Upper Orewa Road bridge crossing (1,865-3,025 m), incorporating the Tributary 2 confluence (~2,065 m).

Two tributaries were identified as entering the Orewa River from the south within the assessed extent:

**Tributary 1** - a short (~280 m) channel with the character of a farm drain, with its confluence located at approximately the 490 m mark.

**Tributary 2** - a longer (~870 m) channel, also predominantly farm-drain in character, with its confluence located at approximately the 2,065 m mark.

Land use and landscape character vary along the assessed extent. At the upstream extent, the Orewa River flows through pastoral farmland, with the surrounding catchment predominantly grazed. Riparian vegetation is largely absent through Segments 1 and 2, transitioning into a bush and small wooded tree corridor, then a larger pine forest section, at the start of Segment 3, as detailed further in Section 4.2.

The Milldale North area is underlain by the Waitemata Group, an Early Miocene sequence dominated by deep-water sandstone and mudstone (flysch) deposited within the tectonically active Waitemata Basin (Spörli, 2007). The valley floor and stream corridor are expected to be mantled by more recent Tauranga Group alluvium/colluvium and fan deposits, typically comprising organic silts and clays bordering watercourses, consistent with the cohesive clay and organic silt bank material observed during the field assessment.

S-map has no data coverage for the Milldale North area. However, a queried IRIS soil layer (NZSC_CLASS: GOA) indicates the soils underlying the Orewa River corridor belong to the Gley order, Orthic Gley group, Typic Orthic Gley class. This classification indicates a poorly-drained, waterlogged soil regime, consistent with the low-lying alluvial setting of the stream corridor and the cohesive clay bank material observed during the field assessment. This classification is coarse (Order/Group/Class level only, with no soil family or textural data available) and should be treated as qualitative supporting context rather than a basis for quantitative analysis.

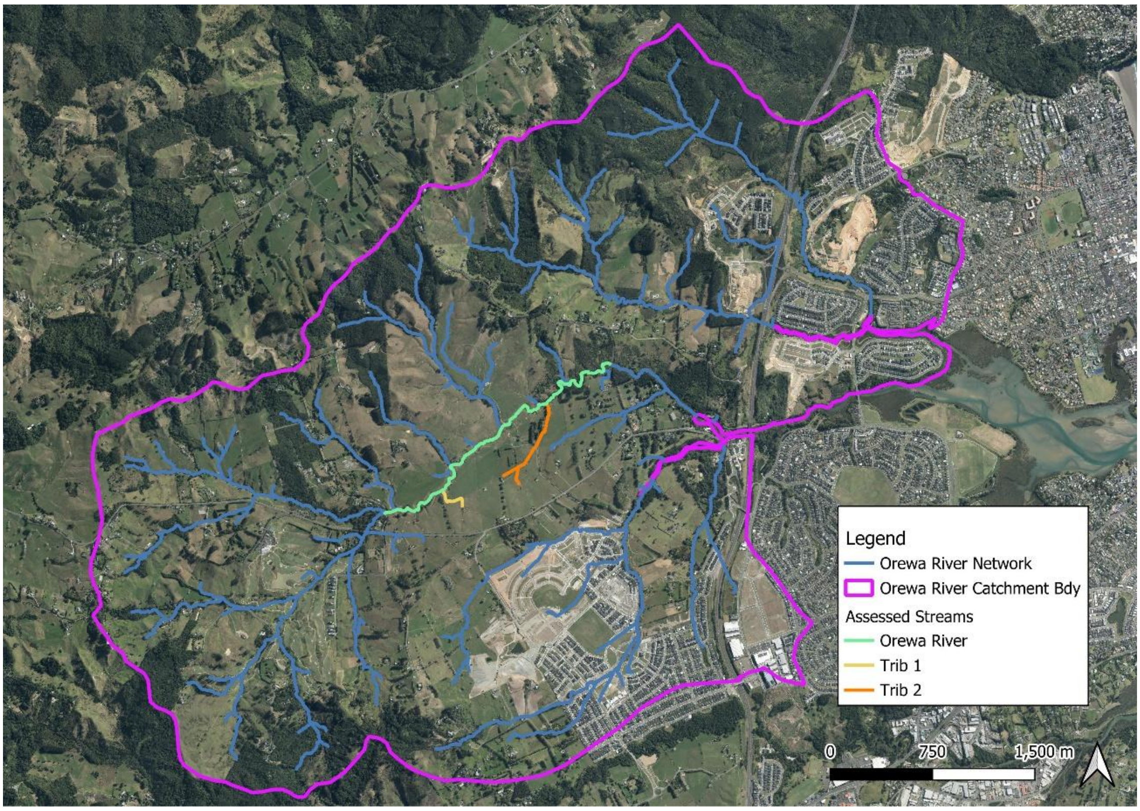



Figure 1. Catchment context map showing the Orewa Catchment boundary, stream network, and surrounding land use, Milldale, Auckland.

# 3. Methodology

## 3.1. Desktop Assessment

A desktop review was undertaken incorporating available geology and soils mapping, aerial imagery, and topographic data for the Milldale North area, to inform the field assessment and provide ongoing context for the geomorphic assessment.

Historical aerial imagery, sourced from Retrolens, was reviewed to assess planform change and channel migration over time. (1940, 1961, 1973.)

## 3.2. Field Assessment

A field-based geomorphic assessment was undertaken over two days, covering the full assessed extent of the Orewa River between the Gervin Road culvert and Upper Orewa Road bridge, together with sections of Tributary 1 and Tributary 2. At each reach, observations were made of channel form and dimensions, bed and bank composition, geomorphic units (e.g. bars, riffles, pools), bank condition and evidence of erosion or instability, riparian vegetation cover, and hydraulic diversity. Photographic records were taken throughout to support the assessment findings.

## 3.3. Geomorphic Change Detection

Geomorphic Change Detection (GCD) was undertaken using LiDAR datasets from 2016 and 2024, sourced from Auckland Council, processed in accordance with the DEM of Difference (DoD) approach described by Wheaton et al. (2010). This method applies a spatially variable level of detection to account for uncertainty in each DEM surface, allowing statistically robust identification of areas of net erosion and deposition between survey epochs.

# 4. Geomorphic Assessment

## 4.1. Geomorphic Assessment Summary

The Orewa River within the assessed extent (Gervin Road to Upper Orewa Road) is a cohesive-clay, passively meandering system that has remained planform-stable over an 80+ year historical record, with active geomorphic adjustment concentrated at a small number of discrete locations rather than occurring system-wide. Figure 2 shows the assessed extent, segment boundaries and tributary locations referred to throughout this section.

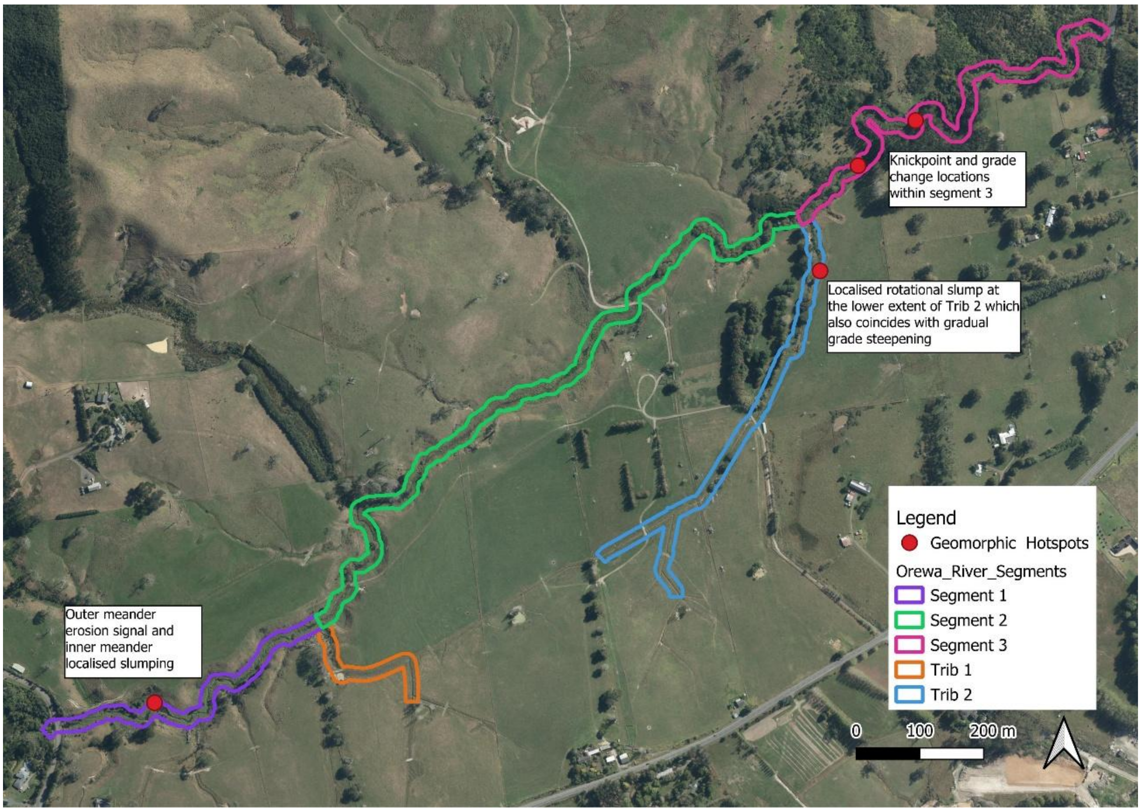


Figure 2. Orewa River segment context map showing the extent of each segment and tributary assessed, and the locations of geomorphic hotspots noted during the field assessment (slumping and knickpoint loci).

