REPORT

Tonkin+Taylor

Beachlands South Structure Plan Change

Water Quality & Sedimentation Modelling Report

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Beachlands South Limited Partnership
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Executive summary

Beachlands South Limited Partnership (BSLP) is seeking a Private Plan Change (PPC) to re-zone approximately 307 ha of land in Beachlands to facilitate urban development of that area.

BSLP engaged Tonkin & Taylor Ltd (T+T) to undertake a modelling study of Whitford Embayment and Waikopua Creek to inform the assessment of potential adverse effects in the Coastal Marine Area arising from sediment and metal runoff associated with implementation of the proposed Structure Plan for the Beachlands South site (Figure 1-1). This report is intended to inform the PPC application.

The site planned for development is located south of Pine Harbour marina in the suburb of Beachlands, Auckland. Five main streams (identified in this report as A through E, north to south) discharge into the CMA from the site. An area of live zoning will be developed first, and then a Future Urban Zone (FUZ), which will be the subject of a future plan change.

Two stages of development are modelled: the period during which earth working will be conducted, and post-earth working / construction, when the landscape is "developed".

For the earth working phase, the analysis focuses on event-scale deposition of sediment that is eroded from earth working sites by rainfall and discharged into the CMA in freshwater runoff. In this case, the modelling results were compared to critical deposition thicknesses and durations of persistence to assess potential adverse effects on the embayment ecosystems. Effects thresholds for all Average Recurrence Interval (ARI) events considered correlate to a deposition thickness of 20 mm persisting for more than 5 days, and deposition of 5 mm persisting for more than 10 days. While these thresholds are applicable to all design events, they have greatest relevance to the 100-y (year) ARI where greatest deposition thickness is modelled.

For the developed landscape, the analysis focuses on annual average sedimentation rate and the accumulation of zinc and copper in the bed sediments of the embayment. ANZECC guidelines provide guidance for interpreting the ecological significance of the former, and the Auckland Council Environmental Response Criteria (ERC) provide thresholds for interpreting the ecological significance of the latter.

For the developed landscape, annual TSS (Total Suspended Solids, measured in tonnes) is predicted to reduce overall by 64% compared with loads under the existing landscape . Copper and zinc will accumulate, but metal concentrations within the surface mixed layer will remain below the ERC amber threshold (19 mg/kg and 124 mg/kg for copper and zinc, respectively).

During the earthworks phase, which includes certain levels of stormwater treatment, sediment runoff from the site will increase compared to sediment runoff from the existing landscape. Modelling indicates the potential for 24 h TSS load (mass, measured in Tonnes) that are:

- 1 to 2 times[1] increase in the mass of TSS discharged for the 95th percentile rainfall event (approximately annual heaviest rainfall event expected)
- 2 to 3 times increase in the mass of TSS discharged for the 2-y ARI rainfall event (likely to occur five times within a 10-y development period)
- 3 to 5 times increase in the mass of TSS discharged for the 10-y ARI rainfall event (likely to once within a 10-y development period)
- 6 to 14 times increase in the mass of TSS discharged for the 100-y ARI rainfall event (10% chance of occurrence within a 10-y development period).

[1] 1 to 2 times means potential 24 h TSS discharged load (tonnes) during earthworks varies between 100% and 200% of the existing situation, alternatively considered as up to 100% higher than existing, or up to double the load.

For the 2-y and 10-y ARI events during the earthworks phase, the extent where the 5-mm deposition threshold (and the 20 mm by default) was exceeded was less than 0.1 ha.

For the 100-y ARI event:

> The 20-mm deposition thickness threshold persisting for more than 5 days was exceeded over areas less than 0.1 ha. The 5-mm threshold was exceeded over greater areas and shown to persist for more than 10 days as outlined below.
>
> *For sediment discharged from streams A and B in a 100 y ARI event,* worse case deposition occurred under spring tide conditions. A peak discharge over high tide had the potential for 3 to 4 ha coverage of 5 mm or more in the upper intertidal area persisting longer than 10 days. Less than 2 ha was similarly affected within the lower intertidal area at other times. During neap-tide conditions modelling indicates the tidal stage at time of discharge becomes less influential on the size of the 5 mm deposition threshold with typically 1 to 2 ha with more than 5 mm deposition persisting longer than 10 days. Longer term (i.e., timescale months to years) exposure to wind waves will result in gradual redistribution of this material to other subtidal areas of the wider embayment.
>
> *For sediment discharged from streams C, D and E in a 100 y ARI event,* deposition areas 3 to 4 ha in size with more than 5 mm occurred under both neap and spring tide conditions, albeit in different locations. Higher tidal currents (ebb/flood) enabled a greater spread of discharge material compared with high tide where reduced currents enabled a more focused and smaller deposition areas in the upper inter-tidal vicinity of the discharge points. Sediment deposited in the vicinity of Waikopua Stream, where it is sheltered from winds and waves, is likely to remain in place.
>
> Considering a 2-3 times increase in sediment during construction for more frequent events such as 2-y ARI, and noting existing rates of sedimentation as high as 3 mm/y, the potential exists for more than 2 mm of accumulated sediment above existing background rates during the construction period (taken indicatively as 10 years) in the vicinity of discharges C,D,E which are existing predominantly silty and muddy environments. Changes in TSS in the order of 2-3 times over the relatively short duration of construction need to be considered in context with long term reductions in TSS by 64% in its developed form.

In conclusion this study indicates:

- Post development resulting in an overall reduction in annual TSS, with likely long-term accumulation of Zinc and Copper within green (acceptable) ERC threshold values.
- During earthworks, the potential exists for increased TSS particularly following extreme lower likelihood rainfall events (e.g. 100-y ARI event). Sediment areas and thicknesses from this report that consider a range of design events are used to inform the T+T ecological assessment report.

1 Introduction

1.1 Background

Beachlands South Limited Partnership (BSLP care of Russell Property Group) engaged Tonkin & Taylor Limited (T+T) to undertake a modelling study of Whitford Embayment and Waikopua Creek to inform the assessment of potential adverse effects in the CMA arising from sediment and metal runoff associated with implementation of the Proposed Structure Plan and PPC for the Beachlands South site. We have carried out this work in accordance with our proposal of 3 December 2020 (T+T,2021a).

The site comprises an area of approximately 307 hectares of land south of the existing Beachlands township and the Pine Harbour Marina, as shown in Figure 1-1. The site encompasses the existing Formosa Golf Resort, the large farm properties to the south, and smaller rural properties along Whitford-Maraetai Road. Figure 1-1 also shows where the main coastal streams, all of which are considered in this assessment, discharge into the Whitford Embayment.

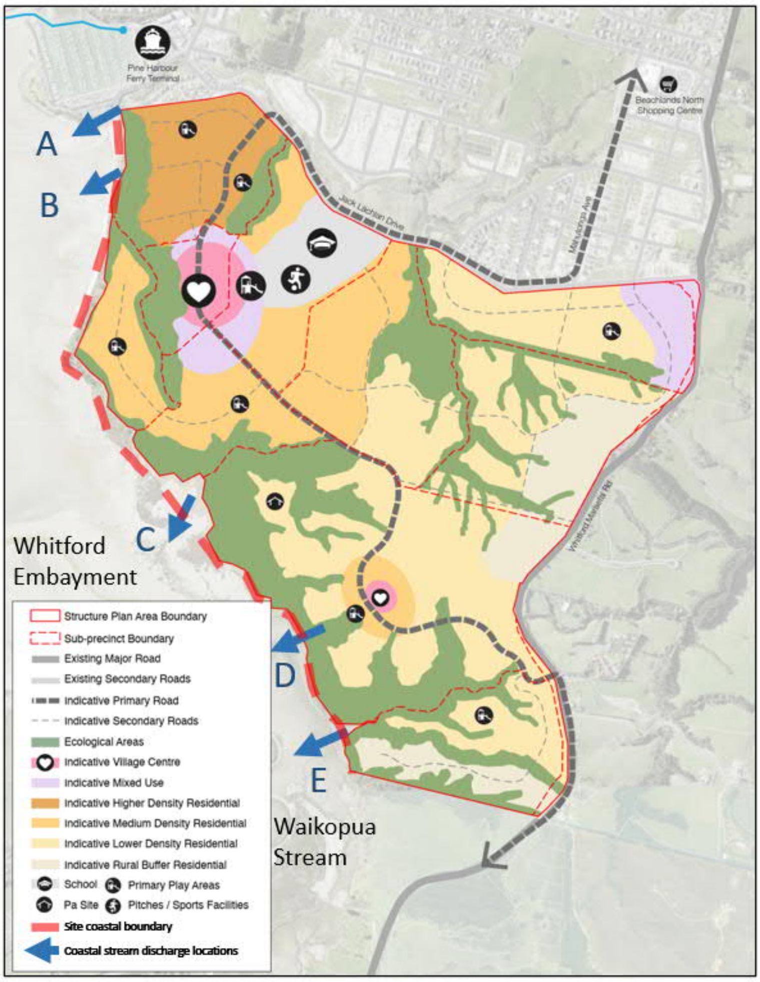

Figure 1-1 Structure Plan

1.2 Proposed Structure Plan and PPC

BSLP is seeking a PPC across multiple contiguous properties in Beachlands, Auckland (shown in Figure 1-1) to expand the existing Beachlands Maraetai coastal town.

The PPC area is currently zoned Rural – Countryside Living under the Auckland Unitary Plan Operative in Part (AUP-OP). Through the Plan Change, the BSLP are seeking to rezone the land to a combination of Business (Mixed Use, Local Centre and Neighbourhood Centre), Open Spaces, various Residential zones and Future Urban zone.

Initially it is proposed to 'Live Zone' the proposed development footprint within the northern portion of the PPC area (the 170 ha Formosa Golf Course at 110 Jack Lachlan Drive, Beachlands) via a plan change (Figure 1-2). Development areas within the live zone comprising a village centre in the northwest of the site, surrounded by mixed used land and higher density housing drain into coastal discharges A and B.

It is proposed to rezone the remaining development footprint within the southern portion of the PPC area as 'Future Urban Zone' . This includes the proposed development footprint within the farm at 620 Whitford-Maraetai Road and various smaller land parcels. These Future Urban Zone areas will be the subject of a further plan change application in due course as shown in Figure 1-2. Medium and lower density housing in the Future Urban Zone discharges into C, D and E.

A treated wastewater discharge location is proposed in the vicinity of stream B as part of this Structure Plan.

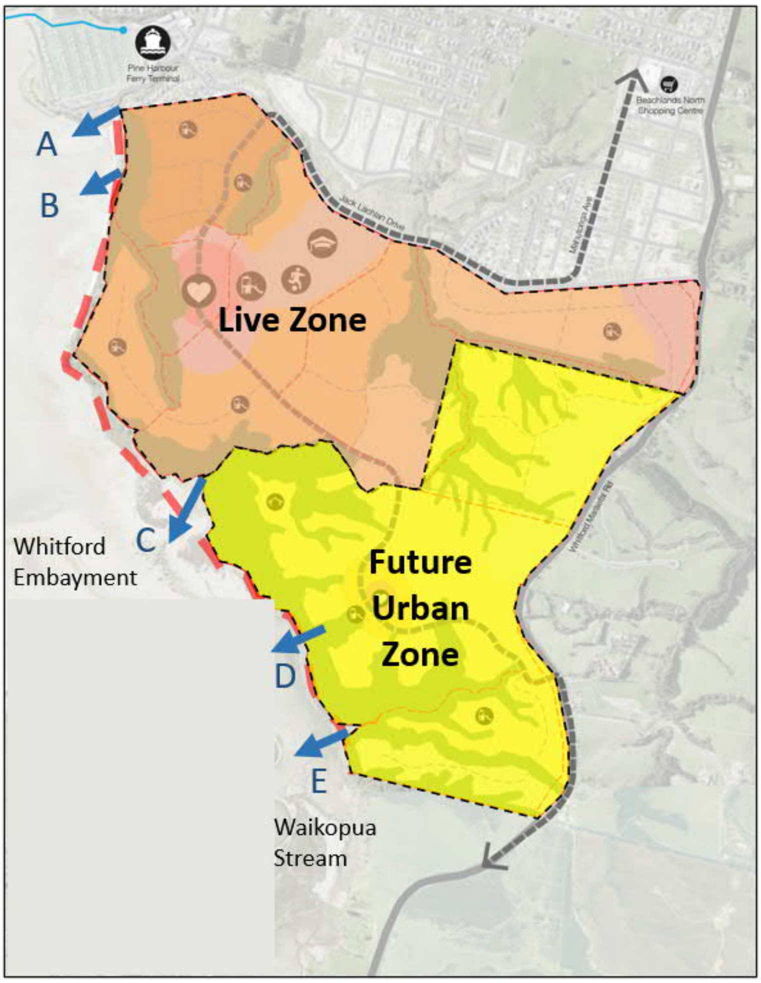

Figure 1-2 Live Zone and Future Urban Zone

1.3 Purpose of this report

This report has been prepared to support the PPC application for Beachlands South, and to assist Auckland Council and decision makers in assessing this application in accordance with the Resource Management Act 1991. This study considers potential effects on water quality and sedimentation associated with the Structure Plan and Plan Change during the following three (consecutive) stages of planned land development:

1. Existing (baseline): Understanding existing sedimentation and water quality is important contextual information regarding the assessment of development effects.
2. During construction: Clearing of land, earthworks and construction can result in disturbed soils being transported downstream and ultimately dispersed and potentially deposited in the adjacent marine environment.
3. Following completion of the development: Ongoing runoff of sediment and metals (specifically copper and zinc) from the developed landscape, dispersing and potentially accumulating in the adjacent marine environment.

The following "effects thresholds" have been used in our study:

- Deposition of sediment in the immediate aftermath of single events (Gibbs and Hewitt ,2004):
  - 20 mm thick, remaining for longer than five days.
  - 5 mm thick, remaining for longer than 10 days.
- Long-term (yearly to decadal) accumulation of sediment: 2 mm sediment accumulation per year above the natural annual sedimentation rate, which has been adopted by Australian and New Zealand Water Quality Guidelines (ANZECC, 2018) as a Default Guideline Value (DGV) for sedimentation.
- Metal (zinc and copper) accumulation in the surface mixed layer of the bed sediments is reported against the Auckland Council Environmental Response Criteria (ERC) "traffic light" system as described in TP168 (ARC, 2004), and shown in the table below. The ERC values are considered more conservative than the trigger values provided in the Australian and New Zealand Water Quality Guidelines (ANZECC, 2018), which are also listed for reference.

Table 1-1 Auckland Council ERC threshold values for sediment quality

Contaminant	Unit	Auckland Council ERC			DGV	GV-High
		Green	Amber (TEL)	Red (ERL)		
Copper	mg/kg dry weight	<19	19-34	>34	65	270
Lead	mg/kg dry weight	<30	30-50	>50	50	220
Zinc	mg/kg dry weight	<124	124-150	>150	200	410

DGV : Default Guideline Values from ANZECC (2018)
GV - High : Guideline Values – High from ANZECC (2018)

Figure 1-3 illustrates key linkages between four key reports (including this one) that progress in a stepwise manner, ending with the Marine Ecological Effects Assessment (T+T, 2021a). The Marine Ecological Effects Assessment provides additional information regarding the suitability of the above thresholds, reference standards and guidelines in this assessment, and potential ecological effects based on findings contained in this report. For completeness the NIWA discharge report is included in Appendix B.

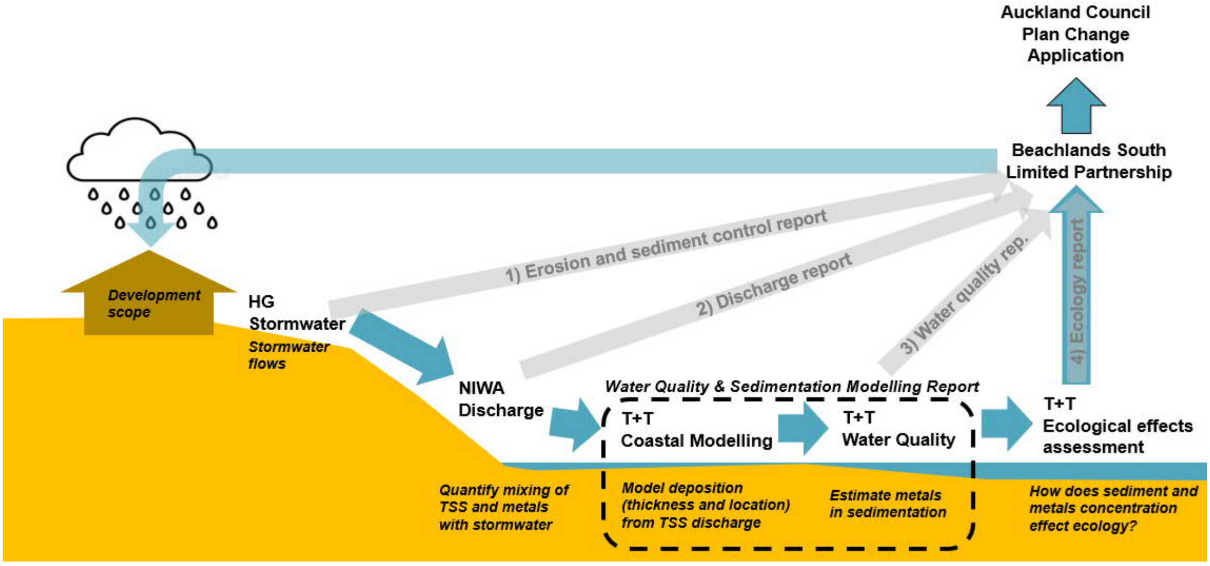

Figure 1-3 Contextual purpose of this report

1.4 Report outline

Section 1 of this report discusses scope, why this work is being undertaken, and general approach, which is illustratively presented in Figure 1-4.

Section 2 provides a description of the physical setting of the site. Figure 1-4 highlights various technical inputs external to this report, use of published data, and collection of field data that inform the physical setting. External information includes Harrison and Grierson (HG) stormwater information that has in-turn been used by NIWA in various models (GLEAMS and Contaminant Load Model, CLM) to inform potential sediment and metals discharges. The scope of field data collection has aimed to build on and corroborate with published information. Measured current, temperature and water level information formed the basis for subsequent validation of numerical modelling.

Section 3 of this report provides information on hydrodynamic and sediment-transport modelling. NIWA's regional hydrodynamic model of the Hauraki Gulf provides coarse information relating to tidal currents, water levels, salinity and temperature driven by boundary water levels, temperature, salinity and atmospheric coupling. A more detailed T+T nested hydrodynamic model takes this coarse information and resolves it to a finer spatial scale to enable sediment transport modelling of terrigenous sediment discharged into the embayment by creeks, where it settles to the bed under gravity, and may be re-eroded from the bed by waves and currents.

Section 4 discusses sediment transport patterns and influences that, in turn, inform sediment model scenarios. Results of the sediment dispersal and deposition modelling are discussed in Section 5.

Section 6 presents the metal accumulation modelling and results.

Section 7 provides a summary of key information and conclusions.

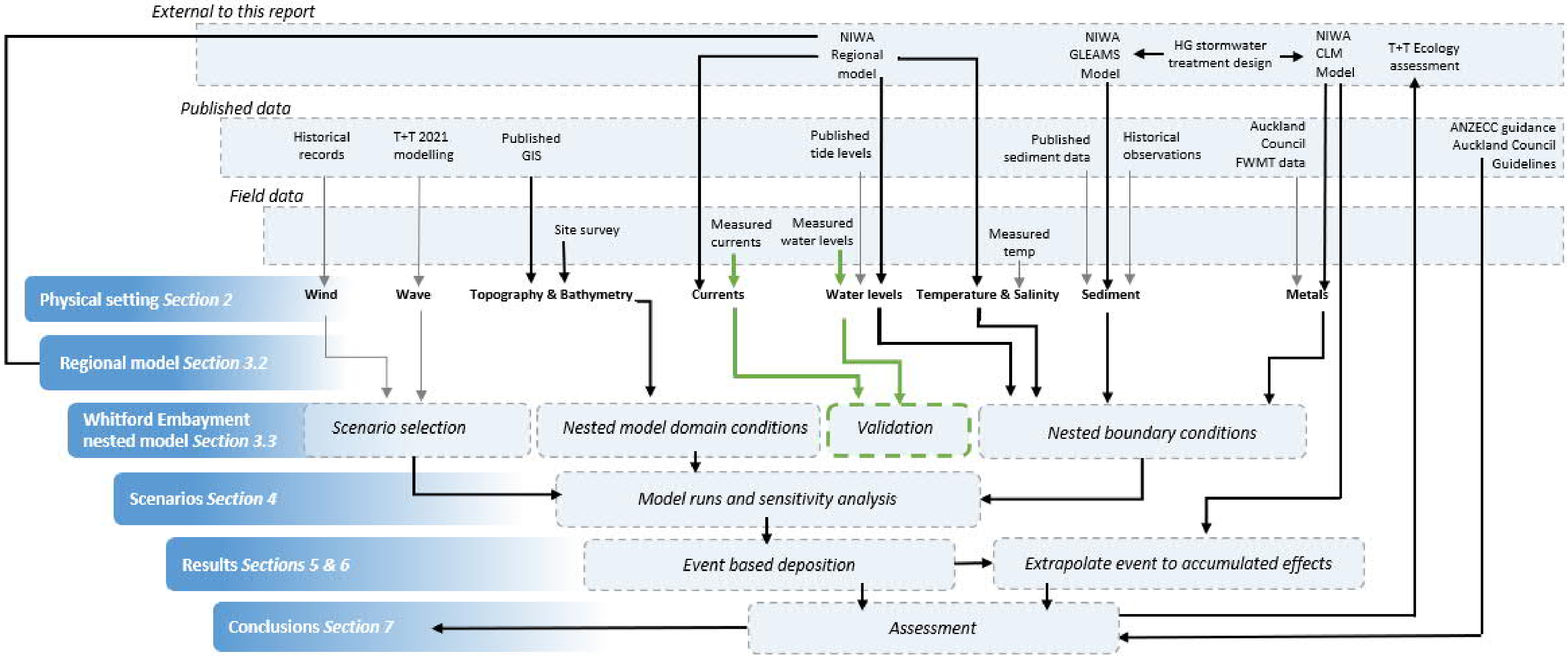

Figure 1-4 Project workflow and general approach

2 Physical setting

2.1 Location

The site is located south of the Pine Harbour marina along the eastern shore of the Whitford Embayment (Figure 2-1).

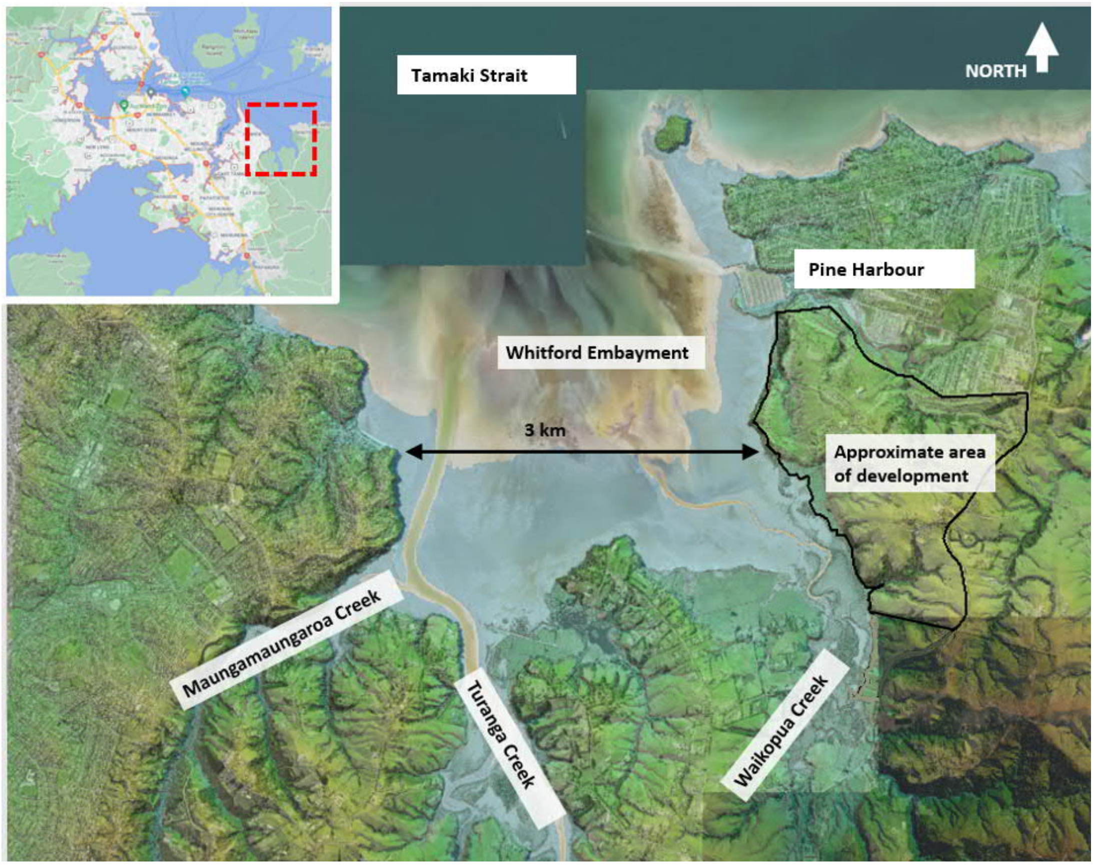

Figure 2-1 Map of the Whitford Embayment

The approximately 3 km of coastal edge bordering the site follows the length of the Jack Lachlan Esplanade Reserve (Figure 2-1). The northern end of the site is separated from the Pine Harbour Marina by a small unnamed stream (hereby referred to in this report as Stream A). Four other streams annotated B through E in Figure 2-1 show discharges along the coastal edge. Moving south towards Waikopua Creek, intertidal sediments turn from sandy to silty, eventually becoming established mangrove habitat.

Figure 2-2 and Figure 2-3 provide aerial images of the embayment looking towards the northern and southern extents, respectively, of the coastal edge bordering the proposed development area. These images highlight a steep cliffed backshore, variable and hummocky beach material at cliff-toe, which in turn is fronted by a very wide and gently sloping intertidal flat.

Figure 2-2 Looking towards northern extent of site

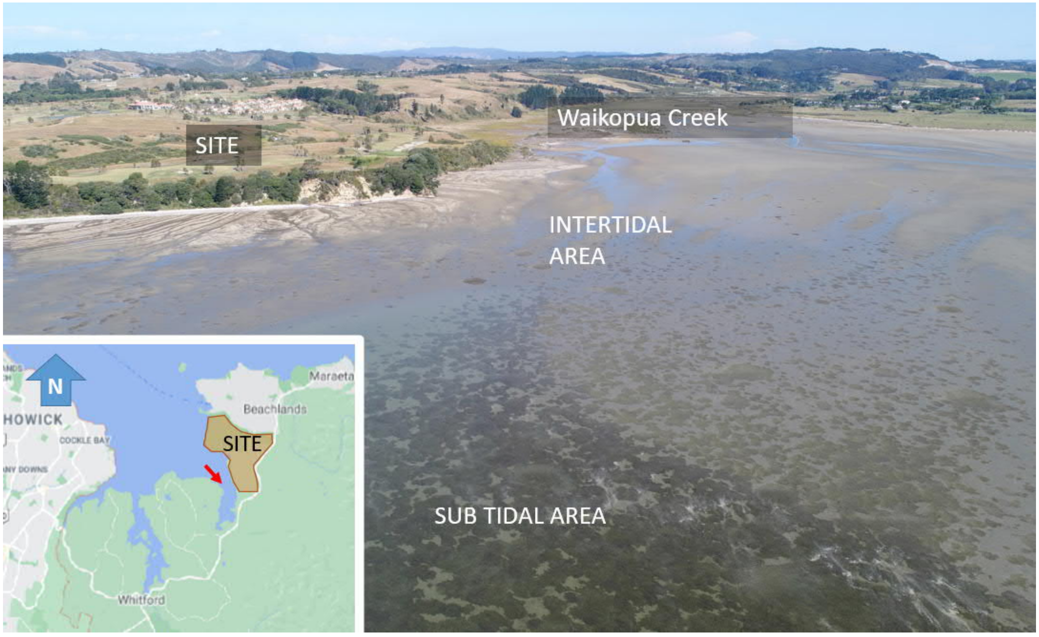

Figure 2-3 Looking towards southern extent of site

2.2 Bathymetry and tributaries

The hydrographic chart of the Whitford Embayment in Figure 2-4 shows close to half of the embayment as being intertidal, with three main tributaries. The Mangemangeroa Creek is the widest and deepest tributary, discharging into the southwestern corner of the embayment.

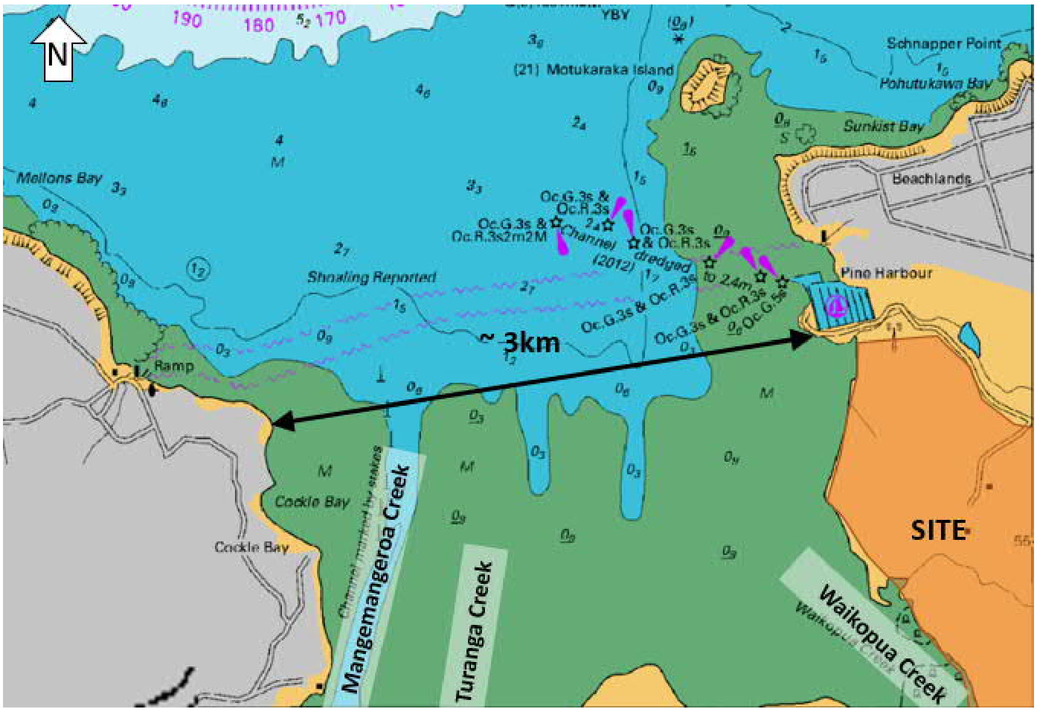

Figure 2-4 Published hydrographic chart of the Whitford Embayment

2.3 Wind

The nearest weather station with a long-term dataset that includes both wind and rainfall data (continuous daily rainfall and hourly wind speed data from January 1980 to January 2013) is Auckland Aero, located approximately 16 km to the southwest. The predominant wind direction at Auckland Aero is from the southwest sector, occurring 42% of the time. Maximum wind speeds generally occur from the southwest and northeast sectors, with typical associated weather systems at these times shown in Figure 2-6. Strong northeast winds are associated with sub-tropical or ex-tropical cyclonic low pressure systems, and strong southwesterlies arise from relatively stable anticyclone conditions over Australia. Similar trends are observed in other nearby areas of Auckland where less complete historical wind records exist, such as 10 km northeast of Beachlands at Musick Point (Cliflo, 2021).

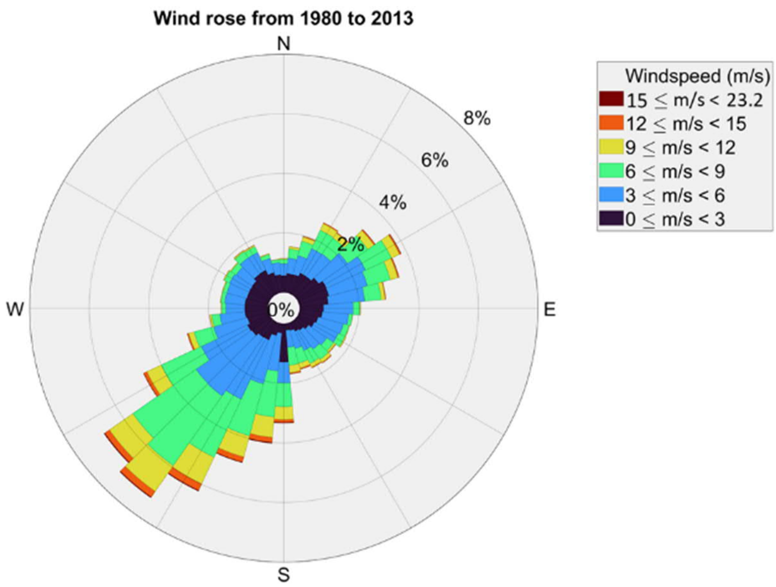

Figure 2-5 Wind rose showing wind speeds and directions at Auckland Aero from January 1980 to January 2013

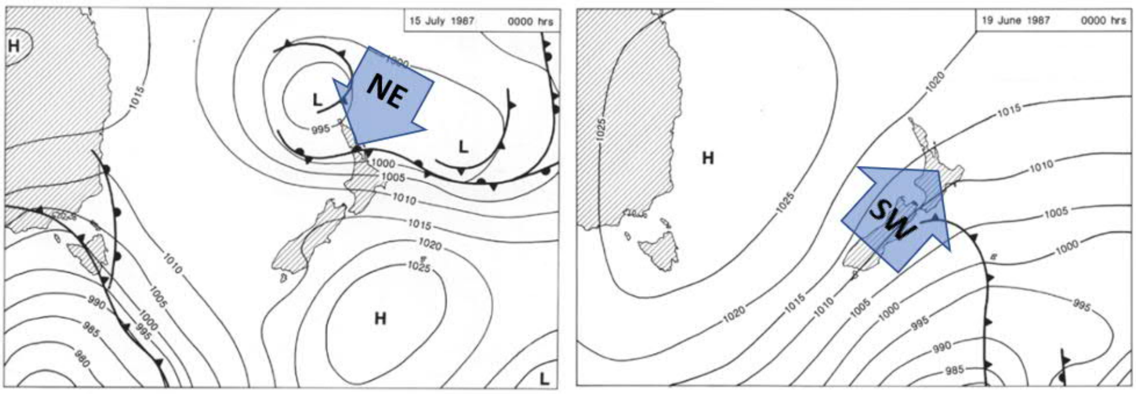

Figure 2-6 Typical weather systems associated with high wind speeds in the Auckland region (Images modified from Chappell, 2013)

2.4 Waves

Previous modelling of extreme waves (T+T, 2020b) using SWAN highlights the sheltering effects of islands within the Hauraki Gulf (particularly Rangitoto, Motutapu, Waiheke and Ponui) to offshore swell (Figure 2-7). Waves in the Whitford embayment are generally limited to short-period waves that are generated by winds acting on the sea surface locally inside of these islands.

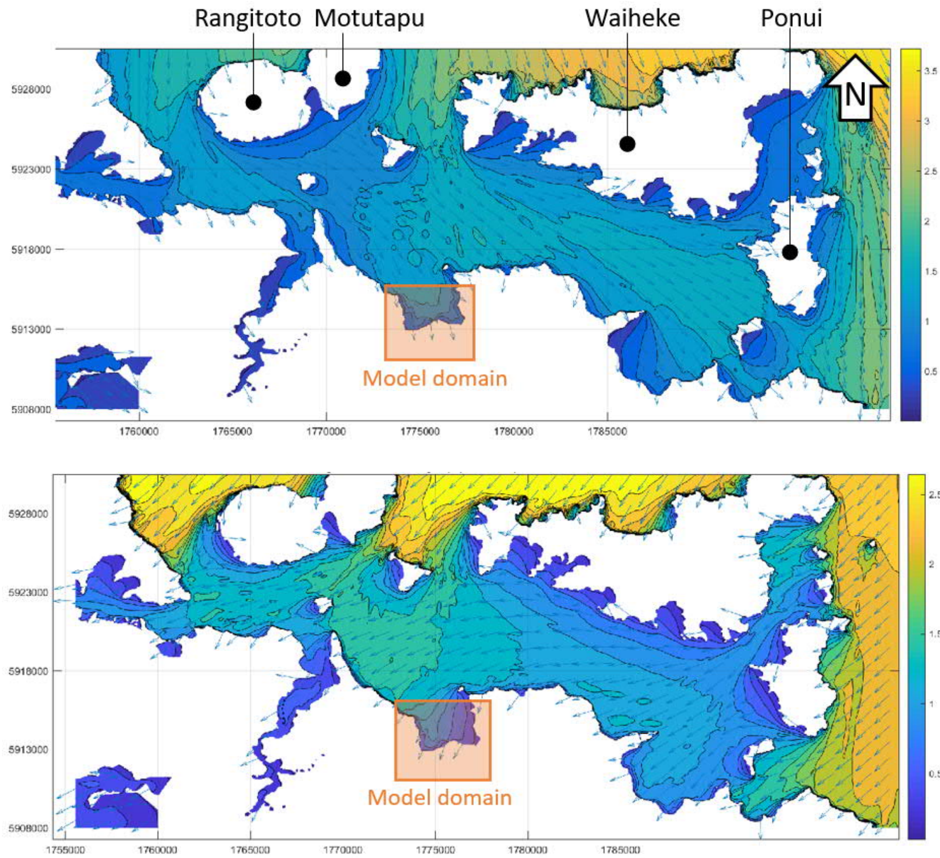

Figure 2-7 Sheltering effects of islands within the Hauraki Gulf

Largest waves impinging on the eastern shoreline of the embayment are expected to be generated by north to northwest winds blowing into the shoreline across approximately 10 km of fetch. This study indicates a 100 ARI design wave height of 1.8 m from 315º (NW) with a peak wave period of 4.5 seconds (s).

Wave heights within the Whitford Embayment depend on the joint probability occurrence of water level and wind. For intertidal settings under a steady wind, wave height will be largest at high tide when fetch is longest and water depth is greatest, and wave height will typically decrease rapidly as the tide falls, and water depths reduce. Depth-limited wave breaking occurs along the shallow edges of the water body, sweeping back and forth across the intertidal flats with the rise and fall of the tide (Figure 2-8).

Figure 2-8 Depth-limited wave breaking of small waves

2.5 Water levels

2.5.1 Published water level information

2.5.1.1 Astronomical tide

The closest long-term tidal station to Beachlands is at the Port of Auckland located some 18 km northwest of the site (see Table 2-1 for tide levels at the Port). Typically, the tide range is 2.88 m and 1.80 m for spring and neap tides, respectively. Levels in Table 2-1 are provided in terms of the LINZ Auckland Chart Datum. Additional published water levels are also included in this table from Stephens & Wadhwa (2012) for a point centrally located within the embayment (ref. 63).

Table 2-1 Predicted tide levels

Nominal level	Port of Auckland (LINZ, 2021)		Beachlands (Stephens & Wadhwa, 2012)	
	Water level CD (m)	Water level RL[1] (m)	Water level CD (m)	Water level RL[1] (m)
Highest Astronomical Tide (HAT)	3.71	1.97	3.57	1.83
Mean High Water Perigean Springs (MHWPS)	-	-	3.39	1.65
Mean High Water Springs (MHWS)[1]	3.35	1.61	-	-
Mean High Water Springs -10 [2] (MHWS – 10)	-	-	3.32	1.58
Mean High Water Neaps (MHWN)	2.38	0.64	-	-
Mean Sea Level (MSL)	1.91	0.17	-	-
Mean Low Water Neaps (MLWN)	1.03	-0.71	-	-
Mean Low Water Springs (MLWS)	0.48	-1.26	-	-
Lowest Astronomical Tide (LAT)	0.06	-1.68	-	-

1. Levels in Auckland Vertical Datum 1946, which is 1.74 m lower than Chart Datum (CD)
2. Where 10% of high tides exceed the level.

2.5.1.2 Storm surge

Storm surge results from the combination of barometric setup from low atmospheric pressure and wind stress from winds blowing along or onshore. This process elevates the water level above the predicted tide. The combined elevation of the predicted tide and storm surge is known as the storm tide. In 2013, NIWA modelled coastal-storm inundation around the coastline of the Auckland region (Stephens et al., 2013). The predicted storm tide levels for a range of return periods for Waikopua are presented in Table 2-2. These levels include local effects of wave set-up that may occur in limited areas of wave breaking along the northern extent of the site. This is likely to be relatively minor in the vicinity of the Waikopua Creek where there is shelter from waves. Published values for the same location excluding wave setup indicate a 1% AEP level of 2.2 m RL (Stephens et al., 2016), indicating approximately 0.26 m of wave setup elsewhere in the embayment for this event magnitude.

Table 2-2 Storm tide levels for Beachlands (Stephens et al., 2013)

Annual Exceedance Probability (AEP)	39%	18%	10%	5%	2%	1%	0.5%
Average Recurrence Interval (ARI)	2 y	5 y	10 y	20 y	50 y	100 y	200 y
Elevation RL[1] (m)	2.08	2.20	2.05	2.26	2.32	2.46	2.49

1. Elevations in Auckland Vertical Datum 1946

Greatest storm surges within the Whitford Embayment are likely to arise under strong northerly winds associated with either subtropical lows or ex-tropical cyclones (discussed in Appendix A), which also bring extreme rainfall.

2.5.2 Measured water levels

Water levels were monitored in three locations within the embayment, detailed in Table 2-3 with locations shown in Figure 2-9. The data are presented in Appendix D.

Table 2-3 Instrumentation details

Instrumentation	Model	Level (m, CD)	Lat	Long	Recording	Date
Pressure sensor north	RBR Solo	-2 m	36.89527 S	174.97605 E	Burst 8192 data points at 8Hz, first ~17 min of every hour	March 19 until April 30, 2021
Pressure sensor south	RBR virtuoso	-1 m	36.88265 S	174.97364 E	Continuous at 4 Hz	March 19 until April 30, 2021
ADCP	Nortek Eco	-0.2 m	36.89238 S	174.97167 E	Continuous at 10 minute intervals	March 19 until April 8, 2021

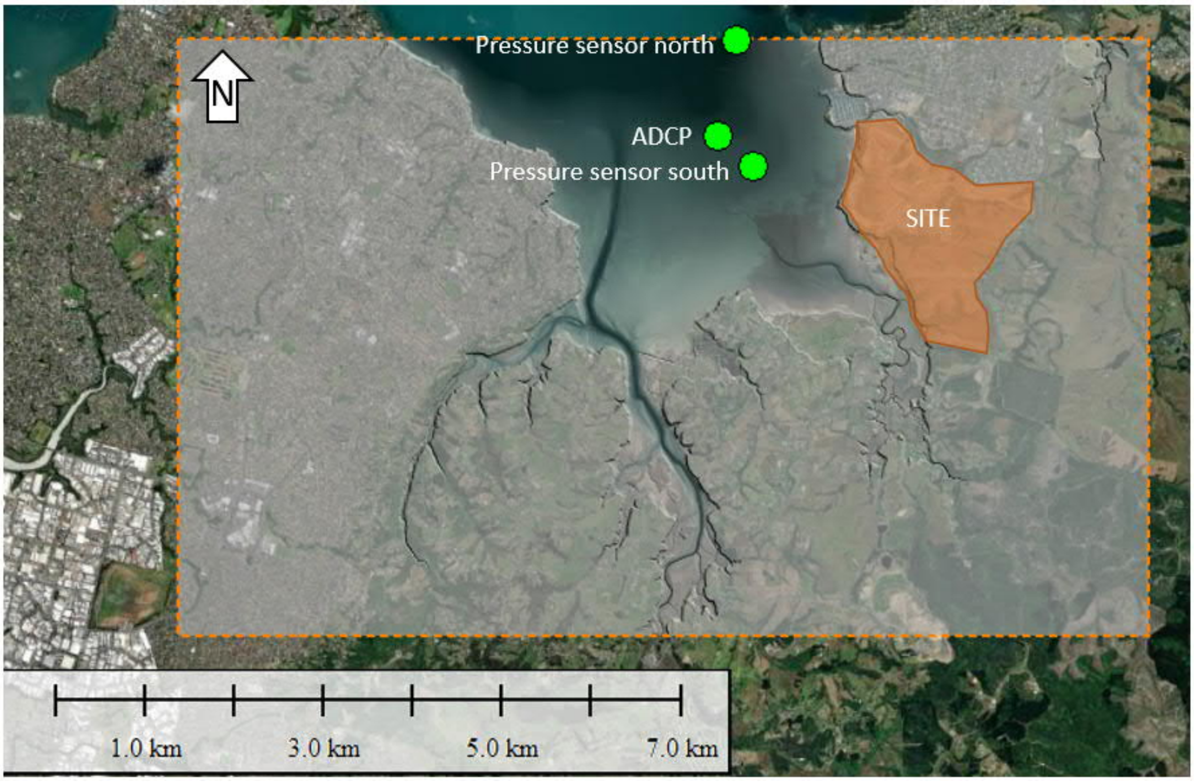

Figure 2-9 Instrumentation location plan

2.6 Currents

An Acoustic Doppler Current Profiler (ADCP) was used to measure current speed and direction at three levels in the water column at the location indicated in Figure 2-9 over the period March 19 until April 8, 2021. The data are presented in Appendix D. Measurements indicate peak currents typically occurring at mid-tide as high as approximately 0.2 m/s over the spring tide, and approximately half this value over the neap tide.