The assessed extent is divided into three segments, distinguished primarily by riparian cover and floodplain confinement. Segments 1 and 2 (Gervin Road to ~1,865 m) are largely devoid of riparian vegetation, with grass extending to the bank edge and the channel confined by relic terrace with only narrow pocket floodplains. Segment 3 (~1,865 m to the Upper Orewa Road bridge) is distinguished by an established riparian corridor, progressing from bush to pine forest and back to bush, and includes the confluence of Tributary 2. Two small farm-drain tributaries (Tributary 1 and Tributary 2) enter the main channel within Segments 1 and 3 respectively, both narrow, incised and largely featureless besides a gradual steepening near their confluences with the Orewa.

Key locations of note include an erosion hotspot at a large outer meander in Segment 1, characterised by active bank erosion and a rotational slump; two knickpoints downstream of the Tributary 2 confluence in Segment 3, associated with locally accelerated incision; and localised slumping on Tributary 2 approaching its confluence, corroborated by Geomorphic Change Detection results. These features are discussed in further detail in Section 4.2.

## 4.2. Geomorphic Condition Summary

### 4.2.1. Channel Form & Planform

The Orewa River is largely confined within relic terrace margins (Figure 3) through the upper and mid-reach extent, with only narrow floodplain pockets present on either side of the channel. Channel width varies considerably along the assessed extent, from approximately 2 m in confined upper sections to wide ponded zones of up to ~10 m. The channel exhibits a meandering planform with alternating pool-riffle-run sequences, transitioning between narrow confined reaches and broader ponded reaches (Figure 4). Notable planform features include a large outer meander identified as an erosion hotspot within Segment 1, and a further large meander bend downstream of the Tributary 2 confluence (Segment 3) with an inner point populated by mature pine trees. Mid-channel and lateral bars are present throughout, including bank-attached bars and vegetated islands formed around woody debris and large trees (Figure 5).

Figure 3. Example of the Orewa River flowing between terrace margins, with narrow floodplain pockets present on either side.

Figure 4. Example of the channel transitioning between wide, ponded reaches and narrow, confined reaches.

Figure 5. Example of lateral bars within the Orewa River, most commonly observed in Segment 1.

Review of historical aerial imagery (1940, 1961 and 1973, sourced from Retrolens) indicates the Orewa River within the assessed extent has retained a broadly stable meandering planform over this period, with no evidence of major anthropogenic modification such as channelisation or realignment (Figure 6). Road crossings are present at both the upstream and downstream extremities of the assessed reach in the 1940 imagery, indicating these crossing points pre-date the assessment period, although the nature of the crossing structure (e.g. culvert vs. bridge) cannot be confirmed from historical imagery alone. The river is characterised as a classic passive meandering system, consistent with the cohesive bank material and lack of significant lateral migration evident across the historical imagery record.

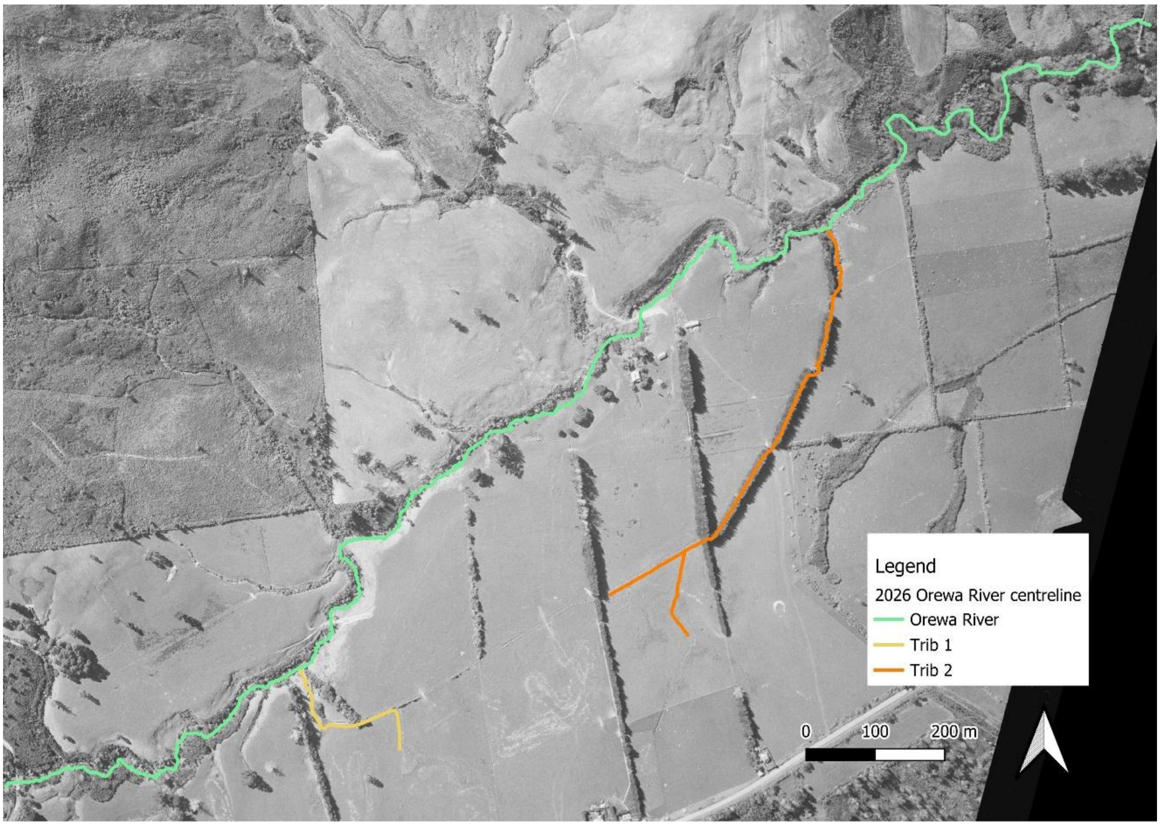



Figure 6. 1961 aerial imagery (Retrolens) with the current stream centreline overlaid, illustrating planform stability relative to the historical record (1940-1973 reviewed).

#### 4.2.2. Bed Material & Sediment

Bed substrate is poorly sorted and angular, comprising large cobble-sized clasts alongside sand to pebble material (Figure 7), observed throughout Segments 1 and 2; the origin of the larger cobble material is unknown. Substrate becomes harder to observe within Segment 3 due to increased flow depth and the general absence of exposed morphological units. A forced riffle sequence with an armour layer beneath matted vegetation was identified downstream of the Gervin Road culvert (Segment 1), along with large rocks in-channel at this same location interpreted as anthropogenically placed. Silty and muddy deposition was observed on outer banks downstream of the Tributary 2 confluence (Segment 3), approximately 1 m above base flow level, indicating flow levels following the recent storm event were substantially elevated above those observed at the time of assessment (Figure 8).