2.7 Temperature

The Acoustic Doppler Profiler (ADCP) at the location in Figure 2-9 was also used to measure temperature at bed level. This data revealed daily variations in temperature of between 0.5 and 1.5 degrees C, with daily highs typically occurring in the early afternoon. Overall, water temperatures cooled by a degree over the monitoring period.

2.8 Sediments

2.8.1 Terrigenous sediments

Terrigenous sediments are those derived from the erosion of soils or rock on land (as opposed to marine) environments. In the Whitford embayment, key sources of terrigenous sediment include material transported to the coastal edge by overland flows and streams identified in Figure 2-1, and material derived from erosion of exposed areas of the coastal edge Figure 2-10.

Figure 2-10 Erosion all exposed areas of the coastal edge (photo taken by T+T on 10 April 2021)

Gibbs and Hewitt (2004) describe terrigenous sediment in the Auckland region as typically being a yellow-orange soil containing a lower clay content than in typical mudflat settings. Laboratory testing by Gibbs and Hewitt of terrigenous material within the Whitford Embayment indicates a large silt sized fraction (3.9– 63 µm), with less than a quarter comprising fine sand (63– 250 µm).

Figure 2-11 shows sediment deposited on a high-tide beach within a discharge channel at Stream C following a period of moderate rainfall (25 mm accumulated over a 24 h period based on Auckland Council, 2021a). Deposited material for the most part resembled a fine silt, with flocculation occurring in pools of water trapped over the intertidal area[2]. As indicated in photo right of Figure 2-11, the flocculated material is often the last to settle, manifesting as a film of overlying sediment that is comparatively easily resuspended.

Figure 2-11: Photo left shows sediment deposited on the high tide beach within discharge channel at Stream C. Photo right shows floc development within intertidal areas approximately 50 m away. Photos taken on 10 April.

[2] Flocculation is the process whereby individual particles cluster together into aggregates (or flocs) which, as a result, become larger and less dense than the individual constituent particles.

The regional geology of the Beachlands area provides information on the origins of terrigenous material entering the embayment. The 2001 GNS 1:250,000 geological map of the Auckland area (Figure 2-12) indicates most surrounding catchments being underlain by Waitemata Group East Coast Bays Formation (ECBF Fm.) flysch, with weathered soils comprising clayey silt and occasional thin beds of sand or sandy silt. The proposed development area is underlain by this material.

Undifferentiated Tauranga Group alluvium, comprising mud, sand and gravel, is limited to areas north of the site (Puketoka Fm.). This may contribute a higher fraction of coarse sediments than ECBF Fm. into Stream A. The map indicates low lying areas around the coastal edge, including stream channels containing river deposits that have likely accumulated within the last 10,000 years.

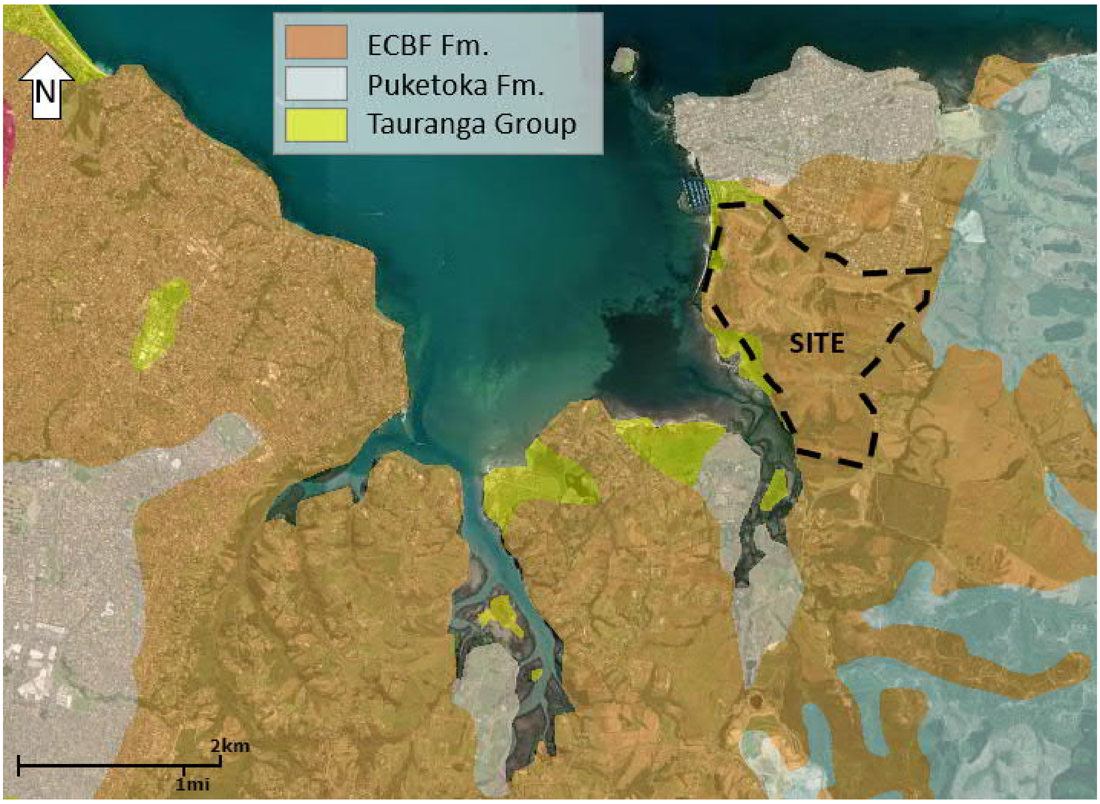

Figure 2-12: Geological area, approximate site boundary marked in red (GNS, 2001)

Observations of sediment plumes within the embayment have been published by Healy (1996), including aerial obliques in Figure 2-13 of the embayment that were taken following a 'northerly storm' in August 1996. Discharge locations are annotated in these figures for clarity. Given the yellow–orange colouration of the plumes, which is consistent with Gibbs and Hewitt (2004) descriptions noted above, the regional geology, and the fact that the plumes emanate from streams (A through E, and Waikopua Creek), it is safe to say that the plumes are composed of terrigenous sediment eroded from the catchment, suspended, and transported in freshwater runoff.

Figure 2-13 Aerial obliques of the embayment following a 'northerly storm' in August 1996 (Healy, 1996) with key discharges considered in this study labelled with arrows

Data from the Freshwater Management Tool (FWMT data provided by Auckland Council, 2021a) has been used to compare sediment runoff from the site to sediment runoff from adjacent catchments. Data from 62 FWMT nodes were grouped spatially into the six catchments as shown in Figure 2-14. TSS (Total Suspended Solids) discharges over a 48-h period inferred from rainfall records to approximately fit a 2.33-y ARI 24-h (hour) event were aggregated for each catchment cluster, with percentage contributions annotated on Figure 2-14. This indicates that the PPC area contributes less than 10% by mass of TSS discharged from the land to the embayment during events of this size. This figure also indicates the PPC area likely contributing less than one third of total TSS entering into the Waikopua Creek for events of this size (7% from site catchments, compared with total 23% and 7% contributions into this creek).

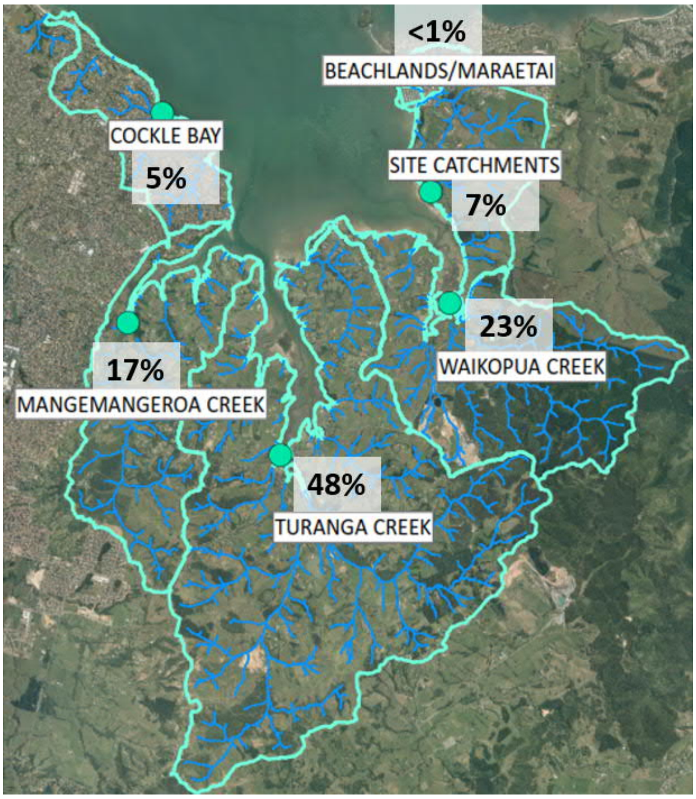

Figure 2-14 Percentage of total suspended solid (TSS) contributions from key catchment clusters surrounding the Whitford embayment

2.8.2 Marine sediments

Sediments within the Whitford Embayment indicatively shown in Figure 2-15 may be broadly characterised as being:

1. Unconsolidated shelly beach deposits, typically narrow and limited to areas with shelter from wind waves.
2. Exposed rock, apparent along the coastal edge of the site, up to 200 m in width.
3. Mudflats, located within the comparatively more protected upper reaches of tributaries, often in the vicinity of mangrove vegetation.
4. Sandflats, accounting for the majority of the embayment area.

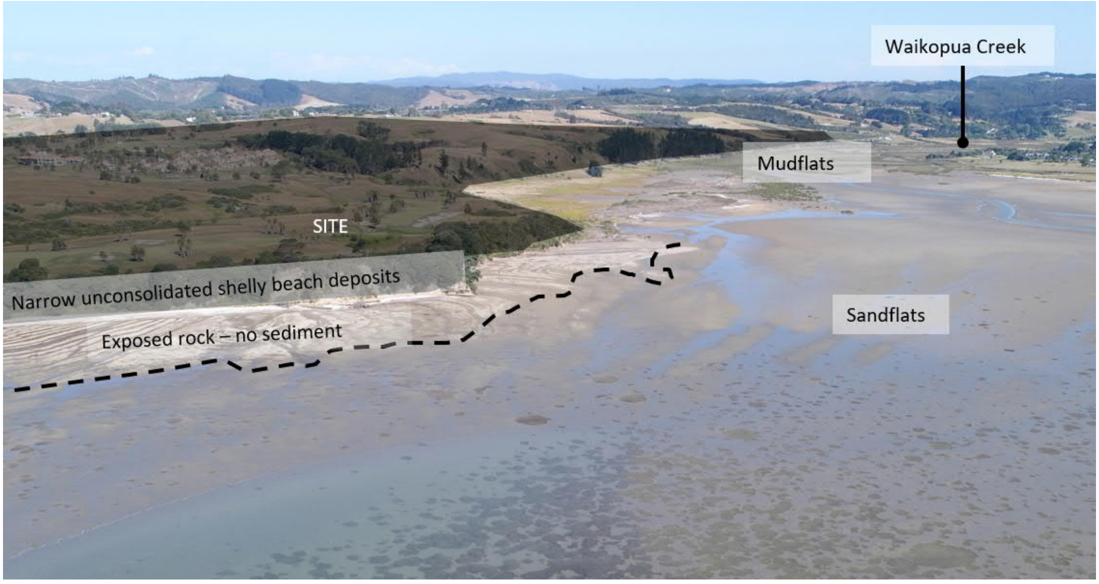

Figure 2-15 Broad characterisation of sediments within the CMA

2.8.2.1 Unconsolidated beach deposits

The northern section of coastline is protected by an accretionary sand and shell spit, primarily consisting of calcium carbonate (shell) overlying fine sand (Figure 2-16), which is typical of sheltered estuarine sites within the inner Hauraki Gulf (Klinac, 2002). Mudstone flats extend seaward from the beach toe. South of the headlands, muddy fine sand is more abundant, with some shell deposits forming ridges in front of the vegetated shoreline (Figure 2-17).

Figure 2-16: Beach section north of headland

Figure 2-17: Chenier ridge seaward of salt marsh south of headlands

2.8.2.2 Mudflat and sandflat areas

Grading distributions published in Gibbs and Hewitt (2004) show distinctive spatial patterns in silt/clay content (Figure 2-18) , and usefully links this information to terrigenous sediments discussed in 2.8.1.

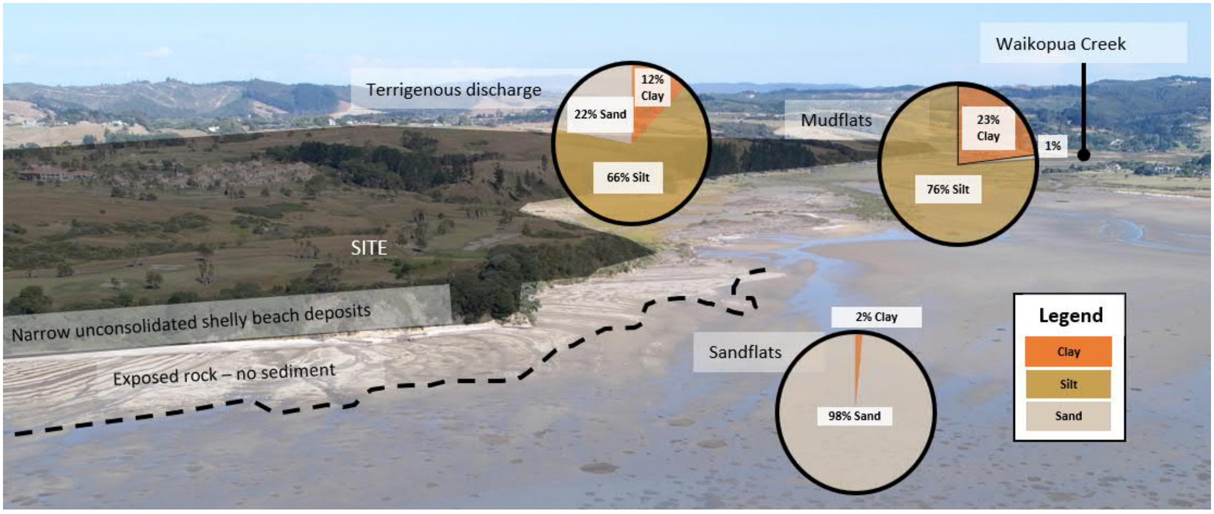

Figure 2-18 Sediment fractions in terrigenous, mudflat and sandflat sediments within the Whitford embayment, based on data from TP264

Auckland Regional Council (Norkko et al., 2002) undertook more widespread sampling throughout the Whitford embayment to characterise sediment types and spatial distribution as indicated in Figure 2-19. From this figure the following key observations are made:

- Sediment has higher silt and clay contents (typically >25%) in sheltered tributaries such as the Waikopua Creek to the south of the site.

- Sediment in exposed intertidal areas has a comparatively lower silt and clay content (typically < 10%). A sharp contrast in silt content is apparent in Figure 2-19 in the location of discharge C, with sandier intertidal areas north, and siltier intertidal areas upstream to the south.
- In subtidal areas, silt and clay content increases with increasing water depth to a maximum value of around 70% on the western side of the Whitford Embayment. Analysis of seabed samples just outside the entrance to the Whitford Embayment (northern extent of Figure 2-19) by Auckland Regional Council (Swales et al., 2002) indicates approximately 4 mm/y of sediment accumulation since the 1950's.

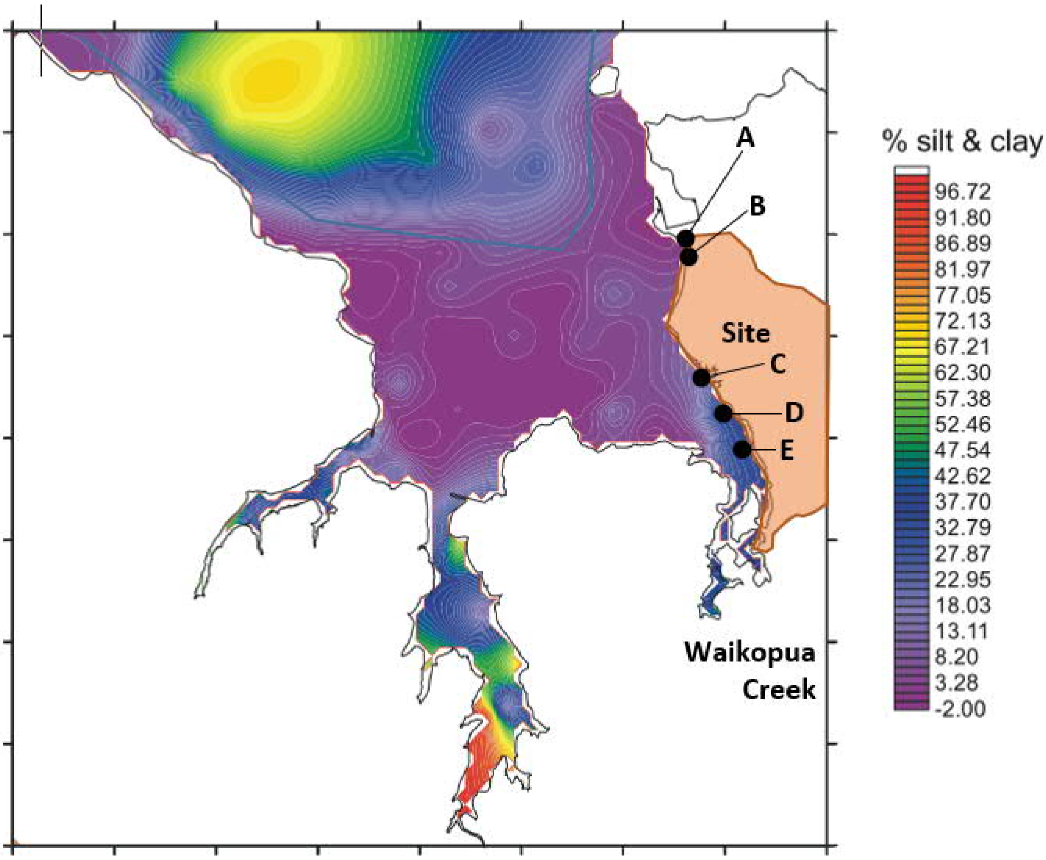

Figure 2-19 Auckland Regional Council (Reproduced from Norkko et al., 2002) sampling throughout the Whitford embayment to characterise sediment types and spatial distribution, with stream location annotations

Monitoring by Ellis et al. (2004) over a period of 7 months within upper intertidal areas indicates sedimentation rates of 0 mm/y in the vicinity of Stream D and between 0 and 2.6 mm/y in the vicinity of Stream E. These are lower rates than those expected in an area with comparatively high silt and clay content shown in Figure 2-19, and may reflect the relatively short duration of monitoring (less than 1 year). More recent ecological sampling undertaken by Hewitt & Calder (2020) opposite Stream C also indicates higher sedimentation in these areas inferred qualitatively from changes in macrofauna ecology (more than the 0 mm/y reported by Ellis et al.(2004). This is consistent with progressive encroachment of mangroves in the vicinity of Stream C shown in Figure 2-20 that is likely to be more informative regarding longer-term Sediment Accumulation Rates (SAR).

For the purposes of this assessment, we have assumed a general 3 mm/y SAR for all discharge areas (C, D and E) within the Waikopua Creek, which represents the upper bound estimate calculated by Ellis et al. (2004).

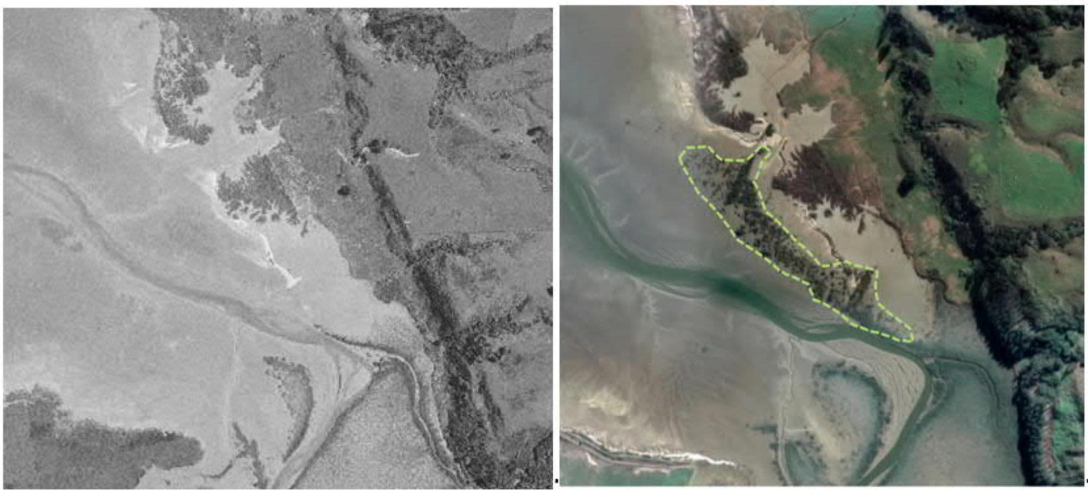

Figure 2-20 Left photo shows mangrove extent in 1961 (Retrolens, 2021). Right photo shows current-day extent (Auckland Council, 2021c) of mangroves and mangrove expansion in Waikopua Creek (delineated in green dashed polygon).

2.9 Metal concentrations in embayment bed sediments

In situ concentrations of zinc and copper in the surface mixed layer of the bed sediments were obtained by T+T at three intertidal sampling locations shown Figure 2-21 in February 2021 with values included in Table 2-4. These concentrations are significantly less than the ERC amber threshold concentrations (see Table 1-1) and are considered representative of the equilibrium metals concentration pre-development.

Figure 2-21 Location of Sites 1, 7 and 8 where sediment samples were collected (green dots), black triangles are other T+T monitoring sites and the red dots are Auckland Council monitoring sites

Table 2-4 Pre-development (present-day) in situ metal concentrations in the bed-sediment surface mixed layer

Discharge locations	Survey site	Copper (mg/kg)	Zinc (mg/kg)
A and B	Site 1	1.84	16.5
C	Site 7	1.19	14.1
D and E	Site 8	2.74	19

2.10 Discharges

2.10.1 Event-based TSS and metal loads

Freshwater runoff data was available from Auckland Council's FWMT tool and separately NIWA GLEAMS modelling outputs for the existing case (Appendix B, Table 2-7, Runoff Volume, Baseline).

The FWMT outputs consisted of daily averaged flow for the period 2003 to 2017 based on Virtual Climate Station Network (VCSN) and 2013 land use data. FWMT rainfall records were used to identify a 2.33 ARI 24 hr rainfall event equivalent, with the TSS loads from this event used to validate the TSS load obtained from the GLEAMS[3] modelling for this same level of event. A comparison of the TSS loads obtained from the FWMT and GLEAMS can be reviewed in Appendix C, which showed that the TSS load obtained from the FWMT and the GLEAMS model for a ~2 year ARI 24-hour event was of the same order of magnitude when accounting for differences in catchment area and ARI events.

Based on earthworks controls that include stormwater collection ponds, NIWA developed modified event runoff volumes (Appendix B, Table 2-7, Runoff Volume, Interim). Runoff volumes were disaggregated into time series data for each of the discharge points using GLEAMS modelling (Appendix B, located in Appendix C of this report).

Event-based (i.e., single rainstorm) TSS loads for the existing and earthworks stage were obtained from NIWA GLEAMS modelling (Appendix B, Table 2-7 termed 'Baseline' and 'Treated-interim' respectively, and additionally Figure 1-4 for context). NIWA have regarded total sediment mass being discharged into the embayment from the stream discharges as equivalent mass in TSS with 24-h loads, with this information summarised in Figure 2-22 for a range of design events.

NIWA have disaggregated these loads into time series (10 min) flow rates and TSS concentration information to inform model boundary conditions, used to model freshwater runoff entering the embayment at these times over the duration of particular design level rainfall events.

[3] A field scale model developed to evaluate the impact of management practices on potential pesticide, nutrient leaching, surface runoff and sediment losses from the field (GLEAMS Model : USDA ARS)

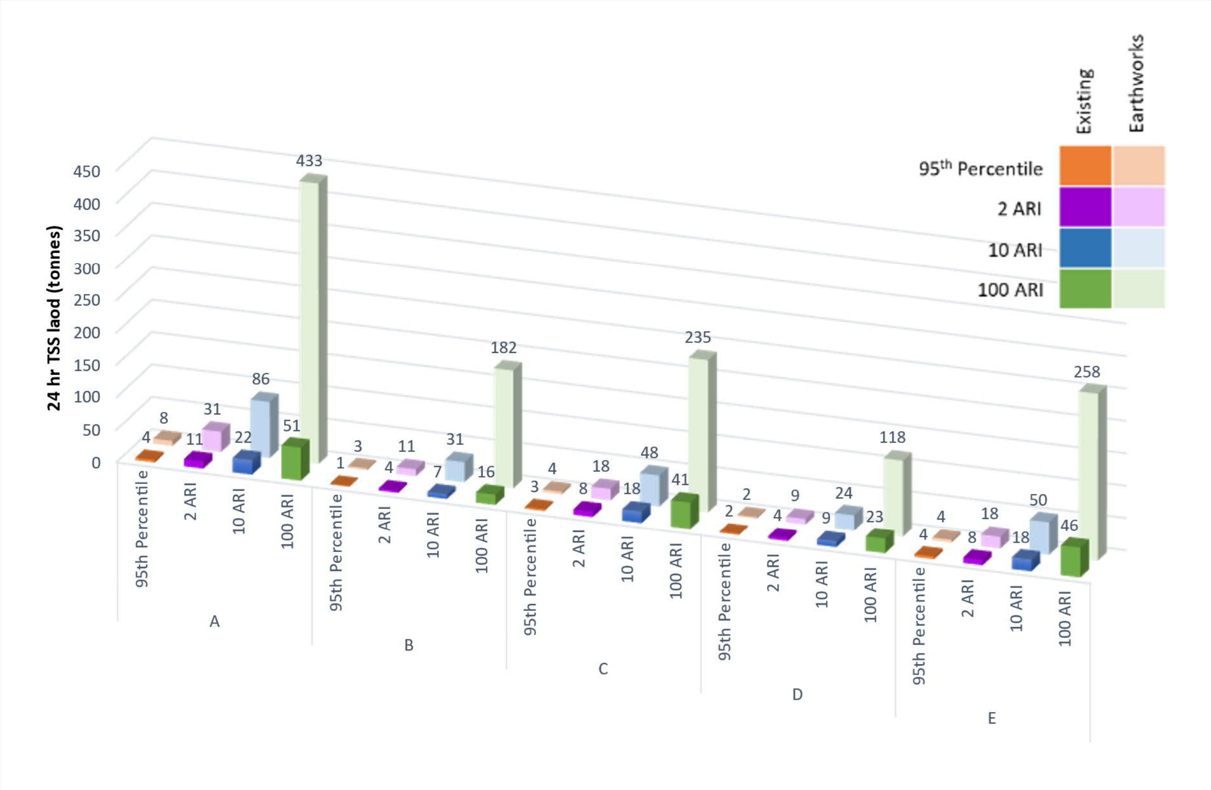

Figure 2-22 24 h TSS loads from each stream outlet for existing baseline and earthworks stages for 95th percentile, 2-y ARI, 10-y ARI and 100-y ARI events.

From Figure 2-22, potential changes in 24 -h TSS (tonnes) from existing to earthworks scenarios for a range of ARI events are in the order of:

- 1 to 2 times[4] for the 95th percentile rainfall event (approximately annual heaviest rainfall event expected).
- 2 to 3 times for the 2-y ARI rainfall event (likely to occur five times within a 10-y development period).
- 3 to 5 times for the 10-y ARI rainfall event (likely to once within a 10-y development period).
- 6 to 14 times for the 100-y ARI rainfall event (10% chance of occurrence within a 10-y development period).

2.10.2 Mean annual sediment and metals loads

Mean annual TSS, zinc and copper loads for the existing and fully developed scenario were provided by NIWA (Appendix B, Tables 3-3, 3-4, 3-5 respectively) and used as inputs for the metal accumulation model in Section 7 and summarised in Figure 2-23.

[4] 1 to 2 times means potential 24 h TSS discharged load (tonnes) during earthworks varies between 100% and 200% of the existing situation, alternatively considered as up to 100% higher than existing, or up to double the load.

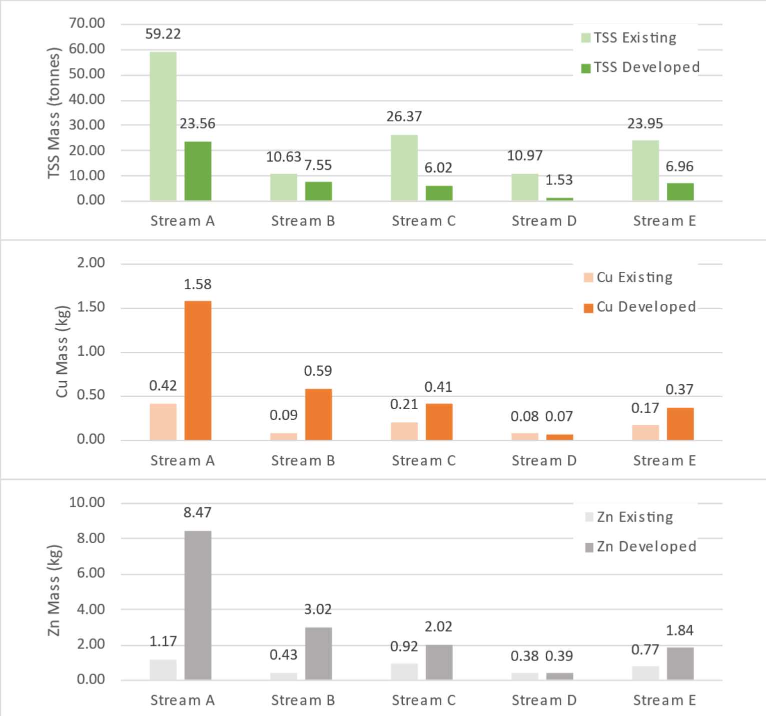

Figure 2-23 Comparison of existing and developed annual mean loads of TSS, Cu and Zn

From mean annual loads in Figure 2-23, the development has the potential to result in:

- Net reduction in TSS mass discharged on an annual basis, approximately equating to an overall 64% reduction[5].
- Net increase in Cu mass discharged on an annual basis, approximately equating to 3 x increase[6].
- Net increase in Zn mass discharged on an annual basis, approximately equating to a 4 x increase by mass.

NIWA produced two sets of numbers that either make no allowance for wetlands ('No wetlands') or assumes that all water falling on impervious surfaces are treated (Wetlands). These will provide maximum and minimum estimates for the mean annual loads of TSS, Zn and Cu under the fully developed scenario, with the most likely scenario resulting in discharges that sit somewhere between these conditions. Values used in our assessment conservatively use 'No-wetlands' figures (i.e., no allowance has been made for wetland treatment in these discharges.)

The fate of metals is inextricably linked to the fate of TSS because of the inorganic sorption phenomena of metals onto sediment that has been widely observed (Chapra, 2008) - so the ratio of metals to TSS was a particularly important input to the accumulation model. The ratios were calculated from the TSS and metals discharge loads provided by NIWA for the various discharge locations. We note that discharge flows from H+G for the existing case were not modified by NIWA to reflect attenuating effects of erosion and sediment control under the earthworks stage, or stormwater infrastructure and water quality devices under the developed stage. These assumptions amongst others are discussed separately in related NIWA reporting (Appendix B).

[5] For example the 59 tonnes of average annual TSS sediment discharged from Stream A could experience a 59% reduction, becoming 24 tonnes as shown in Figure 2-23.
[6] For example the 0.42 tonnes of average annual Cu discharged from Stream A could experience a 3.8 x increase, becoming 1.6 tonnes as shown in Figure 2-23.

3 Hydrodynamic and sediment-transport models

3.1 Overview

As outlined in Figure 3-1, at the top of the model hierarchy is NIWA's regional hydrodynamic model of the Hauraki Gulf. This simulates tidal currents, water levels, salinity and temperature driven by boundary water levels, temperature, salinity and atmospheric coupling in coarse detail over the Hauraki Gulf (wind and atmospheric pressure). This information is not sufficient to inform sediment transport within the Whitford Embayment, which has required T+T to develop a more detailed nested model that simulates hydrodynamics at a higher resolution to undertake this assessment.

The more detailed T+T nested hydrodynamic model takes coarse water level, temperature, salinity and wind speeds from the regional model to simulate currents at its seaward boundary. These are then propagated into the nested model and simulated at a much finer spatial scale to resolve important detail near the site, including the dispersal and mixing of freshwater runoff into the embayment. Waves are superimposed on the nested hydrodynamics by the wave model, which is driven by winds, including sequences of winds, which simulate the passing of different types of weather systems.

The Whitford Embayment sediment transport model simulates dispersal of terrigenous sediment discharged into the embayment by the creeks in Figure 1-1. For this, it uses the currents simulated by the nested hydro model, including the way freshwater is mixed and dispersed, and the waves simulated by the wave model. Sediment is carried by the freshwater runoff, and once it enters the embayment it is dispersed by the tidal and wind-driven currents, settles to the bed under gravity, and may be re-eroded from the bed by waves and currents. Ultimately, the sediments settle on the bed, remain suspended in the water column, or are transported out of the model domain. The results are analysed to determine deposition thicknesses and so on, from which ecological effects can be inferred.

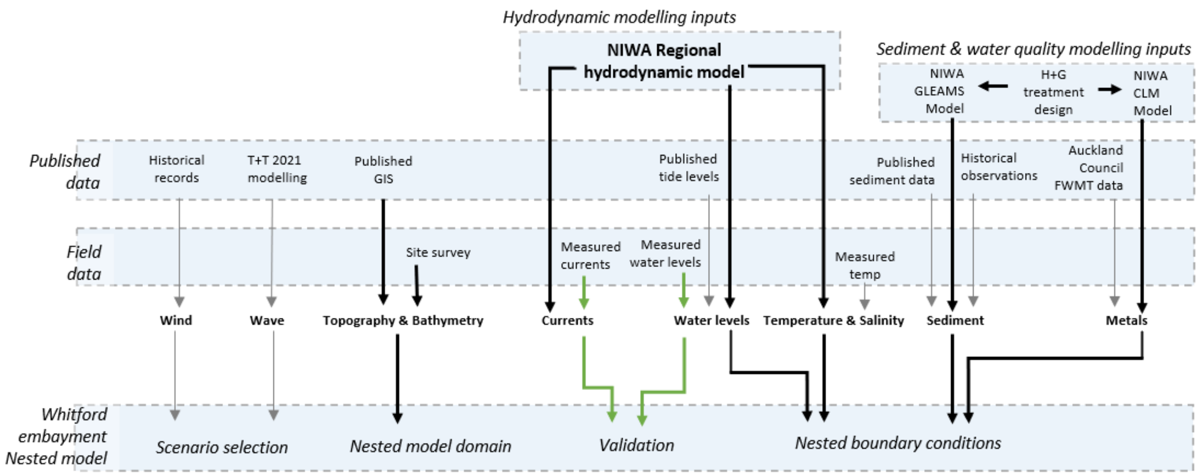

Figure 3-1 Modelling overview

3.2 Regional hydrodynamic model (NIWA)

NIWA's Delft3D model of the area shown in Figure 3-2 is used to inform boundary conditions for the nested model of the Whitford Embayment.

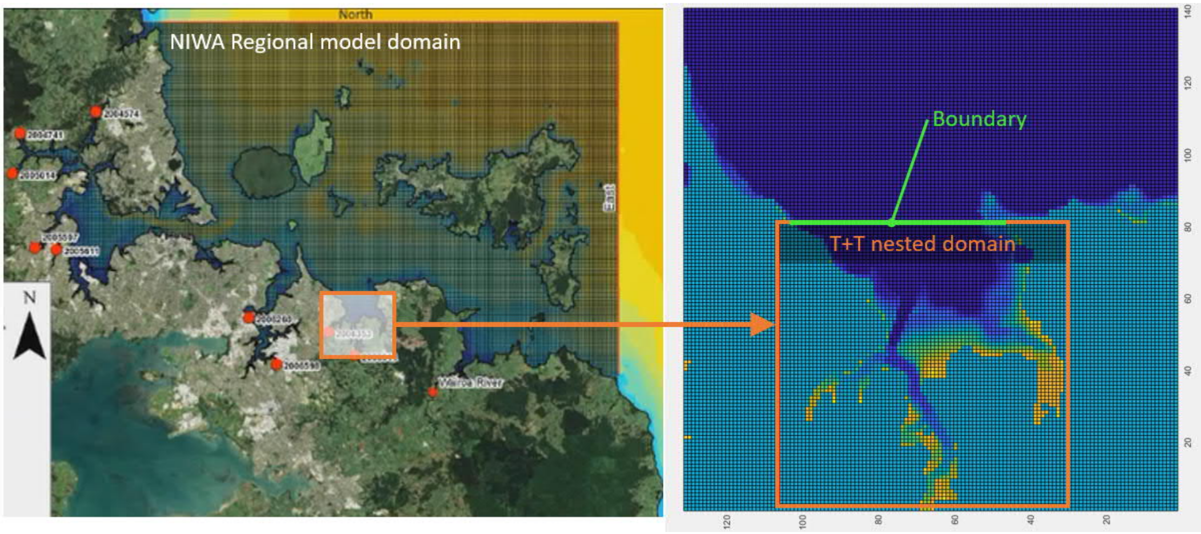

Figure 3-2 NIWA regional model domain with Black lines representing 78 m model mesh and the red dots showing the location of the freshwater sources.

NIWA have developed a Delft3D model (WETS Tamaki Strait Model) over the area shown in Figure 3-2, comprising a 78 m x 78 m rectilinear grid, containing 15 sigma layers. This hydrodynamic model considers temperature, salinity and wind. Temperature and salinity at the northern boundary are informed from the Global HYCOM ocean model. The NIWA model does not take into account of salinity changes at the eastern boundary due to large freshwater inputs from the Firth of Thames (Waihou and Piako Rivers). The regional model includes spatially varying winds, atmospheric pressure and precipitation. These values are informed from a combination of NIWA's NZCSM 1.5 km weather model and a higher resolution 0.333 km grid Auckland model. Because the 0.333 km Auckland model does not cover the full regional model grid, some interpolation between the 1.5 km and 0.333 km model occurs near the north and western model boundaries. The regional model also includes an atmospheric–ocean coupling model, which includes humidity, cloud cover, temperature and incoming solar radiation. These values are spatially constant but varying in time and are informed from a central Tamaki Strait location extracted from the NZCSM 1.5 km weather model. The regional model contains freshwater inputs from eight locations from around Waitemata Harbour and Tamaki Strait (red dots in Figure 3-2); these values are extracted from NIWA's TOPNET catchment forecasting model.

The regional model simulates freshwater discharges into the embayment from the Mangemangeroa and Turanga Creeks, but not the Waikopua. Wind fields over a 0.333 square kilometre grid are used to model wind-driven currents. Waves are forced at the boundary of the regional model by NIWA's RICOM storm surge model and 2 km NZWAVE model. Because the wave model runs uncoupled from the hydrodynamic model, it does not take into account currents and density driven flows from the Deflt3D regional model. The Delft3D Regional model (Tamaki Hydrodynamic) and Swan wave model (Tamaki Wave model) share the same high resolution 333 m Auckland Weather model wind fields.

3.3 Nested Whitford Embayment hydrodynamic model (T+T)

3.3.1 Extent

T+T's nested Whitford Embayment hydrodynamic model comprises a 10 m x 10 m rectilinear grid and 3 sigma layers of equal thickness. The primary reasons for layering are to allow for discharge of sediments suspended in freshwater runoff into the surface layer of the receiving environment and also allow for varying sediment concentrations with elevation in the water column.

3.3.2 Bathymetry

Topographic and bathymetric information from sources listed in Table 3-1 has been used to develop the model bathymetry (hierarchic order based on data quality, highest to lowest).

Table 3-1 Bathymetric sources

Source	Date	Hierarchical order	Projection	Datum	Adjustments
Auckland Council Lidar	2016 - 2017	1	NZTM GD2000	AVD46	Subtracted 1.743 m
LINZ hydrographic survey 1:90 – 1:350K	2020	2	NZTM GD2000	Auckland Chart Datum	Nil
Single beam echo-sounder	2021	3	NZTM GD2000	Sea level	Corrected to CD using locally collected time varying water levels

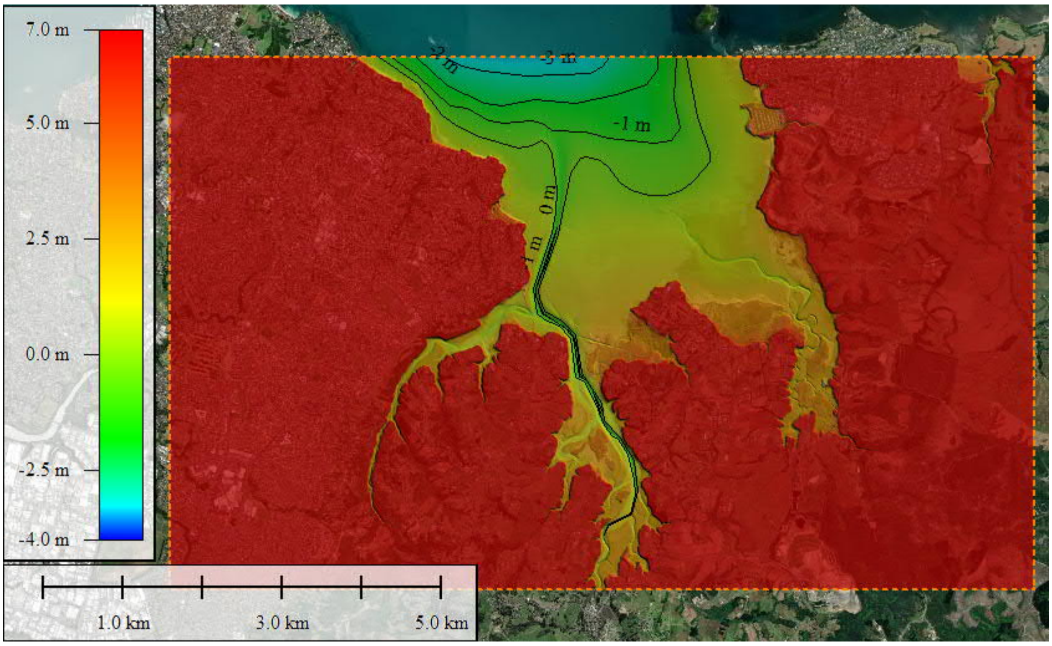

Figure 3-3: Bathymetric LiDAR and bathymetric survey maps including cross-section and average difference

3.3.3 Boundary conditions

As indicated in Figure 3-4, the nested model domain has a seaward northern boundary. No other boundaries have been applied.

3.3.3.1 Water levels

NIWA regional model water levels at an approximate midpoint along the nested boundary in Figure 3-4 (-36.8828, 174.9560) are representative of water levels overall along this boundary, with opposite ends typically fluctuating +/- 5 mm and occasionally as high as +/- 15 mm relative to the midpoint. Considering the approximate 4 km length of the nested boundary and the minimal impact of this water level difference to the hydrodynamics, water levels from the NIWA regional model at the single midpoint location were used to define uniform water levels along the nested boundary.