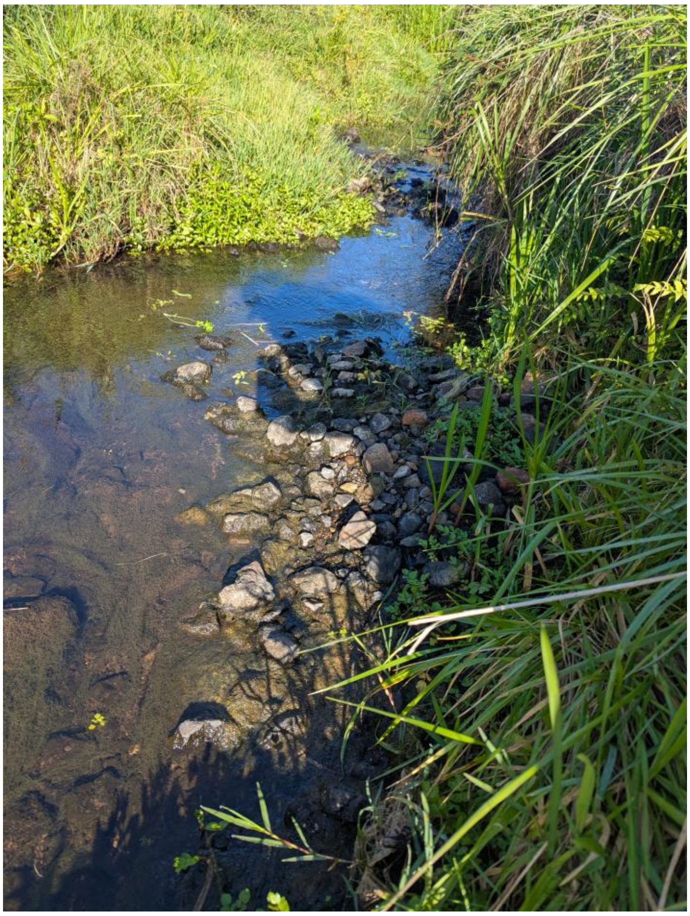


Figure 7. Poorly sorted, angular bed sediment observed on site.

Figure 8. Evidence of silty deposition following the storm event that preceded the Day 2 site visit.

#### 4.2.3. Bank Condition

Banks throughout the assessed extents are predominantly cohesive clay, though character and condition vary by segment. In Segment 1, bank heights range from approximately 0.5-1 m near the upstream extent, increasing to approximately 1.5 m (Figure 9) through the mid to lower segment, where bank heights become asymmetrical between true left and true right and alternate between exposed eroding faces and grassy cover. Recurring instability is evident in Segment 1, including active outer-bank erosion with slumping occurring on the inner bank at the large outer meander erosion hotspot, consistent with the cohesive bank material and elevated moisture conditions (Figure 10). In Segment 2, banks remain cohesive and incised, with undercutting (Figure 11) noted in the upper-mid segment where base flow approaches bank full on the true left; the degree of incision reduces further downstream through Segment 2, coinciding with marginally improved floodplain connectivity. In Segment 3, banks are generally grassed with canopy cover, though differ between true left, where grasses and ferns dominate with some steep exposed clay banks present, and true right, which presents as a lower-graded bank showing evidence of overtopping during elevated flows. Active erosion is not pronounced through much of Segment 3, though incision is locally more pronounced and undercutting was difficult to confirm elsewhere in this segment due to flow depth.

Figure 9. Example of highly incised cohesive banks.

Figure 10. Geomorphic hotspot within Segment 1, outer meander erosion and inner bank slumping just downstream.

Figure 11. One of many locations indicating bank undercutting.

#### 4.2.4. Riparian & Floodplain

Riparian vegetation is largely absent through Segments 1 and 2 of the assessed extent (0-1,865 m), with banks dominated by grass cover extending to the bank edge and only occasional single trees or small patches of trees present (Figure 12). A riparian corridor becomes established at the start of Segment 3 (~1,865 m), beginning as a bush and small wooded tree margin (Figure 13) before transitioning into a larger pine forest section approximately 140 m downstream of the Tributary 2 confluence (Figure 14), extending for approximately 370 m, then returning to a smaller bush-style corridor through to the downstream extent at the Upper Orewa Road bridge.

Figure 12. Example of the upper segments, where riparian vegetation is largely absent and grass extends to the bank edge.

Figure 13. Transition from Segment 2 to Segment 3, marked by the change from no riparian corridor to a lush, established one.

Figure 14. Large wooded riparian section of Segment 3, dominated by pine.

Floodplain connectivity is limited throughout much of the assessed extent, with the channel confined by relic terrace and only narrow pocket floodplains present on either side; connectivity appears marginally improved in the lower-mid reach relative to further upstream, though the channel remains largely disconnected from a functioning floodplain across most of its length (Figure 15).

Figure 15. Example of a disconnected floodplain, with the surrounding upper terraces confining the narrow floodplain pockets.

#### 4.2.5.Hydraulic Features

Base flow through the Day 1 reach (upstream extent to Tributary 2 confluence) was dominantly slow or standing, with limited hydraulic diversity. Flow depth increased progressively downstream through this reach, from approximately 200 mm near the upstream extent to 1.2-1.5 m in Segment 2 (Figure 16). Hydraulic diversity increases markedly downstream of the Tributary 2 confluence, with laminar, turbulent, glide and riffle sequences all present, and bankfull conditions observed on the true left (Figure 17). Flood chutes - channels activated during higher flow events - were identified downstream of the confluence, providing evidence of lateral flow extent during flood conditions (Figure 18).

Figure 16. Hydraulic diversity changed markedly in Segment 3, with alternating riffle sequences, glides and pools.

Figure 17. Hydraulic diversity changed markedly in Segment 3, with alternating riffle sequences, glides and pools.

Figure 18. Example of flood chute activation following the storm event the week prior.

#### 4.2.6. Anthropogenic Influence

Anthropogenic influence includes large rocks placed in-channel near the upstream extent, an informal stock crossing evidenced by a trampled boggy mud trail, and a further overland flow crossing identified in Segment 2. A ponded/backwater zone exhibiting scum and vegetation bloom suggestive of nutrient or effluent input was also observed at the large outer meander erosion hotspot (Figure 19). The surrounding land use is predominantly pastoral farming throughout the assessed extent, with a riparian corridor of bush and pine forest established along Segment 3 contrasting with the largely open, grazed banks of Segments 1 and 2.

Figure 19. Ponded backwater zone with scum and vegetation bloom, suggestive of nutrient or effluent input.

#### 4.2.7. Process Indicators

Two closely-spaced knickpoints were identified downstream of the Tributary 2 confluence, with a further knickpoint noted further downstream; the channel appears more incised between the two closely-spaced knickpoints, indicating localised acceleration of incision between these grade controls (Figure 20). Evidence of a recent flood event (attributed to a storm the week prior to Day 2) includes a trash line and debris veneer on the outer bend of a large pine-tree meander, an inner meander bank height of approximately 2 m above base flow indicating flood stage at this location, flattened grasses confirming flow overtopping of the inner bank, and silty/muddy deposition approximately 1 m above base flow further downstream (Figure 21). These indicators, combined with the confined and incised channel form and cohesive bank material, are consistent with localised, knickpoint-driven grade adjustment at discrete locations within an otherwise stable channel.

Figure 20. Image denoting the lead up to the double knickpoint location and drop in stream grade.

Figure 21. Leaf litter and woody debris marking where floodwater flowed across the upper meander bends in the pine-dominated section of Segment 3, with flattened grass indicating flow direction during the flood event.

## 4.3. Tributary 1

Tributary 1 is a channelised farm drain, approximately 280 m in length, running through the same pastoral farmland as the main Orewa Stream corridor, with a single fenceline running parallel to the channel (Figure 22). The channel is very narrow (approximately 0.5 m wide) through its channelised upper extent, with cohesive, incised banks. No riparian corridor or notable vegetation cover is present along its length. Flow is intermittent and largely obscured by dense instream and channel-margin vegetation, with standing water and no discernible velocity typical along most of its length. Approaching the confluence with the Orewa River, the channel gradually steepens, remaining narrow but flowing through a larger depression down to the confluence itself.

Figure 22. Example of the characteristics of Tributary 1: a narrow farm drain with standing water and dense instream vegetation.

## 4.4. Tributary 2

Tributary 2 is a channelised farm drain, approximately 870 m in length, sharing the same pastoral farmland context and parallel fenceline as Tributary 1 and the main Orewa Stream. The channel is narrow (approximately 0.5 m wide) and incised with cohesive banks through its upper extent, with flow intermittent and largely obscured by dense instream vegetation, consistent with Tributary 1 (Figure 23).

Figure 23. Example of Tributary 2: a narrow, incised farm channel with a riparian corridor present, dense instream vegetation, and low/standing flow.

Unlike Tributary 1, a riparian corridor is present along the true left bank from approximately the midpoint of the tributary (marked by a farm culvert crossing) through to the confluence with the Orewa River. As with Tributary 1, the channel gradually steepens approaching the confluence, remaining narrow but flowing through a larger depression before discharging into the Orewa. Localised slumping was observed at this grade-change zone (Figure 24), corresponding to the concentrated change signal identified in the Geomorphic Change Detection results for the lower ~100 m of Tributary 2 (Section 5.2), indicating genuine bank instability at this location.