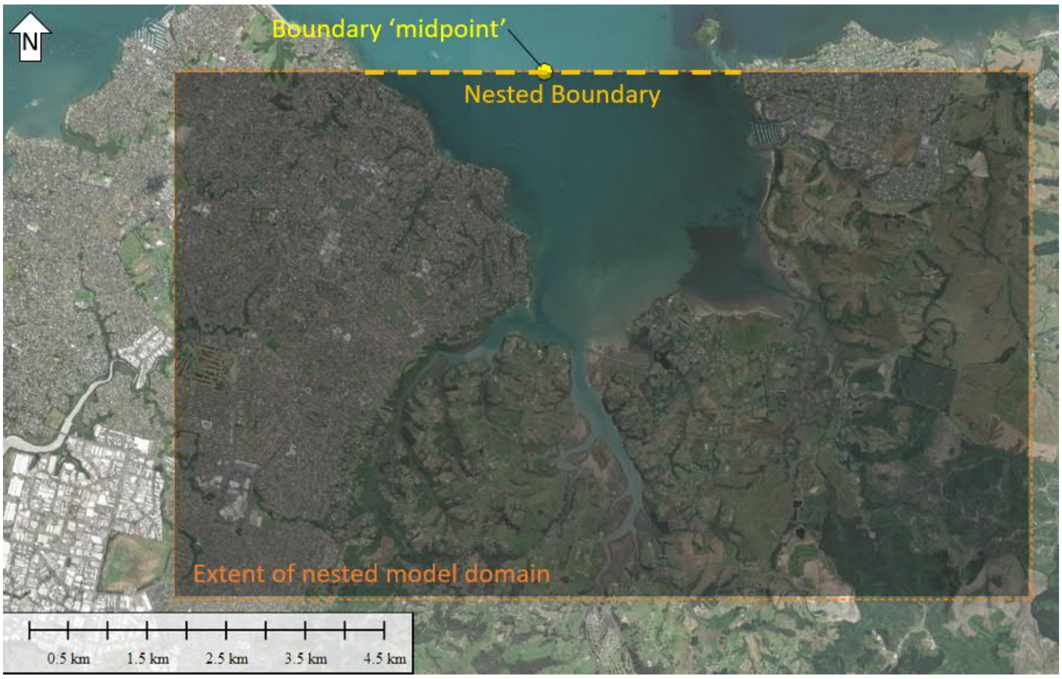

Figure 3-4 Extent of nested model domain

3.3.3.2 Temperature and salinity

Representative temperature and salinity profiles from NIWA's regional model at the midpoint in Figure 3-5 are shown as a function of z/h, where z is elevation above the bed and h is the water depth.

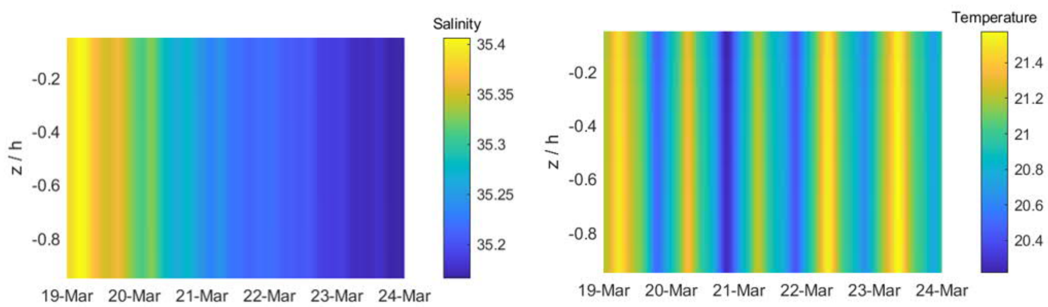

Figure 3-5 Temperature (C°) and salinity (ppt) information as a function of z/h

Figure 3-5 indicates a uniformly mixed water column (no significant stratification) and slow and small fluctuations in salinity (about one week period and typically less than 1 ppt magnitude – parts per thousand). Daily temperature cycles (maximum during the day and minimum during the night) are observed.

ADCP data show no appreciable difference in flow velocities between layers that might arise from density contrasts associated with temperature and salinity stratification (Speight, 2018).

Given that temperature, salinity and current-velocity profiles are typically uniform, we have elected to use regional-model depth-averaged values from the midpoint in Figure 3-4 to inform the nested model boundary conditions.

From Figure 3-6, visual comparison of measured temperatures at the location of the ADCP and adopted model boundary values demonstrate a good fit with respect to daily fluctuations and overall values.

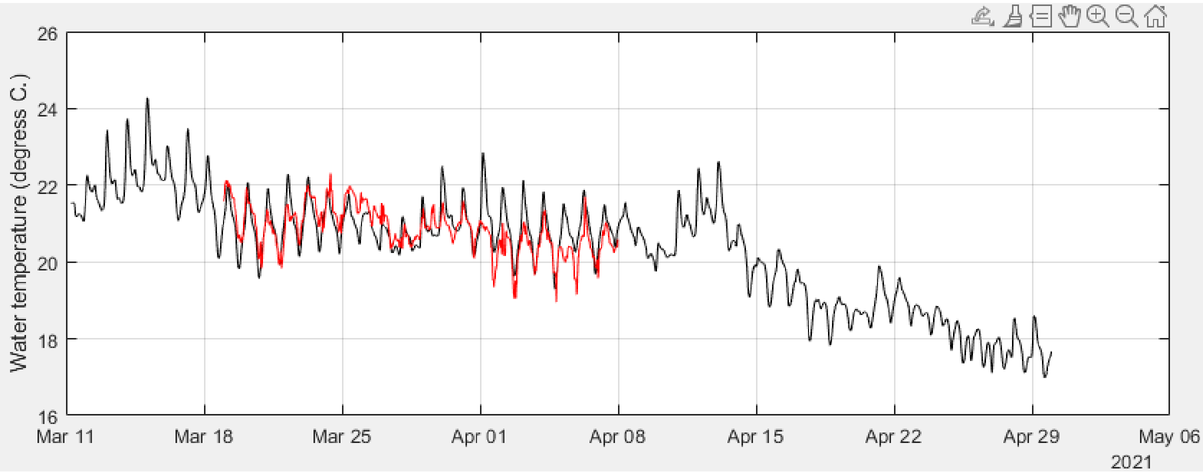

Figure 3-6 Comparison between measured temperatures in the location of the ADCP and modelled boundary values (red line indicates measured values, black line shows adopted boundary values)

3.3.4 Model parameters

The parameters in Table 3-2 were used in the nested hydrodynamic model. With the exception of the time step, these are all default values.

Table 3-2 Parameters used in the nested hydrodynamic model

Parameter	Value
Water density	1024 kg/m^3
Chèzy friction coefficient	65 $m^{1/2}/s$
Horizontal eddy viscosity(m^2/s)	1 m^2/s
Horizontal eddy diffusivity (m^2/s)	10 m^2/s
Smoothing time	60 min
Advection scheme for momentum	cyclic
Computational timestep	0.1 min[1]

[1]-Deltares (2021) suggest to generally adopt a Courant-Friedrichs-Lewy (CFL) number of less than 5.7 to acquire a stable model run for sediment transport. Accordingly, a time step of 0.1 min was adopted for all sediment transport modelling and/or wave modelling to generally achieve suitably low CFL numbers

3.3.5 Wind field

Wind direction and speed over the modelling period of March and April 2021 have been provided by NIWA from the Auckland 0.333 km model (also applied in the NIWA regional model). Time series of wind speed and direction have been extracted from an approximate mid-point within the embayment (174.9465, -36.8909), which is considered representative of the wider embayment and applied as a uniform wind field over the nested model domain.

Additional wind fields have been applied in selected cases to better understand effects of wind on hydrodynamics and sediment transport (discussed in Section 4.4).

3.3.6 Hydrodynamic model performance

Figure 10-9 and Figure 10-10 (Appendix D) provide a visual comparison between modelled and measured water levels, depth-averaged currents, and current direction at the location of the ADCP. Figure 10-11 and Figure 10-12 provide a more quantitative comparison of modelled and measured hydrodynamics at the location of the ADCP.

3.3.6.1 Currents

At the location of the ADCP, it is apparent from Figure 10-11 that current speeds were over-predicted more often than under-predicted. A Root Mean Square Error (RMSE) of 0.03 m/s, amounting to approximately 15% of the largest measured current speed, is considered adequate for the purposes of this model. Figure 10-12 indicates that the model reproduces the north-south component of the current velocity considerably more accurately than it does the east-west component. Figure 10-7 in Appendix D shows typical peak ebb and flood Depth Averaged Velocities (DAV) across the model domain, indicating highest DAV in the vicinity of Mangemangeroa and Waikopua channels.

3.3.6.2 Water levels

At the location of the ADCP, it is apparent from Figure 10-11 that over-prediction and under-prediction of water level were reasonably balanced. RMSE of 86 mm calculated at this location amounts to approximately 6% of the mean tidal range.

3.4 Wave model (T+T)

Waves are superimposed on the nested hydrodynamics by the wave model, which is driven by winds, including sequences of winds, which simulate the passing of different types of weather system. This section describes the wave model and its input parameters.

3.4.1 SWAN wave model

SWAN (version 40.01) is a third-generation wave model that computes random, short-crested wind-generated waves in coastal regions and inland waters. The SWAN model accommodates the processes of wind generation, white capping, bottom friction, quadruplet wave-wave interactions, triad wave-wave interactions and depth-induced breaking (Ris & Booij, 1999).

3.4.2 Model extent and bathymetry

To simulate local wind wave generation in circumstances where wind waves would not be expected to enter the northern embayment entrance, the SWAN model implemented on the nested model domain shown in Section 3.3.1 has been used.

For northerly wind waves, a separate SWAN model covering an extended domain including an additional 10 km of fetch to the north beyond the nested model domain has been used. Wave heights from the midpoint in Figure 3-7 have been used as a boundary condition to the nested model. The same wind speeds used to generate wind waves on the extended model domain were used on the nested Whitford Embayment hydrodynamic model.

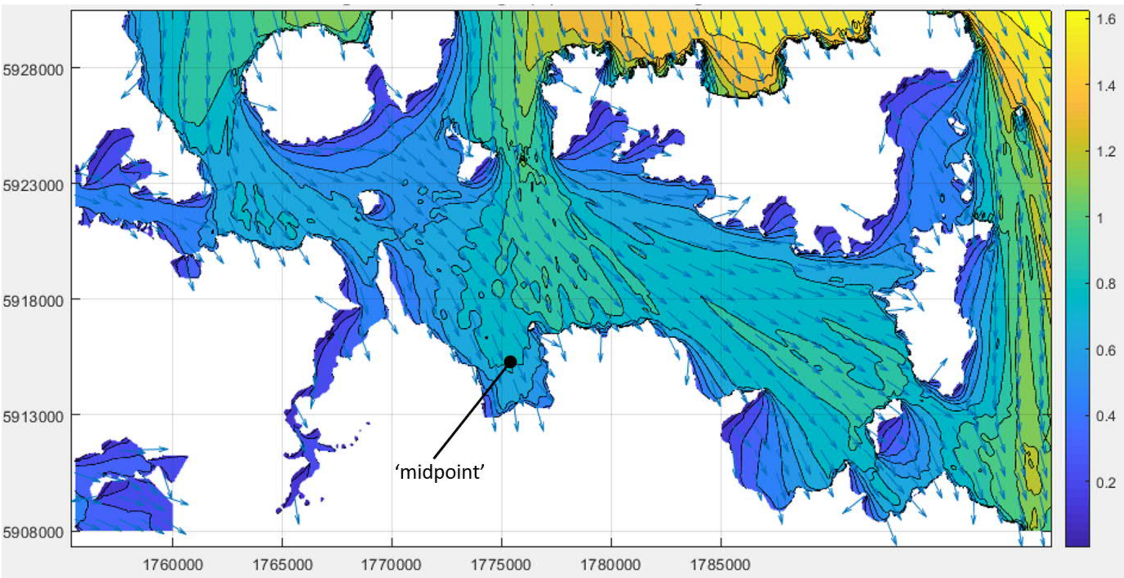

Figure 3-7 Extended model domain

3.4.3 Wave parameters

Spectral space was defined at 10-degree direction bins and 31 logarithmically spaced frequency bins ranging between 3 Hz to 0.05 Hz (i.e., 0.33 to 20 second periods). The representation of wave energy at the seabed is based on the JONSWAP form (Hasselmann et al., 1973), with a default friction coefficient $C_{bottom} = 0.067\ m^2s^{-3}$. Following Komen et al. (1984) the default dissipation coefficient was assigned the value $C_{ds} = 2.36 \cdot 10^{-5}$. Wave heights calculated by empirical means (Goda,2003) had similar periods and significant wave heights within 15% of SWAN model values.

3.5 Sediment transport model (T+T)

The sediment transport model simulates the dispersal, resuspension, transport and deposition of cohesive particulate material. Indicative values for key parameters were initially assessed from published literature, where possible supported with laboratory testing information. Sensitivity of these parameters to model results were established through model re-analysis, informed where possible from observations discussed in Section 2.8.1 and our broader understanding of the coastal setting. This section discusses the selection of key model parameters.

3.5.1 Settling velocity

Settling velocity is the terminal velocity of a particle in still fluid. In cohesive materials, settling velocities can vary significantly depending on flocculation and particle concentration. Flocculation (described in 2.8.1) results in a materially less dense sediment with a lower settling velocity compared to the individual particles that make up the flocs (or aggregates). Higher concentrations of sediment in suspension restrict and slow the overall settling velocity. Figure 3-8, reproduced from (Van Rijn & Barth, 2018), shows these two associated effects in a wide range of cohesive materials. This indicates settling velocity for cohesive sediments ranging between 0.02 mm/s and 2 mm/s.

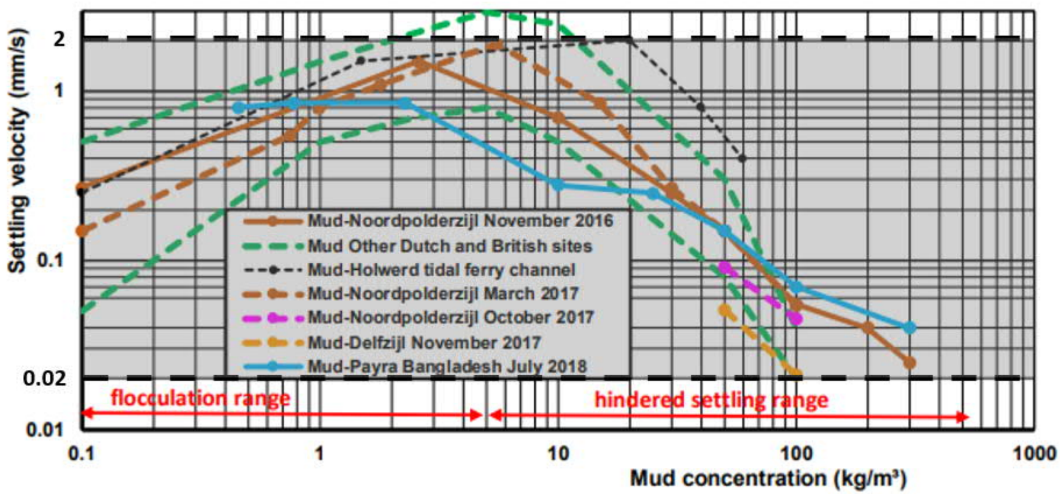

Figure 3-8 Flocculation and hindered settling

Oldman & Swales (1999) used a value of 2 mm/s for settling velocity to study sediment transport within the Mangemangeroa Stream on the southwestern side of the Whitford Embayment (opposite from the site). In the absence of relatable field information, this estimate was based upon the work of Gibbs et al. (1971), which was subsequently shown to be limited in application allowing for natural material densities other than glass beads used in the 1971 experiments (Roux, 1992 & Graf, 1971).

More recent guidance from Whitehouse et al. (2000) recommends using a settling velocity of 1 mm/s for cohesive materials in the absence of specific test data, informed by sensitivity analysis and observed patterns of deposition.

Pritchard (2016) used a bottom withdrawal tube to estimate settling velocity of sediments from Mangere Inlet comprising ~80% clay and silt, which is a similar texture to the Whitford terrigenous sediments. The median settling velocity was 0.2 mm/s, consistent with the lower value of the range of settling velocities presented by Van Rijn & Barth (2018).

As recommended by Whitehouse et al. (2000), sensitivity of the model predictions to variations in settling velocity has been undertaken. Figure 3-9 presents three values: left (2 mm/s), centre (0.7mm/s) and right (0.2 mm/s). True variations in this parameter are likely to occur within a tide cycle due to flocculation, hindered settling, and small variations in terrigenous sediment composition.

Based on a visual comparison, the settling velocity of 0.7 mm/s appears to produce a dispersal pattern that is most consistent with the pattern shown in Figure 2-13. This value also strikes a balance between conservative empirical guidance in the absence of test data and the comparatively much lower values obtained from laboratory testing in similar materials by Pritchard (2016).

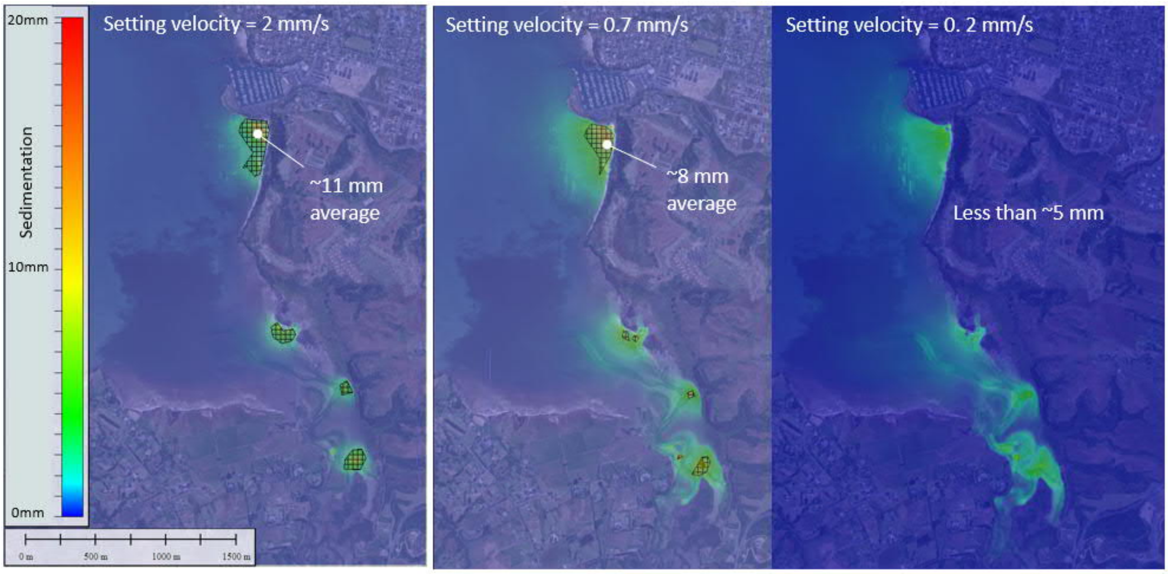

Figure 3-9 Sensitivity of settling velocity parameters based on high spring tide condition

3.5.2 Critical shear stress for erosion and for sedimentation

Critical bed shear stress for erosion is the minimum bed shear stress required to initiate erosion of bed sediment. The critical bed shear stress for sedimentation is the minimum bed shear stress at which sedimentation is no longer possible.

Van Rijn's (2020) literature review suggests that the critical bed shear stress for erosion lies between 0.1 N/m^2 and 1 N/m^2 depending on the level of sediment consolidation, percentage of material with particle diameter less than 63 µm and the dry bulk density of the mud-sand mixture. Whitehouse et al. (2000) suggests the critical bed shear stress for sedimentation can be taken as half the critical bed shear stress for erosion. Based on guidance in Whitehouse et al. (2000), values of 0.25 N/m^2 and 0.125 N/m^2 for erosion and sedimentation, respectively, were used by Pritchard (2016) in the Mangere Inlet study.

Parameters used to model re-erosion by waves

Bed stresses during the NW event are expected to be high and capable of disturbing cohesive sediment previously deposited over the comparatively sandy intertidal area opposite discharges A and B. A sensitivity analysis was undertaken for this event using erosion thresholds of 0.2 and 0.4 N/m^2. Modelling of re-erosion using an erosion threshold of 0.4 N/m^2 indicated less than 0.1 mm (maximum) re-erosion over a high tide cycle (image left of Figure 3-10). Given that extreme wave heights in this setting from rare NW events are expected to result in the highest rates of re-erosion in these areas, a 0.1 mm re-erosion rate would appear to underestimate the observable effects of such an event. To model more realistic sediment resuspension during a severe NW wind event in exposed intertidal areas (where typically low silt is apparent), a critical shear stress for erosion was of 0.2 N/m^2 was used for modelling resulting in up to 1 mm of deposition re-erosion over a single high tide (image right of Figure 3-10).

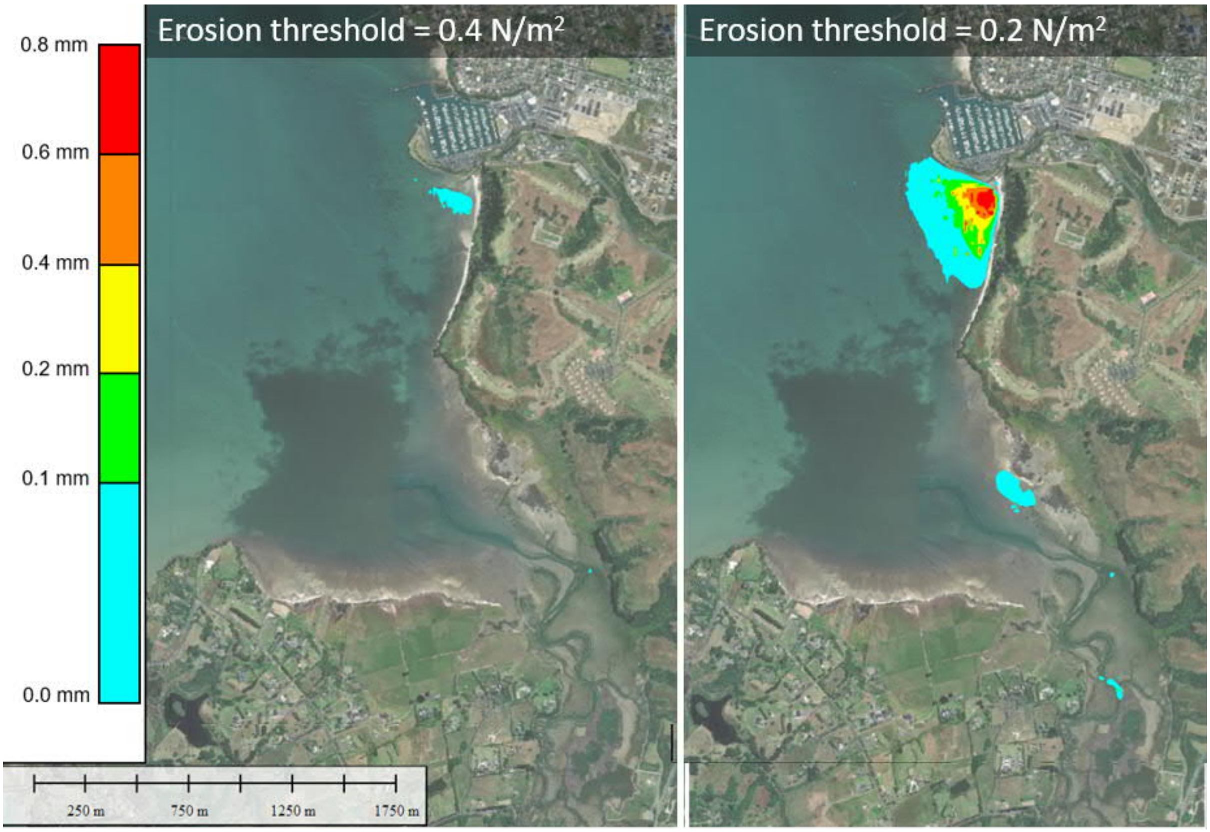

Figure 3-10 Re-erosion rates over a single high tide for a NW event, following a spring high tide deposition, in relation to 0.4 N/m^2 and 0.2 N/m^2 erosion thresholds in image left and image right respectively

Parameters used to model deposition immediately following discharge (before waves)

A sensitivity analysis was undertaken to understand critical sedimentation thresholds of 0.1 and 0.2 N/m^2 on deposition thickness as shown in Figure 3-11. This modelling indicates the deposition thickness as being particularly sensitive to the value used for the critical bed shear stress for sedimentation. Increasing this from 0.1 to 0.2 N/m^2 increases deposition thickness by as much as 30%.

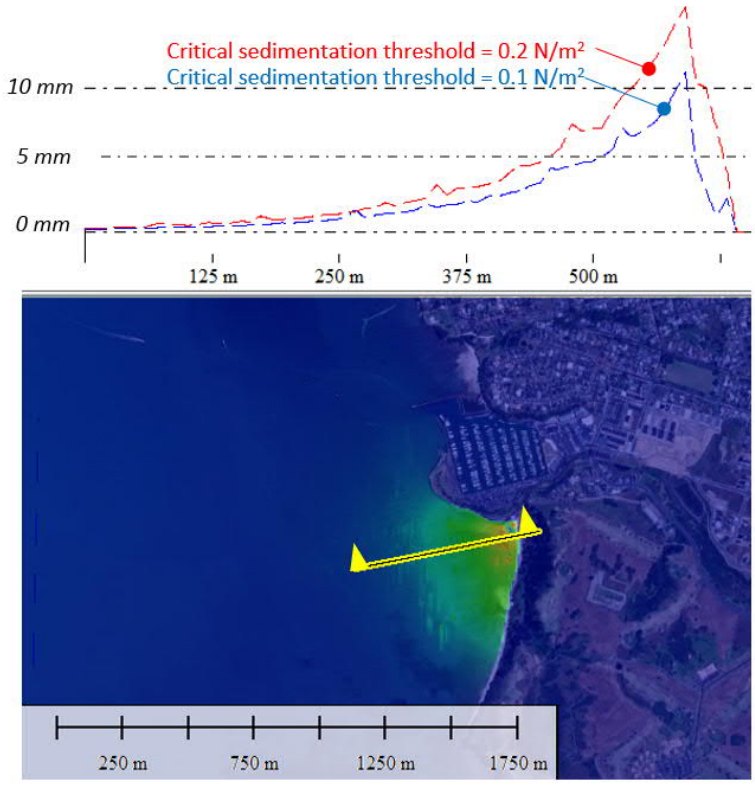

Figure 3-11 Sensitivity of modelled deposition thickness to critical bed shear stress for sedimentation

Approach

Sensitivity analysis performed on critical erosion thresholds in circumstances where significant re-erosion is very likely (severe NW event discussed in Section 4.4), indicates 0.2 N/m^2 as being the most credible parameter in conjunction with published guidance and related testing. Guidance from Whitehouse et al., (2000) recommends a sedimentation threshold half of this value. Noting the sensitivity of the sedimentation threshold to deposition thickness, a conservative sedimentation threshold of 0.2 N/m^2 was used to model initial deposition thickness. Separate model runs were then used to model re-erosion using a more credible erosion threshold of 0.2 N/m^2 .

3.5.3 Summary of model parameters used

Table 3-3 provides a summary of the values used to parameterise the sediment transport model and includes ranges for sensitivity testing.

Table 3-3 Summary of values used to parameterise the sediment transport model

Parameter	Adopted Value	Sensitivity test lower bound	Sensitivity test upper bound
Settling velocity (mm/s)	0.7	0.2	0.2
Critical bed shear stress for sedimentation (N/m^2)	0.2[1]	0.1	0.2
Critical bed shear stress for erosion (N/m^2)	0.2[2]	0.2	0.4
Specific density (kg/m^3)	2650[3]	1600	-
Dry bed density (kg/m^3)	1600[3]	400	-
Reference density for hindered settling (kg/m^3)	700[3]	-	-
Erosion parameter ($kg/m^2/s$)	0.0001[3]	-	-
Advection scheme for transport	cyclic	-	-
Layer discharge	Top layer k = 1[4]	Top layer k = 1	All layers k = 0

1 – For deposition period during and immediately following discharge (before waves added), this value taken as 0.1 to ensure conservative sedimentation thickness.

1 – For wind wave erosion (i.e., after deposition) and higher value of 0.4 was used to ensure conservative

2 – Default Delft3d values

3 - Discharges at model boundaries are applied only to the top (k =1) layer, comprising the top third of the water depth to better replicate effects of this discharge having a lower relative density to that of the receiving environment (freshwater flowing into salt).

4 Sediment transport patterns

This section describes a variety of factors that influence sediment transport patterns in the Whitford Embayment. This will inform the model scenarios discussed in Section 5.

4.1 Effects of tidal stage on sediment transport

Patterns in dispersal of terrigenous sediment discharged in freshwater runoff are shown in Figure 4-1 for discharges at different stages of the tide.

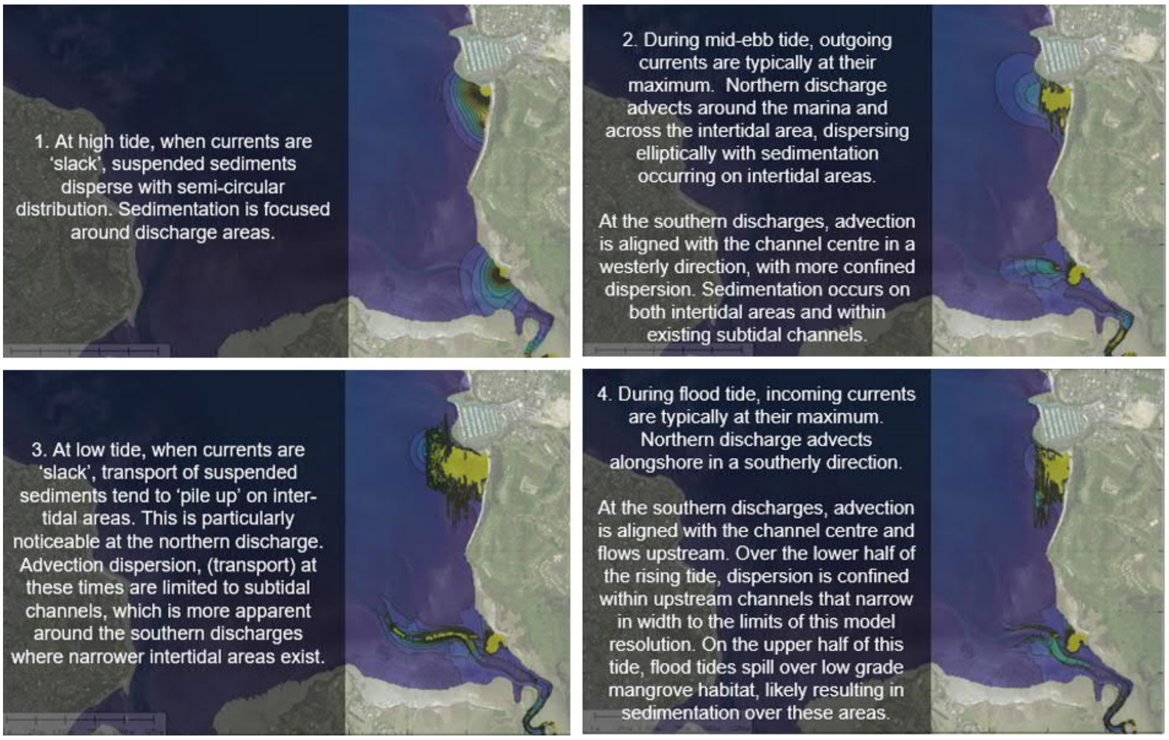

Figure 4-1 Patterns of sediment dispersal for discharges at different stages of tide

Stormwater during rainstorms typically discharges most of its particulate load over just a few hours at peak flow. Figure 4-2 shows patterns of sediment deposition for peak discharge coinciding with different stages of the tide.

At streams A and B, sediment deposition is thickest when peak discharge occurs at high tide, at which time water levels change slowly, resulting in a more focused deposition area close to the high-tide shoreline. When peak discharge occurs at other stages of the tide, deposition is thinner, but spread over larger areas. Subsequent re-erosion of this material by wind waves is discussed in Section 4.4. Longer-term transport of this material into deeper water within the wider embayment is discussed in Section 5.2.

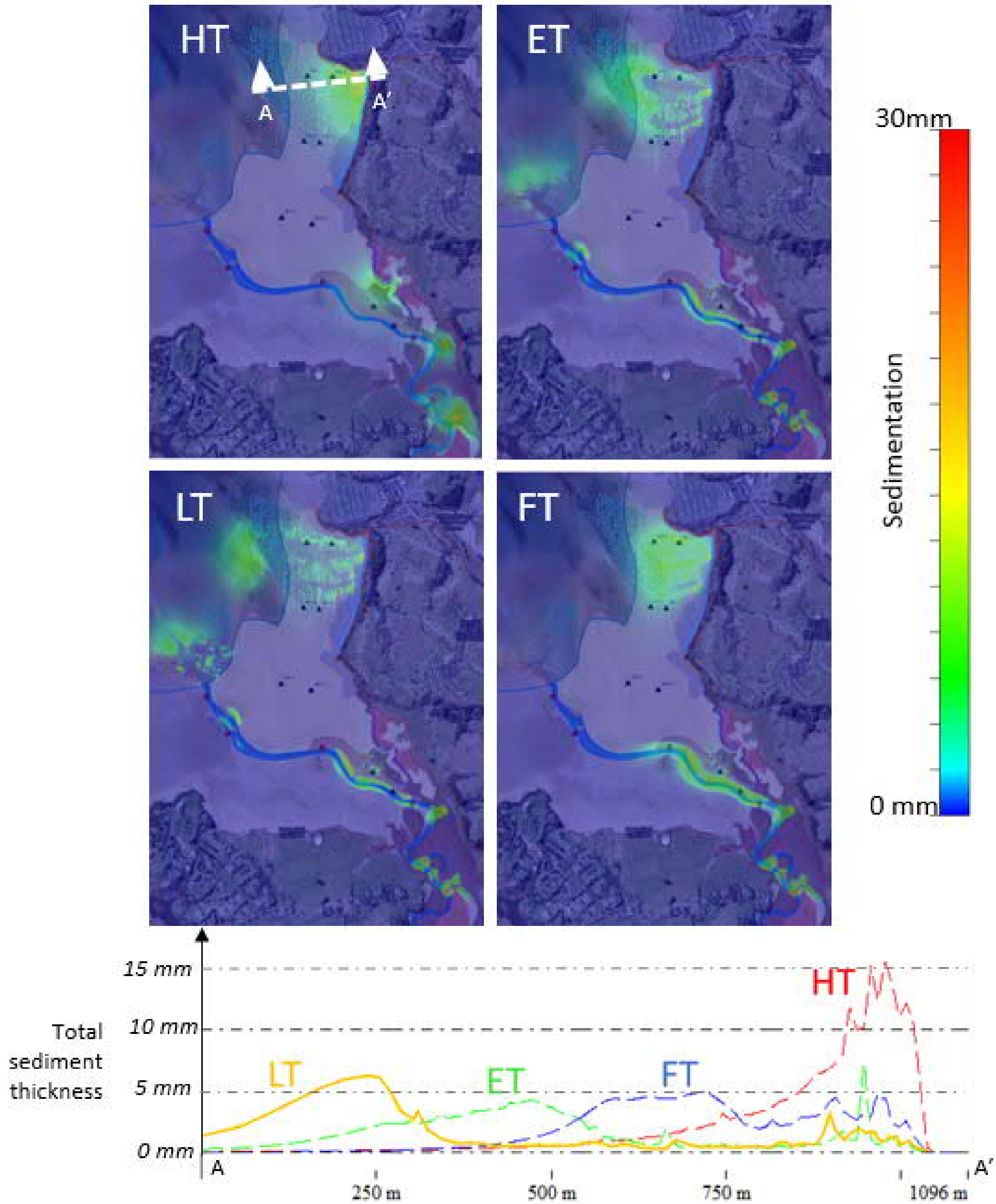

Figure 4-2 Discharge simulations for different tidal stages

For sediment discharged from streams C, D and E, deposition occurred under both neap and spring tide conditions, albeit in different locations. Higher tidal currents over ebb/flood tidal stages enabled a greater spread of discharge material at this time, compared with high tide where reduced currents enabled more focused and smaller deposition areas in the upper inter-tidal vicinity of the discharge points.

4.2 Spring/neap effects on sediment transport

The following two 5-day periods within the monitoring period were used to characterise spring/neap tide effects on sediment dispersal:

- Neap tide 19 March - 23 March 2021, tidal range of ~2 m.
- Spring tide 29 March - 2 April 2021, tidal range of ~3 m.

A 100-y ARI event was discharged over high tide during both the neap and spring periods, with results shown in Figure 4-3.

Under spring tides, deposition occurs across higher ground compared to under neap tides, due to the higher reach of water under the spring tide (about +0.5 m). This is particularly significant for discharges from Waikopua Creek, where “sediment accommodation space” (areas where sediment may deposit) beyond the confines of the main tidal channel increases rapidly with increasing elevation.

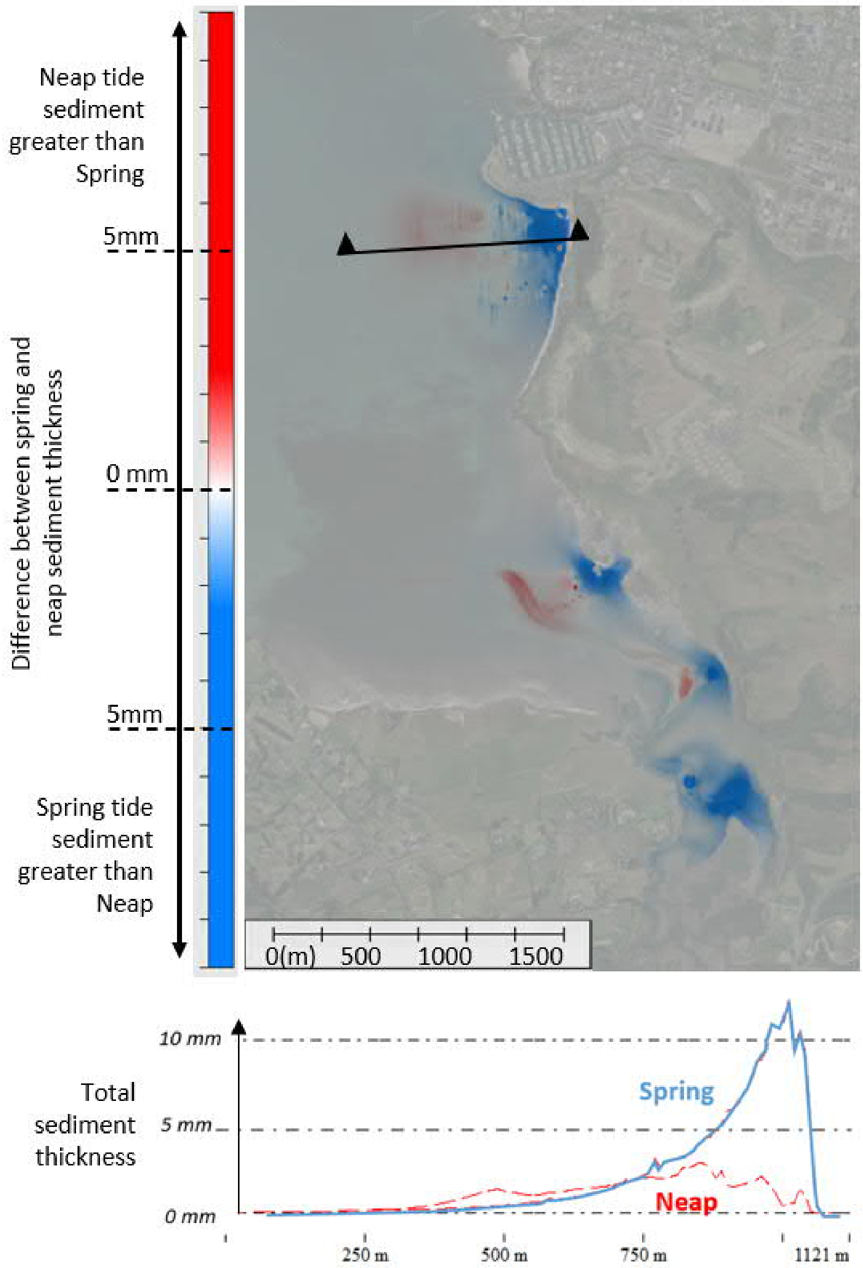

Figure 4-3 Neap vs spring sediment thickness map comparison

Noting the effects on deposition resulting from approximately 0.5 m difference in high water levels between spring and neap tide cycles, a 0.5 m storm surge associated with a 100-y ARI water level is expected to result in a similar effect. This means more deposition over higher intertidal ground due to the elevated water levels at these times.

4.3 Rainfall effects in Waikopua Stream

Heavy rainfall resulting in large freshwater discharges also have the potential to result in elevated backwater profiles along tributaries that feed into the embayment, such the Waikopua Creek. These elevation differences are expected to increase ebb-tide currents, potentially flushing more sediment from the stream channel into the wider embayment than the modelling otherwise indicates.

4.4 Wind and wave effects

Sediment transport in shallow estuaries has been shown to be strongly influenced by wind due to drag on the water surface, and by wind waves (Green & Coco, 2013). These effects can potentially occur:

- During sediment discharge, resulting in more sediment remaining in suspension for longer periods, in-turn resulting in reduced deposition thickness spread over a larger area.
- After deposition, material can be remobilised and transported into other areas of the embayment.

As discussed in Section 2.3, largest wave heights (and longest wave periods) occur under strong northerly winds. Under typically lighter southwest winds, which occur more frequently than northerly winds, fetch is smaller and wave heights are smaller.

To better understand the effects of wind and waves on material eroded from the catchment and discharged to the embayment in freshwater runoff during and immediately after rainstorms, we have reviewed extreme rainfall events and associated winds. The Auckland Aero weather station (Cliflo, 2021), located 16 km southwest of the Beachlands area, provides the nearest rainfall data set that is long and of reliable quality and consistency. Review of six of the largest 24-h rain gauge events over a period of approximately 30 years (based on hourly data) is included in Appendix A. This shows in almost all instances:

- Strong northeast to east winds during the rainfall.
- Northerlies weaken as rain continues to fall.
- Backing of wind to the southwest after rainfall.
- Southwest winds build in the days that follow rainfall to 10 to 20 m/s, but typically around 10 m/s, lasting for at least the duration of a tidal cycle.

The following events have been selected for modelling to characterise typical effects of wind and waves on sedimentation:

- *Rare strong northwesterly event (NW):* 12 m/s northwesterly wind with annual probability of occurrence of around 0.1%, which will generate extreme wave heights from this direction and elevated water levels.
- *Southwesterly winds following an extreme rainfall event (WSW):* 11 m/s southwesterly wind, which is typical of winds that occur over 5 days following extreme rainfall events. It is noted from analysis of wind records that similar windspeeds or greater from related directions (WSW through SSW) has an occurrence of approximately 2%, considered to occur on at least a monthly occurrence.

Figure 4-4, which shows max bed shear stress over a full tide cycle with and without waves[7] during a spring tide illustrate the following:

- Discharges from streams A and B are more exposed to wind waves, which generate larger bed shear stresses than discharges into the Waikopua Creek.
- In exposed areas bed shear stresses associated with the NW wind are much higher than those under the WSW wind.
- Pine Harbour Marina shelters areas of the upper intertidal flat in the vicinity of Stream A, resulting in similar bed stresses under the two winds.
- Bed shear stress in the lower intertidal area peak each side of the high tide.

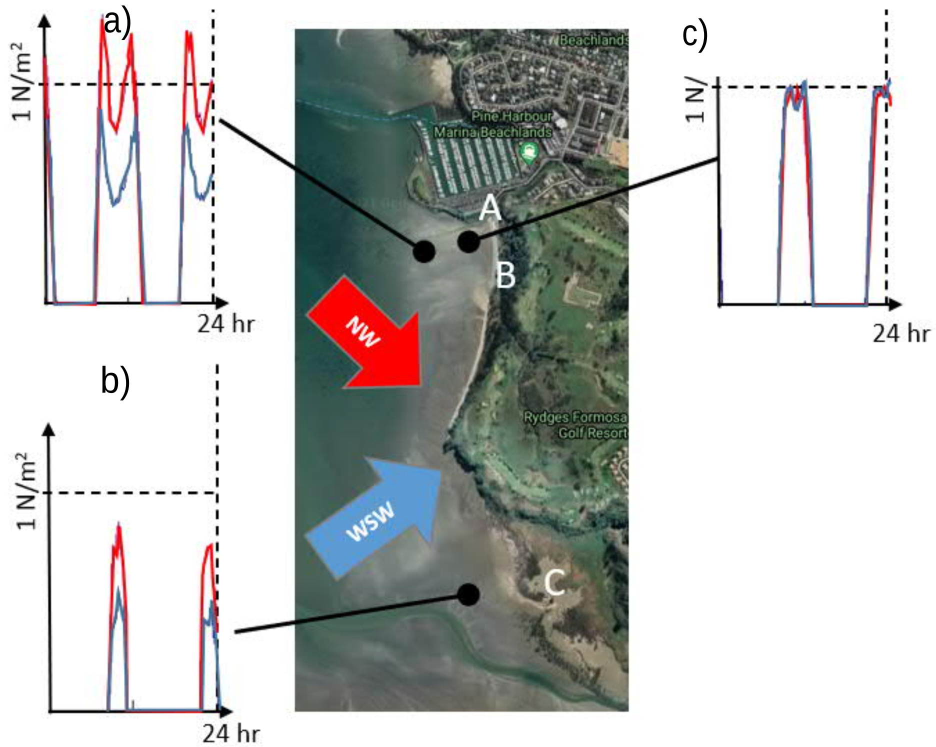

Figure 4-4 Bed shear stresses plotted over two tide cycles for the strong northerly event (NW, blue), and comparatively more frequent south westerly event (WSW, purple)

Wind waves have the potential to resuspend freshly deposited material discharged in the vicinity of Streams A and B. As shown in Figure 4-5, during a NW wind and over a single high tide, sediment thickness reduces as it is eroded from the bed (red dash line) when bed stresses (orange line) exceed the erosion threshold. Higher rates of erosion occur when bed stresses increase. In this scenario bed stresses increase with water depth (blue line) to a maximum at around 1 m water depth, before decreasing again at greater depths.

[7] Max bed shear stress refers to the summation of the current alone stress, and the maximum oscillatory shear stress due to wave action defined in Deltares (2021) and adapted from Soulsby et al. (1993). When no waves occur, the max bed shear stress is influenced by current alone.

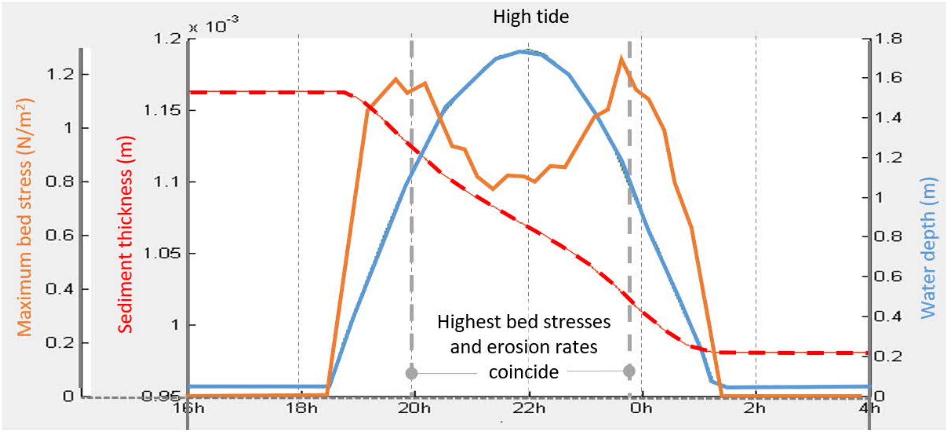

Figure 4-5 Erosion and resuspension of recently deposited sediment from wind waves

Erosion over consecutive high tides in Figure 4-6 show that in lower intertidal areas more exposed to waves from the NW, higher bed shear stresses result in approximately double the rate of resuspension of sediments compared to under a WSW wind.

In upper intertidal areas, NW and WSW winds result in similar erosion rates. These rates are larger than rates in the lower intertidal areas due to the way bed shear stress peaks for a longer duration at a water depth of around 1 m over the phase of tide when water levels change more slowly. Allowing for an approximately 2%[8] occurrence of winds comparable or greater to the WSW wind on a monthly basis could amount to re-erosion in the order of 1 mm in the lower intertidal, and more than this within the upper intertidal over the course of a typical year.

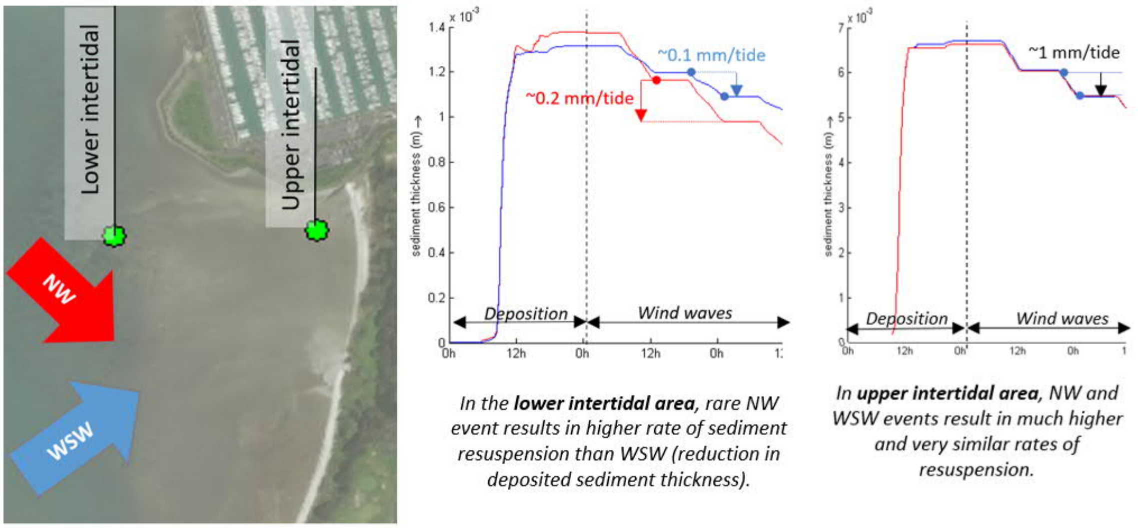

Figure 4-6 Sediment resuspension from wind waves applied over consecutive tidal cycles

Noting that re-erosion rates differ spatially, the duration that sediment remains in place is strongly influenced by location on the intertidal flat. Figure 4-7 compares re-erosion under a WSW wind (applied over a single tide) on low and high spring tide deposition areas. This show more aggressive removal of sediment in upper intertidal areas.

[8] Combination of % occurrence of WSW,SW,SSW greater than or equal to 11 m/s from wind rose determinants shown in Section 2.33.3.5 and derived from 33 year Auckland Aero dataset.

Figure 4-7 Comparing re-erosion rates of lower (low tide) and upper (spring tide) deposition areas

5 Results from modelling of sediment dispersal and deposition

The hydrodynamic and sediment-transport model suite was used to investigate:

- *Earth works stage:* Event-based sediment deposition, particularly in the vicinity of discharges.
- *Developed stage:* Longer-term sedimentation, in the vicinity of discharge areas and across the wider embayment.

Results from discharges A and B have been characterised separately from discharges C, D and E, noting that the former relate to the Live Zone, with the latter discharging from the Future Urban Zone.

5.1 Earth works stage

5.1.1 Design events

T+T has been provided with time series of TSS discharged in freshwater runoff from NIWA (2021), detailed in Appendix B. NIWA results allow for a maximum 5 ha of disturbed ground exposed within sub-catchment areas at any one time. Over a single earthworks season with disturbed ground being progressively built over or stabilised, up to 15 ha may be developed. We understand that earthworks may be undertaken in more than one contributing sub-catchment at any one time.

Since NIWA's modelling above, we understand that maximum proposed disturbed areas within sub-catchments have been reduced from 5 ha to 4 ha. This reduction in disturbed areas would indicate the potential for lower TSS discharged, adding conservatism to this assessment.

Modelling shows deposition areas from A and B at the northern end of the site in the Live Zone, as being quite different from C, D, and E within the Waikopua Stream that drain from the Future Urban Zone. Modelling results indicate these two broad areas as being generally independent of each other.

Noting the different deposition areas, for simplicity modelling has been undertaken with simultaneous discharges from all streams despite the work in the Future Urban Zone being undertaken at a later time.

For the purposes of the event-based assessment, the following three design rainstorm events have been considered:

- 2-y ARI rainstorm, considered as a *'worst certain'* event, with a 39% probability occurring in any single year.
- 10-y ARI rainstorm, considered as a *'worst likely'* event, with a 10% probability occurring in any single year.
- 100-y ARI rainstorm, considered as a *'worst possible'* event, with a 1% probability occurring in any single year.

5.1.2 Scenarios

Section 4 identifies the key variables that influence sediment dispersal and deposition at the event scale. Based on this understanding, the model scenarios shown in Table 5-1 were run. For each scenario, the modelling sequence was:

a Day 1 – Hydrodynamic spin-up.

b Day 2 – Sediment discharge and deposition under no wind waves.

c Day 3- WSW wind waves and resuspension/transport of freshly deposited sediment. Re-erosion rates over a single high tide taken as an equivalent of 10 days typical exposure.

Table 5-1 Event-based deposition modelling scenarios (ticks indicate scenarios modelled)

Baseline stage						Earth works stage					
Peak discharge occurring at:		High	Ebb	Low	Flood	Peak discharge occurring at:		High	Ebb	Low	Flood
Spring	WSW	✔				Spring	WSW	✔	✔	✔	✔
	NW						NW	✔			
Neap	WSW					Neap	WSW	✔	✔	✔	✔
	NW						NW	✔			

Based on T+T numerical modelling of the above scenarios, Table 5-2 and Table 5-3 provide a detailed synthesis of key variables, their likelihood, and the sediment deposition (magnitude and likelihood) based on a 100-y ARI event. This shows:

- For discharges from streams A and B, maximum deposition occurs when peak discharge occurs over high tides, particularly spring tide, resulting in more focused deposition area at a time when water levels vary the least.
- For discharges from streams C, D and E reduced currents and high water levels over the high tide results in a more focused deposition in the upper inter-tidal vicinity of the discharge points. Deposition areas become enlarged when tidal currents increase which assist in spreading discharge, or when water levels are sufficiently low to result in discharge directly entering the stream channel itself.
- The duration that deposited sediment remains in place within the intertidal area primarily depends on how exposed the area is to wind waves. Areas where sediments discharged from A and B are deposited are exposed to wind waves that, over time (more than 10 days), will see the continued removal of the deposited sediment. In contrast, areas where sediments discharged from C, D and E deposit are located within the sheltered confines of the Waikopua Stream and much of this material may remain in place for a longer duration.

Although review of historical weather events shows a low likelihood of strong northwest winds prevailing at the time of discharge, a single scenario model was run to investigate these effects. This showed a substantial reduction in deposition thickness as indicated in Table 5-2.

Table 5-2 Key factors influencing 100-y ARI deposition at stream discharge locations A and B

Influence on discharge	Larger sediment deposition area(s)			Smaller sediment deposition area(s)		
	Condition	Magnitude	Likelihood	Condition	Magnitude	Likelihood
Tidal stage at peak discharge (High, Ebb, Flood, Low) [1] (Section 4.1)	Peak discharge during high tides results in greater sediment deposition over a smaller area in the upper intertidal area	*considering spring high* Existing baseline Less than 0.1 ha > 5mm Earthworks 3.5 ha > 5mm Less than 0.1 ha > 20mm	25% Less likely	Peak discharges outside of high tide times result in reduced deposition, expected to affect a proportionally larger area compared to discharge at high tide	*considering spring low* Existing baseline Less than 0.1 ha > 5mm Earthworks 1.6 ha > 5mm Less than 0.1 ha > 20mm	75% Likely
Discharge during spring vs neap tides (Section 4.2), noting likely comparable to storm surge [1]	Peak discharge during spring tides results in deposition within upper intertidal areas	*considering spring high* Existing baseline Less than 0.1 ha > 5mm Earthworks 3.5 ha > 5mm Less than 0.1 ha > 20mm	50% Even likelihood	Over neap tides, reduced deposition is expected to affect a proportionally larger area compared to discharge at high tide	*considering neap high* Existing baseline Less than 0.1 ha > 5mm Earthworks 2 ha > 5mm Less than 0.1 ha > 20mm	50% Even likelihood
Wind and wave effects during discharge[1] (Section 4.4)	No NW wind/waves during discharge results in settled conditions resulting in greatest potential for deposition	*considering spring high* Earthworks 3.5 ha > 5mm	> ~80% Likely, typically light winds in the 24 hrs that follow heavy rainfall events, based on 5 out of 6 historical occurrences	Moderate to strong NW winds with wave action during discharge keeps material in suspension, meaning less sediment deposition in area of discharge	*considering spring high* Earthworks 0.8 ha > 5mm	< ~20% Unlikely, typically light winds in the 24 hrs that follow heavy rainfall events. Strong winds only occur in 1 out of 6 occurrences
Effects of increased ebb-tidal currents from freshwater (Section 4.3)	No increase in ebb tide depth averaged currents associated with catchment effects	No modelling information to inform this scenario	Less than likely	Rainfall associated with the site discharge, also results in freshwater catchment contributions into the Waikopua Creek, increasing currents and overall reducing potential deposition within the river channel	No modelling information to inform this scenario	Likely
Wind and wave effects after discharge (Section 4.4)	No wind waves after the discharge event results in deposited sediment remaining in place for an extended period	*considering spring high* Existing baseline Less than 0.1 ha > 5mm Earthworks 3.5 ha > 5mm Less than 0.1 ha > 20mm	~30% Less likely. Review of historical events indicate 2 occurrences out of 6 events considered (less and 10m/s)	WSW wind occurs over one high tide within 5 days, and over two high tides within 10 days of the discharge	*considering spring high* Existing baseline Less than 0.1 ha > 5mm Earthworks 3.4 ha > 5mm after 10 days	~70% Likely considering historical events indicate wind and wave effects occurred in 4 out of 6 events considered

[1] - Ignores re-erosion from wind-wave effects within 10 days that follow

Table 5-3 Key factors influencing 100-y ARI deposition at stream discharge locations C, D and E

Influence on discharge	Larger sediment deposition area(s)			Smaller sediment deposition area(s)		
	Condition	Magnitude	Likelihood	Condition	Magnitude	Likelihood
Tidal stage at peak discharge (High, Ebb, Flood, Low) [1] (Section 4.1)	Peak discharge during ebb/flood tides results in greater deposition area spread over lower inter-tidal areas.	*considering neap flood /ebb* Existing baseline 0 ha > 5 mm Earthworks 3.7 ha > 5 mm 0.3 ha > 20mm	50% Less likely	Reduced deposition areas, with more focused deposition (thicker) around upper inter-tidal discharge points	*considering neap high* Existing baseline 0 ha > 5mm Earthworks 2.9 ha > 5mm 0.1 ha > 20mm	25% Likely
Discharge during spring vs neap tides[1] (Section 4.2)	Peak discharge during neap tides results in larger deposition areas spread over lower inter-tidal areas	*considering neap flood* Existing baseline 0 ha > 5mm Earthworks 3.7 ha > 5mm Less than 0.1 ha > 20mm	50% Even likelihood	Over spring tides, more focused deposition in upper inter-tidal areas around discharge points result in reduced deposition areas.	*considering spring flood* Existing baseline Less than 0.1 ha > 5mm Earthworks 2.3 ha > 5mm Less than 0.1 ha > 20mm	50% Even likelihood
Effects of increased ebb-tidal currents from freshwater (Section 4.3)	No increase in ebb tide depth averaged currents associated with catchment effects	No modelling information to inform this scenario	Less than likely	Rainfall associated with the site discharge, also results in freshwater catchment contributions into the Waikopua Creek, increasing currents and overall reducing potential deposition within the river channel	No modelling information to inform this effect	Likely

[1] - Ignores re-erosion from wind-wave effects within 10 days that follow

On the basis of sensitivity analyses and the various considerations in Table 5-2 and Table 5-3, it is evident that areas of more than 20 mm deposition thickness do not exceed 0.1 ha, and that the primary consideration relates to areas with more than 5 mm sediment deposition thickness persisting for greater than 10 days. Table 5-4 compares these areas for a range of scenarios for discharges from A and B and Table 5-5 for discharges from C, D and E.

Table 5-4 Area that sediment discharged from A and B deposit at a thickness of more than 5 mm persisting for greater than 10 days

Peak discharge occurring at:		High	Ebb	Low	Flood
2-y ARI	Spring	<0.1 ha	<0.1 ha	<0.1 ha	<0.1 ha
	Neap	<0.1 ha	<0.1 ha	<0.1 ha	<0.1 ha
10-y ARI	Spring	<0.1 ha	<0.1 ha	<0.1 ha	<0.1 ha
	Neap	<0.1 ha	<0.1 ha	<0.1 ha	<0.1 ha
100-y ARI	Spring	3.4 ha	1.5 ha	0.6 ha	1.6 ha
	Neap	2.0 ha	1.2 ha	0.9 ha	2.0 ha

Table 5-5 Area that sediment discharged from C,D and E deposit at a thickness of more than 5 mm persisting for greater than 10 days

Peak discharge occurring at:		High	Ebb	Low	Flood
2-y ARI	Spring	<0.1 ha	<0.1 ha	<0.1 ha	<0.1 ha
	Neap	<0.1 ha	<0.1 ha	<0.1 ha	<0.1 ha
10-y ARI	Spring	<0.1 ha	0.4 ha	0.4 ha	0.2 ha
	Neap	0.35 ha	0.4 ha	0.3 ha	0.3 ha
100-yARI	Spring	1.9 ha	3.6 ha	3.6 ha	2.3 ha
	Neap	2.9 ha	3.7 ha	3.4 ha	3.7 ha

5.1.3 Discussion

We note in Section 2.8 an existing annual Sedimentation Accumulation Rate (SAR) of up to +3 mm/y in the upper reaches of the Waikopua Stream, with approximately a third of this sediment accumulation due to sediment originating from the development area. This implies that the development site contributes ~+1 mm to the SAR in the vicinity of discharges C, D and E. A 2–3 times increase in sediment runoff for more frequent events (such as 2-y ARI) during construction has the potential to add more than +2 mm of accumulated sediment above the existing background rate over the duration of the construction period in the deposition areas shown in Figure 7-1.

Potential changes in TSS in the order of 2-3 times over the course of construction need to be considered in context with long term reductions in TSS in its developed form discussed in Section 5.2 below.

5.2 Developed stage

NIWA have undertaken an assessment of annual TSS loads for the developed case. This indicates a net 64% reduction overall in annual TSS loads compared with the existing baseline. Over the longer term:

For sediment discharged from streams A and B:

- Within a month it is likely that moderate SW winds accompanied by wind waves will have partially removed recently deposited sediment.
- Within a typical year, during which a comparatively rarer NW event(s) occurs, more substantial re-erosion of this material is likely.
- Upon reaching areas of the embayment where higher tidal currents occur (i.e., tributary channels and the western side of the embayment), the majority of material is likely to be transported in suspension towards a subtidal deposition area over time (Figure 5-1).

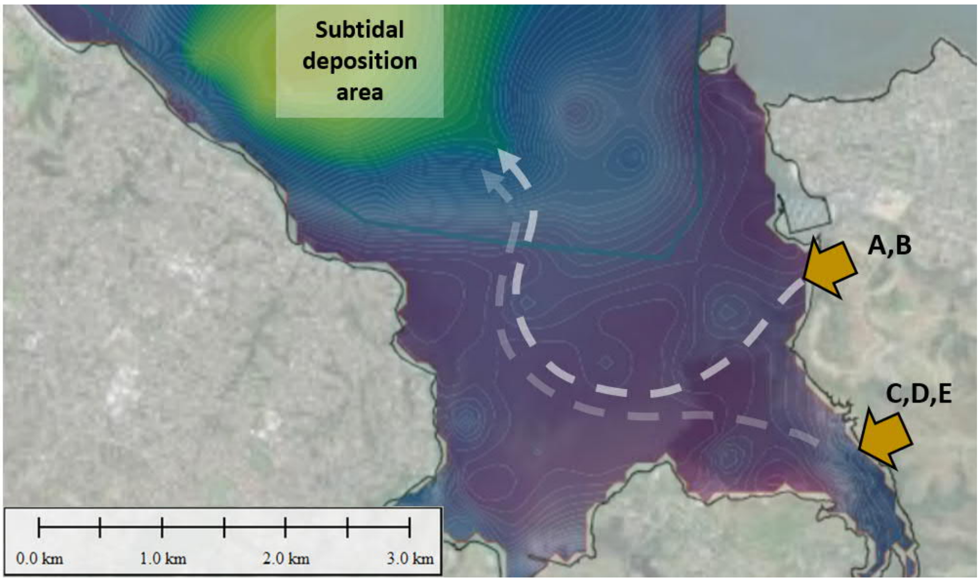

Figure 5-1 Long term transport trends within the Whitford Embayment (Annotated image showing fines contents reproduced from TP158, 2002)

For sediment discharged from Streams C, D and E:

- If the peak discharge coincides with a high tide (even more so during spring tide cycles, or during storm surge), more sediment will be deposited on the upper inter-tidal area. This material will likely remain and accumulate in place.
- If the peak discharge occurs over lower stages of tide, more sediment will reach the main stream channel. This material is likely to be transported in suspension towards a subtidal deposition area (Figure 5-1):
  - Possibly within days in the instance of high river flows from rainfall coinciding with sediment discharge into the channel.
  - Within 12 months with progressive resuspension from tidal currents (particularly during spring tides or in combination with moderate rainfall events).
  - Within years, during which extreme rainfall events result in sufficiently high ebb-tide currents resulting in erosion of stream bed sediment.

6 Treated wastewater discharge

The Wastewater Reticulation and WWTP Concept Design report (GWE, 2022) discusses three options for the disposal of treated wastewater. ‘Option 2 – Polishing Wetland and Discharge to the Coastal Marine Area’ involves the discharge of water into the upper reaches of a stream that leads to Discharge B. Treated wastewater is intended to mix with the existing stream through a series of wetlands before it meets with the coastal marine area.

As shown in Figure 6-1, the existing stream is confined at times by beach sediment that is periodically eroded during heavy rainfall events, before accumulating again. Due to the high quality of wastewater treatment, ponding of this discharge is considered acceptable. We understand that no physical works to bypass periodic beach sediment accumulation has been considered necessary.

Increasing overall discharge from this location due to added treated wastewater may reduce sediment accumulation, resulting in reduced beach width at the mouth of this discharge. The narrow accumulation of this beach sand in the upper intertidal merges with low grade (<1° fall) sand flats. At low tide these sand flats extend approximately 600 m to the west with stream discharge at these times likely via a series of shallow intertidal channels.

This study does not specifically model mixing of discharge over successive tide cycles to understand dilution effects, however it’s comparatively exposed location within the Whitford Embayment and separation distance from the Waikopua Creek indicate more suitable opportunities for mixing and dilution of discharge with coastal waters over successive tides.

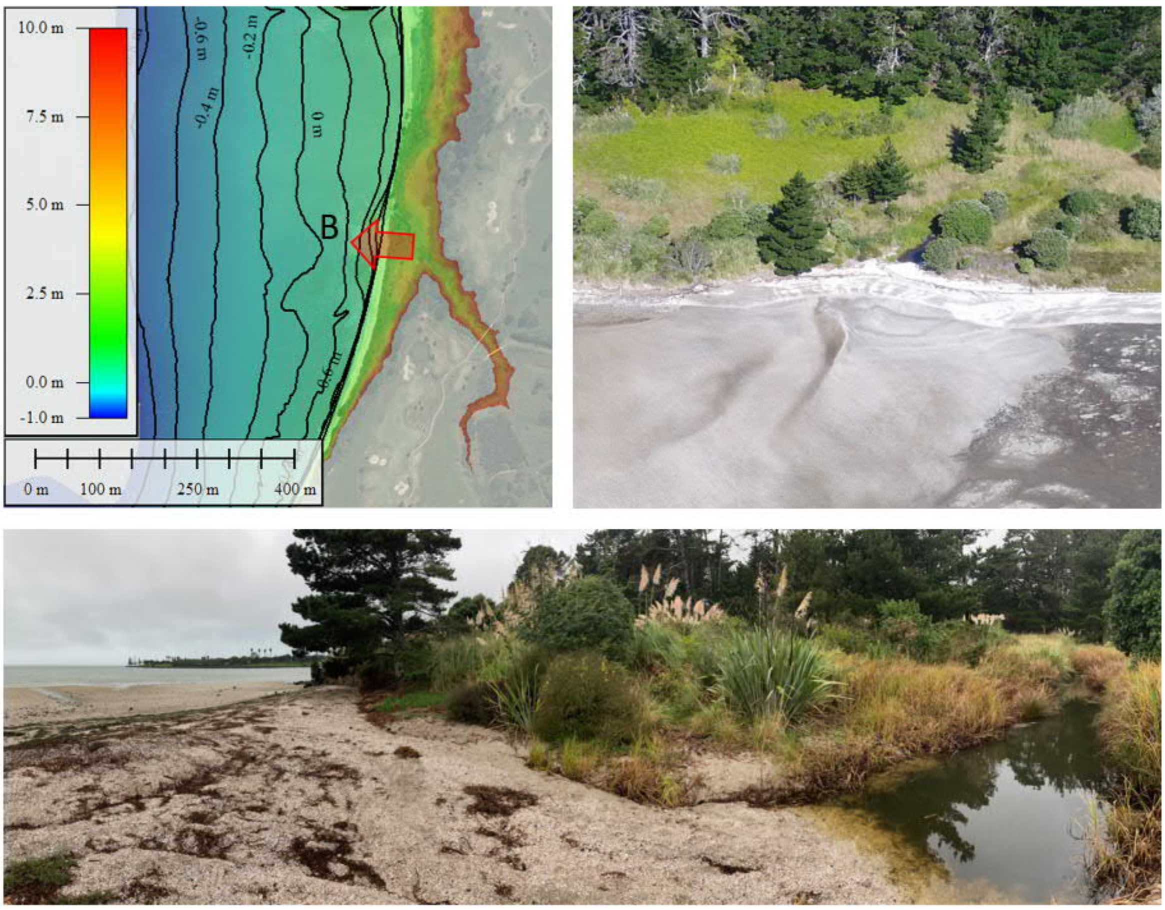

Figure 6-1 Proposed treated wastewater location at Discharge B

7 Metal accumulation in embayment bed sediments

An analytical model was used to predict the accumulation of zinc (Zn) and copper (Cu) in the surface mixed layer of the embayment bed sediments. Both metals are washed from the mature urban landscape and discharged into the embayment attached to sediment particulate matter in freshwater runoff. The model is based on the methodology developed by Green (2015). Details regarding the metal-accumulation model are included in Appendix F.

Potential metal depositional footprints are shown in Figure 7-1 below, informed by the event-based modelling of sediment deposition in areas where bed shear stress exerted by waves and currents tends to be minimum (upper intertidal areas away from higher tidal currents and wind waves).

Figure 7-1 Depositional zones for the site discharges

Values used for parameters in the metal-accumulation model are listed in Table 7-1.

Table 7-1 Values of parameters used in the metal-accumulation model

Parameter	Value	Source
Annual-average sedimentation rate (mm/y)	3.25	Approximate median value for deposition rates reported for the Auckland East-Coat Bays as reported in Green (2016)
Wet bulk bed density (kg/m^3)	1850	Derived from the dry bed density in Table 3.3, using a void factor of 25% to obtain the wet bulk density

F, fraction of annual load derived from the discharge deposited in the depositional zone of interest	0.067[a]	Based the relative contribution of TSS loads from the site catchment to total TSS loads to the catchment (T+T,2021a)
Fraction of total metals dissolved due to speciation	0	Ellwood et al. (2008) presented a wide range of dissolution values, but a value of zero was used in the end to remain conservative.
λ, thickness of SML (cm)	5	Green (2008)

a - In some cases a lower value (20% reduction) was used to avoid sedimentation that exceeded the available source.

The metal concentrations in the SML predicted by the metal-accumulation model at 50 and 100 years after full development and at equilibrium are shown in the table below. No ERC threshold (19 mg/kg and 124 mg/kg for copper and zinc amber thresholds, respectively) is predicted to be exceeded.

Table 7-2 Metal concentration in the bed-sediment SML at 50 and 100-y after full development, and at equilibrium.

Deposition zone	Copper concentration (mg/kg)				Zinc concentration (mg/kg)			
	Initial	50-y	100-y	Equilibrium	Initial	50-y	100-y	Equilibrium
A, B	1.84	6.24	6.40	6.4	16.5	39.88	40.69	40.72
C	1.19	2.75	2.8	2.8	14.1	21.81	22.08	22.09
D, E	2.74	3.14	3.16	3.16	19	21.06	21.13	21.13

8 Conclusions

For the developed landscape, annual TSS (Total Suspended Solids, measured in tonnes) is predicted to reduce by 64% compared with loads under the existing landscape. Copper and zinc will accumulate, but metal concentrations within the surface mixed layer will remain below the ERC amber threshold (19 mg/kg and 124 mg/kg for copper and zinc, respectively).

During the earthworks phase, which includes certain levels of stormwater treatment, sediment runoff from the site will increase compared to sediment runoff from the existing landscape. Potential changes in 24 h TSS load are:

- 1 to 2 times[9] increase in the mass of TSS discharged for the 95th percentile rainfall event (approximately annual heaviest rainfall event expected)
- 2 to 3 times increase in the mass of TSS discharged for the 2-y ARI rainfall event (likely to occur five times within a 10-y development period)
- 3 to 5 times increase in the mass of TSS discharged for the 10-y ARI rainfall event (likely to once within a 10-y development period)
- 6 to 14 times increase in the mass of TSS discharged for the 100-y ARI rainfall event (10% chance of occurrence within a 10-y development period).

For the 2-y and 10-y ARI event's the 5-mm threshold (and the 20-mm by default) was not shown to be exceeded over areas greater than 0.1 ha.

For the 100-y ARI event:

The 20-mm deposition thickness threshold persisting for more than 5 days was exceeded over areas less than 0.1 ha. The 5-mm threshold was exceeded over greater areas and shown to persist for more than 10 days as outlined below.

For sediment discharged from streams A and B in a 100 y ARI event, worse case deposition occurred under spring tide conditions. A peak discharge over high tide had the potential for 3 to 4 ha coverage of 5 mm or more in the upper intertidal area persisting longer than 10 days. Less than 2 ha was similarly affected within the lower intertidal area at other times. During neap-tide conditions modelling indicates the tidal stage at time of discharge becomes less influential on the size of the 5 mm deposition threshold with typically 1 to 2 ha with more than 5 mm deposition persisting longer than 10 days. Longer term (i.e. timescale in years) exposure to wind waves will result in gradual redistribution of this material to other subtidal areas of the wider embayment.

For sediment discharged from streams C, D and E in a 100 y ARI event, deposition areas 3 to 4 ha in size with more than 5 mm occurred under both neap and spring tide conditions, albeit in different locations. Higher tidal currents (ebb/flood) enabled a greater spread of discharge material compared with high tide where reduced currents enabled a more focused and smaller deposition areas in the upper inter-tidal vicinity of the discharge points. Sediment deposited in the vicinity of Waikopua Stream, where it is sheltered from winds and waves, is likely to remain in place.

Considering a 2-3 times increase in sediment during construction for more frequent events such as 2-y ARI, and noting existing rates of sedimentation as high as 3 mm/y, the potential exists for more than 2 mm of accumulated sediment above existing background rates during

[9] 1 to 2 times means potential 24 h TSS discharged load (tonnes) during earthworks varies between 100% and 200% of the existing situation, alternatively in this instance earthworks values could be considered up to 100% higher than existing, or also viewed as potential doubling of load in tonnes in the worst instance.

the construction period (taken indicatively as 10 years) in the vicinity of discharges C,D,E which are existing predominantly silty and muddy environments. Potential changes in TSS in the order of 2-3 times over the relatively short duration of construction need to be considered in context with long term reductions in TSS by 64% in its developed form.

In conclusion this study indicates:

- Post development resulting in an overall reduction in annual TSS, with likely long-term accumulation of Zinc and Copper within green (acceptable) ERC threshold values.
- During earthworks, the potential exists for increased TSS particularly following extreme lower likelihood rainfall events (e.g., 100-y ARI event). Sediment areas and thicknesses from this report that consider a range of design events are used to inform the T+T ecological assessment report.

9 Applicability

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

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3. Ben Perry (T+T coastal engineer) providing modelling support

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Appendix A: Wind and rainfall information

Extreme rainfall events

Extreme rainfall events occurring in the Auckland region are associated with lows of sub-tropical origin or ex-tropical cyclones (Pascoe, n.d.). Synoptic charts showing examples of these weather systems are shown in Figure 10-1.

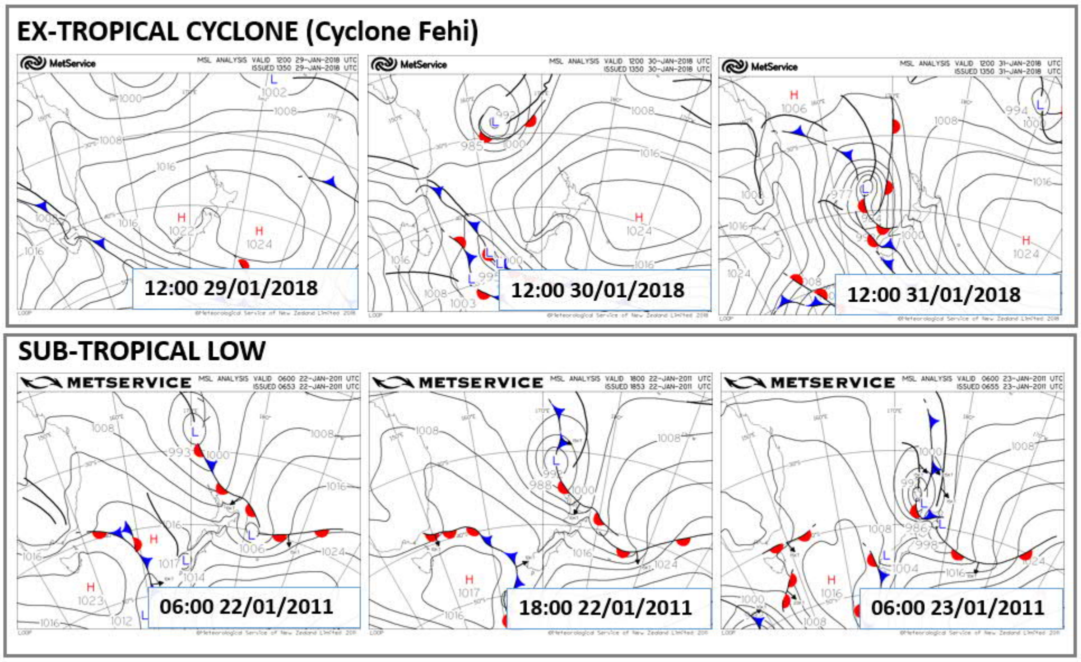

Figure 10-1 Weather systems typically associated with heavy rainfall in the Auckland region

Pascoe (n.d.) notes high variability in rainfall across the Auckland region due to convective activity, often in summer, frequently resulting in a large number of events that produce a 100-y ARI rainfall *somewhere or other*. With particular relevance to the Beachlands area, sheltering by the Coromandel Peninsula often reduces rainfall associated with airflows from the east

Kidson (2000) defined 12 synoptic weather types to assist with the characterisation of New Zealand weather patterns. Griffiths (2013) showed two particular Kidson synoptic weather types(Figure 10-2) as being typical of extreme rainfall events in the Auckland Region:

- The ‘Northeast’ (NE) anticyclonic, and to a lesser extent.
- Trough-Southwesterly (TSW) associated with cyclonic, unsettled conditions.

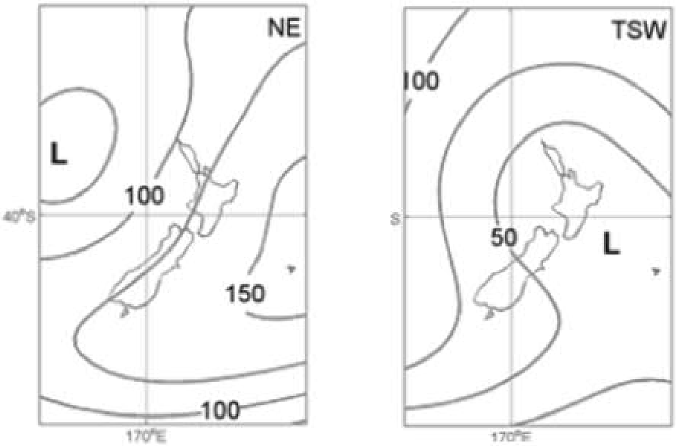

Figure 10-2 Kidson weather types identified by Griffiths (2013) as being associated with extreme rainfall events in the Auckland region. Similarities between synoptics in this figure and Figure 10-1 are apparent.

The Auckland Aero weather station (Cliflo, 2021), which is located 16 km southwest of the Beachlands area, provides the closest rainfall data set of good duration and of reliable quality and consistency. Figure 10-3 shows six of the largest 24-hr rain gauge events (indicated by red stars) over a period of approximately 30 years (based on hourly data).

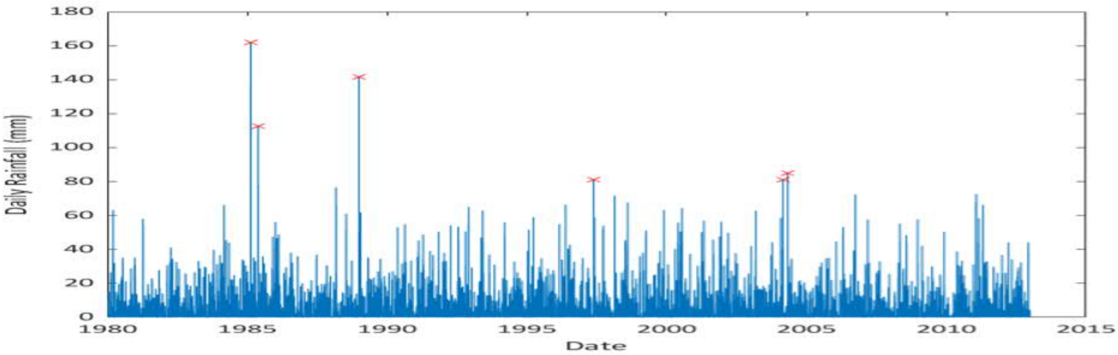

Figure 10-3 Auckland aero rainfall record

Figure 10-4 in Appendix A summarises recorded wind speed and direction following the six largest rainfall events. This shows in almost all instances:

- Strong northeast to east winds during the rainfall.
- Typically northerlies weaken during the day of the rainfall event.
- Backing of wind to the southwest occurs after rainfall.
- Southwest winds build to 10-20 m/s, but typically around 10 m/s, in the days that follow the rainfall, lasting for at least the duration of a tidal cycle.

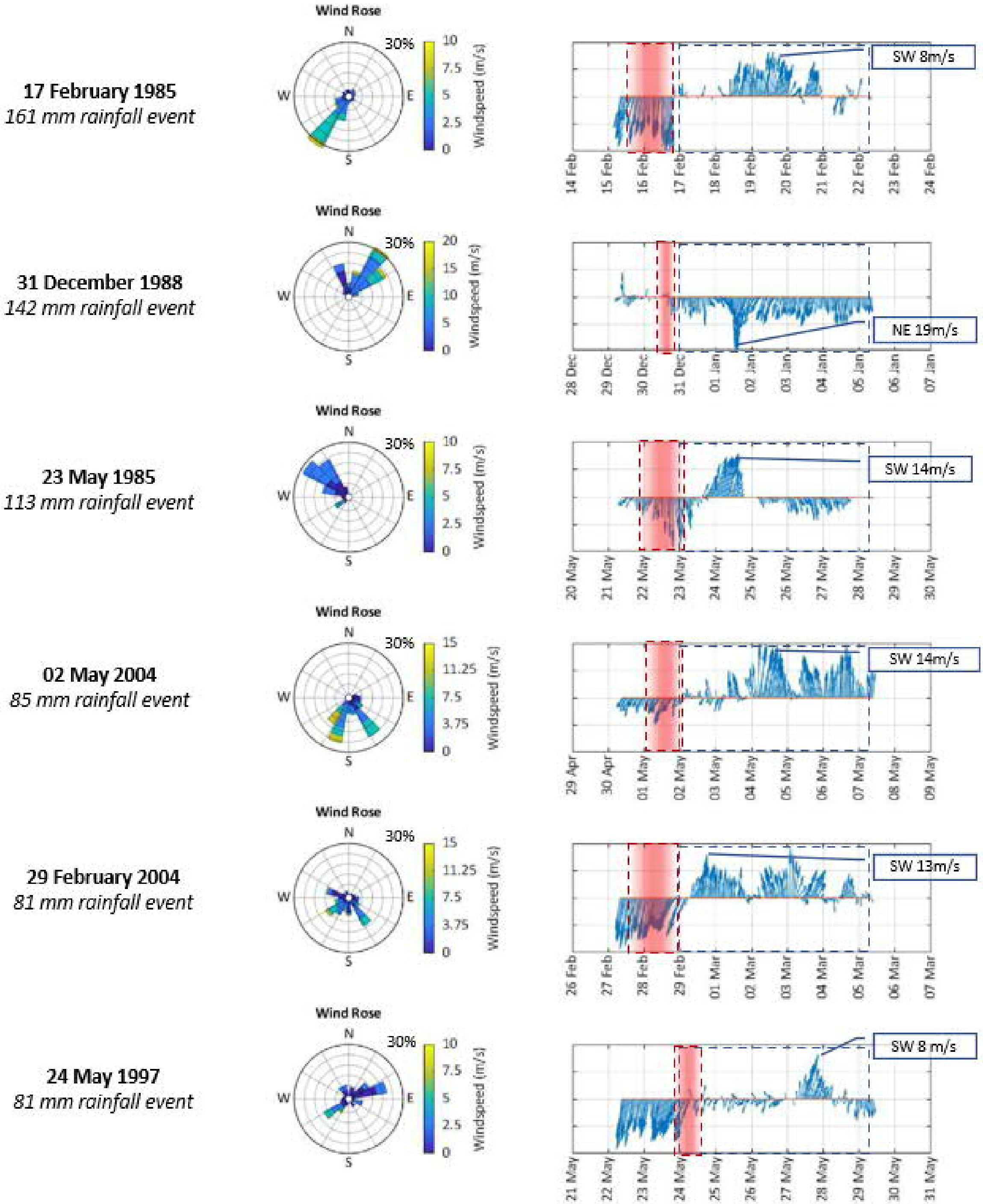

Figure 10-4 Wind speed and direction during and following extreme rainfall events at Auckland Aero

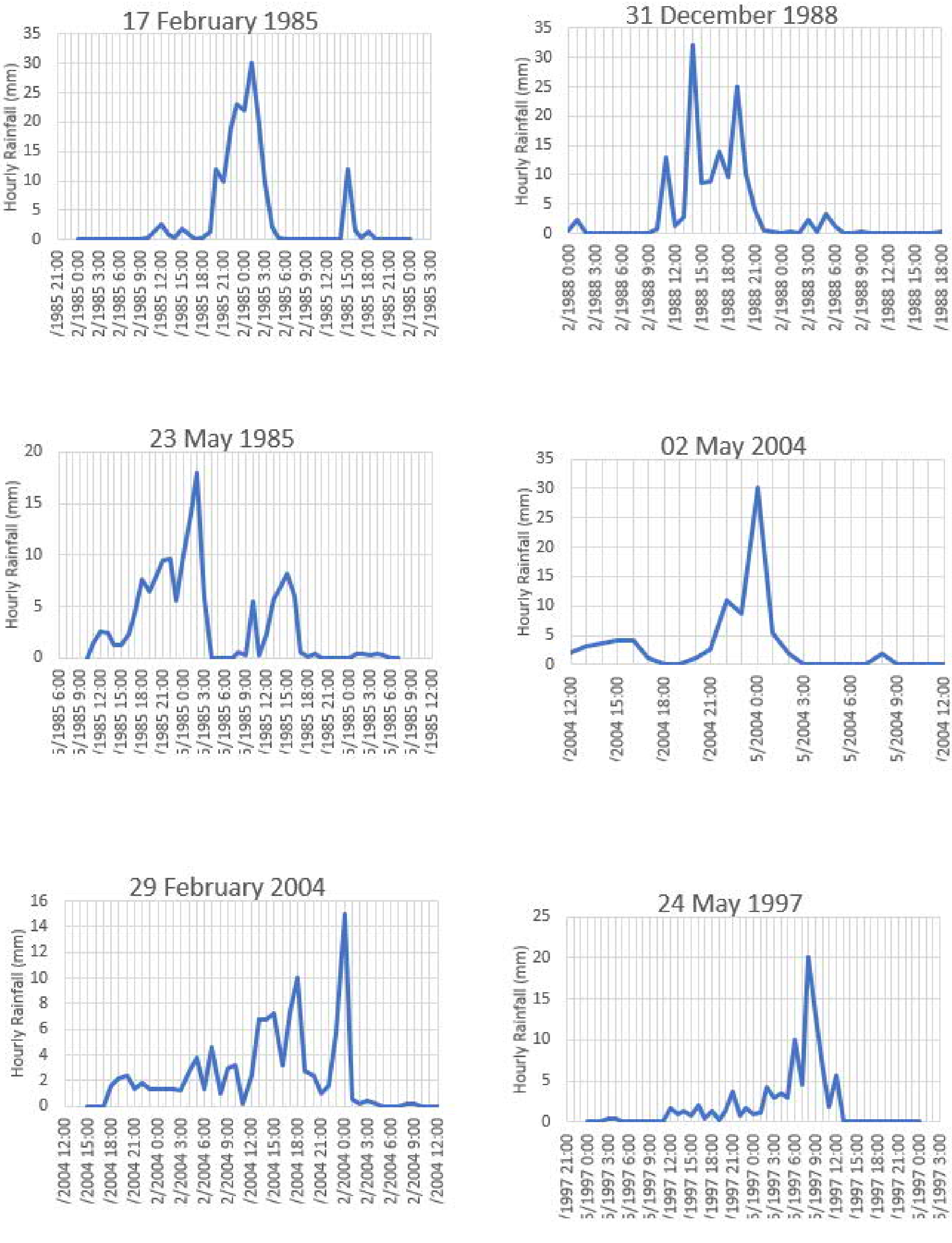

Figure 10-5 Rainfall during and following extreme rainfall events at Auckland Aero (Cliflo 2021)

Monitoring during instrumentation period

Rainfall data from a local rainfall gauge maintained by Auckland Council approximately 1 km south of the site is shown in Figure 10-6 (Auckland Council, 2021b). This indicates rainfall events clustered towards the end of March and over the first few days of April.