Figure 24. Localised slumping at the lower extent of Tributary 2, near the gradual grade change in the stream bed.

## 5. Geomorphic Change Detection

Geomorphic Change Detection was undertaken for the Orewa River (Segments 1-3) and both assessed tributaries (Tributary 1 and Tributary 2), using a DEM of Difference (DoD) approach between the 2016 and 2024 Auckland Council LiDAR datasets, clipped to a 10 m buffer either side of each stream centreline. A minimum level of detection (LoD) threshold of 0.2 m was applied to all datasets to exclude non-significant change.

### 5.1. Results

Table 1. GCD volumetric summary, Orewa Stream network (2016–2024).

| Parameter | Segment 1 | Segment 2 | Segment 3 | Tributary 1 | Tributary 2 |
|---|---|---|---|---|---|
| Total Area of Lowering ($m^2$) | 2,130 | 6,995 | 6,673 | 1,065 | 3,165 |
| Total Area of Raising ($m^2$) | 9,255 | 14,162 | 15,766 | 4,728 | 13,781 |
| Average Depth of Lowering (m) | 0.18 | 0.15 | 0.21 | 0.14 | 0.12 |
| Average Depth of Raising (m) | 0.17 | 0.13 | 0.21 | 0.15 | 0.12 |
| Total Volume of Lowering ($m^3$) | 385 | 1,038 | 1,416 | 154 | 388 |
| Total Volume of Raising ($m^3$) | 1,565 | 1,833 | 3,265 | 709 | 1,626 |

## 5.2. Interpretation

All five datasets return a net positive (depositional) volume when assessed across the full 10 m buffered corridor. However, this result is not considered representative of true fluvial sediment behaviour within the active channel. Visual inspection of the DoD rasters shows the in-channel signal is dominated by erosion (red), with negligible blue (depositional) signal present within the wetted channel itself. This indicates no meaningful vertical aggradation is occurring within the active channel, consistent with the incision and exposed cohesive bank conditions recorded during the field assessment. The net positive volumetric result at the corridor scale is instead attributed to two primary sources of non-fluvial signal: (i) residual vegetation/grass height differences between the 2016 and 2024 LiDAR epochs, given the imperfect classification of bare earth beneath pasture and low grass cover outside the channel margins, and (ii) water surface elevation differences between the two LiDAR captures, which can register as false elevation change where flow depth or water level varied between epochs. Both effects would be expected to bias the corridor-wide volumetric result toward apparent deposition without reflecting true bed-level change.

Segment 3 (Figure 27) returns the widest detected range (-3.35 m to +2.30 m) and highest erosion volume of the three Orewa segments, associated with the Upper Orewa Road bridge structure at the downstream end of this segment. This signal is interpreted as a combination of genuine geomorphic change, with erosion evident around the bridge supports, and a structural DEM artefact arising from the bridge deck and abutments between survey epochs. As these two effects cannot yet be reliably separated, the magnitude of genuine erosion at this location should be treated as indicative rather than precise.

Tributary 2 (Figure 29) shows a distinct pattern of localised change concentrated in its lower ~100 m, immediately upstream of its confluence with the Orewa River. While the tributary's longitudinal profile is otherwise comparatively flat, grade increases over this lower section, and the DoD shows a corresponding concentration of change signal in this reach. This is consistent with localised slumping observed and photographed during the field assessment at this location, indicating the GCD result here reflects genuine bank instability rather than vegetation or water-surface artefact.

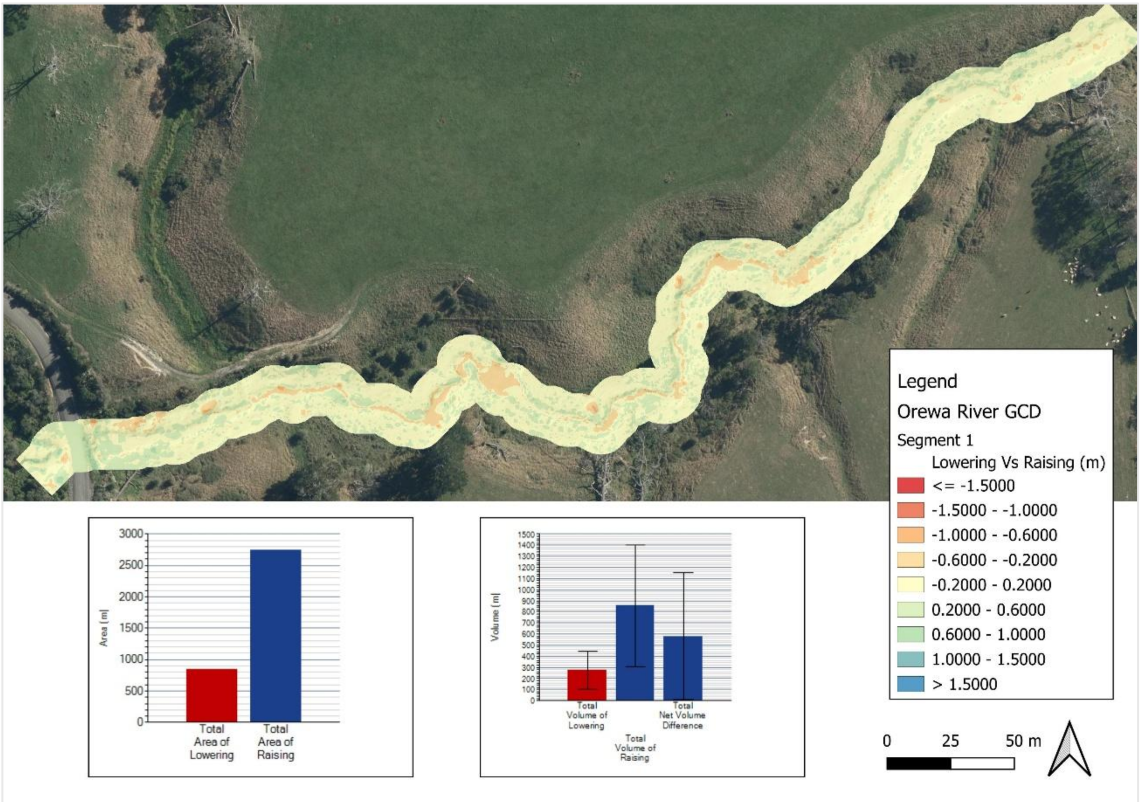



Figure 25. Geomorphic Change Detection outputs for Segment 1 (2016–2024).

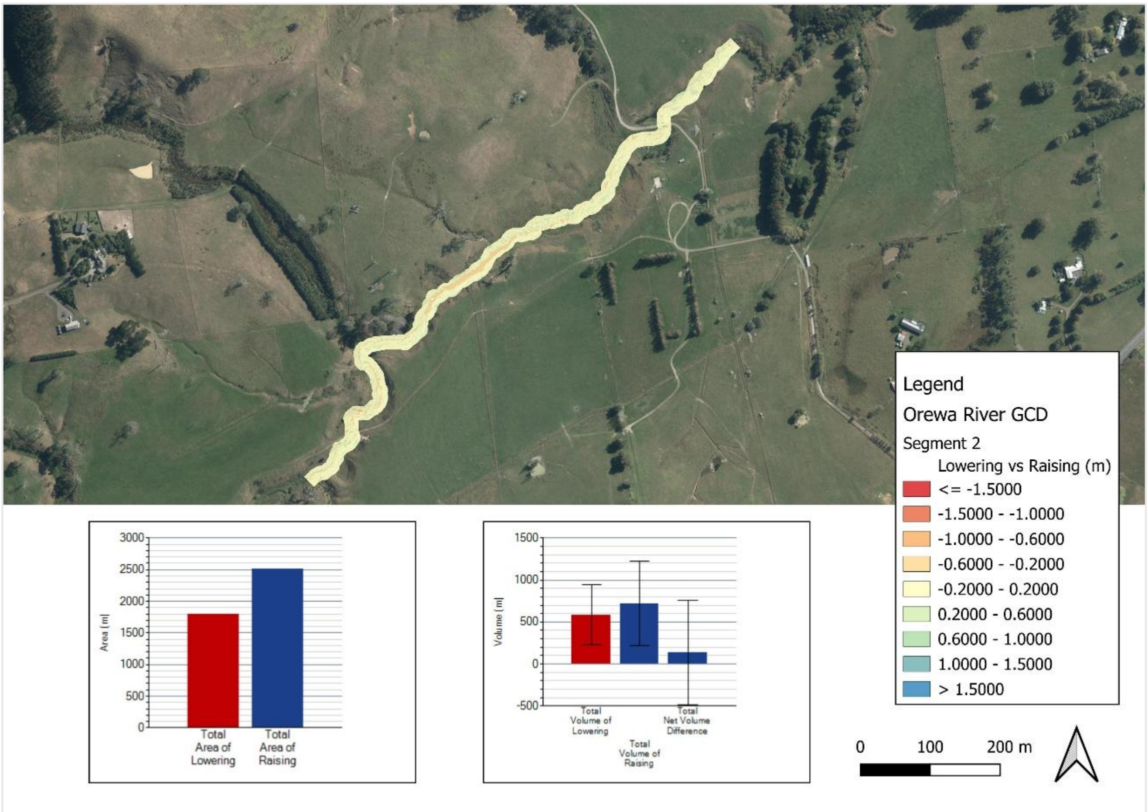



Figure 26. Geomorphic Change Detection outputs for Segment 2 (2016–2024).

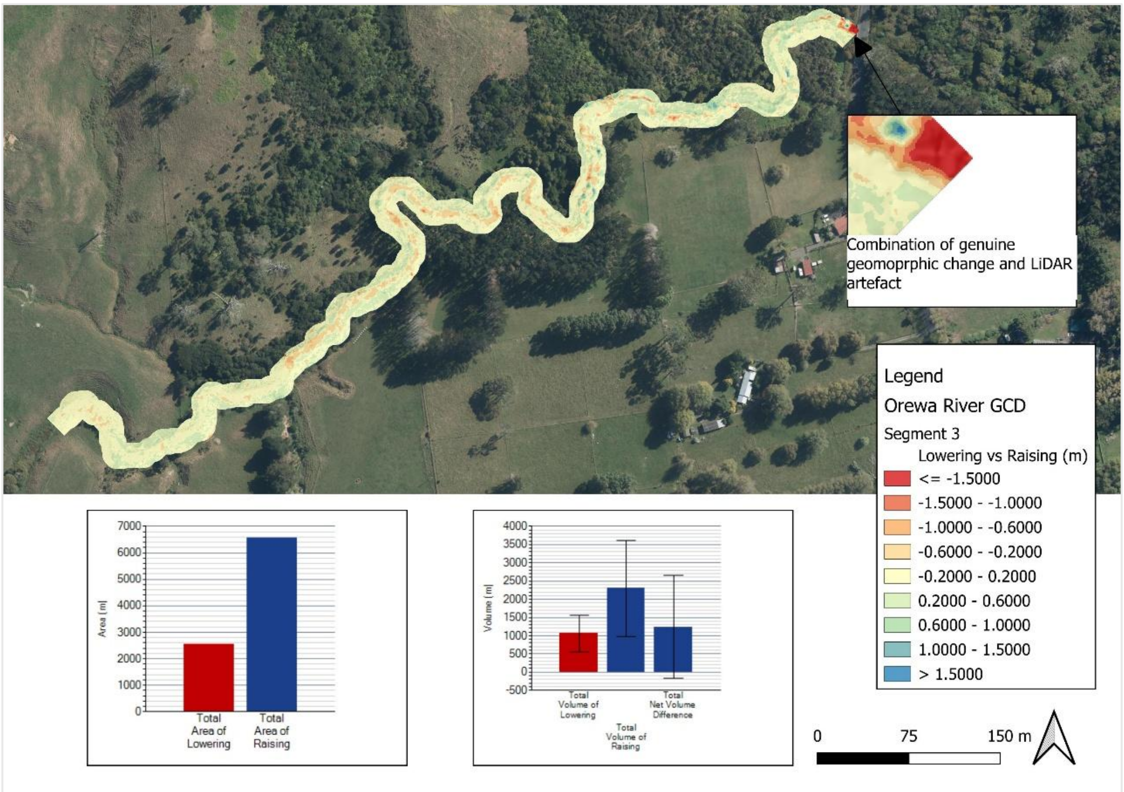



Figure 27. Geomorphic Change Detection outputs for Segment 3 (2016-2024), showing the dominant erosion signal at the bridge crossing. This reflects a combination of genuine erosion around the bridge supports and LiDAR-to-DEM artefacts between survey epochs.

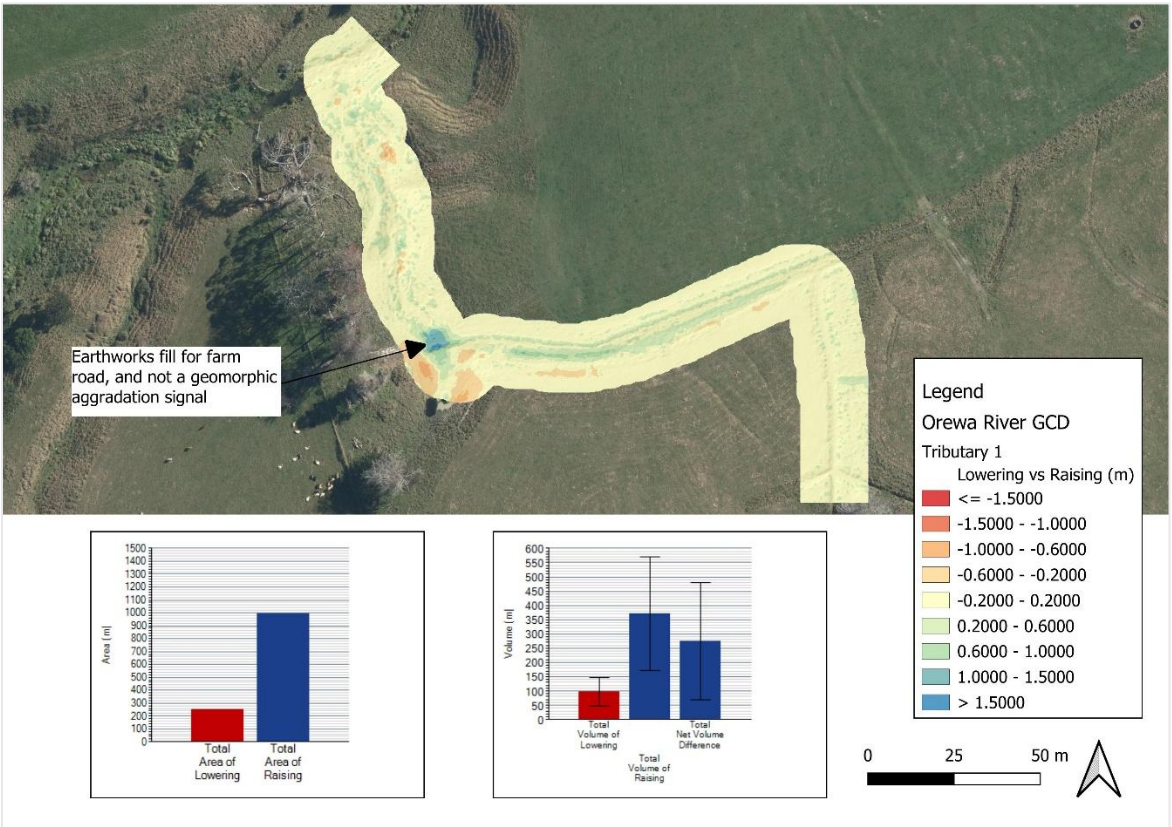



Figure 28. Geomorphic Change Detection outputs for Tributary 1 (2016-2024). The discrete raising signal shown was determined to be earthworks fill placed to repair the adjacent farm road, rather than genuine geomorphic change.