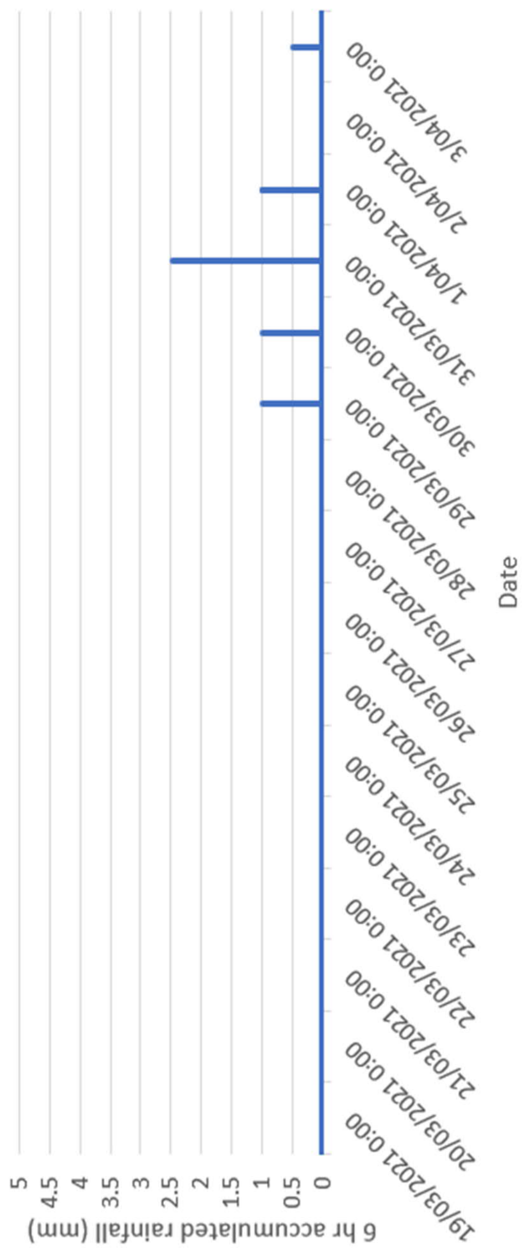

Figure 10-6 Local rainfall data collected over the time of instrumentation (Auckland Council, 2021b)

Appendix B: NIWA discharge modelling

Beachlands South Development

Estimates of Construction-Phase and Mature-Phase Contaminant Loads

Prepared for Beachlands South Ltd Partnership

December 2021

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Contents

Tables

Figures

Executive summary

Beachlands South Limited Partnership are applying for a change to the Auckland Unitary Plan associated with the proposed development of land in Whitford Embayment catchment, south of the suburb of Beachlands. NIWA was commissioned to provide estimates of contaminant loads associated with earthworks during the construction phase of the development, and for the development in its mature form. These estimates are to be provided as inputs to a wider modelling exercise to assess the potential effects of the development on Whitford Embayment and its tributary, Waikopua Creek.

For the construction phase, we have used the GLEAMS model, combined with information on earthworks staging and the performance of erosion and sediment control measures, to estimate runoff and sediment loads under an interim earthworks scenario. Specifically:

- Mean annual runoff and sediment loads, with and without erosion and sediment control measures, for a 15-ha representative catchment in four different slope classes, and in the context of loads discharged to Whitford Embayment at five different outlets (A – E); and
- Event specific (24-hr) runoff and sediment loads for a range of return periods (2, 5, 10, 20, 50 and 100 years) including disaggregation to a 10-minute timestep.

For the mature phase, we have used the C-CALM model, combined with information on land cover and stormwater treatment measures, to estimate total suspended solids (TSS), zinc (Zn) and copper (Cu) loads under a fully-developed scenario. Specifically:

- Mean annual TSS, Zn and Cu loads, with and without planned stormwater treatment, for the proposed stormwater catchments as well as by outlet to Whitford Embayment.

Construction phase

As the project is at an early stage, a specific catchment analysis of the proposed earthworks areas is yet to be undertaken. Instead, Harrison Grierson (consulting engineers for the project) provided an interim earthworks scenario assuming a representative 15 ha catchment with uniform slope, worked over a single season. The sequence of works is carried out in three 5 ha subcatchments, with a maximum of 5 ha disturbed area at any one time.

Estimated mean annual runoff volumes for the 15-ha representative catchment under the interim earthworks scenario show only a slight increase over baseline (existing land cover) values across slope classes. Estimated mean annual treated sediment loads are between six and 25 times higher than the equivalent baseline loads across slope classes. Though the magnitude of the treated sediment loads increases with slope, the relative difference between the baseline and interim earthworks scenarios is greatest for the lowest slope class (0° – 3°) and reduces in magnitude with increasing slope. Mean annual untreated load estimates are around an order of magnitude higher than the equivalent treated loads. 24-hr treated sediment load estimates are between approximately six and 36 times higher than the equivalent baseline loads over all slope classes and across the range of events with different ARIs.

The runoff and sediment loads estimated for the 15-ha representative catchment were placed in the context of discharges to Whitford Embayment based on conservative assumptions around the location and extent of works in a set of indicative earthworks catchments provided by Harrison Grierson.

Estimates of mean annual runoff volumes discharged to Whitford Embayment under the interim earthworks scenario show little change compared with baseline values, across outlets. Estimated mean annual treated sediment loads are between around two and three times higher than the equivalent baseline values across outlets. The relative increase is higher for Outlets A and B (at the northern end of the project area) than for Outlets C – E which are further towards Waikopua Creek. Estimated mean annual untreated sediment loads are around four times higher than the equivalent treated values (and between 10 and 16 times higher than the equivalent baseline loads). 24-hr treated sediment load estimates for the 2-yr ARI event under the interim earthworks scenario are between two and three times higher than the equivalent baseline loads across outlets. For the higher return periods, the increase over baseline is between two- to four-fold for the 10-yr ARI event and five- to 11-fold for the 100-yr ARI event across outlets.

Mature phase

Due to difficulties in assessing the land use category area in each stormwater catchment expected to be treated by wetlands, estimates of mean annual TSS, Zn and Cu loads under the fully-developed scenario were prepared for two cases reflecting the maximum / minimum extent of stormwater treatment: "wetlands" (at-source treatment of carriageway areas plus wetland treatment of all impervious areas), and "no wetlands" (at-source treatment of carriageway areas only).

Estimated mean annual TSS loads discharged to Whitford Embayment under the fully-developed scenario are between 60 – 90 % ("wetlands") and 30 – 90 % ("no wetlands") lower than the equivalent baseline values, across outlets. The reduction in loads reflects lower TSS yields for roofs and ecological areas under the fully-developed scenario, as well as stormwater treatment. The greatest reduction in load occurs for Outlet D, resulting from both a change in land cover under the fully-developed scenario and a reduction in catchment area, as stormwater runoff from much of the original catchment area under the existing land cover is routed to other outlets.

Mean annual treated loads of Zn estimated under the fully-developed scenario are up to 4.1 times higher ("wetlands") and 7.2 times higher ("no wetlands") than equivalent baseline values for some outlets, but show little change (or even some reduction) for others. The relative increase for Outlets A and B, in the north of the project area, is greater than for Outlets C – E which are closer to Waikopua Creek. Over the entire plan change area, the mean annual Zn load discharged to Whitford Embayment under the fully-developed scenario is expected to represent between an approximately two-fold ("wetlands") and four-fold ("no wetlands") increase over baseline.

Mean annual treated loads of Cu estimated under the fully-developed scenario are up to 2.7 times higher ("wetlands") and 6.6 times higher ("no wetlands") than equivalent baseline values for some outlets, but also show little change (or even some reduction) for others. Spatially, the pattern is similar to Zn, with the greatest proportional increase in Cu load occurring for Outlet B. Over the entire plan change area, the mean annual Cu load discharged to Whitford Embayment under the fully-developed scenario is expected to represent between around a 30 % increase ("wetlands") and a three-fold increase ("no wetlands") over baseline.

Based on the estimated extent of wetland treatment in each stormwater catchment, we expect the mean annual treated loads of TSS, Zn and Cu discharged to Whitford Embayment under the fully-developed scenario to be closer to (though still more than) the "wetlands" values for Outlets A – C, and closer to (though still less than) the "no wetlands" values for Outlets D – E.

1 Introduction

1.1 Background

Beachlands South Limited Partnership (Beachlands South LP) are applying for a private plan change to the Auckland Unitary Plan in association with the development of land adjoining the Whitford Embayment and its tributary, Waikopua Creek. The proposed development area (the project area) drains to the eastern shoreline of the embayment south of Beachlands (Figure 1-1) and comprises the Formosa Golf Resort at 110 Jack Loughlin Dr (around 170 ha) and the pastoral land at 620 Whitford-Maraetai Rd (around 80 ha). The plan change area covers the project area and also properties from 680 to 770 Whitford-Maraetai Rd (the 'future urban zone') which are not in the applicant's ownership but may be considered for future urban development.

Beachlands South LP have commissioned NIWA to provide estimates of contaminant generation associated with different phases of the development. These include: (1) estimates of runoff and sediment generation associated with earthworks during the construction phase of the proposed development, and (2) estimates of typical urban contaminants associated with the mature development in its final state. These estimates are to be provided to other parties to enable integrated assessment of the potential effects of the development on the embayment.

1.2 Scope

The scope of the assessment was to provide estimates of contaminant generation associated with earthworks during the construction phase of the proposed development, and from the mature development in its final state. Specifically, the following estimates were required:

1. Construction phase
   - Mean annual runoff volumes and sediment loads for an interim earthworks scenario reflecting the typical area over which earthworks may occur in a single season, for a range of slopes consistent with those in the project area;
   - Event-specific (24-hr) runoff volumes and sediment loads for a range of return periods (2, 5, 10, 20, 50 and 100 years) associated with the interim earthworks scenario; and
   - Indicative estimates of mean annual and event-specific runoff volumes and sediment loads discharged to Whitford Embayment, including disaggregation to a 5-minute time step.
2. Mature phase
   - Mean annual sediment and metal (zinc, copper) loads for the fully-developed state.

In both cases, the estimates were compared with baseline values representative of the current state. The spatial extent for the construction phase assessment is limited to the project area, as this is the only area that will be subject to any change in runoff and sediment loads as a result of earthworks for the proposed development. Any earthworks related to the potential development of the properties from 680 – 770 Whitford-Maraetai Rd would occur in future and therefore would not have a cumulative effect.

Conversely, the spatial extent for the mature phase assessment includes both the project area and the 'future urban zone', as this represents a worst-case assessment for discharges to the embayment should development of the full plan change area occur in future.

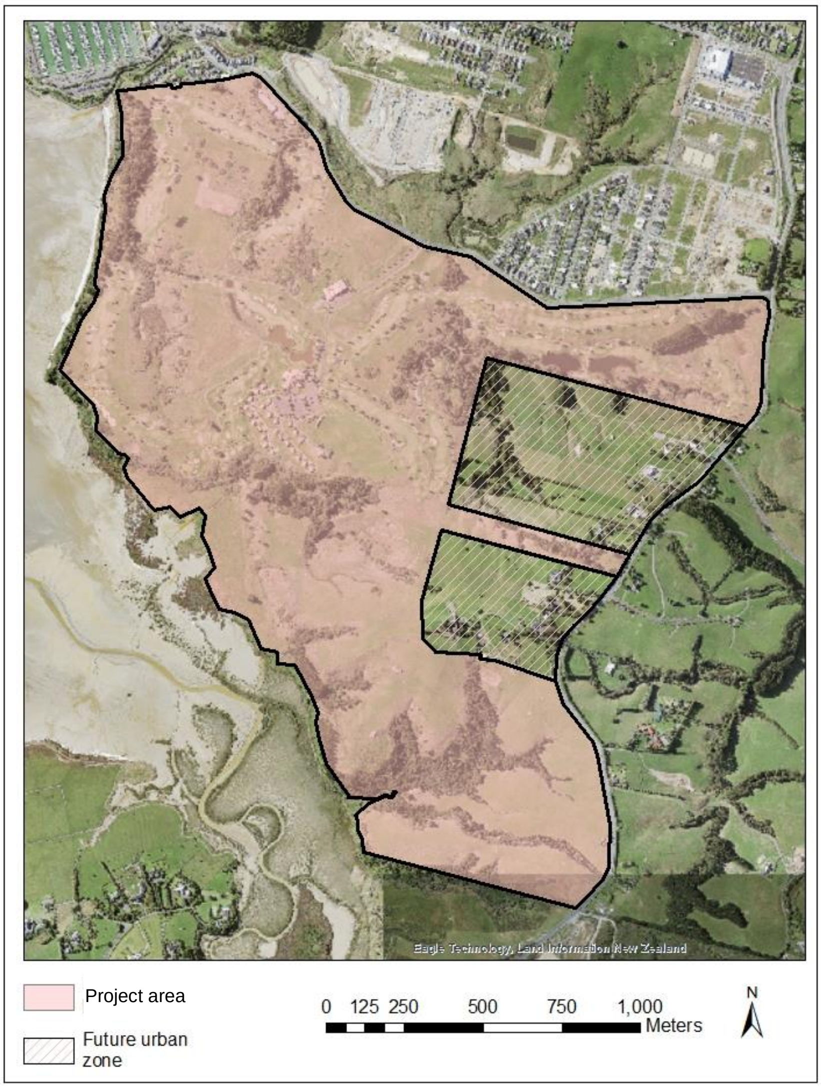

Figure 1-1: Plan change area. The plan change area includes the proposed development area (the project area), as well as the 'future urban zone' (the properties from 680 – 770 Whitford-Maraetai Rd which are not in the applicant's ownership but may be subject to future urban development).

1.3 Content and structure of this report

This report documents the methods and results for the assessments as outlined above. Section 2 contains details of the construction phase estimates while Section 3 describes the mature phase estimates. Details of the methods include summary descriptions of the models used, model input data and assumptions and post-processing of outputs where required.

1.4 Terminology

This report refers to "untreated" and "treated" loads. These are defined as follows:

- Untreated loads are the loads generated within the project / plan change area, prior to runoff entering any erosion and sediment control / stormwater treatment measures.
- Treated loads are the loads exiting erosion and sediment control / stormwater treatment measures, and which are discharged to the embayment.

2 Construction phase

2.1 Methods

Runoff and sediment loads associated with construction earthworks in the project area were estimated using the GLEAMS[1] model, following an established methodology adopted by NIWA in similar previous studies (Section 2.1.2). The methodology involves the following steps:

1. Collation and analysis of geospatial data on land cover, soil type and slope for the project area under baseline (existing land cover) conditions as well as all earthworks stages.
2. Running GLEAMS with a long-term climate record to generate daily runoff depth and sediment yield time series for a unit area of each possible land cover, soil type and slope combination identified in (1).
3. Aggregating the outputs from (2), with and without erosion and sediment control (ESC) measures, to derive mean annual runoff depth and sediment yield estimates for the project area reflecting changing land cover as the project progresses through seasons and stages.
4. Conducting frequency analyses to estimate 24-hr runoff volume and sediment loads for a range of return periods; and
5. Disaggregating the 24-hr runoff volume and sediment load estimates from (4) to a sub-hourly time step based on representative hydrographs.

2.1.1 Land cover, soil type and slope

Existing land cover was taken from the New Zealand Land Cover Database (LCDB) v5.0[2] and has the reference year 2018. The project area is predominantly pasture and urban parkland (including the golf resort), with some vegetated areas bordering streams. There is also a small area classed as built-up land within the golf resort; comprising the clubhouse, parking area and surrounding villas. The imperviousness of the built-up area was estimated using Land Information New Zealand (LINZ) building outlines[3] and aerial imagery[4] at approximately 39 %. There are also several ponds on the golf course which were designed primarily for irrigation[5] and are assumed not to act as sediment retention ponds.

This analysis used Land Information New Zealand (LINZ) building outlines[6] and aerial imagery[7] to delineate impervious surfaces

Land cover during the earthworks period was assumed to vary in a sequence through bare earth, mulched and fully stabilized covers. The relative proportion of these at any given time was determined from assumptions regarding the earthworks staging (see Section 2.1.7).

Soil type information was taken from the New Zealand Fundamental Soil Layers[8] developed by Manaaki Whenua Landcare Research. Existing soils in the project area are classified as Yellow Ultic soils, characterized as having clay subsoils with slow permeability and dispersible surface horizons

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[1] Groundwater Loading Effects of Agricultural Management Systems (Knisel, 1993)
[2] https://lris.scinfo.org.nz/layer/104400-lcdb-v50-land-cover-database-version-50-mainland-new-zealand/
[3] Downloaded from https://koordinates.com/from/data.linz.govt.nz/layer/101290/
[4] Supplied as a base layer in ArcGIS
[5] J. Dobrowolski, pers. comm. 5 May 2021.
[6] Downloaded from https://koordinates.com/from/data.linz.govt.nz/layer/101290/
[7] Supplied as a base layer in ArcGIS
[8] https://soils.landcareresearch.co.nz/soil-data/fundamental-soil-layers/

that are prone to erosion[9]. These soils were modelled as a single soil type following Senior et al. (2003). Soils during the earthworks period represent bare earth following the removal of topsoil and were modified from the existing soils to reflect the absence of the original upper soil horizon.

Existing slopes (in 3° intervals) were provided by Harrison Grierson, erosion and sediment control engineers for the project, based on a topographical survey of the project area. Final-state slopes were yet to be confirmed therefore all estimates were based upon existing slopes.

2.1.2 GLEAMS model

GLEAMS is a physically based model developed for continuous simulation of runoff and sediment losses on a field-scale. The model operates on unique combinations of land cover, soil type and slope. For each combination, GLEAMS simulates runoff and sediment losses from an arbitrary hillslope by applying a long-term climate record (comprising daily rainfall as well as monthly temperature, wind and solar radiation data), combined with a set of parameters reflecting soil and land cover characteristics. The output is a long-term series of daily runoff depth and sediment yield (load per unit area) for each combination, reflecting the range of climate conditions that may be experienced. Runoff volumes and sediment loads for an entire catchment or project area can then estimated by aggregating the GLEAMS outputs according to the area in each combination.

The model has been used in a number of past assessments of construction sediment loads, including those associated with urban development adjacent to the project area (Elliott & Stroud, 2007) and in the catchments of the Weiti River (Moores & Hoang, 2019) and the Okura River (Yalden & Moores, 2014) estuaries, as well as the Puhoi – Warkworth extension of State Highway 1 (Harper et al. 2013). In addition, GLEAMS has been used to estimate sediment generation from rural areas in peer-reviewed studies of the Central Waitemata Harbour (Parshotam & Wadhwa, 2008) and the Southeastern Manukau Harbour (Parshotam et al. 2008). GLEAMS is also part of WAM[10] which was used to model the effect of potential rural intensification scenarios in the Whitford catchment (Senior et al. 2003).

Further information on the application of GLEAMS can also be found in a New Zealand review of modelling methods for assessing the performance of erosion and sediment control (Basher et al. 2016).

2.1.3 Long-term climate record

The long-term climate record used by GLEAMS comprises daily rainfall and monthly temperature, wind and solar radiation data. For this project, we used a 50-year climate record (1971 – 2020) extended from an earlier climate record (1963 – 2001) developed for the Whitford catchment modelling study (Senior et al. 2003). Rainfall data for the earlier record was primarily derived from measurements at Cockle Bay (1963 – 1999; about 4 km west of the project area) and Ardmore (1999 – 2001; about 15 km south of the project area). Extension of the climate record between 2002 – 2020 is based on data from NIWA's National Climate Database[11] and Auckland Council's Environmental Data Portal[12] for the closest available sites. This comprises:

- Rainfall data from Ardmore (C74091) between January 2002 – September 2013 and Clevedon Coast RAWS @ Forest (659012) between October 2013 – December 2020.

[9] https://soils.landcareresearch.co.nz/describing-soils/nzsc/soil-order/ultic-soils
[10] Watershed Assessment Model
[11] https://cliflo.niwa.co.nz/
[12] https://environmentauckland.org.nz/

- Temperature data from Ardmore (C74091) between January 2002 – November 2016 and Ardmore Aero AWS (C74094) between December 2016 – December 2020.
- Wind data from Wiri (C64985) between January 2002 – April 2011, Mangere EWS (C64972) between May 2011 – December 2018 and Mangere 2 EWS (C64973) between January 2019 – December 2020.
- Solar radiation data from Auckland Aero (C74082) between January 2002 – December 2020.

2.1.4 Post-processing of model outputs

Per the steps outlined in the methodology, GLEAMS was run for each possible land cover, soil type and slope combination identified from the geospatial analysis, resulting in long term time series of daily runoff depth and sediment yield for each combination. For both the existing land cover and the interim earthworks scenario, the following post-processing steps were applied to these outputs to provide a data set from which mean annual and event-scale runoff and sediment load estimates could be generated.

1. **Generating time series of runoff volumes and untreated sediment loads**

   Aggregation of the GLEAMS outputs to provide time series of runoff volumes and untreated sediment loads involves summing the runoff depths and sediment yields for each combination, weighted by the area in each combination in any one month. For the existing land cover, the area in each combination is drawn from the geospatial analysis. For the interim earthworks scenario, the areas were based on staging information provided by Harrison Grierson (Section 2.1.7).

2. **Erosion and sediment control measures**

   For the interim earthworks scenario we have assumed the following ESC measures apply, as specified by Harrison Grierson:

   - Mulching and stabilization of bare earth areas on completion of bulk earthworks;
   - Chemically-treated sediment retention ponds (SRPs) for the capture and treatment of sediment from all areas of bulk earthworks.

   While the ponds are likely to be sized in exceedance of GD05[13] requirements, for the purposes of the interim earthworks scenario it was considered appropriate to assume pond performance in line with GD05 expectations. The performance of ESC measures was modelled by applying load reduction factors (LRFs) to the time series of untreated sediment yields produced by GLEAMS, so that:

   $$Treated\ yield = Untreated\ yield \times (1 - LRF_E) \times (1 - LRF_S) \quad (2.1)$$

   where LRF_E is an erosion control LRF and LRF_S is a sediment control LRF.

   LRFs adopted in previous studies were confirmed by the project's principal erosion and sediment control consultant[14]. The LRFs for erosion controls were 0.85 for mulch and 0.93 for full stabilisation. Table 2-1 presents the LRFs for sediment retention ponds.

[13] Auckland Council guideline document, 2016/005 (GD05): Erosion and sediment control guide for land disturbing activities in the Auckland Region https://www.aucklanddesignmanual.co.nz/regulations/technical-guidance
[14] C. McGregor, pers. comm. 7 May 2021.

Table 2-1: Assumed load reduction factors for sediment control measures.

Sediment control device	Load reduction factor, by return period		
	2-year ARI	10-year ARI	50-year ARI
SRP (chemically-treated)	0.95	0.85	0.65

LRFs for sediment retention ponds are specified for 2-, 10- and 50-year Annual Recurrence Interval (ARI) events. They are assumed to be inversely related to ARI because ponds become less effective with the reduced retention time associated with bigger events.

3. **Generating time series of treated sediment loads**

Time series of treated sediment loads were calculated by applying the LRFs described above to the time series of untreated sediment loads relating to bulk earthworks and stabilisation. This required threshold daily loads to be established to determine whether to apply the relevant 2-, 10- or 50-year ARI sediment control LRF to each daily untreated load. These thresholds were determined from estimates of the 6- and 30-year ARI daily loads; these being the mid-points between the three LRF classes. Table 2-2 summarises the application of the LRFs according to the value of each untreated daily sediment load.

Table 2-2: Application of sediment control LRFs to estimate treated sediment loads.

Value of untreated sediment load	LRF for estimation of treated sediment load
< 6-year ARI	2-year ARI
6-year ARI to 30-year ARI	10-year ARI
> 30-year ARI	50-year ARI

The 6- and 30-year ARI daily untreated sediment loads were estimated by frequency analysis of the 50-year time series outputs from GLEAMS. This involved fitting a distribution to a ranked series of sediment loads, from which the magnitude of the relevant ARI event could be estimated (Section 2.1.6).

We note that there is no requirement to calculate treated runoff volumes because the LRF-based method adopted to model SRPs does not factor in runoff attenuation.

2.1.5 Estimation of mean annual runoff volumes and sediment loads

Mean annual runoff volume and sediment load estimates were prepared directly from the time series of daily runoff volumes and sediment loads as follows:

$$\textit{Mean annual runoff volume} = \frac{1}{N}\sum_i \textit{runoff volume}_i \tag{2.2}$$

$$\textit{Mean annual sediment load} = \frac{1}{N}\sum_i \textit{sediment load}_i \tag{2.3}$$

where $\textit{runoff volume}_i$ and $\textit{sediment load}_i$ are, respectively, the runoff volume and sediment load on day i and N is the number of years in the time series.

2.1.6 Estimation of event runoff volumes and sediment loads

The project required estimates of 24-hr runoff volumes and sediment loads associated with 2-, 5-, 10-, 20-, 50- and 100-year ARI events. A partial duration frequency analysis approach was adopted whereby all values above a certain threshold are selected. This differs from the alternative annual maxima approach, whereby the highest values from each year of record are adopted. While the two approaches give similar results for the more extreme events, the partial duration analysis tends to give more conservative (i.e., slightly higher) estimates for low ARI events.

For this project, the partial duration approach involved ranking the 50-year time series of daily runoff volumes, treated and untreated sediment loads, and setting thresholds which resulted in the 50 largest values being selected for each. Generalized Pareto distributions were then fitted to the selected values and the 2-, 5-, 10-, 20-, 50- and 100-year ARI events were estimated from these distributions. It should be noted that there is considerable uncertainty around the 100-year ARI events given that the records consist of only 50 years of data.

2.1.7 Interim earthworks scenario

Earthworks associated with the proposed development are anticipated to occur over a total area of approximately 120 ha and are required to form road corridors, superlot platforms and stormwater management devices as well as to allow for the installation of drainage and utilities[15].

As the project is at an early stage, a specific catchment analysis of the proposed earthworks areas is yet to be undertaken. Instead, Harrison Grierson provided an interim earthworks scenario assuming a representative 15 ha catchment with uniform slope, worked over a single season. The sequence of works is carried out in three 5 ha subcatchments, with a maximum of 5 ha disturbed area at any one time. Figure 2-1 shows the assumed areas of earthworks and other land covers in each month (see also Table A-1 in Appendix A).

The representative catchment is not spatially referenced within the project area. Instead, runoff and sediment load estimates were prepared for four different slope classes: 0 – 3°, 3° – 6°, 6° – 9° and 9° – 12° to indicate the magnitude of loads that may be expected given the range of typical slopes in the project area. As a conservative approach, we have assumed an existing land cover consistent with the golf course (which produces the lowest baseline loads and will therefore result in the largest increase under earthworks).

2.1.8 Estimates of discharges to Whitford Embayment

To inform the wider assessment of effects of the development on Whitford Embayment, we have placed the runoff and sediment load estimates for the interim earthworks scenario in the context of discharges to the embayment, based on a set of conservative assumptions about the location and timing of earthworks in the project area as described below.

A set of five indicative earthworks catchments were provided by Harrison Grierson (Figure 2-2). These catchments were clipped to the project area – the spatial extent for this part of the assessment (Section 1.2). Runoff from the indicative earthworks catchments is assumed to enter the embayment at five outlet points, denoted A – E. Additional areas outside the extent of these catchments, but within the project area, are shown cross-hatched in Figure 2-2.

[15] As referenced in the project's draft Erosion and Sediment Control Report prepared by Harrison Grierson

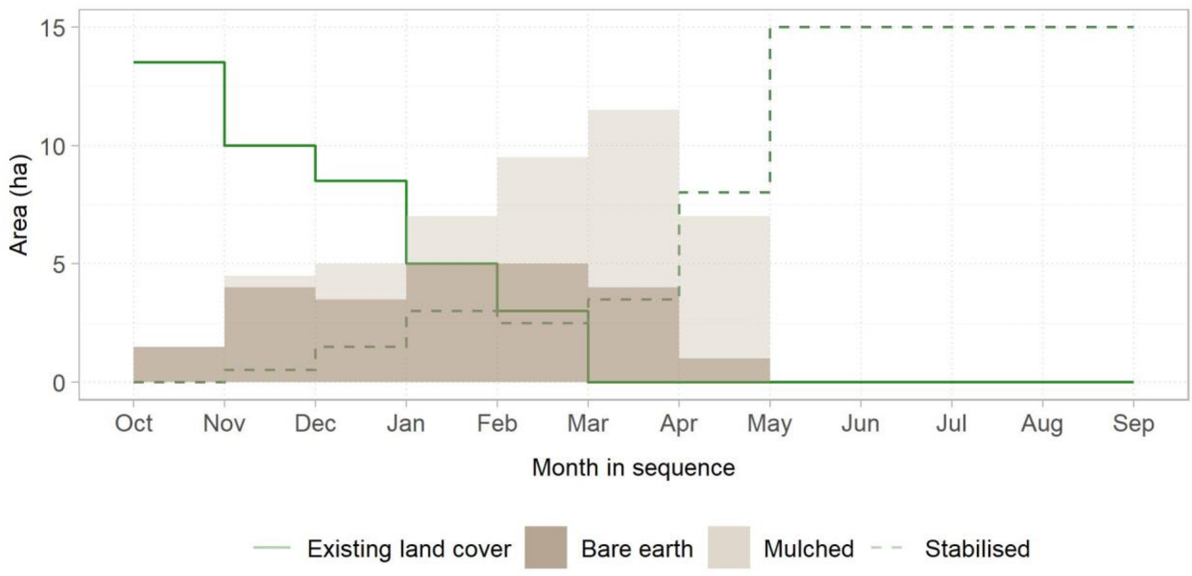

Figure 2-1: Assumed areas of earthworks and other land covers in each month.

In consultation with Harrison Grierson, and for the purposes of this assessment, it was assumed that within each of the five indicative earthworks catchments 15 ha of earthworks can be completed in a single season, with a maximum of 5 ha exposed at any one time[16]. As a conservative approach, we have also assumed that: (a) earthworks occur concurrently in all five catchments, and (b) the earthworks area in each catchment covers the steepest 15 ha of the developable area.

We note that this is an indicative scenario designed to inform the plan change assessment while a specific catchment analysis of the proposed earthworks areas is still being undertaken. It does not preclude earthworks in areas outside of the indicative earthworks catchments (cross-hatched in Figure 2-2), however it is considered representative of the likely magnitude and extent of works in a single season.

Daily time series of runoff and sediment loads for the earthworks area in each indicative earthworks catchment were estimated according to the following steps:

1. Daily time series of runoff and sediment loads for the 15-ha representative catchment in each slope class (from the interim earthworks scenario) were converted to yields.
2. These representative yields were then aggregated according to the earthworks area in each catchment in each slope class (Table 2-3)[17].

Daily time series of runoff and sediment loads for the total area in each catchment were then estimated by first subtracting the daily runoff and sediment loads assessed for the earthworks area under the existing land cover from those for the total area, then adding the values described above. Mean annual runoff volumes and sediment loads, and 24-hr event loads, for the total area in each catchment were then prepared from the daily time series following the methods described in previous sections.

[16] As specified in the project's draft Erosion and Sediment Control Report.
[17] Areas with slope greater than 12° were added to the 9° – 12° slope class. These areas represent a relatively small proportion of the steepest 15 ha in each indicative earthworks catchment (between 1 – 5 ha).

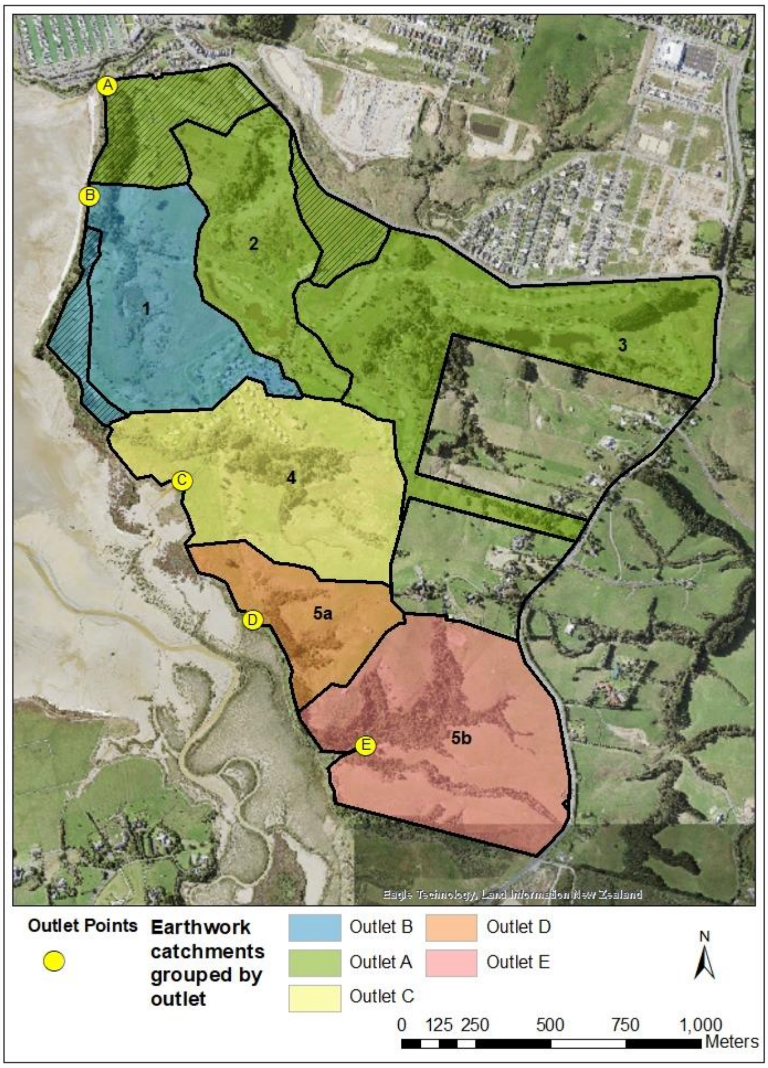

Figure 2-2: Indicative earthworks catchments. The indicative earthworks catchments, labelled 1 - 5, are coloured by assumed outlet point to Whitford Embayment. Cross-hatched areas, also coloured by outlet point, are outside the extent of the indicative earthworks catchments provided, but within the project area and therefore contribute to the assessment (see text).

Table 2-3: Interim earthworks catchments. Slope breakdown of the steepest 15 ha of developable area in each catchment.

Quantity		Interim earthworks catchment					
		1	2	3	4	5a	5
Catchment area (ha)		32.60	28.22	54.72	43.63	17.42	48.93
Developable area (ha)		23.27	23.29	41.06	24.26	8.64	27.96
Slope class area (ha)*	0° – 3°	0.00	0.48	0.00	0.00	0.81	0.00
	3° – 6°	8.40	8.02	0.00	4.91	3.31	2.53
	6° – 9°	3.67	3.75	4.86	4.88	1.96	7.48
	9° – 12°	2.93	2.75	10.14	5.21	2.56	4.99
	Total	**15.00**	**15.00**	**15.00**	**15.00**	**8.64**	**15.00**

*Area of the steepest 15 ha of the developable area in each slope class

The caveat to this approach is that existing land cover for the earthworks area under the interim scenario is assumed to be consistent with the golf course, which may not necessarily correspond with the existing land cover for the steepest 15 ha of the developable area in each catchment. For sediment loads this will result in an even more conservative assessment, as the golf course land cover is associated with the lowest sediment yields. Runoff from the golf course land cover is, however, somewhat higher than from pasture or forested land covers (consistent with the greater grass cover), therefore the estimates of runoff volume discharged to the embayment under this approach should be considered as indicative only.

2.1.9 Disaggregation of event runoff volumes and sediment loads

The project required the 24-hr runoff volume and sediment load estimates for the 2-, 10- and 100-yr ARI events to be disaggregated to a 10-minute time step, to inform hydrodynamic modelling of sediment deposition in the embayment. This involved the development of design storm hydrographs and their use to distribute the daily runoff and load estimates, according to the following steps:

1. Design rainfall hyetographs for each ARI were developed using estimates of 24-hr duration rainfall depths from NIWA's High Intensity Rainfall Design System (HIRDS) and the design rainfall distribution given in Auckland Council (2021).
2. Design runoff hydrographs for each ARI and each indicative earthworks catchment[18] were estimated using the HEC-HMS hydrological modelling software with the rainfall inputs from (1). This involved:
    (a) Representing the catchment areas as two sub-basins (bulk earthworks and existing land cover);
    (b) Estimating rainfall losses using the SCS curve method; and
    (c) Routing the runoff from the bulk earthworks area through a reservoir representing the storage and discharge characteristics of sediment retention ponds.
3. Suspended sediment concentrations (SSCs) based on the hydrographs from (2) were estimated at each 10-minute time step using relationships derived from previous monitoring of an SRP (Moores & Pattinson 2008; see also Appendix B).
4. Design event 24-hr total runoff and sediment loads were calculated from (2) and (3).
5. Disaggregated runoff (m^3/s) and sediment load (kg) estimates were prepared by scaling the design event runoff and sediment load estimates at each time step (t) according to

$$runoff_F(t) = runoff_D(t) \times \left(total\ runoff_F / total\ runoff_D\right) \quad (2.4)$$

$$load_F(t) = load_D(t) \times \left(total\ load_F / total\ load_D\right) \quad (2.5)$$

   where F is the frequency analysis estimate and D is the design event estimate.

The result is a set of time series (at 10-minute time steps) in which the daily runoff and sediment load estimates derived from the frequency analysis (Section 2.1.6) are distributed according to the shape of the hydrographs from the design event analysis.

[18] Including cross-hatched areas shown in Figure 2-2

2.2 Results

2.2.1 Interim earthworks scenario

Mean annual runoff volumes and sediment loads

Table 2-4 presents estimates of mean annual runoff volumes, treated and untreated sediment loads for the 15-ha representative catchment by slope class, for each land cover (existing, bulk earthworks and stabilised) and in total. We note that the mean annual runoff volume does not vary with slope class, because GLEAMS estimates of runoff vary only by land cover and soil type, not slope.

The estimated mean annual runoff volume under the baseline and interim earthworks scenarios is approximately equal, with an increase of only 2 % between scenarios. A similar proportion of the mean annual runoff under the interim earthworks scenario is generated from bulk earthworks and stabilised land covers, with a much smaller proportion from existing land cover (as expected from the progression of land cover shown in Figure 2-1).

The estimated mean annual treated sediment loads under the interim earthworks scenario are between 6.7 and 24.7 times higher than the equivalent baseline loads over all slope classes. The maximum relative increase occurs at the lowest slope class (0° – 3°), as the rate at which GLEAMS estimates of sediment yields increase with slope is greater at shallower than at steeper slopes. For the lower slope classes, the majority of the mean annual treated sediment load (between 53 % and 68 %) is generated from bulk earthworks land covers, whereas for the higher slope classes the majority of the load (between 53 % and 57 %) is generated from the stabilised land cover. The relatively high stabilised loads reflect the fact that yields for this land cover are higher than those adopted for the existing land cover (an existing land cover consistent with the golf course was deliberately chosen to produce the maximum earthworks effect; see Section 2.1.7), and this land cover is exposed to rainfall over the winter months.

Mean annual untreated sediment load estimates are around an order of magnitude higher than the equivalent treated load estimates, with a maximum of approximately 305 tonnes for the highest slope class (9° – 12°) compared to the treated value of around 48 tonnes. The reduction factor between the untreated and treated mean annual sediment loads for the bulk earthworks land cover is around 91 % for all slope classes, reflecting the range of pond performance across different event sizes (Table 2-1) and the frequency of these events in the 50-year time series.

Event runoff volumes and sediment loads

Table 2-5 presents estimates of 24-hr runoff volumes, treated and untreated sediment loads for the 15-ha representative catchment for 2-, 5-, 10-, 20-, 50- and 100-yr ARI events, by slope class. As with the mean annual runoff volumes, the 24-hr runoff volumes do not vary with slope class.

There is essentially no change in the 24-hr runoff volumes estimated for the baseline and interim earthworks scenarios for the 2-yr and 5-yr ARI events. For the less frequent events, estimates of the 24-hr runoff volume under the interim earthworks scenario increase between 4.9 % (10-yr ARI) and 38.3 % (100-yr ARI) over baseline values, with the effect increasing with return period.

The 24-hr treated sediment load estimates under the interim earthworks scenario are between 6.4 and 36.4 times higher than the equivalent baseline loads over all slope classes across the range of ARI events. Similar to the mean annual loads, the greatest relative increase at each ARI level occurs at the lowest slope class; for example, at the 2-yr ARI, the estimated 24-hr treated sediment load under the interim earthworks scenario is 11.8 times higher than the equivalent baseline load at the lowest slope class (0° – 3°), and 6.4 times higher at the highest slope class (9° – 12°). The relative increase is also typically greater at higher return periods, with the maximum increase of 36.4 times the baseline occurring for the 100-yr ARI event.

The 24-hr untreated sediment load estimates under the interim earthworks scenario are between 4.5 and 12.4 times higher than the equivalent treated load estimates (and between 42.3 and 183.1 times higher than the equivalent baseline loads). The greatest proportional reductions between untreated and treated loads across slope classes occur for the 2-yr ARI event while the lowest occur for the 100-yr ARI event, consistent with the reduction in pond performance for extreme events.

Table 2-4: Mean annual runoff volumes, treated and untreated sediment loads for the 15-ha representative catchment by slope class. Baseline values represent the runoff volumes and (untreated) sediment loads under the existing land cover.

Quantity	Land cover	Baseline				Interim earthworks				Increase over baseline			
		0 – 3°	3° – 6°	6° – 9°	9° – 12°	0 – 3°	3° – 6°	6° – 9°	9° – 12°	0 – 3°	3° – 6°	6° – 9°	9° – 12°
Runoff volume (m^3)	Existing	25463	25463	25463	25463	3644	3644	3644	3644	-21819	-21819	-21819	-21819
	Bulk earthworks	-	-	-	-	10889	10889	10889	10889	10889	10889	10889	10889
	Stabilised	-	-	-	-	11360	11360	11360	11360	11360	11360	11360	11360
	Total	**25463**	**25463**	**25463**	**25463**	**25893**	**25893**	**25893**	**25893**	**430**	**430**	**430**	**430**
	Depth (mm)	**170**	**170**	**170**	**170**	**173**	**173**	**173**	**173**	**3**	**3**	**3**	**3**
Treated sediment load (tonnes)	Existing	0.10	1.40	4.21	8.45	0.01	0.18	0.55	1.12	-0.09	-1.22	-3.66	-7.33
	Bulk earthworks	-	-	-	-	1.68	7.61	14.99	23.14	1.68	7.61	14.99	23.14
	Stabilised	-	-	-	-	0.78	6.55	17.37	32.54	0.78	6.55	17.37	32.54
	Total	**0.10**	**1.40**	**4.21**	**8.45**	**2.47**	**14.34**	**32.91**	**56.80**	**2.37**	**12.94**	**28.70**	**48.35**
	Yield (tonnes km^{-2})	**0.67**	**9.33**	**28.07**	**56.33**	**16.47**	**95.60**	**219.40**	**378.67**	**15.80**	**86.27**	**191.33**	**322.34**
Untreated sediment load (tonnes)	Existing	0.10	1.40	4.21	8.45	0.01	0.18	0.55	1.12	-0.09	-1.22	-3.66	-7.33
	Bulk earthworks	-	-	-	-	18.59	88.19	178.29	279.67	18.59	88.19	178.29	279.67
	Stabilised	-	-	-	-	0.78	6.55	17.37	32.54	0.78	6.55	17.37	32.54
	Total	**0.10**	**1.40**	**4.21**	**8.45**	**19.38**	**94.92**	**196.21**	**313.33**	**19.28**	**93.52**	**192.00**	**304.88**
	Yield (tonnes km^{-2})	**0.67**	**9.33**	**28.07**	**56.33**	**129.20**	**632.80**	**1308.07**	**2088.87**	**128.53**	**623.47**	**1280.00**	**2032.53**

Table 2-5: ARI 24-hr runoff volumes, treated and untreated sediment loads for the 15-ha representative catchment by slope class. Baseline values represent the runoff volumes and (untreated) sediment loads under the existing land cover.

Quantity	ARI (years)	Baseline				Interim earthworks				Increase over baseline			
		0 – 3°	3° – 6°	6° – 9°	9° – 12°	0 – 3°	3° – 6°	6° – 9°	9° – 12°	0 – 3°	3° – 6°	6° – 9°	9° – 12°
Runoff volume (m^3)	2	5982	5982	5982	5982	5809	5809	5809	5809	-173	-173	-173	-173
	5	8292	8292	8292	8292	8269	8269	8269	8269	-23	-23	-23	-23
	10	10328	10328	10328	10328	10830	10830	10830	10830	502	502	502	502
	20	12652	12652	12652	12652	14208	14208	14208	14208	1556	1556	1556	1556
	50	16233	16233	16233	16233	20386	20386	20386	20386	4153	4153	4153	4153
	100	19390	19390	19390	19390	26817	26817	26817	26817	7427	7427	7427	742713
Treated sediment load (tonnes)	2	0.05	0.50	1.36	2.64	0.59	3.72	9.14	16.93	0.54	3.22	7.78	14.29
	5	0.08	0.75	2.04	3.98	2.10	11.61	23.05	35.81	2.02	10.86	21.01	31.83
	10	0.12	0.99	2.71	5.27	3.39	15.68	33.57	52.48	3.27	14.69	30.86	47.21
	20	0.17	1.30	3.54	6.87	4.40	20.00	38.98	63.21	4.23	18.70	35.44	56.34
	50	0.26	1.84	4.95	9.56	5.89	26.29	51.73	79.72	5.63	24.45	46.78	70.16
	100	0.37	2.36	6.33	12.16	13.48	56.75	108.28	163.99	13.11	54.39	101.95	151.83
Untreated sediment load (tonnes)	2	0.05	0.50	1.36	2.64	7.29	36.06	71.88	111.61	7.24	35.56	70.52	108.97
	5	0.08	0.75	2.04	3.98	13.70	64.50	126.22	193.73	13.62	63.75	124.18	189.75
	10	0.12	0.99	2.71	5.27	20.59	93.18	180.50	275.40	20.47	92.19	177.79	270.13
	20	0.17	1.30	3.54	6.87	29.94	129.95	249.60	378.94	29.77	128.65	246.06	372.07
	50	0.26	1.84	4.95	9.56	47.60	194.97	370.69	559.51	47.34	193.13	365.74	549.95
	100	0.37	2.36	6.33	12.16	66.58	260.50	491.67	739.09	66.21	258.14	485.34	726.93

2.2.2 Discharges to Whitford Embayment

Mean annual runoff volumes and sediment loads

Table 2-6 presents estimates of mean annual runoff volumes, treated and untreated sediment loads discharged to Whitford Embayment from the interim earthworks catchments, aggregated by outlet.

The mean annual runoff volumes estimated for the interim earthworks scenario are approximately equal to the baseline values, with a factor increase of just 1.01, of 1 %, across outlets.

Estimates of the mean annual treated sediment loads under the interim earthworks scenario are between 2.4 and 3.4 times higher than the equivalent baseline values across outlets. The relative increase is higher for Outlets A and B than Outlets C – E, as the proportion of the earthworks area in the lower slope classes (0° – 3°, 3° – 6°) is higher for the interim earthworks catchments discharging to these outlets (see Table 2-3).

The estimated mean annual untreated sediment loads under the interim earthworks scenario are approximately four times higher than the equivalent treated value across outlets. For example, the mean annual untreated sediment under the interim earthworks scenario for Outlet A is 427.52 tonnes (13 times greater than the equivalent baseline value), compared with the treated value of 69.75 tonnes.

Table 2-6: Mean annual runoff volumes, treated and untreated sediment loads discharged to Whitford Embayment by outlet location. Baseline values represent the runoff volumes and (untreated) sediment loads under the existing land cover. Increase represents the relative difference between scenarios, both in magnitude and as the factor by which baseline values are multiplied (in parentheses).

Quantity	Outlet	Baseline scenario	Interim earthworks scenario	Increase
Runoff volume (m^3)	A	165228	166088	860 (1.01)
	B	66824	67254	430 (1.01)
	C	61553	61983	430 (1.01)
	D	17610	17857	247 (1.01)
	E	47594	48024	430 (1.01)
	Total	**358809**	**361206**	**2397 (1.01)**
Treated sediment load (tonnes)	A	32.95	102.70	69.75 (3.1)
	B	10.49	35.35	24.86 (3.4)
	C	22.63	54.60	31.97 (2.4)
	D	11.07	26.07	15.00 (2.4)
	E	22.15	56.60	34.45 (2.6)
	Total	**99.29**	**275.32**	**176.03 (2.8)**
Untreated sediment load (tonnes)	A	32.95	460.47	427.52 (13.0)
	B	10.49	170.56	160.07 (16.3)
	C	22.63	223.17	200.54 (9.9)
	D	11.07	109.96	98.89 (9.9)
	E	22.15	236.97	214.82 (10.7)
	Total	**99.29**	**1201.13**	**1101.84 (12.1)**

Event runoff volumes and sediment loads

Table 2-7 presents estimates of 24-hr runoff volumes, treated and untreated sediment loads discharged to Whitford Embayment from the interim earthworks catchments, aggregated by outlet, for 2-, 5-, 10-, 20-, 50- and 100-yr ARI events.

There is no appreciable change in the 24-hr runoff volume estimated between the interim earthworks and baseline scenarios for the 2-, 5- and 10-yr ARI events, across outlets. For the less frequent events, estimates of the 24-hr runoff volume under the interim earthworks scenario increase between 4 % (20-yr ARI) and 21 % (100-yr ARI) over baseline values, with the effect typically increasing with return period, across outlets.

The 24-hr treated sediment load estimates for the 2-yr ARI event under the interim earthworks scenario are between 2.1 and 3 times higher than the equivalent baseline loads across outlets. For the 10-yr ARI, the relative increase is only slightly higher (between 2.7 and 4.4 times). The largest relative increase occurs for the 100-yr ARI event, where the treated load estimates are between 5.2 and 11.4 times higher than the baseline values across outlets. Similar to the mean annual sediment loads, the relative increase for Outlets A and B is higher than for Outlets C – E at each ARI level, reflecting the higher proportion of earthworks area in lower slopes discharging to these outlets.

The 24-hr untreated sediment load estimates under the interim earthworks scenario are between 2.2 and 5.9 times higher than the equivalent treated loads across outlets (and between 9.5 and 26.5 times higher than the equivalent baseline loads), for all ARI events. The greatest relative difference between untreated and treated loads occurs for the 2-yr ARI event while the lowest occurs for the 100-yr ARI event, consistent with poorer pond performance for extreme events.

Details of the disaggregated 24-hr runoff and sediment loads for the 2-, 10- and 100-yr ARI events at 10-minute time steps are discussed in Appendix C.

Table 2-7: 24-hr ARI runoff volumes, treated and untreated sediment loads discharged to Whitford Embayment under the interim earthworks scenario by outlet. Baseline values represent the runoff volumes and (untreated) sediment loads under the existing land cover. Interim values represent the interim earthworks scenario. Increase represents the relative difference between scenarios, both in magnitude and as the factor by which baseline values are multiplied (in parentheses).

ARI (years)	Outlet	Runoff volume (m^3)			Treated sediment load (tonnes)			Untreated sediment load (tonnes)		
		Baseline	Interim	Increase	Baseline	Interim	Increase	Baseline	Interim	Increase
2	A	39122	38776	-346 (0.99)	11.06	31.03	19.97 (2.8)	11.06	164.40	153.34 (14.9)
	B	14433	14260	-173 (0.99)	3.53	10.54	7.01 (3.0)	3.53	61.99	58.46 (17.6)
	C	14482	14309	-173 (0.99)	8.49	17.67	9.18 (2.1)	8.49	80.91	72.42 (9.5)
	D	5188	5087	-101 (0.98)	4.17	8.70	4.53 (2.1)	4.17	40.24	36.07 (9.7)
	E	14200	14027	-173 (0.99)	8.37	18.21	9.84 (2.2)	8.37	85.78	77.41 (10.3)
	Total	**87425**	**86459**	**-966 (0.99)**	**35.62**	**86.15**	**50.53 (2.4)**	**35.62**	**433.32**	**397.70 (12.2)**
5	A	54348	54301	-47 (0.99)	16.87	54.90	38.03 (3.3)	16.87	285.69	268.82 (16.9)
	B	19976	19952	-24 (0.99)	5.37	19.06	13.69 (3.6)	5.37	108.51	103.14 (20.2)
	C	20517	20493	-24 (0.99)	13.27	30.87	17.60 (2.3)	13.27	140.41	127.14 (10.6)
	D	7411	7395	-16 (0.99)	6.50	15.22	8.72 (2.3)	6.50	69.94	63.44 (10.8)
	E	20372	20348	-24 (0.99)	13.22	32.06	18.84 (2.4)	13.22	149.00	135.78 (11.3)
	Total	**122624**	**122489**	**-135 (0.99)**	**55.23**	**152.11**	**96.88 (2.8)**	**55.23**	**753.55**	**698.32 (13.6)**
10	A	68031	69033	1002 (1.01)	22.39	86.29	63.90 (3.9)	22.39	406.54	384.15 (18.2)
	B	24958	25460	502 (1.02)	7.11	30.95	23.84 (4.4)	7.11	154.95	147.84 (21.8)
	C	25886	26387	501 (1.02)	17.80	47.87	30.07 (2.7)	17.80	199.58	181.78 (11.2)
	D	9500	9786	286 (1.03)	8.86	23.75	14.89 (2.7)	8.86	99.72	90.86 (11.3)
	E	26073	26575	502 (1.02)	18.08	50.34	32.26 (2.8)	18.08	212.12	194.04 (11.7)
	Total	**154448**	**157241**	**2793 (1.02)**	**74.24**	**239.20**	**164.96 (3.2)**	**74.24**	**1072.91**	**998.67 (14.5)**

Table 2-7 cont. 24-hr ARI runoff volumes, treated and untreated sediment loads discharged to Whitford Embayment under the interim earthworks scenario by outlet.

ARI (years)	Outlet	Runoff volume (m^3)			Treated sediment load (tonnes)			Untreated sediment load (tonnes)		
		Baseline	Interim	Increase	Baseline	Interim	Increase	Baseline	Interim	Increase
20	A	83912	87026	3114 (1.04)	29.10	137.90	108.80 (4.7)	29.10	560.00	530.90 (19.2)
	B	30746	32303	1557 (1.05)	9.20	51.59	42.39 (5.6)	9.20	214.04	204.84 (23.3)
	C	32063	33620	1557 (1.05)	23.30	75.62	52.32 (3.3)	23.30	274.58	251.28 (11.8)
	D	12020	12915	895 (1.07)	11.87	37.71	25.84 (3.2)	11.87	137.71	125.84 (11.6)
	E	32851	34408	1557 (1.05)	24.26	80.66	56.40 (3.3)	24.26	292.40	268.14 (12.1)
	Total	**191592**	**200272**	**8680 (1.05)**	**97.73**	**383.48**	**285.75 (3.9)**	**97.73**	**1478.73**	**1381.00 (15.1)**
50	A	108895	117199	8304 (1.08)	40.31	262.30	221.99 (6.5)	40.31	828.20	787.89 (20.6)
	B	39850	44003	4153 (1.10)	12.64	104.57	91.93 (8.3)	12.64	317.49	304.85 (25.1)
	C	41678	45831	4153 (1.10)	32.44	142.58	110.14 (4.4)	32.44	405.41	372.97 (12.5)
	D	16167	18559	2392 (1.15)	17.21	71.33	54.12 (4.1)	17.21	204.51	187.30 (11.9)
	E	43814	47966	4152 (1.09)	35.11	154.74	119.63 (4.4)	35.11	432.96	397.85 (12.3)
	Total	**250404**	**273558**	**23154 (1.09)**	**137.71**	**735.52**	**597.81 (5.3)**	**137.71**	**2188.57**	**2050.86 (15.9)**
100	A	131358	146213	14855 (1.11)	50.99	432.99	382.00 (8.5)	50.99	1095.52	1044.53 (21.5)
	B	48038	55466	7428 (1.15)	15.89	181.59	165.70 (11.4)	15.89	420.82	404.93 (26.5)
	C	50234	57661	7427 (1.15)	41.10	235.13	194.03 (5.7)	41.10	535.58	494.48 (13.0)
	D	20064	24346	4282 (1.21)	22.59	117.52	94.93 (5.2)	22.59	271.46	248.87 (12.0)
	E	53941	61368	7427 (1.14)	45.96	258.05	212.09 (5.6)	45.96	573.28	527.32 (12.5)
	Total	**303635**	**345054**	**41419 (1.14)**	**176.53**	**1225.28**	**1048.75 (6.9)**	**176.53**	**2896.66**	**2720.13 (16.4)**

3 Mature phase

3.1 Methods

Mean annual sediment (total suspended solids; TSS) and metal (zinc; Zn, and copper; Cu) loads associated with the mature phase of the development were estimated using the C-CALM[19] model. The methodology involves the following steps:

1. Collation and analysis of land cover and stormwater treatment information for the plan change area (including the project area and future-urban-zone; see Section 1.2) consistent with a fully-developed scenario.

2. Applying C-CALM with the land cover areas and stormwater treatment options identified in (1) to generate mean annual loads of TSS, Zn and Cu for the fully-developed scenario.

For comparison, mean annual TSS, Zn and Cu loads were also estimated for the baseline (existing land cover) scenario based on GLEAMS sediment yields (Section 3.1.6).

3.1.1 C-CALM

C-CALM was developed by NIWA as a planning tool at the urban catchment or stormwater management unit scale; it embeds Auckland Council's CLM[20] spreadsheet model into a GIS platform, and has greater flexibility in assessing stormwater treatment options. C-CALM estimates mean annual loads of TSS, Zn and Cu generated from diffuse sources in the catchment, represented as land cover types (e.g., roofs, roads, and paved surfaces). For each catchment, the mean annual load (kg) is calculated as the sum of the contribution from each source type, i.e.,

$$\textit{Mean annual load} = \sum_{n=1}^{N} area_n \times yield_n \times TF_n \times (1 - LRF_n) \qquad (3.1)$$

where N is the number of diffuse sources present, and $area_n$ (m^2), $yield_n$ ($kg/m^2/yr$), TF_n and LRF_n are the area, mean annual contaminant yield, treated fraction of the area and load reduction factor associated with stormwater treatment for source type n.

A point of difference between C-CALM and the CLM is that C-CALM splits metals into dissolved and particulate fractions. It also has variable treatment efficiencies based on catchment properties, sediment particle size distribution (PSD), and has more flexibility in the choice and design of treatment options, including allowing complex treatment-train scenarios (Semadeni-Davies, 2008). The default particulate metal fractions used in C-CALM are: 5 % for all roof types, 60 % for all roads and paved surfaces, and 95 % for all other (permeable) surfaces. The partitioning for roofs and permeable surfaces was extrapolated from analysis of Auckland stormwater data, while the partitioning for roads and paved surfaces is based on a statistical analysis of data from around the country on total and particulate Zn and Cu median concentrations in untreated road runoff. These data are held in NIWA's Urban Runoff Quality Information System (URQIS) database[21] (Gadd et al. 2013; Gadd et al. 2014).

[19] Catchment Contaminant Annual Loads Model (Semadeni-Davies et al. 2010; Semadeni-Davies & Wadhwa, 2014)
[20] Contaminant Load Model (Auckland Regional Council 2010; Timperley et al. 2010)
[21] http://urqis.niwa.co.nz

3.1.2 Source types and contaminant yields

The C-CALM source types (land covers) and associated contaminant yields relevant to this assessment are listed in Table 3-1. The yields for roofs and roads are the same as the default CLM values, however the yields for paved and permeable surfaces have been modified for the purposes of this assessment, as described below.

Table 3-1: Relevant CLM and C-CALM land covers and associated contaminant yields. Yields for roofs and roads are the same as the default CLM values (Auckland Regional Council 2010). Yields for paved and permeable surfaces have been modified for this assessment as described in the text.

Source	Type	Yield ($g/m^2/yr$)		
		TSS	Zn	Cu
Roofs	Zinc/aluminium, coated	5	0.0200	0.0016
	Concrete tile	16	0.0200	0.0033
Roads (vehicles per day; vpd)	< 1000	21	0.0044	0.0015
	1000 – 5000	28	0.0266	0.0089
	5000 – 20000	53	0.1108	0.0370
Paved surfaces	Residential	21	0.0044	0.0015
	Commercial	21	0.0044	0.0015
Permeable surfaces	Urban grassland and trees	22	0.0008	0.0002
	Urban bush	4	0.0001	0.00003

Unlike the CLM yields for roofs and roads, which were derived from actual observations (sampling) of runoff concentrations, the yields for paved surfaces were derived from model calibration (Auckland Regional Council 2010). As such, the CLM yields for paved surfaces incorporate the “true” paved surface yields plus errors in the yields for all other sources. These yields are therefore only applicable to sites of similar size and complexity to the calibration catchments. The calibration catchments, including Mission Bay (100 % residential) and Aotea Square (100 % commercial), differ substantially in age to the proposed development and could reflect a very different land cover mix (e.g., older roofing materials). The default CLM contaminant yields for paved surfaces were therefore not considered applicable for this assessment. Instead, for paved surfaces we have adopted the same contaminant yields as for the lowest-trafficked road class, because the paved surfaces under the fully-developed scenario will be largely carparks, driveways and Joint-Owned Access Lots (JOALs), as well as footpaths etc.

The CLM TSS yields for urban grassland and trees were also derived as part of model calibration and are recognised to be somewhat uncertain (Auckland Regional Council 2010). For consistency with the assessment of sediment loads under the existing land cover, we have adopted the average of the GLEAMS yields for the golf course land cover across all slope classes, weighted by the proportion of the plan change area in each slope class[22]. This results in a TSS yield of 22 $g/m^2/yr$ for urban grassland and trees compared with the default CLM value of 45 $g/m^2/yr$. Corresponding metal yields were derived by multiplying the adjusted TSS yield by representative background concentrations of Zn and Cu found in Auckland soils (35 and 7 mg/kg, respectively; Auckland Regional Council 2010).

[22] Based on existing slopes since final-state slopes were not available.

Ecological areas in the proposed development are expected to be heavily planted and are assumed to be largely represented by the urban bush land cover. Similar to urban grassland and trees, TSS yields for urban bush have been derived from the average of the GLEAMS yields for bush land cover across all slope classes, weighted by the proportion of the plan change area in each slope class. Corresponding metal yields were derived by multiplying the TSS yield by the representative background concentrations for Zn and Cu.

3.1.3 Land cover areas

Land use categories and associated areas under the fully-developed scenario were provided by Jasmax, urban design consultants for the project, by stormwater catchment[23]. The stormwater catchments for the plan change area are shown in Figure 3-1 and the land use categories are shown in Figure 3-2. The associated land use areas are listed in Table 3-2.

In consultation with Jasmax and Harrison Grierson, the land use category areas were mapped to the C-CALM land covers in Table 3-1 as follows:

- Ecological areas were assumed to be 80 % urban bush, 10 % urban grassland and trees and 10 % paved surfaces[24].
- Gross residential areas are a mix of JOALs / home-zones (very low trafficked areas, but impervious surfaces) and net (developable) residential lot area. The fraction of gross residential area in each stormwater catchment in JOALs / home-zones and net residential lot area was specified by Jasmax. JOALs / home-zones were assumed to be 100 % paved surfaces. Net residential areas are a mix of gardens, roofs (building area) and driveways / paved surfaces. The proportion of net residential area in roofs and paved surfaces was specified by Jasmax based on expected housing / population densities, and the remainder was assumed to be urban grassland and trees. This results in an imperviousness of between 40 – 65 % for net residential areas across stormwater catchments.
- In the absence of more detailed information, the existing residential area was assumed to have the same land cover breakdown as the net residential area with 65 % imperviousness (i.e., 50 % roof area, 15 % paved surfaces and 35 % urban grassland and trees). This is intended to balance the fact that the existing residential area is much lower density based on aerial photographs (and therefore should have a smaller roof area), however it may involve older roof types which are higher yielding.
- Golf course and open space areas were assumed to be 10 % paved surfaces and 90 % urban grassland and trees.
- The estimated roof area for the hotel and grounds was specified by Jasmax. The remaining area was divided between paved surfaces and urban grassland and trees based on an assumed imperviousness of 65 %.
- The fraction of light industrial areas in roofs and paved surfaces was specified by Jasmax. The remaining light industrial area was assumed to be urban grassland and trees, resulting in an imperviousness of 95 %.

[23] Stormwater catchments for the plan change area under the fully-developed scenario were provided by Harrison Grierson.
[24] M. Fletcher, pers. comm. 8 Nov 2021

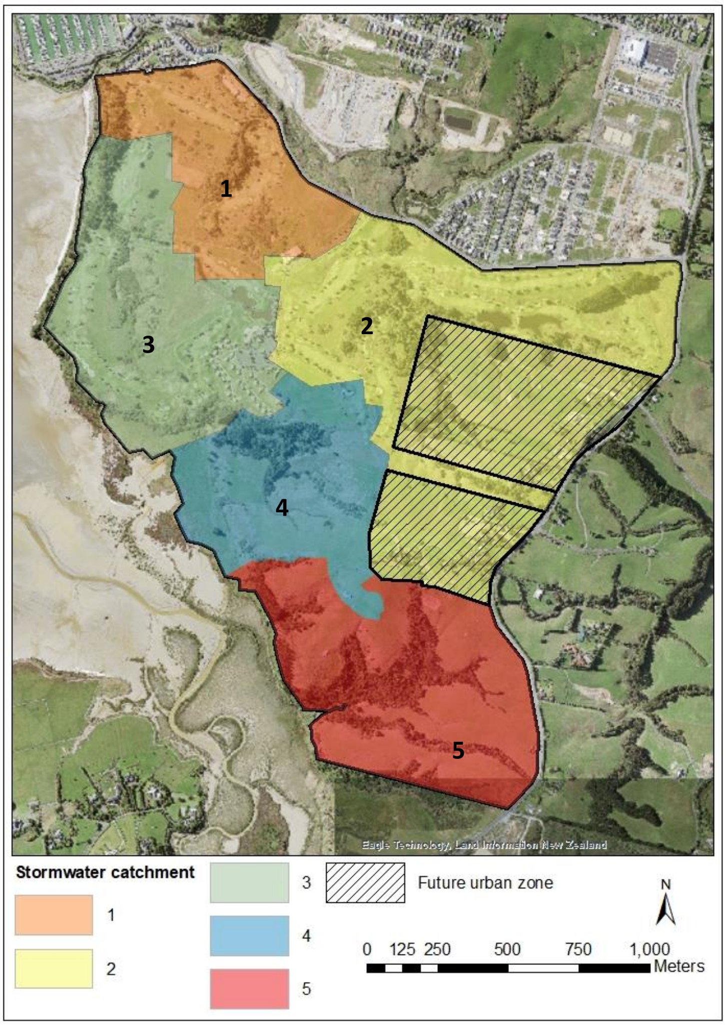

Figure 3-1: Stormwater catchments for the plan change area under the fully-developed scenario.

- The land use area in each road class represents a mix of carriageway, paved surfaces and permeable areas. Carriageway areas in each road class and stormwater catchment were provided by Harrison Grierson. The remaining areas were divided between paved surfaces and urban grassland and trees based on an assumed imperviousness of 90 %.
- The estimated paved surface area for the school was specified by Jasmax. The remaining area was divided between roofs and urban grassland and trees based on an assumed imperviousness of 70 %.
- The fraction of village centre areas in roofs and paved surfaces were specified by Jasmax. The remaining area was assumed to be urban grassland and trees, resulting in an imperviousness of 90 %.
- The wastewater management area was assumed to be 90 % paved surfaces and 10 % urban grassland and trees.
- In the absence of more detailed information, the widening of Whitford-Maraetai Rd was assumed to represent the same land cover mix as roads in the 5000 – 20000 vpd category (based on an existing traffic volume of around 10000 vpd[25]).

[25] From the NZTA Road Stormwater Screening (RSS) model (Gardiner et al. 2016)

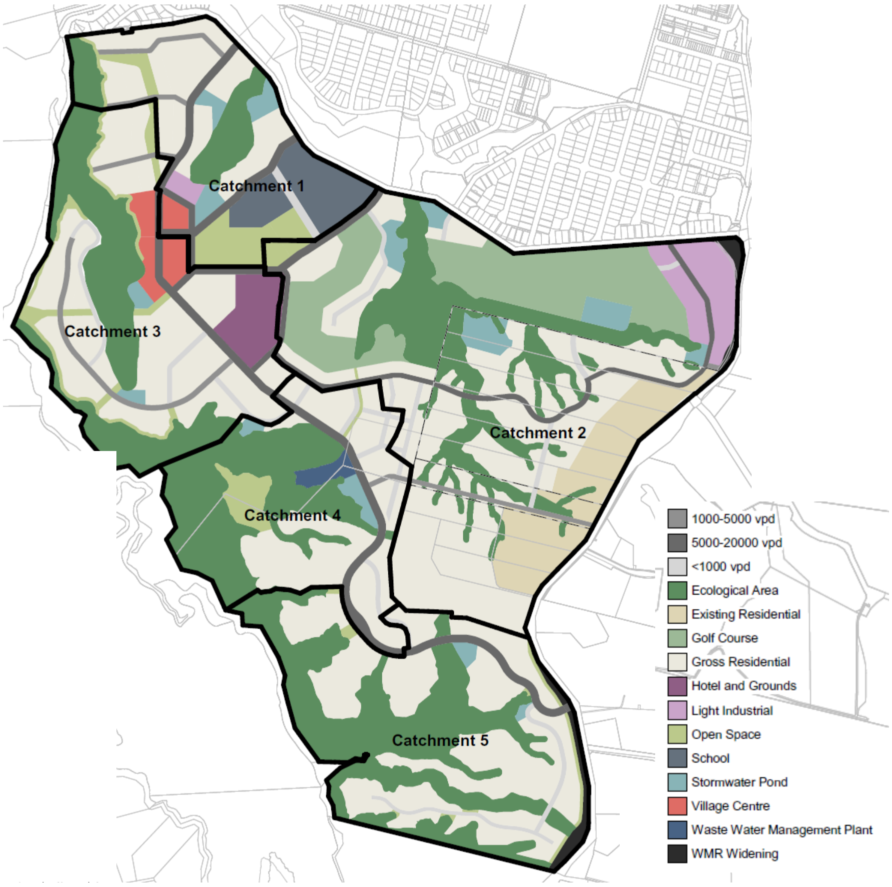

Figure 3-2: Land use for the fully-developed scenario by stormwater catchment. Source: Jasmax.

Table 3-2: Land use categories and areas for the fully-developed scenario by stormwater catchment.

Land use category	Stormwater catchment area (ha)				
	1	2	3	4	5
Ecological area	5.46	22.22	16.89	17.55	25.71
Existing residential	0	12.29	0	0	0
Golf course	0	21.07	0	0	0
Gross residential	12.37	38.11	23.13	14.96	26.74
Hotel and grounds	0	0	4.12	0	0
Light industrial	0.66	5.57	0	0	0
Open space	4.75	0.81	3.55	2.20	1.08
Roads < 1000 vpd	0.59	2.14	1.50	1.40	1.64
Roads 1000 – 5000 vpd	1.10	0.93	3.32	0.20	0
Roads 5000 – 20000 vpd	3.01	3.91	1.90	2.66	1.50
School	6.48	0	0	0	0
Stormwater pond	1.90	4.03	0.71	0.97	0.51
Village centre	0.68	0	2.79	0	0
Wastewater management plant	0	0	0	1.00	0
Whitford-Maraetai Rd widening	0	0.82	0	0	1.53
Total	**37.00**	**111.90**	**57.91**	**40.94**	**58.71**

Roof areas in all land use categories were assumed to be an equal mix of zinc / aluminium (coated) and concrete tile, consistent with the expected use of low-yielding roofing materials for the development. Stormwater pond areas are not contaminant generating and were excluded from further analysis. A table of the land cover areas is included in Appendix D.

3.1.4 Stormwater treatment

Stormwater treatment measures under the fully-developed scenario were provided by Harrison Grierson. As specific design details were not yet available, in accordance with GD01[26] all carriageway areas were assumed to be treated to a level of 75 % long-term removal efficiency for TSS, likely via bioretention swales.

In addition to at-source treatment of carriageway areas, runoff from some stormwater subcatchments will be routed through wetlands, designed primarily for water quantity rather than quality control[27]. Owing to difficulties in assessing what fraction of each land use category area will discharge to wetlands, we have estimated loads for the following two cases representing the minimum and maximum extent of possible stormwater treatment:

1. At-source treatment of carriageway areas with no additional wetland treatment ("no wetlands"); and
2. At-source treatment of carriageway areas with additional wetland treatment of all impervious areas ("wetlands").

Wetlands were also assumed to provide 75 % long-term removal efficiency for TSS. While the CLM models the removal of total Zn and Cu, C-CALM models the removal of particulate and dissolved metals separately on the assumption that different treatment processes are in operation (e.g., settling vs. bioretention). Particulate metal removal is simulated in C-CALM by adopting the same removal efficiency as for TSS. For dissolved metals, a wide range of removal efficiencies is reported in the literature, ranging between around 10 – 95 % for dissolved Zn and 5 – 95 % for dissolved Cu for bioretention, swales and wetlands (Semadeni-Davies 2008). We have adopted mid-range values of 40 % removal of dissolved Zn and Cu for bioretention swales, 40 % removal of dissolved Zn and 50 % removal of dissolved Cu for wetlands, guided by a review of literature on the performance of bioretention, grass swales and wetlands carried out as part of C-CALM development (Semadeni-Davies 2008), and load reduction factors derived from paired data for these devices from the International Stormwater BMP Database[28]. While most of the data in the database come from North America, the database also contains data from stormwater monitoring around the world including New Zealand.

The "no wetlands" and "wetlands" cases, respectively, will provide maximum and minimum estimates for the mean annual loads of TSS, Zn and Cu under the fully-developed scenario. Based on the draft stormwater catchment layout plan provided by Harrison Grierson, around 72 % of the plan change area (excluding ecological areas) is expected to be treated by wetlands. This figure varies by stormwater catchment, between around 30 % for Stormwater Catchment 5, suggesting loads for this catchment may be closer to (though still less than) the "no wetlands" estimates, and 66 – 96 % for Stormwater Catchments 1 – 4, suggesting loads for these catchments may be closer to (though still more than) the "wetlands" estimates.

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[26] Auckland Council Guidance Document 2017/001, for Stormwater Treatment Devices in the Auckland Region (GD01)
[27] C. McGregor, pers. comm. 28 Oct 2021
[28] https://bmpdatabase.org/urban

3.1.5 Discharges to Whitford Embayment

To inform the wider assessment of effects of the development on Whitford Embayment, mean annual loads of TSS, Zn and Cu were estimated by outlet point to the embayment (Outlets A – E; shown in Figure 2-2), as well as by stormwater catchment (as described above).

The stormwater catchments largely correspond with the five outlet points, except for some subcatchment areas from which runoff is not routed through wetlands, and which were identified in the project's draft stormwater catchment layout plan provided by Harrison Grierson. Further details are as follows:

- Stormwater Catchment 1 and 2 discharge to Outlet A.
- Stormwater Catchment 3 discharges to Outlet B, less a portion of the area in the south of the catchment (comprising gross residential, open space and ecological areas) from which stormwater runoff is not routed through wetlands, and which discharges to Outlet C. We have estimated the proportion of gross residential, open space and ecological areas in Stormwater Catchment 3 that discharge to Outlet C based on the ratio of predominantly residential subcatchments treated / not treated by wetlands in the draft stormwater catchment layout plan.
- Stormwater Catchment 4 discharges to Outlet C, less a portion of the area in the south of the catchment (comprising gross residential and ecological areas) from which stormwater runoff is not routed through wetlands, and which discharges to Outlet D. As above, we have estimated the proportion of gross residential and ecological areas in this catchment that discharge to Outlet D based on the ratio of predominantly residential subcatchments treated / not treated by wetlands in the draft stormwater catchment layout plan.
- Stormwater Catchment 5 discharges primarily to Outlet E. A portion of the area in the north-west of the catchment (comprising gross residential, open space and ecological areas), from which stormwater runoff is not routed through wetlands, discharges to Outlet D. We have estimated the proportion of gross residential, open space and ecological areas in Stormwater Catchment 5 that discharge to Outlet D in the manner described above.

C-CALM was applied with adjusted land cover areas based on the above to determine mean annual loads of TSS, Zn and Cu discharged to Whitford Embayment for each outlet location. A table of land cover areas is shown in Appendix E.

Based on the estimated proportion of each stormwater catchment treated by wetlands, the loads for Outlets A – C are likely to be closer to (though still more than) the "wetlands" estimates, whereas the loads for Outlets D – E are likely to be closer to (though still less than) the "no wetlands" values.

3.1.6 Existing land cover

To provide context for the estimated mean annual loads discharged to Whitford Embayment under the fully-developed scenario, mean annual loads of TSS, Zn and Cu were also prepared for the baseline (existing land cover) scenario, by outlet.

The CLM (and by extension C-CALM) is not considered applicable for catchments with a significant amount of rural land (Auckland Regional Council 2010). For this reason, and for consistency with the baseline sediment loads estimated under the interim earthworks scenario, we have derived mean annual loads of TSS, Zn and Cu for the plan change area under the existing land cover as follows:

1. Mean annual TSS loads discharged from the project area (less the area classified as 'built-up' under LCDB5; Section 2.1.1) were estimated from the GLEAMS 50-year timeseries of daily sediment loads under the existing land cover, as described in Section 2.1.5.

2. In the absence of detailed slope information, mean annual TSS loads discharged from the future-urban-zone area under the existing land cover (comprising pasture and exotic forest) were estimated from the GLEAMS yields for these land covers assuming the same proportional slope breakdown as in the wider catchments.

3. Mean annual Zn and Cu loads for the above areas were estimated by multiplying the mean annual TSS loads from (1) and (2) by the background soil concentrations of 35 and 7 mg/kg for Zn and Cu, respectively.

4. Mean annual TSS, Zn and Cu loads for the area classified as 'built-up' under LCDB5 (comprising the golf course club house area and surrounding villas) were estimated using C-CALM, with the yields listed in Table 3-1 and land cover areas calculated from GIS analysis. The land cover area is approximately 13 % roofs (assumed to be concrete or tile), 26 % paved surfaces (car parks, driveways) and 61 % urban grassland and trees.

We note that the catchment areas discharging to each outlet under the baseline and fully-developed scenarios do not necessarily match, as stormwater runoff from some areas that discharge to a particular outlet under the existing land cover is routed via wetlands to a different outlet under the fully-developed scenario.

3.2 Results

3.2.1 Mean annual loads by stormwater catchment

Tables 3-3 to 3-5 present estimates of mean annual treated and untreated loads (and associated yields) of TSS, Zn and Cu under the fully-developed scenario by stormwater catchment. Treated values are presented as a range between two cases: "wetlands" (at-source treatment of carriageway areas plus wetland treatment of all impervious areas), and "no wetlands" (at-source treatment of carriageway areas only).

Estimated mean annual treated loads of TSS vary between 3.34 – 11.97 tonnes ("wetlands") and 5.48 – 17.70 tonnes ("no wetlands") across stormwater catchments. Yield values range between around 80 – 110 kg/ha ("wetlands") and 130 – 160 kg/ha ("no wetlands"). Stormwater Catchments 1 – 3 have noticeably higher yields for TSS (and also Zn and Cu) for the "no wetlands" case, reflecting the higher proportion of roofs and paved surfaces in these catchments. Mean annual untreated loads of TSS vary between 5.89 – 18.43 tonnes, with yields of around 140 – 170 kg/ha.

Mean annual treated load estimates for Zn range between 1.20 – 3.44 kg ("wetlands") and 1.78 – 6.05 kg ("no wetlands") across stormwater catchments. Yield values range between around 20 – 36 g/ha ("wetlands") and 35 – 65 g/ha ("no wetlands"). Mean annual untreated loads of Zn vary between 2.29 – 6.94 kg, with yields of around 40 – 80 g/ha.

Estimated mean annual treated loads of Cu vary between 0.15 – 0.49 kg ("wetlands") and 0.37 – 1.10 kg ("no wetlands") across stormwater catchments. Yield values range between around 3 – 6 g/ha ("wetlands") and 7 – 13 g/ha ("no wetlands"). Mean annual untreated loads of Cu vary between 0.53 – 1.44 kg across stormwater catchments, with yields of around 9 – 20 g/ha.

As noted in Section 3.1.4, based on the estimated proportion of each stormwater catchment treated by wetlands, we expect the mean annual treated loads for Stormwater Catchments 1 – 4 to be closer to (though still more than) the “wetlands” values, while the mean annual treated loads for Stormwater Catchment 5 are likely to be closer to (though still less than) the “no wetlands” values.

Table 3-3: Mean annual treated and untreated TSS loads under the fully-developed scenario by stormwater catchment.

Quantity	SW Catchment	Area (ha)	Treated		Untreated
			Wetlands	No wetlands	
Load (tonnes)	1	37.00	3.34	5.86	6.33
	2	111.90	11.97	17.70	18.43
	3	57.91	4.72	8.46	9.01
	4	40.94	3.54	5.48	5.89
	5	58.71	5.69	8.13	8.42
	Total	**306.46**	**29.26**	**45.63**	**48.08**
Yield (kg/ha)	1	37.00	90.27	158.38	171.08
	2	111.90	106.97	158.18	164.70
	3	57.91	81.51	146.09	155.59
	4	40.94	86.47	133.85	143.87
	5	58.71	96.92	138.48	143.42
	Total	**306.46**	**95.48**	**148.89**	**156.89**

Table 3-4: Mean annual treated and untreated Zn loads under the fully-developed scenario by stormwater catchment.

Quantity	SW Catchment	Area (ha)	Treated		Untreated
			Wetlands	No wetlands	
Load (kg)	1	37.00	1.33	2.42	3.04
	2	111.90	3.44	6.05	6.94
	3	57.91	1.85	3.36	3.89
	4	40.94	0.98	1.78	2.29
	5	58.71	1.20	2.12	2.41
	Total	**306.46**	**8.80**	**15.73**	**18.57**
Yield (g/ha)	1	37.00	35.95	65.41	82.16
	2	111.90	30.74	54.07	62.02
	3	57.91	31.95	58.02	67.17
	4	40.94	23.94	43.48	55.94
	5	58.71	20.44	36.11	41.05
	Total	**306.46**	**28.72**	**51.33**	**60.60**

Table 3-5: Mean annual treated and untreated Cu loads under the fully-developed scenario by stormwater catchment.

Quantity	SW Catchment	Area (ha)	Treated		Untreated
			Wetlands	No wetlands	
Load (kg)	1	37.00	0.20	0.48	0.72
	2	111.90	0.49	1.10	1.44
	3	57.91	0.27	0.64	0.86
	4	40.94	0.15	0.37	0.56
	5	58.71	0.18	0.42	0.53
	Total	**306.46**	**1.29**	**3.01**	**4.11**
Yield (g/ha)	1	37.00	5.41	12.97	19.46
	2	111.90	4.38	9.83	12.87
	3	57.91	4.66	11.05	14.85
	4	40.94	3.66	9.04	13.68
	5	58.71	3.07	7.15	9.03
	Total	**306.46**	**4.21**	**9.82**	**13.41**

3.2.2 Mean annual loads by outlet to Whitford Embayment

Tables 3-6 to 3-8 present estimates of mean annual treated and untreated loads (and associated yields) of TSS, Zn and Cu under the baseline and fully-developed scenarios by outlet to Whitford Embayment. Treated values are presented as a range between two cases: “wetlands” (at-source treatment of carriageway areas plus wetland treatment of all impervious areas), and “no wetlands” (at-source treatment of carriageway areas only).

Estimated mean annual treated loads of TSS under the fully-developed scenario are between 60 – 90 % (“wetlands”) and 30 – 90 % (“no wetlands”) lower than the equivalent baseline values across outlets. The greatest proportional reduction in load occurs for Outlet D, reflecting both a change in land cover under the fully-developed scenario (with a high proportion of ecological area) and a change in catchment area (with around a 35 % reduction in catchment area as stormwater runoff is routed via wetlands to other outlets). Estimated mean annual untreated loads of TSS under the fully-developed scenario are between 20 – 90 % lower than the equivalent baseline values across outlets.

Estimated mean annual yields of TSS under the fully-developed scenario range between 82.10 – 107.16 kg/ha (treated; “wetlands”), 133.15 – 158.23 kg/ha (treated; “no wetlands”) and 133.15 – 166.29 kg/ha (untreated) across outlets, compared with 286.28 – 635.37 kg/ha under the baseline scenario.

Mean annual treated load estimates for Zn under the fully-developed scenario are up to 4.1 times higher (“wetlands”) and 7.2 times higher (“no wetlands”) than the equivalent baseline values across outlets. The relative increase for Outlets A and B is greater than for Outlets C – E, due to the higher levels of imperviousness in the catchment areas of these outlets. Notably, for Outlet D, the “wetlands” mean annual Zn load is around 40 % lower than the baseline value, while the “no wetlands” load shows no appreciable change. As noted for TSS, the results for Outlet D reflect increased yields of Zn from impervious surfaces under the fully-developed scenario and the reduction in catchment area due to routing of stormwater runoff to other outlets. Estimated mean annual untreated loads of Zn under the fully-developed scenario are up to 8.5 times higher than the equivalent baseline values across outlets.

Estimated mean annual yields of Zn under the fully-developed scenario range between 20.02 – 33.25 g/ha (treated; "wetlands"), 33.94 – 58.78 g/ha (treated; "no wetlands") and 33.94 – 69.10 g/ha (untreated) across outlets, compared with 7.77 – 22.24 g/ha under the baseline scenario.

Mean annual treated loads of Cu estimated under the fully-developed scenario are up to 2.7 times higher ("wetlands") and 6.6 times higher ("no wetlands") than the equivalent baseline values across outlets. The relative increase for Outlet B is significantly higher than for the remaining outlets, likely due to a higher proportion of road area in the catchment of Outlet B, particularly in the 1000 – 5000 vpd class. As with Zn, there is a reduction in the "wetlands" mean annual Cu load discharged to Outlet D compared with the baseline value, while the "no wetlands" load shows no appreciable change, reflecting both an increase in Cu yields from impervious surfaces under the fully-developed scenario and the reduction in catchment area due to routing of stormwater runoff to other outlets. Estimated mean annual untreated Cu loads under the fully-developed scenario are up to 8.8 times higher than the equivalent baseline values across outlets.

Estimated mean annual yields of Cu under the fully-developed scenario range between 2.61 – 4.76 g/ha (treated; "wetlands"), 6.09 – 11.48 g/ha (treated; "no wetlands") and 6.09 – 15.38 g/ha (untreated) across outlets, compared with 2.36 – 5.45 g/ha under the baseline scenario.

As noted in Section 3.1.5, based on the estimated proportion of the stormwater catchment area contributing to each outlet treated by wetlands, we expect the mean annual treated loads for Outlets A – C to be closer to (though still more than) the "wetlands" values, while the mean annual treated loads for Outlets D – E are likely to be closer to (though still less than) the "no wetlands" values.

Table 3-6: Mean annual treated and untreated TSS loads discharged to Whitford Embayment under the fully-developed scenario by outlet. Baseline values represent the (untreated) loads under the existing land cover. Values in parentheses indicate the ratio between the fully-developed and baseline scenarios.

Quantity	Outlet	Baseline	Treated		Untreated
			Wetlands	No wetlands	
Load (tonnes)	A	59.22	15.32 (0.3)	23.56 (0.4)	24.76 (0.4)
	B	10.63	4.16 (0.4)	7.55 (0.7)	8.10 (0.8)
	C	26.37	3.85 (0.1)	6.02 (0.2)	6.44 (0.2)
	D	10.97	1.11 (0.1)	1.53 (0.1)	1.53 (0.1)
	E	23.95	4.83 (0.2)	6.96 (0.3)	7.25 (0.3)
	Total	**131.14**	**29.27 (0.2)**	**45.62 (0.3)**	**48.08 (0.4)**
Yield (kg/ha)	A	391.80	107.16 (0.3)	158.23 (0.4)	166.29 (0.4)
	B	286.28	82.10 (0.3)	146.96 (0.5)	157.67 (0.6)
	C	542.30	88.36 (0.2)	135.13 (0.2)	144.56 (0.3)
	D	635.37	96.61 (0.2)	133.15 (0.2)	133.15 (0.2)
	E	457.80	97.30 (0.2)	138.80 (0.3)	144.58 (0.3)
	Total	**427.88**	**98.11 (0.2)**	**148.86 (0.3)**	**156.89 (0.4)**

Table 3-7: Mean annual treated and untreated Zn loads discharged to Whitford Embayment under the fully-developed scenario by outlet. Baseline values represent the (untreated) loads under the existing land cover. Values in parentheses indicate the ratio between the fully-developed and baseline scenarios.