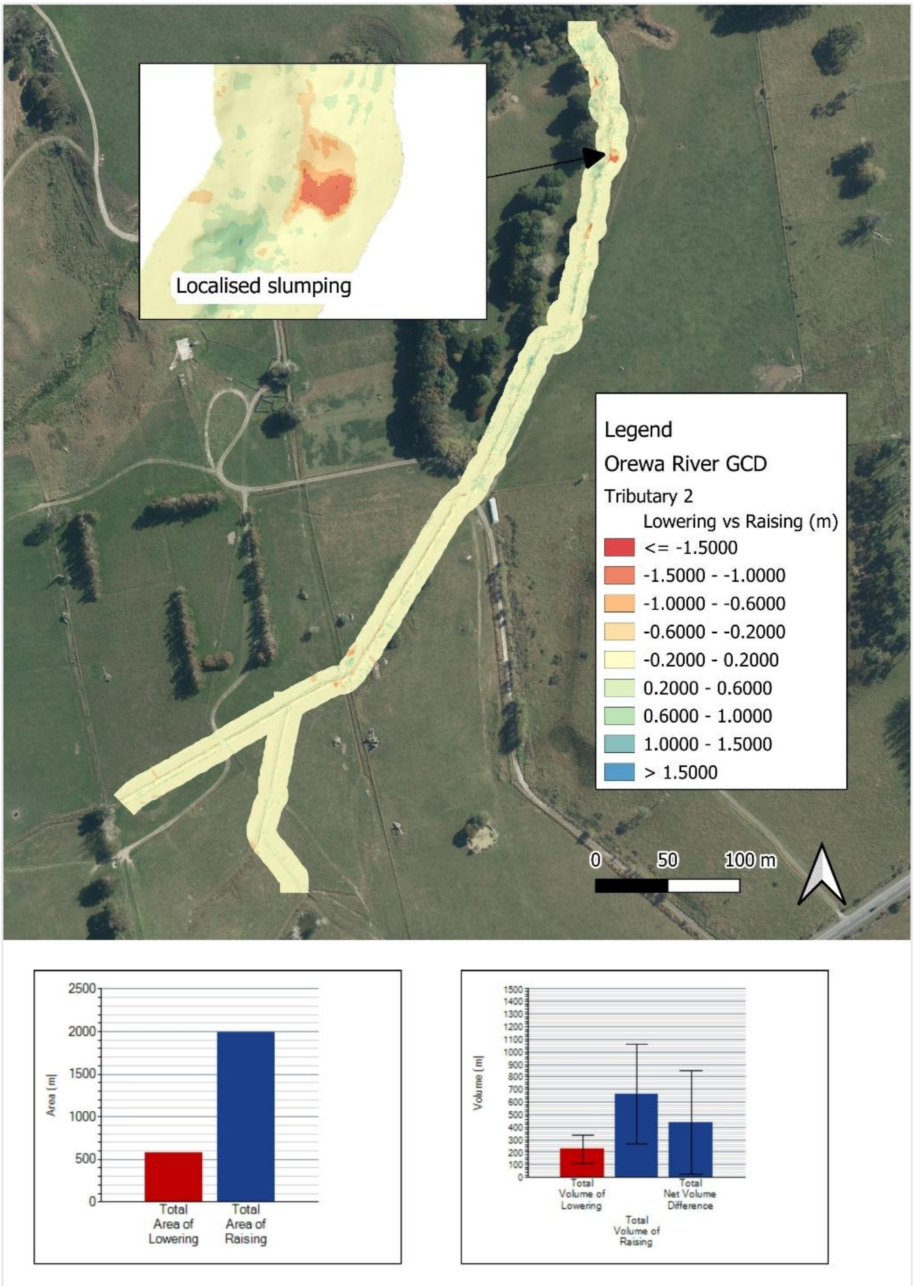



Figure 29. Geomorphic Change Detection outputs for Tributary 2 (2016-2024), showing a distinct erosion signal at the lower end of the tributary, consistent with the localised slumping confirmed during the site visit.

## 6. Discussion

Historical aerial imagery (1940, 1961 and 1973, Figure 6) shows the Orewa River has maintained a broadly stable meandering planform over an 80+ year record, with no evidence of channelisation, realignment, or significant lateral migration. This stability is consistent with the cohesive bank material identified along the corridor, since lateral channel-migration rates depend most strongly on the channel-bank height, the water discharge, and the resistance of channel banks to erosion (Hickin & Nanson, 1984; Nanson & Hickin, 1986).

Planform stability at this decadal scale does not, however, indicate an absence of geomorphic process. Heavy channel incision (up to approximately 1.5 m) and terrace confinement through Segments 1 and 2, with only narrow pocket floodplains remaining, point to a system that has progressed through an historical adjustment phase. Channel evolution models developed for disturbed alluvial channels describe this kind of trajectory as a sequence of process-oriented stages, characterised as premodified, constructed, degradation, threshold, aggradation, and restabilisation (Simon, 1989), and the incised, terrace-confined form observed here is consistent with a system that has largely settled into a threshold or restabilisation-type form rather than one presently undergoing active, progressive incision. Floodplain connectivity improves only marginally through the mid-section of Segment 2, and no location within the assessed extent displays a fully reconnected, functioning floodplain.

Instability within this broadly stable system is concentrated at a small number of discrete locations rather than being system wide. The most notable of these is the Segment 1 erosion hotspot meander (approximately chainage 958 m), where active outer-bank erosion, a rotational slump on the inner bank, and marked local channel widening were observed. Two knickpoints downstream of the Tributary 2 confluence in Segment 3 similarly indicate localised grade adjustment, with incision visibly more pronounced between the two grade controls. On Tributary 2, localised slumping at the confluence-approach grade change was directly corroborated by the GCD results (Figure 29), which identified a concentrated zone of elevated change in the lower approximately 100 m of the tributary.

The GCD results (Figures 25-29) reinforce this localised versus system-wide pattern. While all five datasets return a net positive (depositional) corridor-wide volume, visual inspection shows the in-channel signal itself to be erosion-dominated, with negligible genuine depositional signal within the wetted channel. This is consistent with the recognised sensitivity of multi-epoch LiDAR DEM differencing to vegetation-related error, since point cloud density more accurately quantifies uncertainty due to vegetation than bare or sparsely-vegetated surfaces. The net positive result is therefore attributed to residual vegetation height differences between the 2016 and 2024 epochs and potential water surface elevation differences, rather than genuine floodplain or terrace aggradation - leaving the Tributary 2 change zone as the clearest and most reliable, genuine signal in the dataset.

Isolated evidence of floodplain activation during flood flow was nonetheless observed, despite the generally disconnected character of the corridor at base flow. At the Segment 3 pine tree meander section of river, flow was observed to have overtopped the inner bank during a storm event the week prior to the Day 2 site visit, evidenced by flow-aligned grasses and a trash line approximately 2 m above base flow level, with flood chutes and silty deposition further downstream providing additional evidence of the channel's lateral extent during elevated flow.

Overall, the Orewa River within the assessed extent presents as a geomorphically stable, cohesive, incised meandering system at the whole-reach scale, with active adjustment concentrated at discrete, spatially isolated locations (Segment 1 hotspot, the Segment 3 knickpoint zone, and the Tributary 2 confluence approach) rather than indicating widespread or progressive destabilisation.

# 7. Conclusion

The Orewa River within the assessed extent is a cohesive-clay, passively meandering system that has remained planform-stable over an 80+ year historical record, consistent with the erosion-resistant nature of the fine-grained bank material identified along the corridor. Active geomorphic adjustment is not occurring at a system-wide scale but is instead concentrated at a small number of discrete locations: an erosion hotspot at a large outer meander in Segment 1, a pair of knickpoints downstream of the Tributary 2 confluence in Segment 3, and localised bank slumping on Tributary 2 approaching its confluence with the Orewa River. Geomorphic Change Detection results corroborate the Tributary 2 slumping as a genuine instability signal, while the broader corridor-wide GCD signal is attributed to LiDAR-related artefacts rather than genuine aggradation. These findings should be considered alongside future design and modelling work for the site, with the identified instability locations warranting particular attention should any works be proposed in their vicinity.

# 8. References

Hickin, E.J., & Nanson, G.C. (1984). Lateral migration rates of river bends. *Journal of Hydraulic Engineering*, 110(11), 1557-1567.

Nanson, G.C., & Hickin, E.J. (1986). A statistical analysis of bank erosion and channel migration in western Canada. *Geological Society of America Bulletin*, 97(4), 497-504.

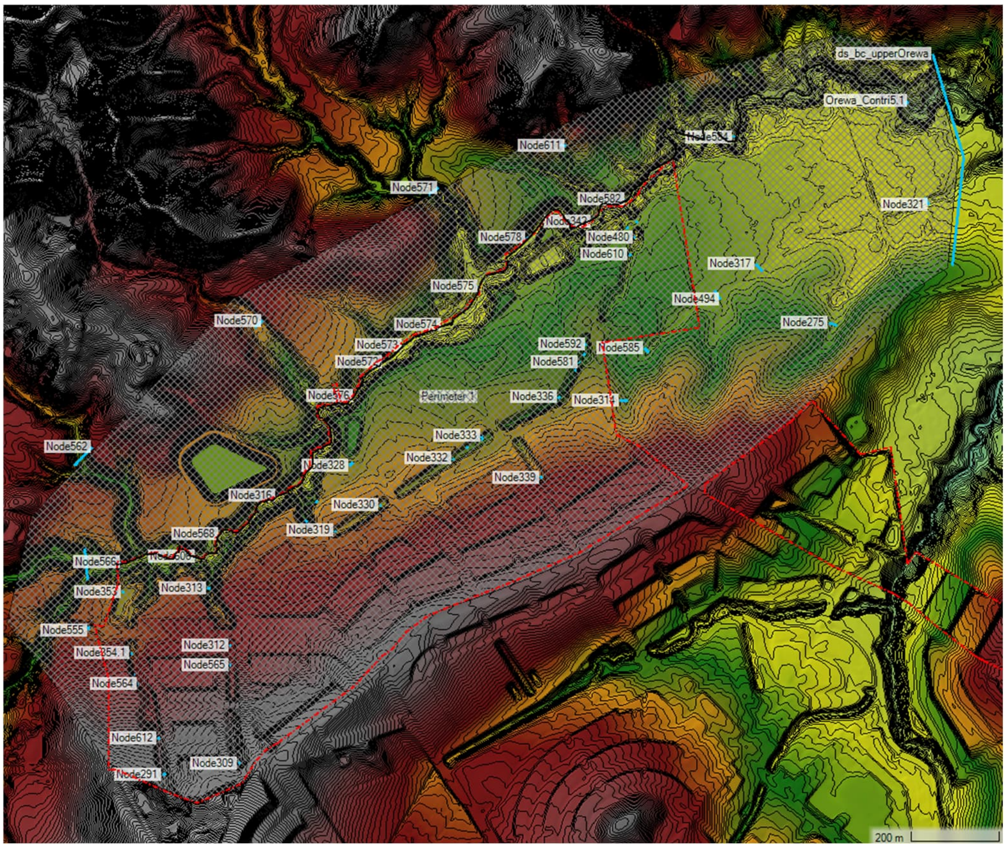
Retrolens. (n.d.). *New Zealand aerial photography archive*. Retrieved from retrolens.nz

Simon, A. (1989). A model of channel response in disturbed alluvial channels. *Earth Surface Processes and Landforms*, 14(1), 11-26.

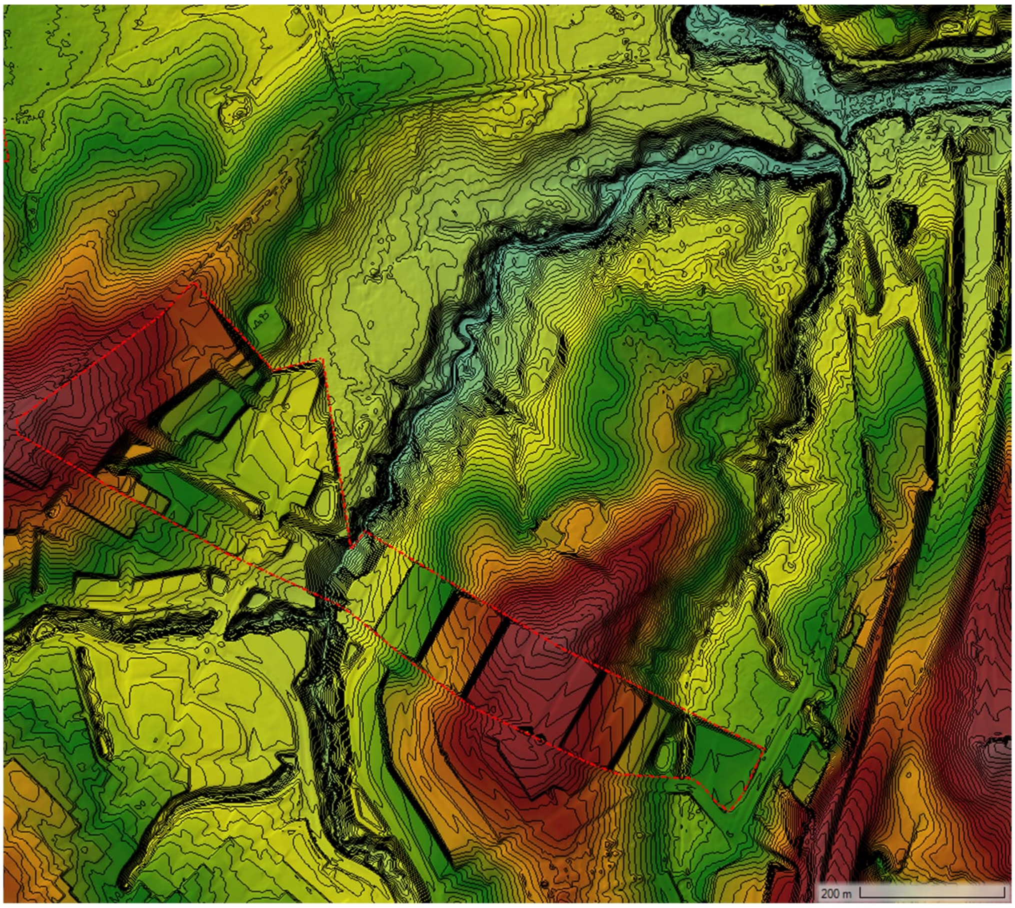
Spörli, K.B. (2007). Superposed deformation in turbidites and syn-sedimentary slides of the tectonically active Miocene Waitemata Basin, northern New Zealand. Basin Research, 19(1), 199-216.

Wheaton, J.M., Brasington, J., Darby, S.E., & Sear, D.A. (2010). Accounting for uncertainty in DEMs from repeat topographic surveys: improved sediment budgets. *Earth Surface Processes and Landforms*, 35(2), 136-156.

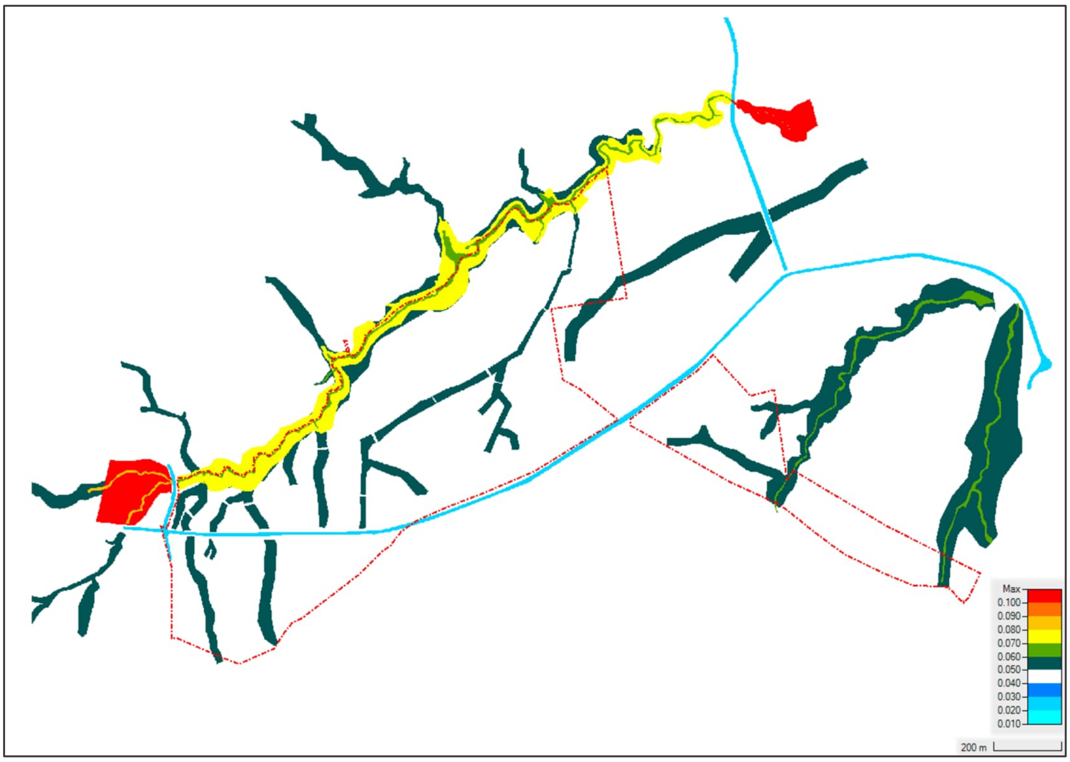
# Appendix 2 – Hydraulic model parameters