Quantity	Outlet	Baseline	Treated		Untreated
			Wetlands	No wetlands	
Load (kg)	A	1.17	4.76 (4.1)	8.47 (7.2)	9.98 (8.5)
	B	0.43	1.69 (3.9)	3.02 (7.0)	3.55 (8.3)
	C	0.92	1.12 (1.2)	2.02 (2.2)	2.53 (2.8)
	D	0.38	0.23 (0.6)	0.39 (1.0)	0.39 (1.0)
	E	0.77	1.04 (1.4)	1.84 (2.4)	2.13 (2.8)
	Total	**3.67**	**8.84 (2.4)**	**15.74 (4.3)**	**18.58 (5.1)**
Yield (g/ha)	A	7.77	33.29 (4.3)	56.88 (7.3)	67.02 (8.6)
	B	11.67	33.35 (2.9)	58.78 (5.0)	69.10 (5.9)
	C	18.96	25.71 (1.4)	45.34 (2.4)	56.79 (3.0)
	D	22.24	20.02 (0.9)	33.94 (1.5)	33.94 (1.5)
	E	14.68	20.95 (1.4)	36.69 (2.5)	42.48 (2.9)
	Total	**12.01**	**29.63 (2.5)**	**51.36 (4.3)**	**60.63 (5.0)**

Table 3-8: Mean annual treated and untreated Cu loads discharged to Whitford Embayment under the fully-developed scenario by outlet. Baseline values represent the (untreated) loads under the existing land cover. Values in parentheses indicate the ratio between the fully-developed and baseline scenarios.

Quantity	Outlet	Baseline	Treated		Untreated
			Wetlands	No wetlands	
Load (kg)	A	0.42	0.68 (1.6)	1.58 (3.8)	2.16 (5.1)
	B	0.09	0.24 (2.7)	0.59 (6.6)	0.79 (8.8)
	C	0.21	0.17 (0.8)	0.41 (2.0)	0.60 (2.9)
	D	0.08	0.03 (0.4)	0.07 (0.9)	0.07 (0.9)
	E	0.17	0.16 (0.9)	0.37 (2.2)	0.48 (2.8)
	Total	**0.97**	**1.28 (1.3)**	**3.02 (3.1)**	**4.10 (4.2)**
Yield (g/ha)	A	2.78	4.76 (1.7)	10.61 (3.8)	14.51 (5.2)
	B	2.36	4.74 (2.0)	11.48 (4.9)	15.38 (6.5)
	C	4.34	3.90 (0.9)	9.20 (2.1)	13.47 (3.1)
	D	4.45	2.61 (0.6)	6.09 (1.4)	6.09 (1.4)
	E	3.20	3.22 (1.01)	7.38 (2.3)	9.57 (3.0)
	Total	**3.14**	**4.29 (1.4)**	**9.85 (3.1)**	**13.38 (4.3)**

4 Summary

Modelling of contaminant loads associated with the proposed development of approximately 250 ha of land in the Whitford Embayment has been conducted to inform an application for a change to the Auckland Unitary Plan. The assessment of contaminant loads has involved:

1. Using the GLEAMS model, combined with information on earthworks staging and the performance of erosion and sediment control measures, to estimate runoff and sediment loads associated with the construction phase of the development under an interim earthworks scenario. Specifically:
   - Mean annual runoff and sediment loads, with and without ESC, for a 15-ha representative catchment in four different slope classes, and in the context of loads discharged to Whitford Embayment; and
   - Event specific (24-hr) runoff and sediment loads for a range of return periods (2, 5, 10, 20, 50 and 100 years) including disaggregation to a 10-minute timestep.
2. Using the C-CALM model, combined with information on land cover and stormwater treatment measures, to estimate TSS, Zn and Cu loads associated with the mature phase of the development under a fully-developed scenario. Specifically:
   - Mean annual TSS, Zn and Cu loads, with and without stormwater treatment, for proposed stormwater catchments as well as by outlet to Whitford Embayment.

Construction phase

For the 15-ha representative catchment, estimated mean annual runoff volumes under the interim earthworks scenario increase only slightly over baseline values across slope classes. Estimated mean annual treated sediment loads are between approximately six and 25 times higher than the equivalent baseline loads across slope classes. For the lower slope classes (< 6°), the majority of the mean annual treated load is generated from bulk earthworks land covers, whereas for the higher slope classes a significant proportion of the load is generated from stabilised land covers. Mean annual untreated load estimates are around an order of magnitude higher than the equivalent treated loads. 24-hr treated sediment load estimates are between approximately six and 36 times higher than the equivalent baseline loads over all slope classes and across the range of ARI events.

Estimated mean annual runoff volumes discharged to Whitford Embayment under the interim earthworks scenario are approximately equal to baseline values. Estimated mean annual treated sediment loads are around 2 – 3 times higher than the equivalent baseline values across outlets. The relative increase is higher for Outlets A and B (at the northern end of the project area) than for Outlets C – E which are further towards Waikopua Creek. Estimated mean annual untreated sediment loads are around four times higher than the equivalent treated values. 24-hr treated sediment load estimates for the 2-yr ARI event under the interim earthworks scenario are between two and three times higher than the equivalent baseline loads across outlets. For the higher return period events, the increase over baseline is between two- to four-fold for the 10-yr ARI and five- to 11-fold for the 100-yr ARI across outlets.

The estimates of sediment loads discharged to Whitford Embayment under the interim earthworks scenario reflect conservative assumptions around the extent and location of works in the indicative earthworks catchments. Specifically:

- The area worked in each indicative earthworks catchment is assumed to cover the steepest 15 ha, resulting in the highest magnitude loads under the scenario;
- All five indicative earthworks catchments are assumed to be worked concurrently; resulting in the greatest earthworks extent under the scenario; and
- The existing land cover for the earthworks area is assumed to be consistent with the golf course, resulting in the greatest relative increase under the scenario.

Mature phase

Due to difficulties in assessing the land use category area in each stormwater catchment expected to be treated by wetlands, estimates of mean annual TSS, Zn and Cu loads under the fully-developed scenario were prepared for two cases reflecting the maximum / minimum extent of stormwater treatment: "wetlands" (at-source treatment of carriageway areas plus wetland treatment of all impervious areas), and "no wetlands" (at-source treatment of carriageway areas only).

Estimated mean annual treated TSS loads discharged to Whitford Embayment under the fully-developed scenario represent a substantial reduction over baseline values across outlets (between 60 – 90 % for "wetlands" and 30 – 90 % for "no wetlands"). The reduction in loads reflects lower TSS yields for roofs and ecological areas under the fully-developed scenario as well as stormwater treatment. The greatest reduction in load occurs for Outlet D, resulting from both a change in land cover under the fully-developed scenario and a reduction in catchment area, as stormwater runoff is routed to other outlets.

Mean annual treated loads of Zn estimated under the fully-developed scenario are up to 4.1 times higher ("wetlands") and 7.2 times higher ("no wetlands") than the equivalent baseline values across outlets. The relative increase for Outlets A and B, in the north of the project area, is greater than for Outlets C – E which are closer to Waikopua Creek. Over the entire plan change area, the mean annual treated Zn load discharged to Whitford Embayment under the fully-developed scenario is expected to represent between a two-fold ("wetlands") and a four-fold ("no wetlands") increase over baseline.

Mean annual treated loads of Cu estimated under the fully-developed scenario are up to 2.7 times higher ("wetlands") and 6.6 times higher ("no wetlands") than the equivalent baseline values across outlets. Spatially, the pattern is similar to Zn, with the greatest proportional increase in Cu load occurring for Outlet B. Over the entire plan change area, the mean annual Cu load discharged to Whitford Embayment under the fully-developed scenario is expected to represent between a 30 % ("wetlands") and a three-fold increase ("no wetlands") over baseline.

We expect that treated estimates of mean annual TSS, Zn and Cu loads discharged to Whitford Embayment under the fully-developed scenario will be closer to (though still more than) the "wetlands" values for Outlets A – C, and closer to (though still less than) the "no wetlands" values for Outlets C – E based on the estimated extent of wetland treatment in each stormwater catchment.

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Appendix A Assumed land cover change

Table A-1 summarises the staging sequence for the interim earthworks scenario (Section 2.1.7). This sequence indicates the assumed percentage of three 5 ha catchments in bare earth and other land covers in each month of a single earthworks season followed by a winter stabilisation period.

Table A-1: Percentage of area in bare earth and other land covers. SRP refers to treatment by sediment retention ponds.

Year	Month	Catchment 1 (5 ha)				Catchment 2 (5 ha)				Catchment 3 (5 ha)			
		Existing	Bare earth + SRP	Mulched + SRP	Stabilised	Existing	Bare earth + SRP	Mulched + SRP	Stabilised	Existing	Bare earth + SRP	Mulched + SRP	Stabilised
1	Oct	70	30	0	0	100	0	0	0	100	0	0	0
	Nov	0	80	10	10	100	0	0	0	100	0	0	0
	Dec	0	40	30	30	70	30	0	0	100	0	0	0
	Jan	0	20	40	40	0	80	0	20	100	0	0	0
	Feb	0	0	70	30	0	60	20	20	60	40	0	0
	Mar	0	0	70	30	0	0	70	30	0	80	10	10
	Apr	0	0	70	30	0	0	0	100	0	20	50	30
	May – Jun	0	0	0	100	0	0	0	100	0	0	0	100

Appendix B Flow-sediment concentration relationships for disaggregation of ARI event sediment loads

Figure B-1 shows the relationship between runoff and suspended sediment concentration (SSC) in chemically-treated outflow from a sediment retention pond monitored as part of a study located at the ALPURT B2 motorway project (Moores and Pattinson, 2008). Despite a degree of scatter, the R^2 value of approximately 0.7 suggests that this relationship provides an acceptable model for estimating SSC in chemically-treated runoff from the earthworks part of the project area.

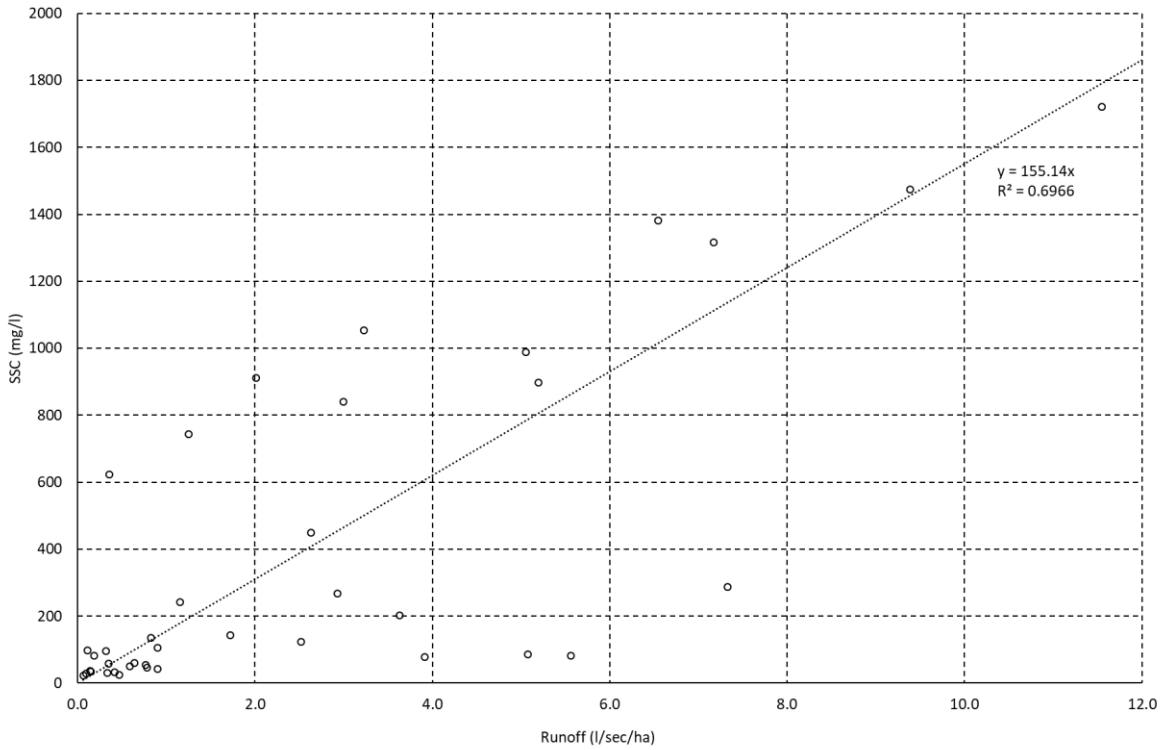

Figure B-1: Relationship between runoff and suspended sediment concentration in chemically-treated outflow from a sediment retention pond, ALPURT B2.

No equivalent data was available to investigate a relationship between runoff and SSC from the area of existing land cover. Instead, the ratio between the existing land cover and treated earthworks yields estimated by GLEAMS was used to scale the relationship shown in Figure B-1 for use in estimating SSC in runoff from the existing land cover. This involved multiplying the slope of the relationship shown above by 0.22.

Appendix C Disaggregated runoff and sediment loads

Figures C-1 and C-2 present plots of the estimated ARI event daily runoff volume and treated sediment loads, respectively, under the interim earthworks scenario, disaggregated to a 10-minute time series by outlet to Whitford Embayment. Note that, although the plots show the period 3:00 am on one day to 3:00 am the next, the full time series of disaggregated runoff and sediment loads spans a 3-day period. This reflects the fact that modelling of the runoff response from earthworks areas considered the influence of ESC devices (see Section 2.1.9). While the rainfall inputs used to generate these plots were of 24-hr duration, the retention and attenuation of earthworks runoff by ESC devices generated outflow time series that continue for some time following the main recession.

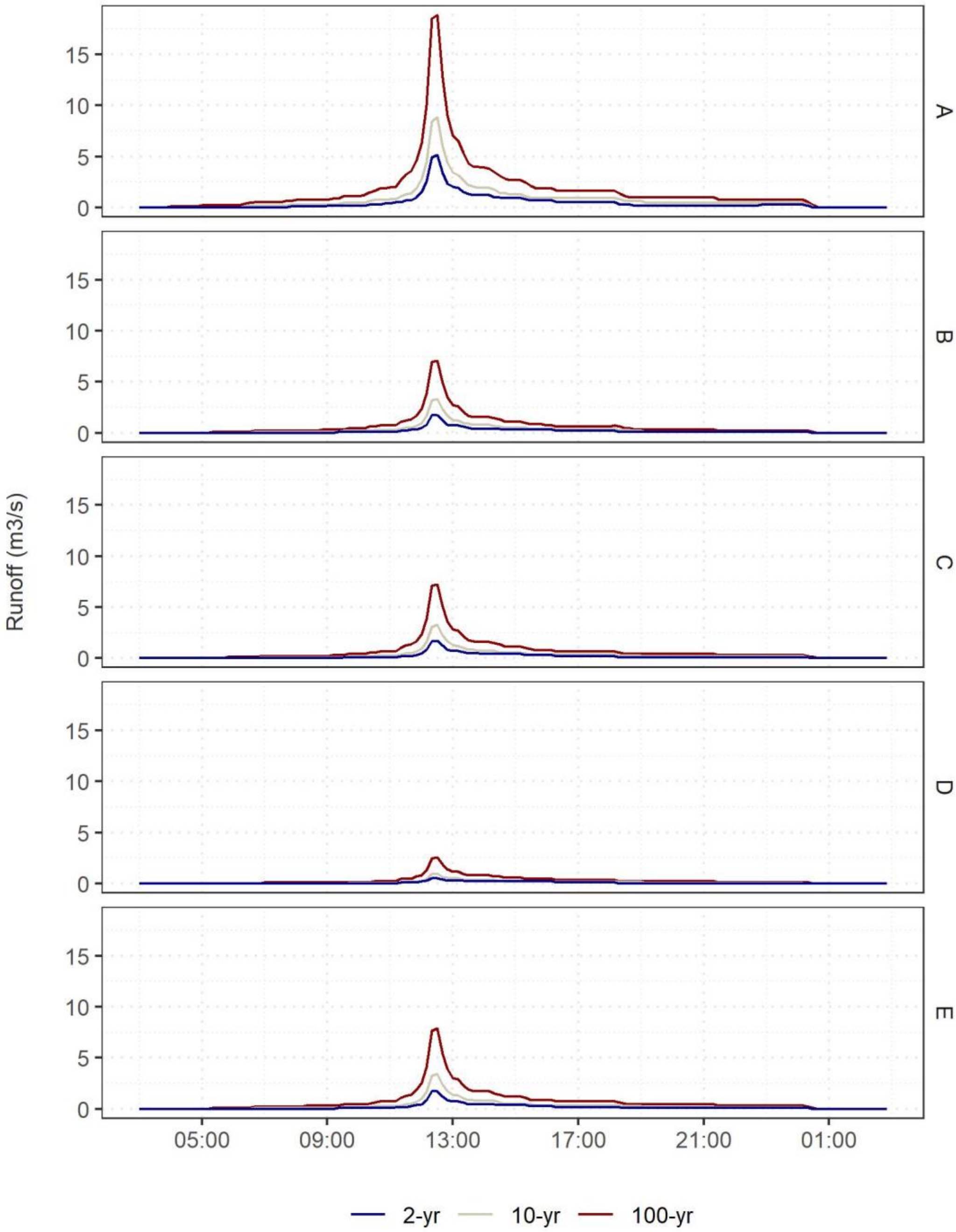

Figure C-1: Time series of disaggregated 24-hr ARI runoff volumes by outlet.

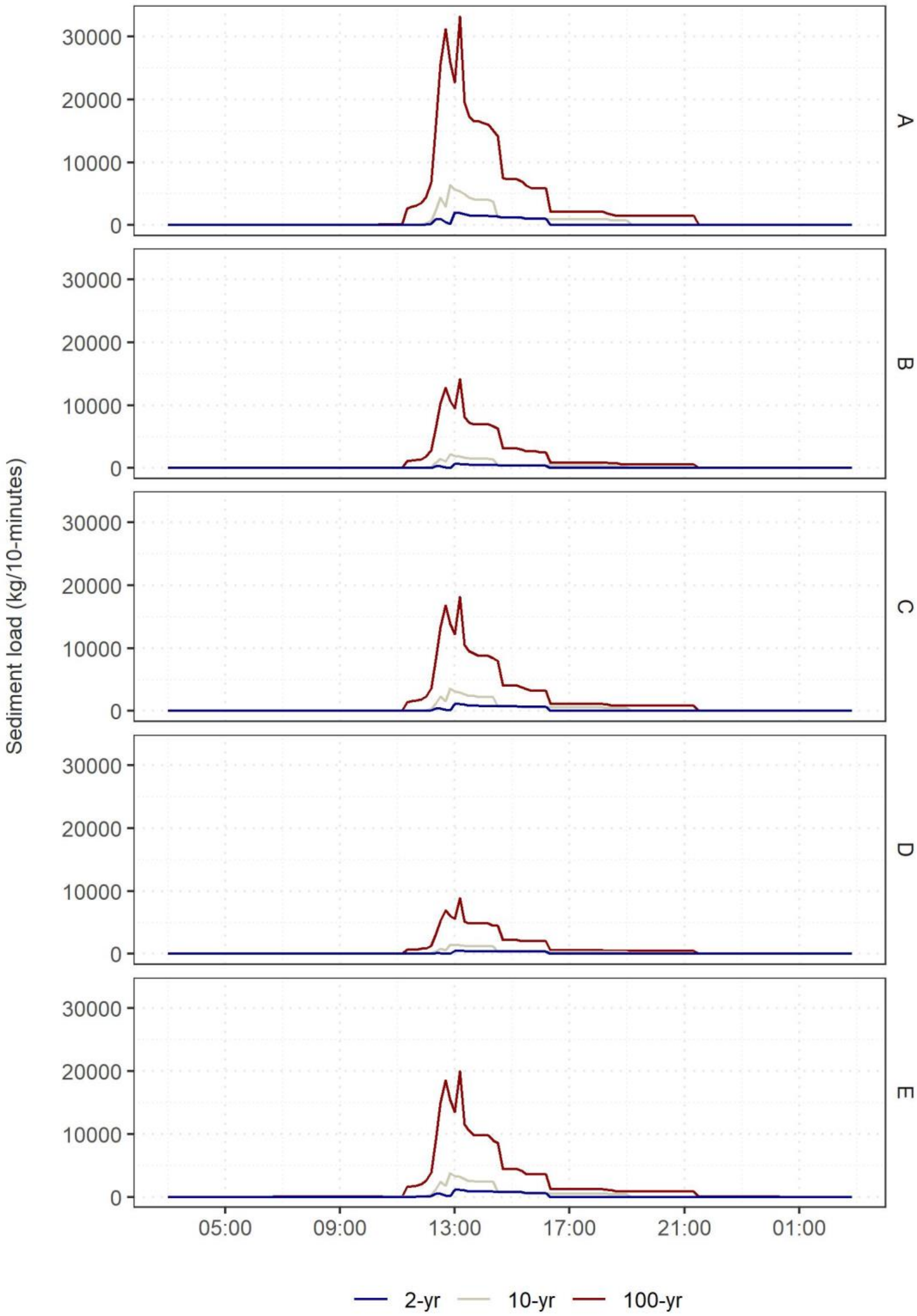

Figure C-2: Time series of disaggregated 24-hr ARI sediment loads by outlet.

Appendix D Stormwater catchment land cover areas

Table D-1 presents the area of each stormwater catchment (excluding stormwater pond area) in the relevant CLM and C-CALM land covers, based on the land use category areas provided and the assumptions described in Section 3.1.3. Table D-2 shows the percentage of stormwater catchment area in each land cover.

Table D-1: Stormwater catchment areas in relevant CLM and C-CALM land covers.

Source	Type	Stormwater catchment area (ha)				
		1	2	3	4	5
Roofs	Zinc/aluminium, coated	3.39	9.80	5.19	2.23	3.01
	Concrete tile	3.39	9.80	5.19	2.23	3.01
Roads (vehicles per day; vpd)	< 1000	0.27	0.96	0.68	0.63	0.74
	1000 – 5000	0.40	0.33	1.09	0.07	0.00
	5000 – 20000	0.87	1.28	0.54	0.76	0.43
Paved surfaces	Residential	5.76	19.41	10.43	6.13	8.96
	Commercial	6.08	5.98	7.23	3.27	3.04
Permeable surfaces	Urban grassland and trees	10.58	42.53	13.34	10.62	18.45
	Urban bush	4.36	17.78	13.51	14.03	20.56
Total		**35.10**	**107.87**	**57.20**	**39.97**	**58.20**

Table D-2: Percentage of stormwater catchment areas in relevant CLM and C-CALM land covers.

Source	Type	Stormwater catchment area (ha)				
		1	2	3	4	5
Roofs	Zinc/aluminium, coated	9.7	9.1	9.1	5.6	5.2
	Concrete tile	9.7	9.1	9.1	5.6	5.2
Roads (vehicles per day; vpd)	< 1000	0.8	0.9	1.2	1.6	1.3
	1000 – 5000	1.1	0.3	1.9	0.2	0.0
	5000 – 20000	2.5	1.2	0.9	1.9	0.7
Paved surfaces	Residential	16.4	18.0	18.2	15.3	15.4
	Commercial	17.3	5.5	12.6	8.2	5.2
Permeable surfaces	Urban grassland and trees	30.1	39.4	23.3	26.5	31.7
	Urban bush	12.4	16.5	23.7	35.1	35.3
Total		**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

Appendix E Outlet catchment land cover areas

Table E-1 presents the catchment area for each outlet to Whitford Embayment (excluding stormwater pond areas) in the relevant CLM and C-CALM land covers, based on the stormwater catchment land use category areas provided, and the assumptions described in Sections 3.1.3 and 3.1.5. Table E-2 shows the percentage of outlet catchment area in each land cover.

Table E-1: Outlet catchment areas in relevant CLM and C-CALM land covers.

Source	Type	Outlet catchment area (ha)				
		A	B	C	D	E
Roofs	Zinc/aluminium, coated	13.19	4.54	2.68	0.68	2.53
	Concrete tile	13.19	4.54	2.68	0.68	2.53
Roads (vehicles per day; vpd)	< 1000	1.23	0.68	0.63	0.00	0.74
	1000 – 5000	0.73	1.09	0.07	0.00	0.00
	5000 – 20000	2.15	0.54	0.76	0.00	0.43
Paved surfaces	Residential	25.18	8.86	7.16	1.97	7.53
	Commercial	12.06	7.23	3.27	0.00	3.04
Permeable surfaces	Urban grassland and trees	53.1	11.71	11.52	3.61	15.56
	Urban bush	22.14	11.48	14.80	4.55	17.28
Total		**142.97**	**50.67**	**43.57**	**11.49**	**49.64**

Table E-2: Percentage of outlet catchment areas in relevant CLM and C-CALM land covers.

Source	Type	Outlet catchment area (ha)				
		A	B	C	D	E
Roofs	Zinc/aluminium, coated	9.2	9.0	6.2	6.0	5.1
	Concrete tile	9.2	9.0	6.2	6.0	5.1
Roads (vehicles per day; vpd)	< 1000	0.9	1.3	1.4	0.0	1.5
	1000 – 5000	0.5	2.1	0.2	0.0	0.0
	5000 – 20000	1.5	1.1	1.7	0.0	0.9
Paved surfaces	Residential	17.6	17.5	16.4	17.1	15.2
	Commercial	8.4	14.3	7.5	0.0	6.1
Permeable surfaces	Urban grassland and trees	37.1	23.1	26.4	31.4	31.4
	Urban bush	15.6	22.6	34.0	39.5	34.7
Total		**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

Appendix C: Review of FWMT Data

Tonkin+Taylor

Job No: 1014358.0050
07 December 2021

Beachlands South Limited Partnership
c/o Russell Property Group
PO Box 17254
Greenlane
Auckland 1540

Attention: John Dobrowolski

Dear John

Beachlands South Structure Plan Change - Comparison of TSS outputs from the FWMT and GLEAMS models

1 Overview

Auckland Council have provided Tonkin & Taylor Ltd (T+T) with Total Suspended Solids (TSS) and water quality information from its Freshwater Management Tool (FWMT) to assist in the estimation of existing discharges from the 250 ha area in relation to the proposed Structure Plan for the Beachlands South Partnership development area. This letter report reviews information received from Auckland Council, and compares this information with independent quantitative assessment by NIWA. This review notes the following key findings:

- The FWMT mean annual TSS yields are comparable with the mean annual sediment yields calculated from the Auckland Council data.
- The FWMT flow outputs are comparable with observed flows at the available gauging station over the entire simulation period (2003 -2017) and shows improved performance over the calibration period (2013 – 2017).
- The TSS load from the NIWA assessment is comparable with FWMT outputs for the ~2 year Annual Recurrence Interval (ARI) event.

2 Introduction

Auckland Council has provided TSS discharge information obtained from the FWMT for the whole catchment contributing to the estuary shown in Figure 2.1. The FWMT information represents present day conditions and TSS data from it will be used as an independent sense check of the present day TSS information to be obtained from NIWA using the GLEAMS model, which has functionality to represent conditions pre, during and post construction phases.

TSS information from the GLEAMS model will be used as boundary conditions to a three-dimensional hydrodynamic model to assess the effects of higher sediment loads from construction of the proposed development in Beachlands, shown as the development area in Figure 2.1.

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Figure 2.1: Site Locality Plan showing development area, in red

3 Freshwater Management Tool Data Review

The FWMT is being built to help Auckland Council meet the requirements of the National Policy Statement for Freshwater Management (NPS-FM)[1]. It is an integrated contaminant load and in-stream concentration model which will be used by Auckland Council as a decision support tool for implementing the NPS-FM. The FWMT is intended to be Auckland Council's tool that replaces their static Contaminant Load Model (CLM) and is therefore the latest information on contaminant generation.

The FWMT estimates stream flow and pollutant concentrations using land use to derive estimated yields of contaminants to be supplied to the routing network. The output of the FWMT comprises a 15 year hindcast dataset of contaminant discharges from streams for suspended solids and metals.

3.1 Received data

T+T received FWMT data from Auckland Council on the 22nd February 2021. Data was received for 62 nodes (not all shown) around the site as displayed in Figure 3.5, for a date range of 2003 - 2017. The FWMT's output for each day contained a daily averaged outflow rate in m^3/s, and a daily flow-weighted contaminant concentration in mg/L for the following water quality parameters;

- Total Zinc (TZn).
- Total Copper (TCu).
- Total Suspended Solids (TSS).
- Total Nitrogen (TN).
- Total Phosphorous (TP).

[1] C. Grant, C. Hellberg, D. Bambic, C. Clarke (2018), *Development of a freshwater management tool to support integrated watershed planning for Auckland waterways,* 2018 Stormwater Conference. Sourced from https://www.waternz.org.nz/Article?Action=View&Article_id=1511

TSS is primarily used in this analysis. Contaminant yields are edge of stream data prior to in -waterbody processing. It is noted that the FWMT data was supplied as daily averages for flows, and edge-of-stream data for contaminants were annualised estimates. This is considered a limitation of the water quality inputs for the hydrodynamic model, which can use high frequency data as boundary conditions.

3.2 Limitations of dataset

Auckland Council stated the following limitations on the FWMT output data;

- Peer review is ongoing for the tool.
- At present, the model is only calibrated between 2013-2017.
- The tool is based on 2013 land use, thus does not include areas that have been developed since 2013.
- Rainfall data is based on Virtual Climate Station Network data (VCSN).
- The tool is considered poorly calibrated for metals in rural catchments.

3.3 Data review

A comprehensive review of the FWMT outputs was carried out to determine further limitations and relevance of the outputs to the site. These are described below.

3.3.1 Rainfall

FWMT obtains rainfall values from NIWA's Virtual Climate Station Network (VCSN). Virtual Climate station Network (VCSN) data are estimates of daily rainfall and other parameters on a regular (~5x5km) grid covering the whole of New Zealand. The estimates are produced every day, based on the spatial interpolation of actual data observations made at climate stations located around the country[2].

To assess the accuracy of the VCSN rainfall at the site, it was compared to the nearest rain gauge, as displayed on Environment Auckland's dashboards[3]. The location of the nearest rain gauge (Clevedon Coast @ Forest) compared to the location of the nearest VCSN data point is shown in Figure 3.1. Rainfall data for the Clevedon Coast @ Forest gauge was recorded between September 2013 and December 2017.

[2] *NIWA, https://niwa.co.nz/climate/our-services/virtual-climate-stations*
[3] Environment Auckland Data Hub, sourced from https://environmentauckland.org.nz/

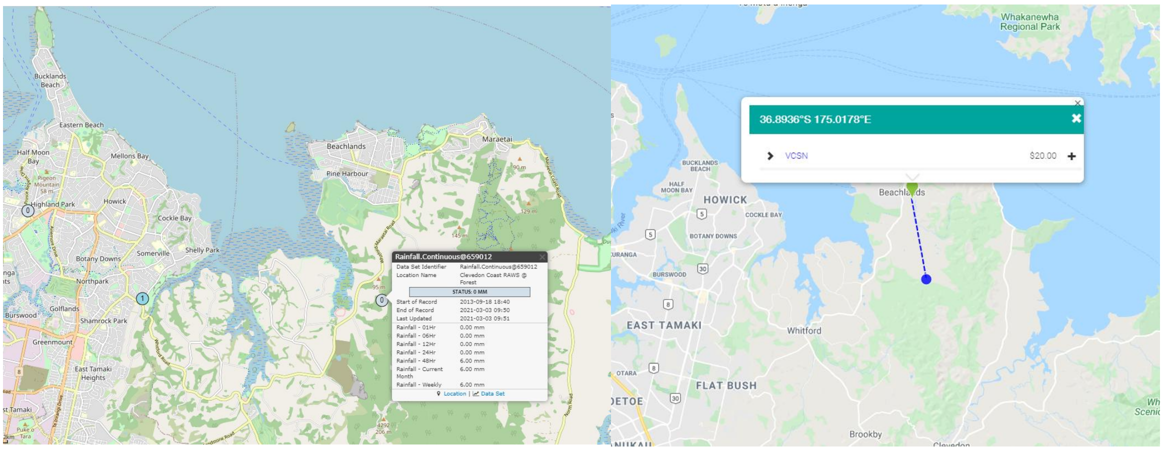

Figure 3.1: Locations of Environment Auckland Rain Gauge (Clevedon Coast @ Forest) and closest (36.8936°S, 175.0178°E) VCSN data point locations, respectively

Comparison of the rainfall data is shown in Figure 3.2. The data sets show reasonable cumulative rainfall comparison (rainfall volume) but does not show good timing or scale alignment at a 1:1 comparison.

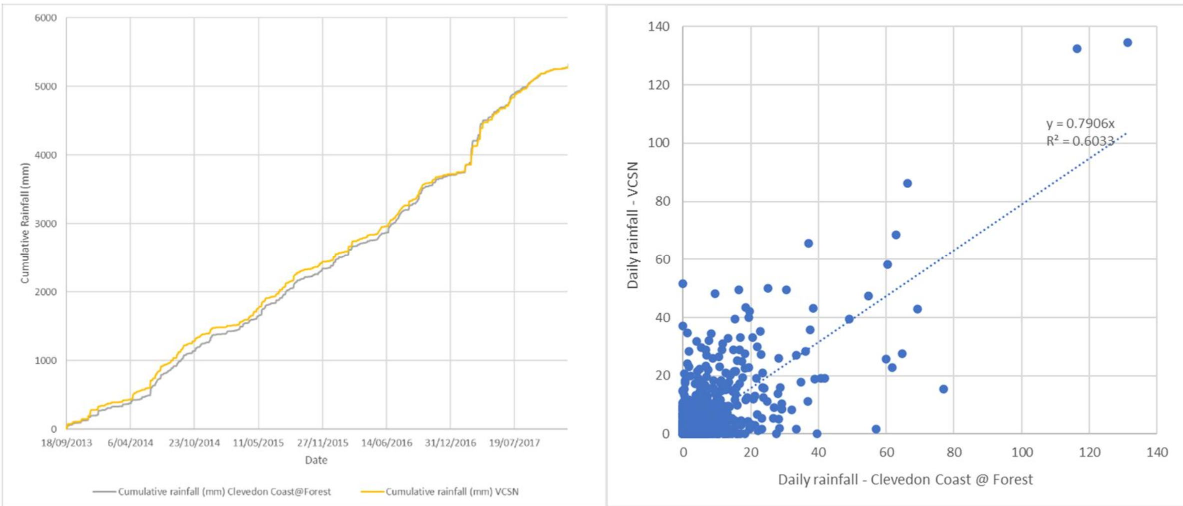

Figure 3.2: Comparison of VCSN rainfall data vs Clevedon Coast @ Forest recorded rainfall

3.3.2 Stream flows

Stream inflows from the Mangemangeroa creek are recorded from 2000 to present day at a 5 to 15 minute time step. This data was compared to flows from the corresponding node in the FMWT data (Node_160188). The location of the Mangemangeroa gauge relative to the FWMT node is shown in Figure 3.3.

Figure 3.3: Location of Mangemangeroa Gauge (left) vs Mangemangeroa catchment node from FWMT (right), respectively

Comparison of the two stream flows is shown in Figure 3.4. Generally, the FWMT overestimates flows by around 9-28%. There is statistically good calibration for 2003-2017, and very good calibration for 2013-2017.

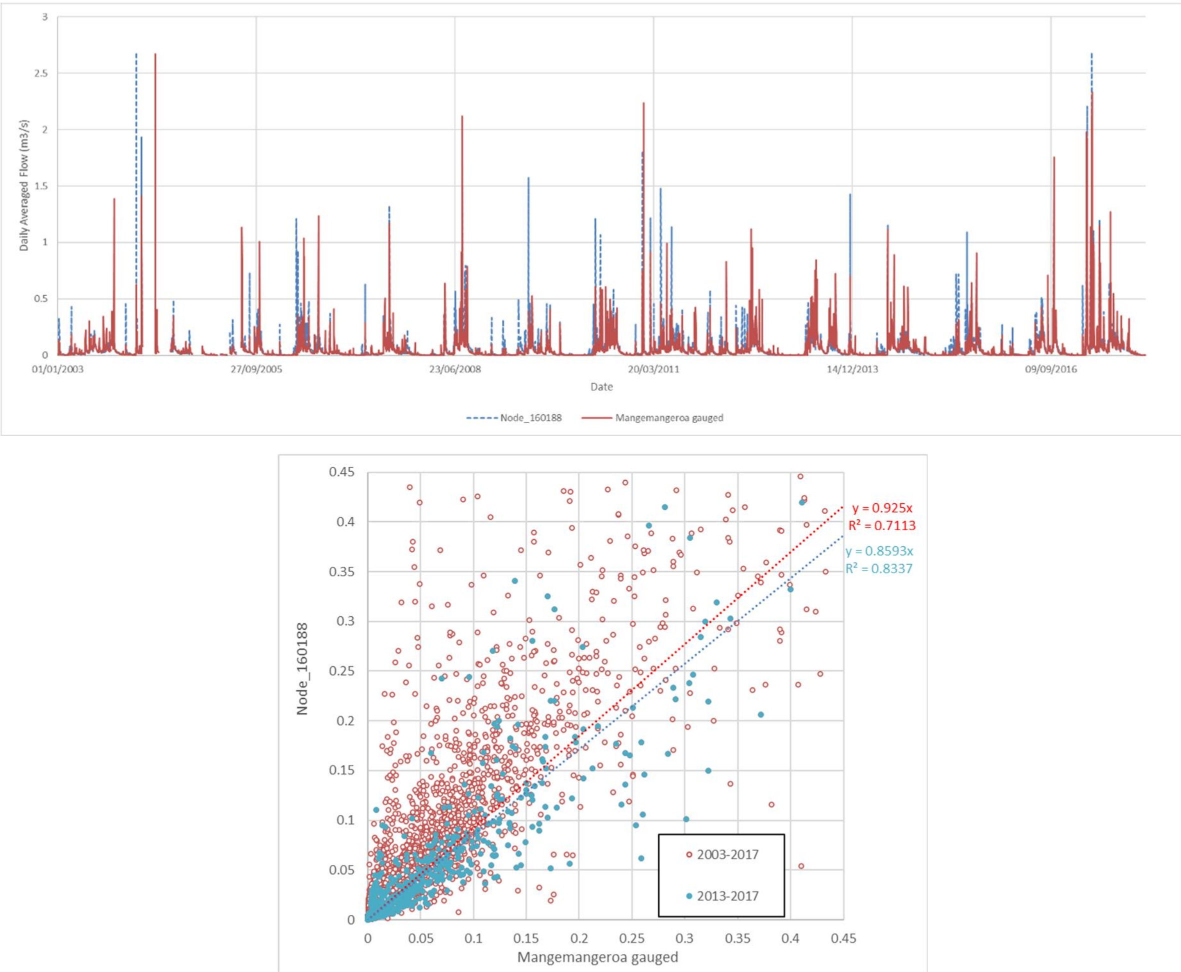

Figure 3.4: Comparison of Mangemangeroa creek flow data vs FWMT daily average flows

3.3.3 TSS Concentrations

Auckland Council have estimated sediment yields at Mangemangeroa gauge in two separate investigations, conducted in 2009 and in 2013. Comparison of the data is shown in Table 3.1 and Table 3.2 from the 2009 and 2013 reports, respectively. These comparisons indicate that the mean annual sediment yields from the FWMT are representative (although higher) of the observed mean annual yields, but individual event yields are not as well represented by the FWMT (see Table 3.2).

The sediment analysis report from 2013 covers collected samples from January to December 2012, and event sediment yields were calculated for 27 events occurring throughout the 1-year duration of sediment monitoring. The total sediment yield from storm events over the monitoring period was 752.4 tonnes, equating to a specific sediment yield of 167 tonnes/km^2/year.

Table 3.1: Mean Annual Sediment Yields

	Auckland Council1	FWMT	
Years	2000 - 2008	2003 - 2008	2003 - 2017
Mean annual sediment yields (t/km^2/year)	89±7	145	158

1. Values obtained from "Analysis of Sediment Yields within the Auckland Region", Auckland Regional Council, 2009

Table 3.2: Results from 2012 Sediment Analysis

2012 sediment analysis		Auckland Council1	FWMT
Annual sediment yield (t/km^2/year)		167	78.7
Events	3/7/2012	24.73	32.81
	22/7/2012	25.14	5.69
	26/7/2012	253.30	1.54
	29/7/2012	33.75	12.41
	30/7/2012	7.03	10.87

1. Values obtained from "Quantifying catchment sediment yields in the Auckland Region", Auckland Regional Council, 2013

3.4 Catchment characteristics

The data from the 62 FWMT nodes that Auckland Council supplied were grouped spatially into the 6 catchments to compare relative TSS loads from the contributing catchments, as shown in Figure 3.5.

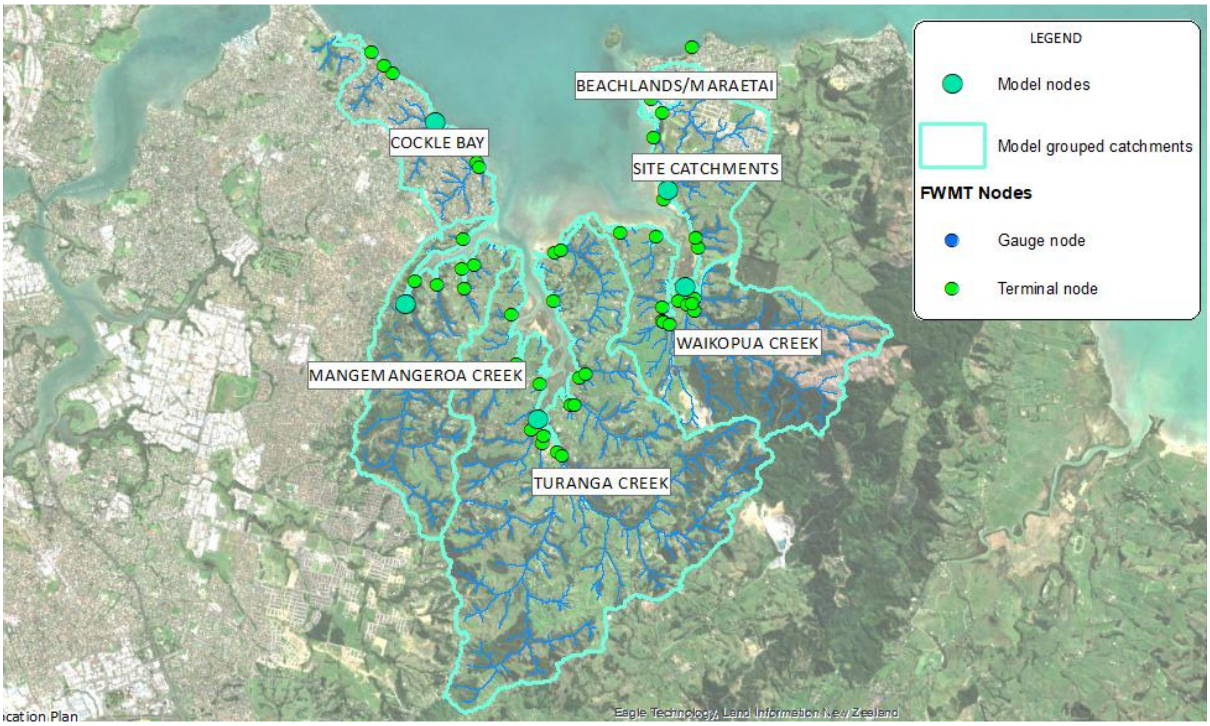

Figure 3.5: Grouped catchments for relative comparison of TSS loads

The site catchments, as named, are shown in Figure 3.6.