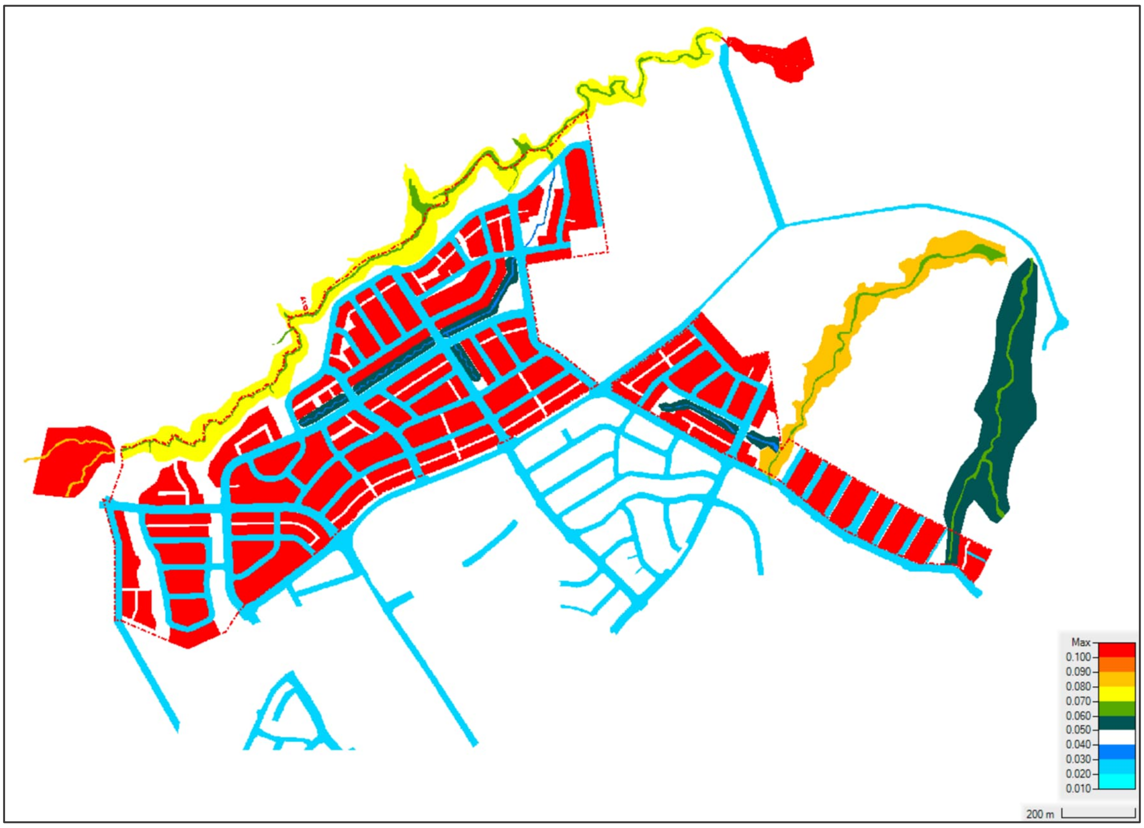

FigureA1 1: Orewa River catchment cutdown model




FigureA1 2:Waterloo Creek catchment cutdown model



FigureA1 3: Predevelopment Mannings




FigureA1 4: Post development Manning's

# Appendix 3 – Management Toolbox

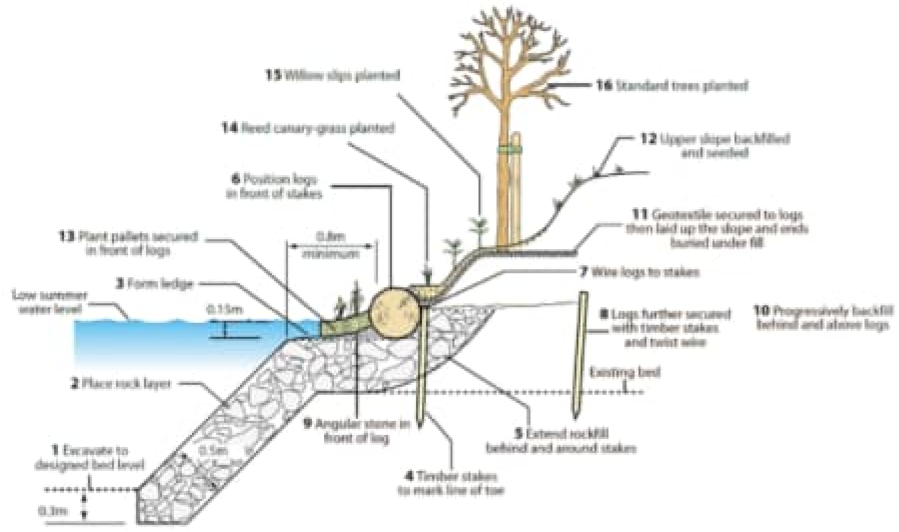
*Table A3 1: Erosion mitigation measure toolbox*

| Mitigation measure | Description | Why implement? | Potential advantages | Potential disadvantages | Relevance |
|---|---|---|---|---|---|
| Wingwall or scruffy dome outlets with aprons/rock riprap | End of pipe network installations designed in accordance with readily available standards | Manage localised erosion potential from pipe outlets (from networks and devices (wing walls for culvert inlets/outlets]) | General easy to design and install | May require works within stream beds potentially upsetting aquatic habitats | Multiple outlet locations and culverts on both Orewa River and Waterloo Creek |
| Riparian margin | Native vegetation establishment and management include the management of both remnant vegetation and the establishment of new plant species growing on or in a site, reach or waterway | Vegetating riparian land through targeted species selection and placement can improve channel stability and reduce sediment transport | Streambank stability, improved water quality, enhanced riparian vegetation and improve terrestrial and aquatic ecosystem health | - | For both Orewa River and Waterloo Creek riparian allowance has been accounted for |
| Stock management | Managing the access of livestock to waterways including riparian land | Retain or enhance the health of riparian vegetation and associated increased resistance against erosion forces and reduced sediment transport from the reach | Streambank stability, improved water quality, enhanced riparian vegetation and improve terrestrial and aquatic ecosystem health | Increased weed problems | Noted that along the true left bank of Orewa River adjacent to the development site are third party lands that keep stock. The applicant does not have direct control over this |
| Bank battering | Modification of the riverbank to a design bank angle to reduce erosion and enable vegetation establishment | Provide a stable surface for vegetation; accelerate recovery from past channel incision | Increase recovery rate, reduce erosion and downstream sedimentation, increase success rate for vegetation | Removes bank diversity, habitat features, can destabilize banks post-flood | This will be implemented as part of Stage 16 and 17 at Waterloo Creek and modified Stream 7 |
| Bed load sediment retention | Use of bed seeding or sediment trapping structures to stabilize and rehabilitate streams | Capture sediment load downstream using structures that increase roughness | Promotes sediment deposition and seed accumulation, incision control | May cause local instabilities, flood risks, structural displacement | Would require further assessment |
| Engineered log jams | Large timber amalgams to create hydraulic and habitat influence | Provide habitat and influence sediment erosion/deposition | Maintains bed diversity, increases channel complexity, reduces stream power | Can cause instabilities, structural displacement, flood risks | Maybe considered for Stream 7 |
| Large wood installation | Placement of wood in streams to create habitat, reduce sediment transport, and support vegetation | Increase roughness, reduce velocity, encourage sedimentation and vegetation | Stabilizes mobile beds, supports instream vegetation | Instabilities, flood risks, structural displacement | Would require further assessment and review of placement locations |
| Log sills | Large logs placed across the stream to create habitat and control bed erosion | Create pool habitat, support fish migration, and sediment trapping | Stabilizes incising beds, creates hydraulic diversity | Risk of undermining and erosion if not well-anchored | Would require further assessment and review of placement locations |
| Wood revetment | Protective structures of logs to stabilize riverbanks | Armour riverbanks using bioengineered techniques | Reduces erosion, promotes sediment deposition and vegetation | May shift erosion elsewhere, disrupt meander evolution | Would require further assessment and review of placement locations |
| Pile fields | Lines of timber piles placed in streams to reduce velocity and promote sedimentation | Reduce near-bank velocity and enhance riparian vegetation through sediment accumulation | Erosion control, promotes sediment deposition and vegetation | Instream disturbance, unsuitable for cobble bed streams | Would require further assessment and review of placement locations |
| Rock beaching | Placement of rock on banks to protect from erosion | Protect economic assets, used with other structures for erosion control | Immediate protection, erosion control, reduced sediment loads | May cause downstream erosion, disrupts meander, habitat loss | Maybe considered for Stream 7 |
| Rock chutes | Excavation and placement of rock to form weirs and dissipate energy | Control channel gradient, support fish passage, reduce erosion | Stable beds, fish passage, pool-riffle sequences, sediment storage | Sediment starvation, poorly designed structures affect fish passage | Maybe considered for Stream 7 |

*Table A3 2: Stream erosion mitigation implementation examples*

| Mitigation Measure | Example |
|---|---|
| Root wads |   |

| | |
|---|---|
| Root wads and riprap |  |
| Rock mattresses |  |

| | |
|---|---|
| | <br><br>Figure 12. Profile for log toe revetment. Source: River Restoration Manual 4.3 |
| Matting/netting |  |

| | |
|---|---|
| Combination riprap on lower banks and erosion mats on upper banks | <br> |