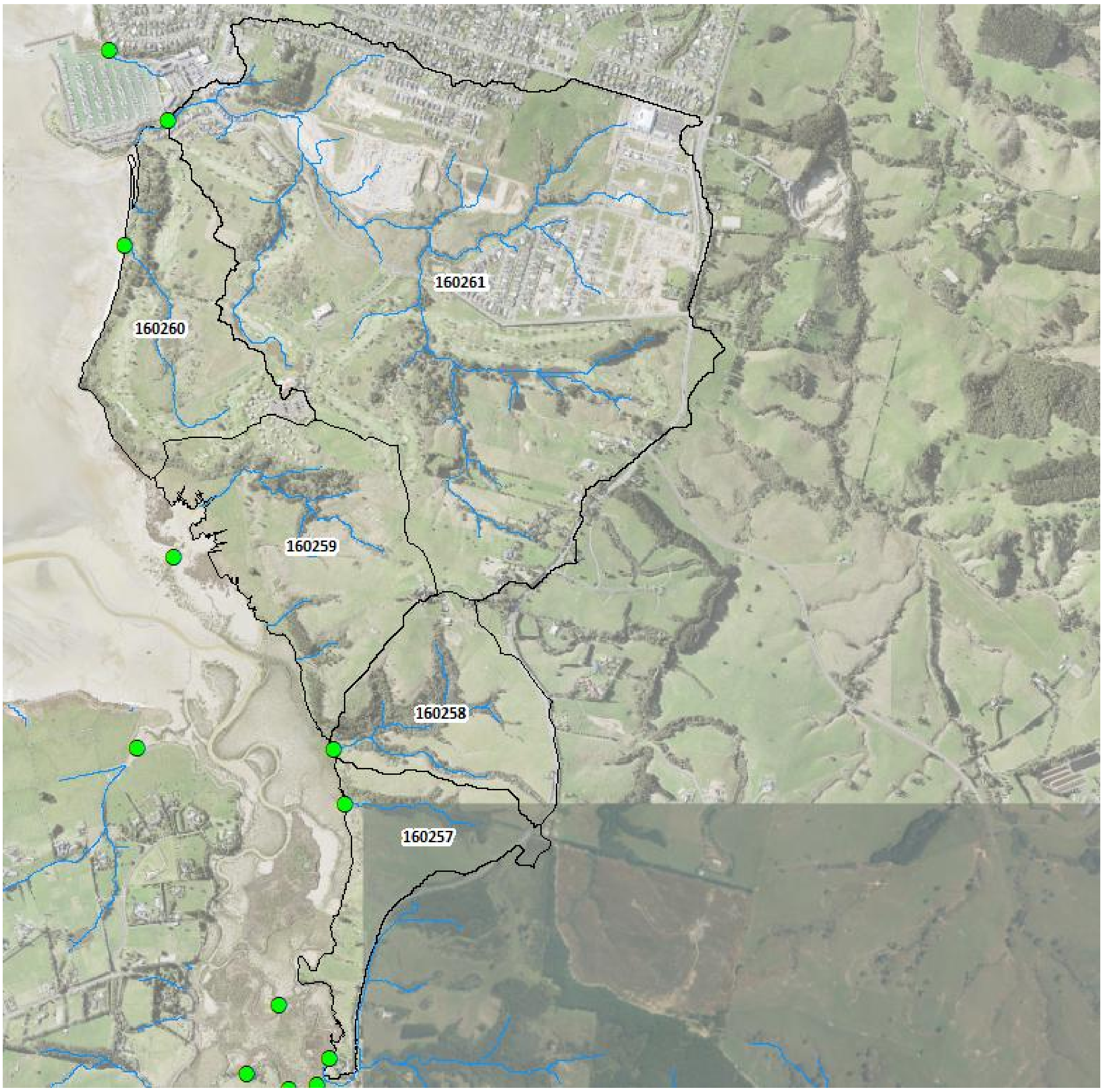

Figure 3.6: FWMT Catchments within the site catchment

3.5 Data review conclusions

From the review of the FWMT data review, the following conclusions have been drawn and applied to further use of the data;

- Due to the data only being calibrated from 2013 – 2017, this is the only data that will be used in further analysis. The earlier portion of the outputs shows less reliability.
- The FWMT typically overestimates flow and is thus more conservative when it comes to daily mean flows compared to observed data.
- Mean annual yields of TSS are reasonable when compared to Auckland Council data.

4 Flood Modelling

Harrison Grierson have developed a flood model for the site catchment. The model contains 2.33 year, 10 year and 100 year ARI 24-hour storm runs at a 5 minute timestep. T+T were provided hydrographs from the model at the points displayed in Figure 4.1. The model results are considered the best representation of event-based stream flow in the catchment and were applied as inflows to the hydrodynamic model.

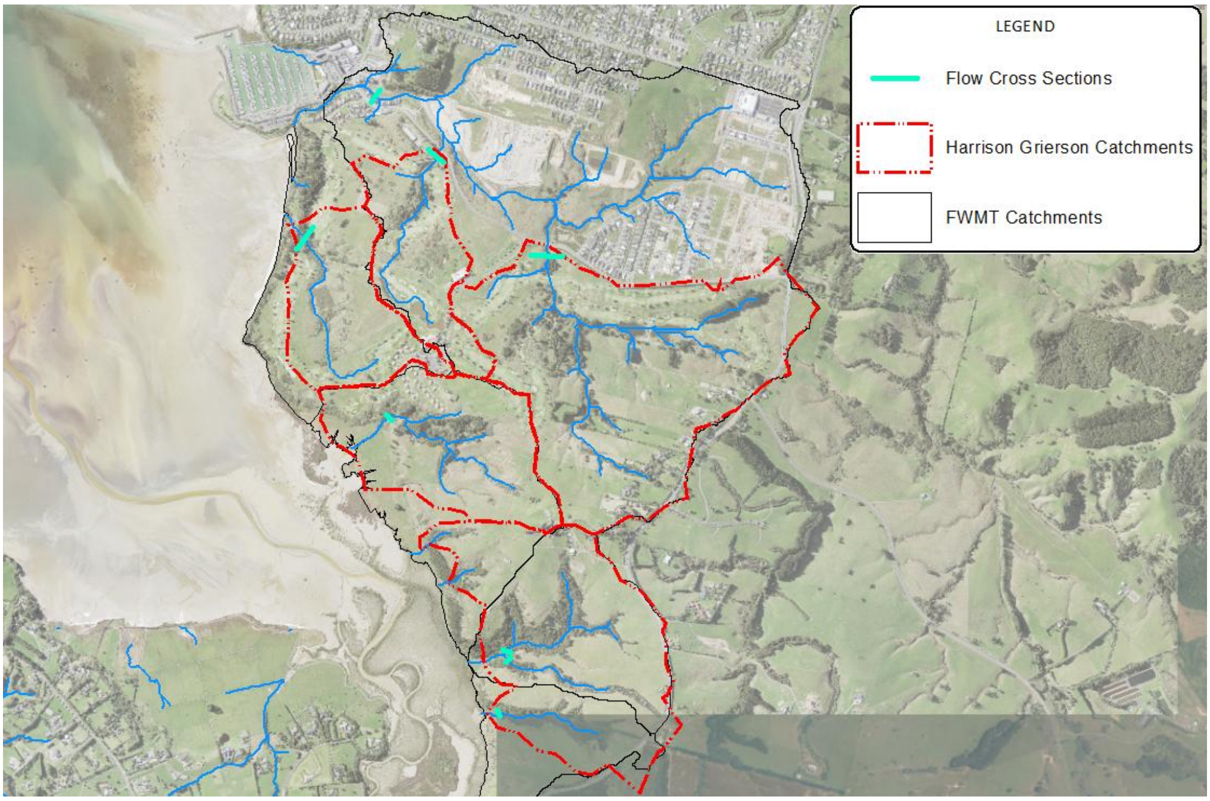

Figure 4.1: Harrison Grierson flow hydrograph cross sections

5 Water Quality inputs

There are two potential sources of water quality inputs for the hydrodynamic modelling - from the FWMT and from NIWA GLEAMS modelling. NIWA modelling outputs contained 24 hr TSS loads for an array of different ARI events ranging from 2.33 year ARI to 100 year ARI, for an existing and mid construction scenario.

The TSS inputs provided by NIWA in the form of 24hr TSS loads were sensed checked against outputs from the FWMT for the 2.33 ARI event, because the FWMT output did not contain a suitable 100-year ARI event and because the GLEAMS model would eventually be used to represent the TSS boundary conditions for the hydrodynamic modelling. The methodology used to prepare outputs from the FWMT that could be compared with the GLEAMS output is described below. The process is also used to calculate the relative sediment contribution of the site catchment to sediment load in the bay.

5.1 FWMT inputs

5.1.1 Site catchment methodology

TSS outputs from the FWMT corresponding to a ~2.33 ARI design event was selected from the output record for comparison with the GLEAMS modelling, which was driven by flows obtained from the Harrison Grierson flood model for the 2.33 ARI design event. The two-step procedure is as follows:

1 Identify events in the site catchments for input into the hydrodynamic model using flood frequency methodology. Daily average concentrations and flows from 2013 – 2017 were analysed to come up with a representative 2.33-year ARI event.

2 Once representative ARI events had been determined, the corresponding 48-hour TSS loads were initially compared against ARI, as shown in Figure 5.1. The event shown (April 2017) was chosen as it had the highest loads and was deemed the most representative for a 2.33-year ARI event. In the end, however, a 24-hour load period was chosen for TSS loads to properly compare the FWMT outputs to the GLEAMS 24 hour loads. As flood frequency analysis was only conducted against one node (260160, displayed in Figure 5.1), the four other site catchments were checked to ensure the April 2017 event was of similar magnitude for all site sub-catchments.

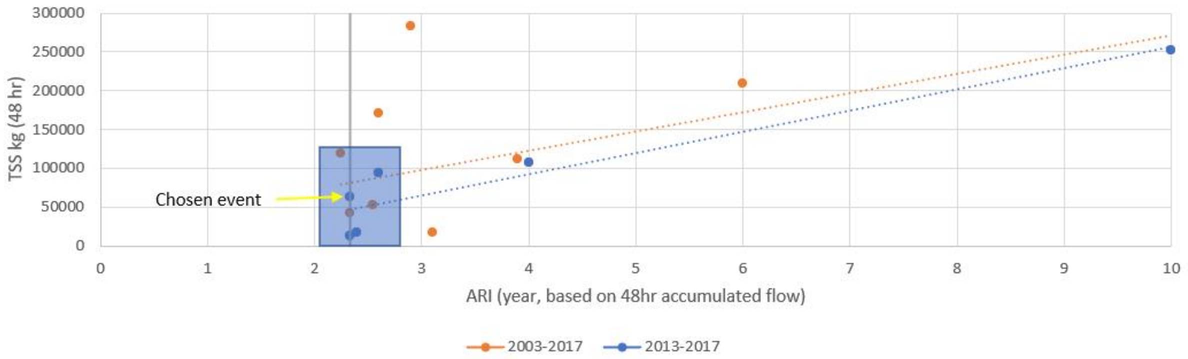

Figure 5.1: TSS Loads for rainfall events between 2.33 and 10 year ARI

5.1.2 Surrounding catchment methodology

For all other catchments outside of the site catchment, there were no flood model hydrographs available to apply to the sediment loads. The only flow gauge data available was at the Mangemangeroa gauge.

To obtain representative hydrographs for the other four catchments, TP108 flows were calculated for all catchments and scaled against the Mangemangeroa flow. The scale factors (based on catchment area) in Table 5.1 were applied to the gauge flow for the April 2017 event to create representative hydrographs for the remaining catchments. Representative hydrographs for each catchment are shown in Figure 5.2.

TSS loads for the wider catchment were applied similarly to that of the site catchments, but the wider catchments contained multiple terminal nodes, so these were added together to obtain a total TSS load for each catchment.

Table 5.1: Hydrograph scale factors for wider catchments

Site	Scale factor from Mangemangeroa flow
Beachlands	20.03%
Waikopua	183.82%
Turanga	295.13%
Mangemangeroa	100.00%
Cockle Bay	128.09%

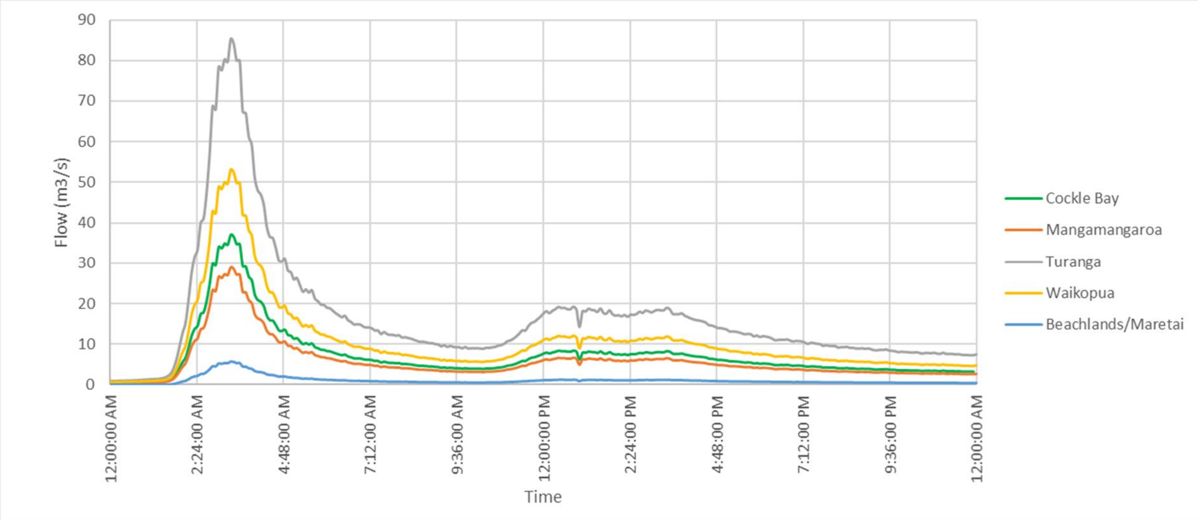

Figure 5.2: Flow hydrographs for wider catchments for the April 2017 event

5.1.3 Summary of FWMT inputs

The total 24 hour TSS loads for all catchments are summarised in Table 5.2. Site catchments make up around 7% of the total load from the whole area.

Table 5.2: Summary of 24 hour TSS loads from each catchment for the April 2017 event

Catchment		TSS Load 24h (kg)	Contributing % grouped	Contributing % total
Site catchments	160257	8,992	6.71%	0.51%
	160258	10,748		0.61%
	160259	26,077		1.47%
	160260	11,660		0.66%
	160261	61,617		3.47%
Cockle Bay		82,479	4.65%	
Mangemangeroa		309,443	17.44%	
Turanga		857,857	48.34%	
Waikopua		396,386	22.34%	
Beachlands/Maraetai		9,273	0.52%	
	Total	1,774,530	100.00%	

5.2 GLEAMS Inputs

NIWA undertook modelling using GLEAMS software to determine existing case and mid-construction TSS loads for the site. The catchments that NIWA used in their analysis are shown in Figure 5.3. This process is fully documented in a separate NIWA report.

Figure 5.3: NIWA GLEAMS catchments (note blue areas contain no earthworks under the mid construction case)

For the TSS outputs from the GLEAMS model NIWA used the following assumptions in their approach to develop existing case, and treated and untreated mid construction case loads (email communication dated 29/09/2021);

- Assuming the steepest 15 ha of each catchment (taking a maximum slope of 12 degrees) are worked in a single earthworks season, with a maximum of 5 ha exposed area at any one time. The estimates represent a worst-case sediment load scenario, as;
  - They assume the steepest 15 ha are worked in each catchment, and
  - The baseline land cover is assumed to be consistent with the golf course, which produces the lowest estimate of baseline loads.
- Using load reduction factors to simulate treatment by sediment retention ponds during the earthworks season. This approach assumes no attenuation of runoff by the ponds, and won't reflect the improved treatment performance anticipated for the different pond sizing from GD05 described in the erosion and sediment control report.

5.3 FWMT vs GLEAMS data – Existing case

The 100 year GLEAMS data was not able to be directly compared to the FWMT data as there was no representative 100 year ARI event in the FWMT calibrated dataset. A comparison of a ~2 year ARI events was therefore performed instead. See Table 5.3 for the comparison.

There are a few key differences in the two data sets, which provide some explanation to the differences shown in Table 5.3;

- The FWMT data is for an ARI of 2.33 years, whereas the GLEAMS data has an ARI of 2 years
- The catchments used in both approaches are different. In general, the FWMT catchments are typically larger.
- The GLEAMS model assumes that the baseline land cover is consistent with the golf course, which produces the lowest estimate of baseline loads.

A combination of all these factors likely explain some of the differences between the total loads, in the two datasets.

The comparison shows that for the ~2 year ARI event the FWMT is more conservative. However, since the two models are structurally different, and in combination with the other differences mentioned above it should not be expected that they will produce the same outputs.

Table 5.3: FWMT data compared to GLEAMS results, for the 2.33 and 2 year ARI existing case

FWMT Existing Case			GLEAMS Existing case		
FWMT Catchment	Total Area (ha)	TSS load 24h (tonnes)	Discharge Location	Total Area (ha)	TSS load 24h (tonnes)
160257	36	9	N/A	N/A	N/A
160258	44	11	E	49	8
160259	68	26	C&D	61	13
160260	53	12	B	44	4
160261	286	62	A	97	10
	Total Load	120		Total Load	36

A proportional reduction ($^{251\ ha}/_{487\ ha}$) to account for the larger catchment areas used in the FWMT and a similar proportional reduction ($^{2}/_{2.33}$) to account for the difference in the magnitude of the ARI events, resulted in a FWMT TSS load of 52 tonnes, which compares favourably with the 36 tonnes obtained from the GLEAMS outputs.

6 Applicability

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

We understand and agree that our client will submit this report as part of an application for the Beachlands South Structure Plan Change and that Auckland Council as the consenting authority will use this report for the purpose of assessing that application.

Tonkin & Taylor Ltd

Environmental and Engineering Consultants

Report prepared by:	Authorised for Tonkin & Taylor Ltd by:
....	....
Alex White Water and Environmental Engineer	Peter Millar Project Director

Technical reviewed by:

....

Wageed Kamish
Senior Water Resources Engineer

WKAM
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Appendix D: Hydrodynamic data and modelled outputs

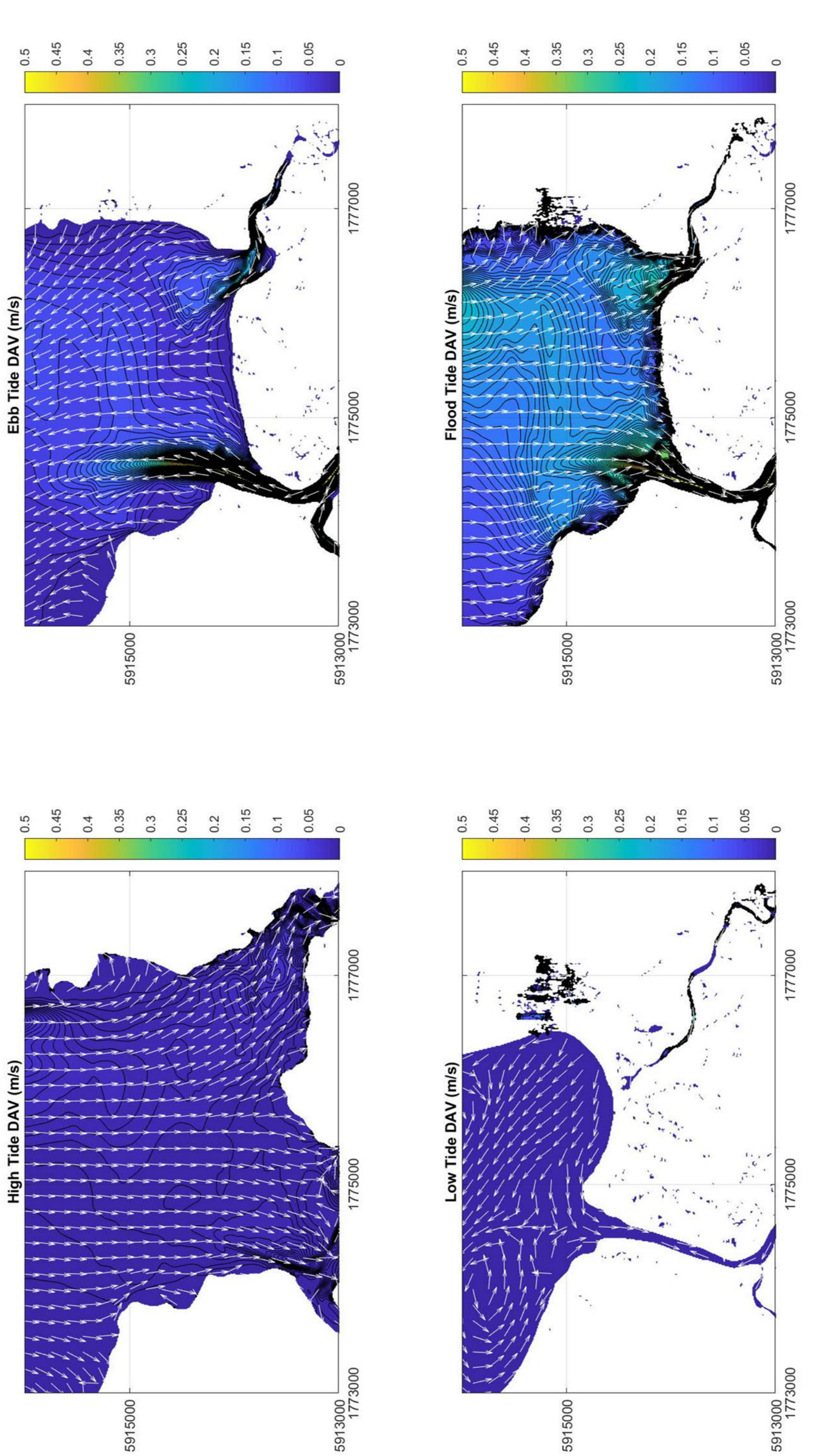

Figure 10-7 Typical Depth-Averaged Velocities (DAV)

Water level data and analysis of tidal constituents

Analysis of water levels between Mar 19 and April 30 in the location of Pressure Sensor North has been undertaken with T-tide (Pawlowicz, 2002). By way of example, visual review of reconstructed water levels in Figure 10-8 from T-tide constituents in the location of Pressure Sensor North indicate a reasonable fit with measured data. Quantitative comparison between constituent reconstruction of water levels and measured water levels at each of the instrument locations indicate average errors of less than 1%.

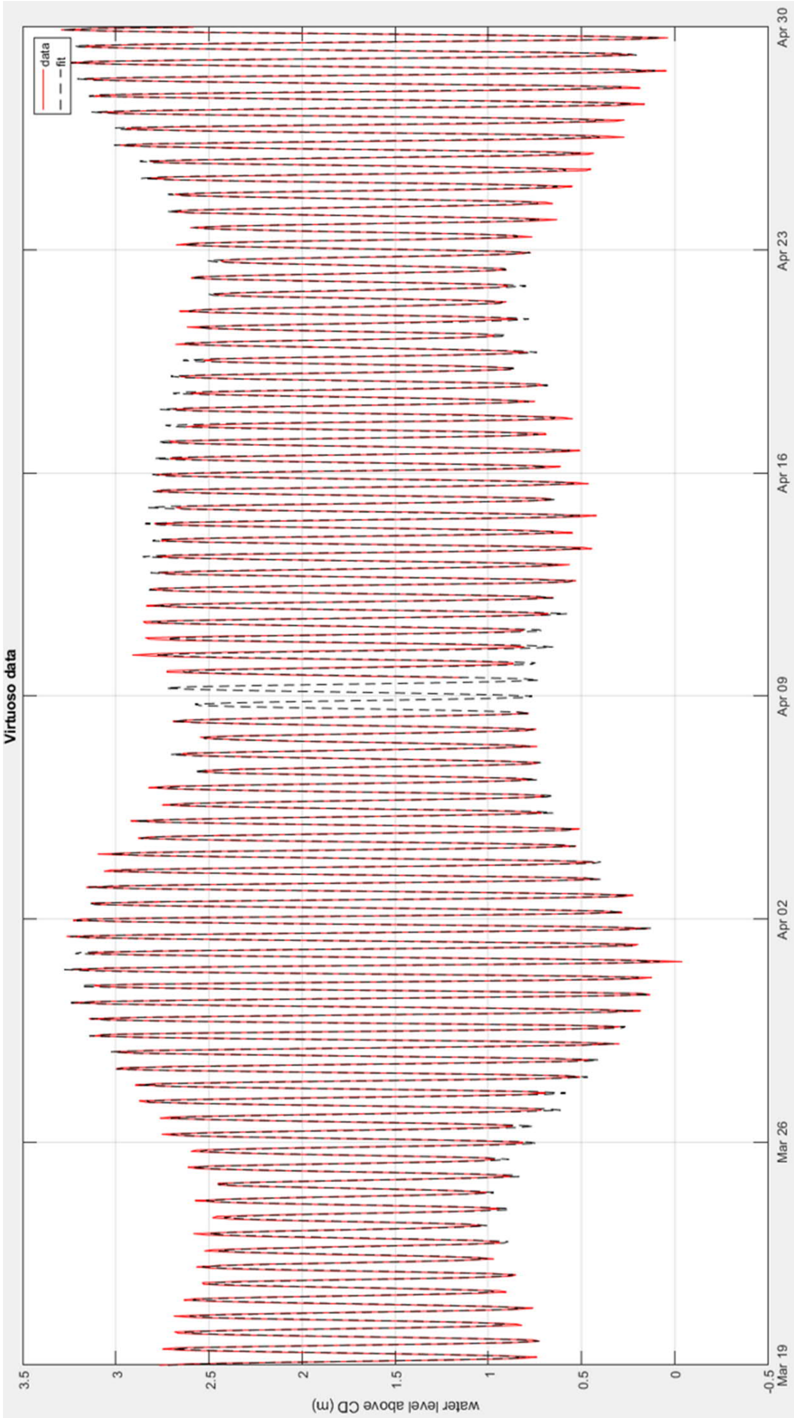

Figure 10-8 Visual review of reconstructed water levels from T-tide constituents (black dash line), derived from measured data (red solid line).

ADCP data

The ADCP provided measurements of current velocity at three elevations above the seabed. Measurements indicate current speeds being relatively uniform across the three elevations. Compass calibration due to interference of ferrous mooring equipment was undertaken based on the first week's data set, requiring a systematic correction of 42.41 deg.

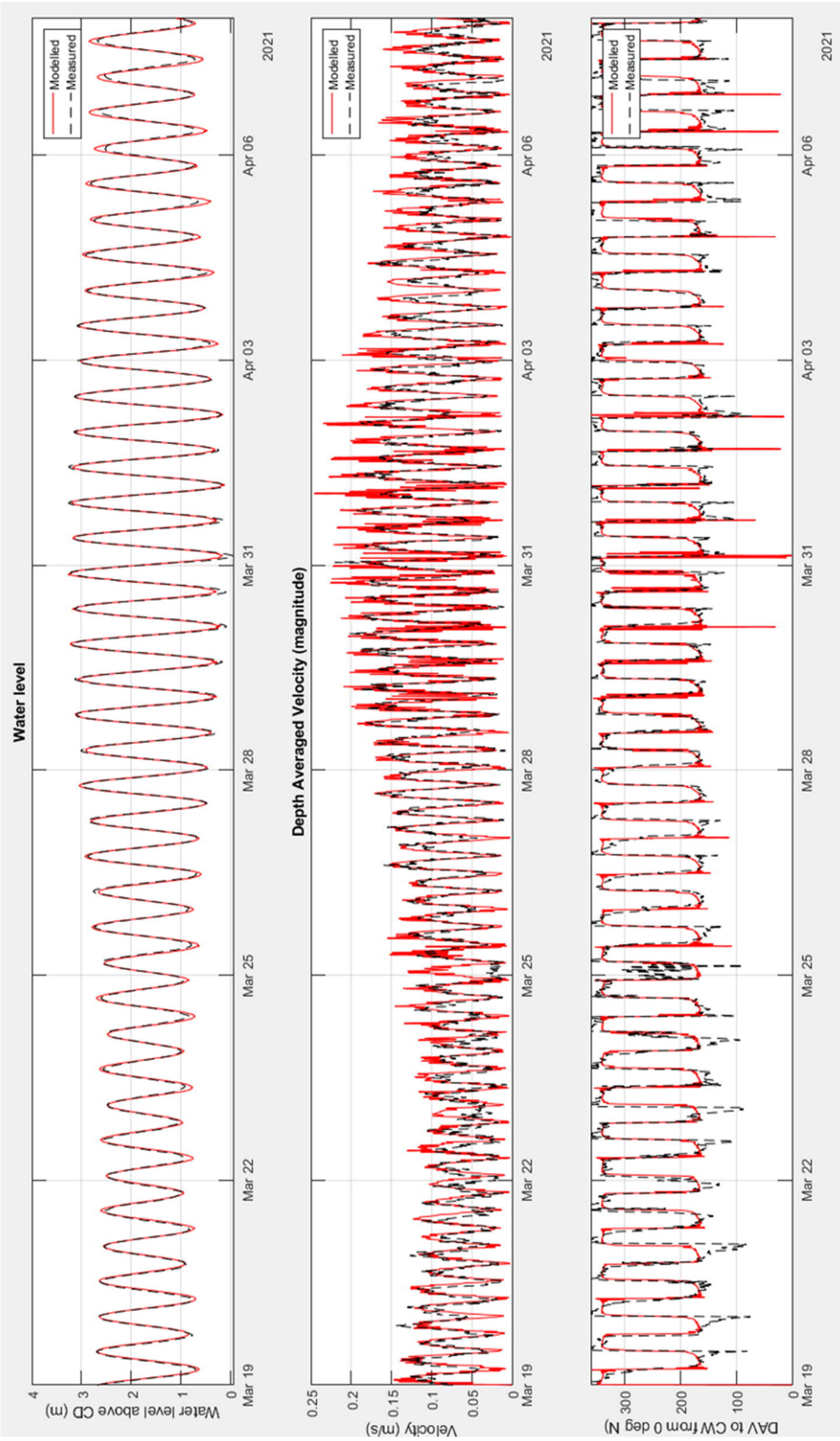

Figure 10-9 Time series comparison showing modelled values in red, and measured values with black dashed lines in the location of the ADCP

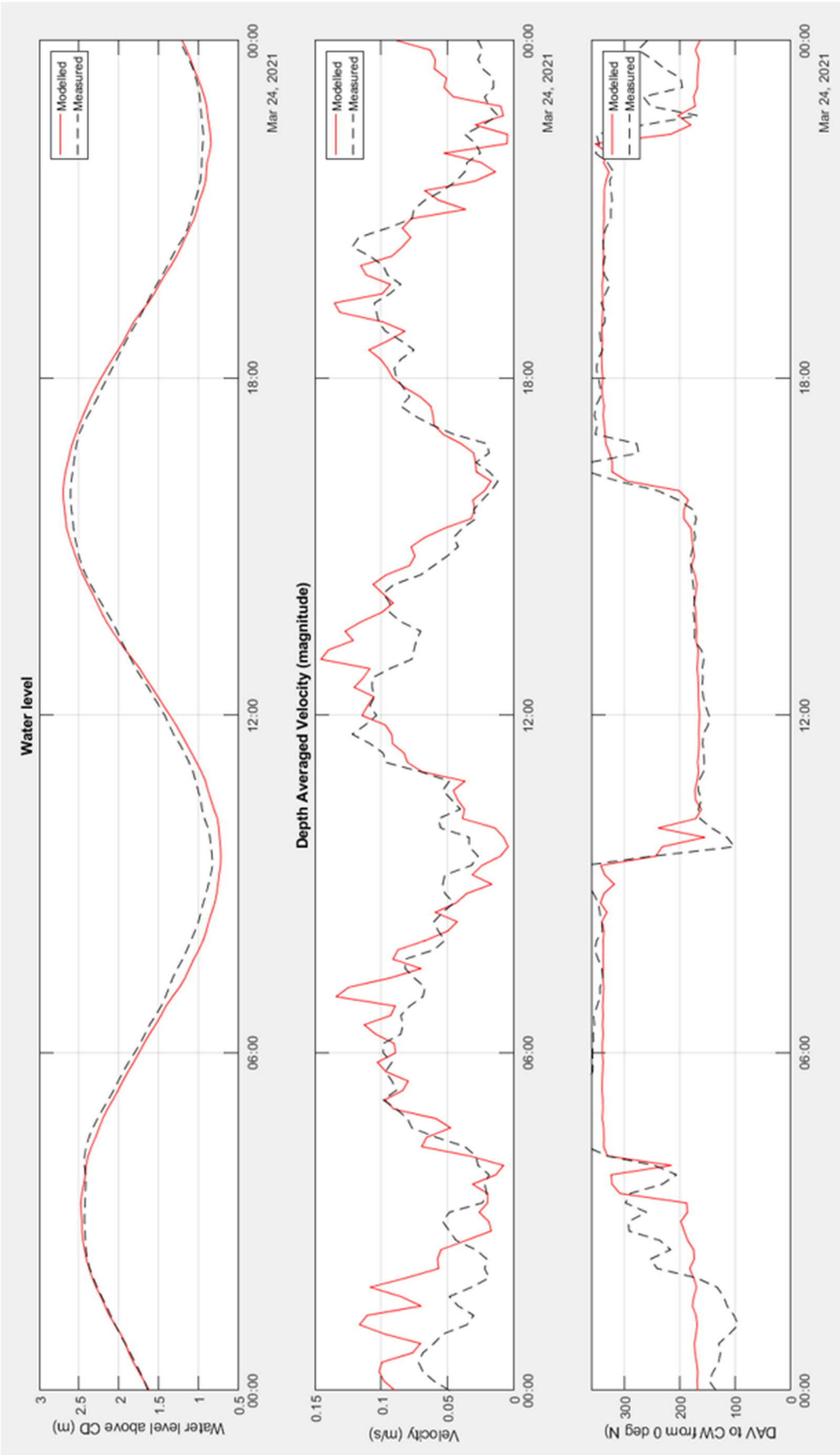

Figure 10-10 Select 24 h period comparing modelled and measured values in the location of the ADCP

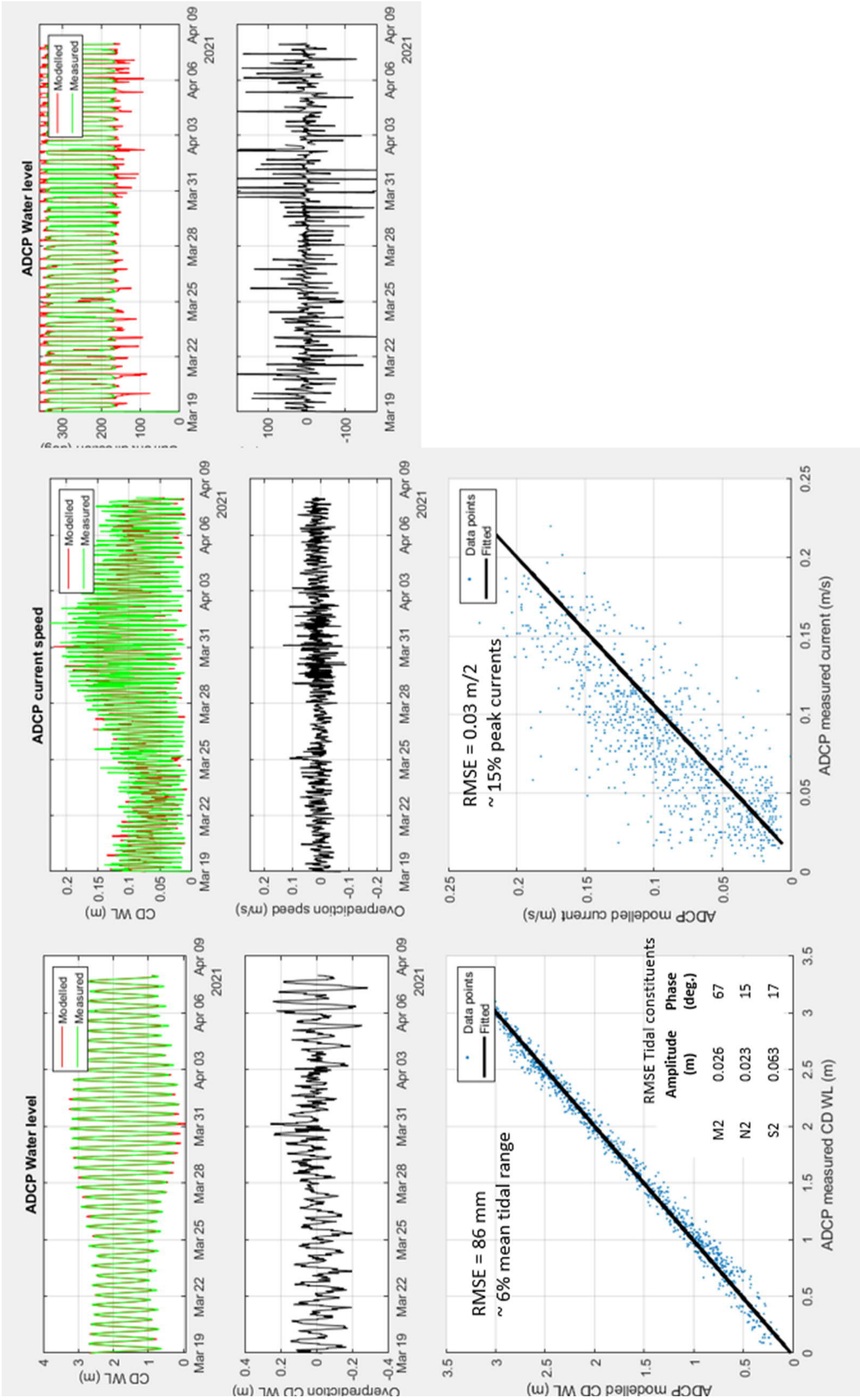

Figure 10-11 Numerical comparison of measured vs modelled data for water level and current speeds in the location of the ADCP

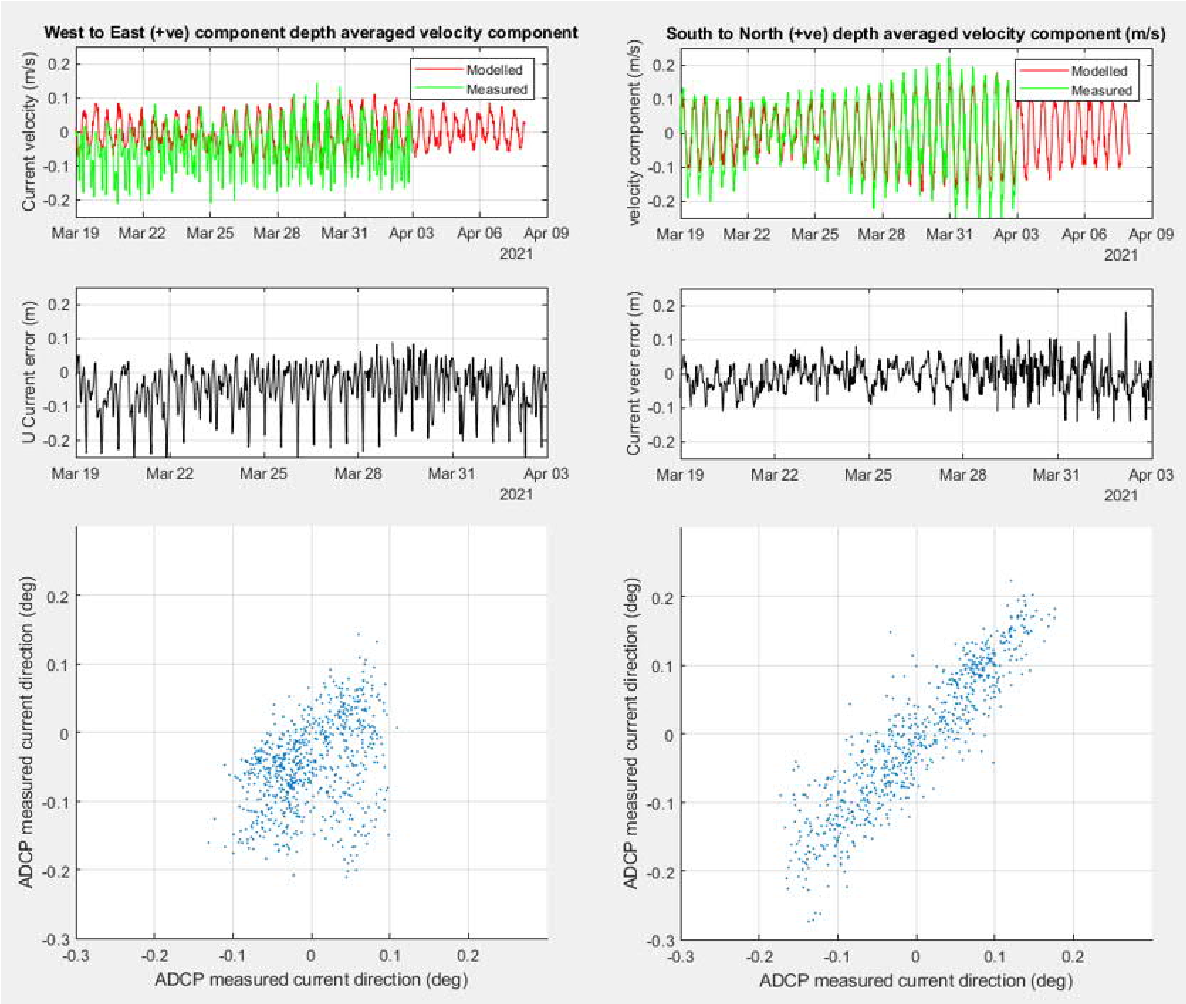

Figure 10-12 Review of currents in cartesian (+ve flowing to north and east directions)

Appendix E: Event based sediment transport modelling

The following outputs have a standardised scale from 0 to 20 mm. Brown lines show areas where more than 5 mm deposition may occur immediately following the rainfall event in question. The cross hatched area indicates where more than 5 mm of sediment could persist after a period of 10 days.

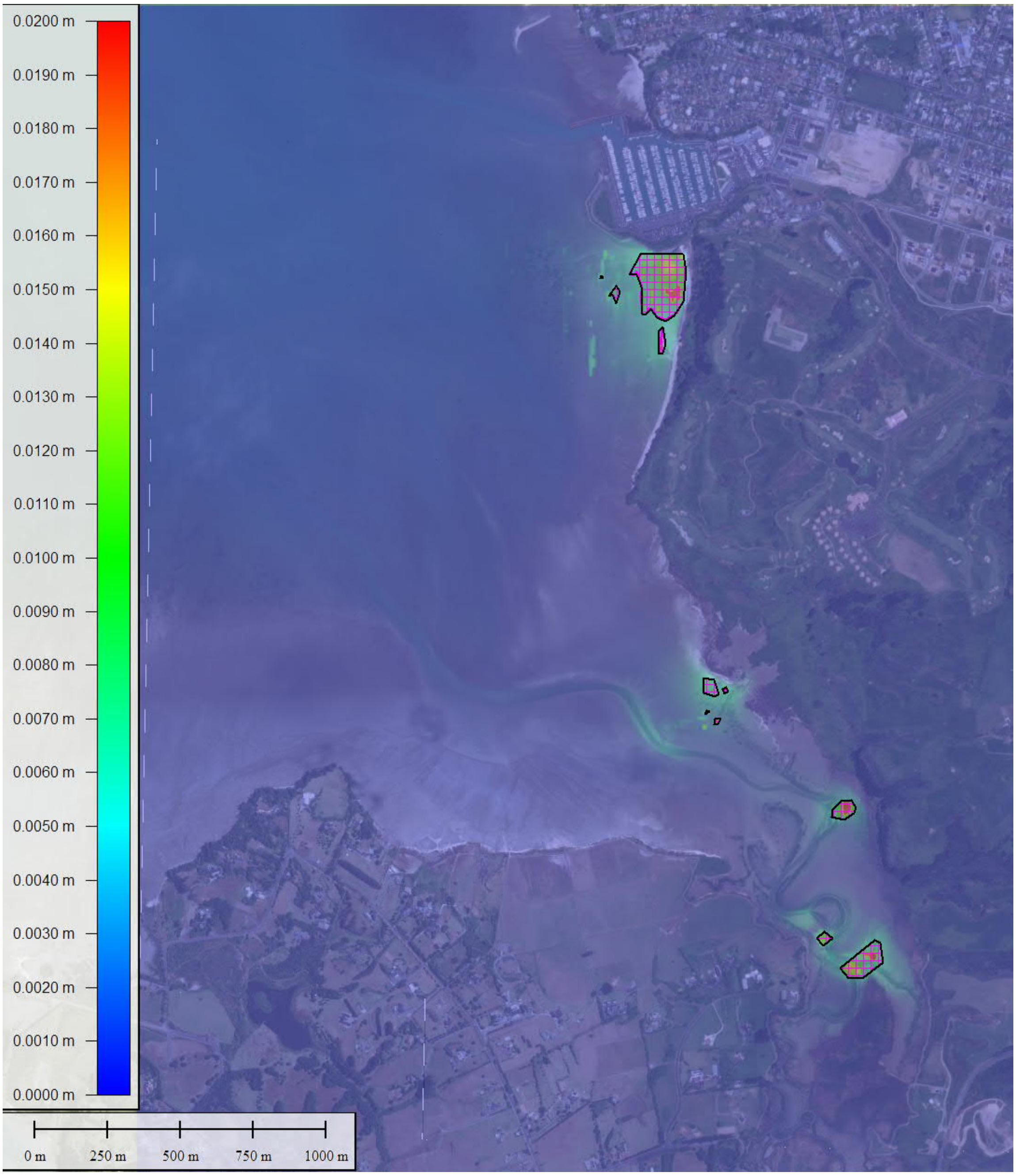

Figure 10-13 100 ARI TSS assuming Spring tide, HT peak discharge

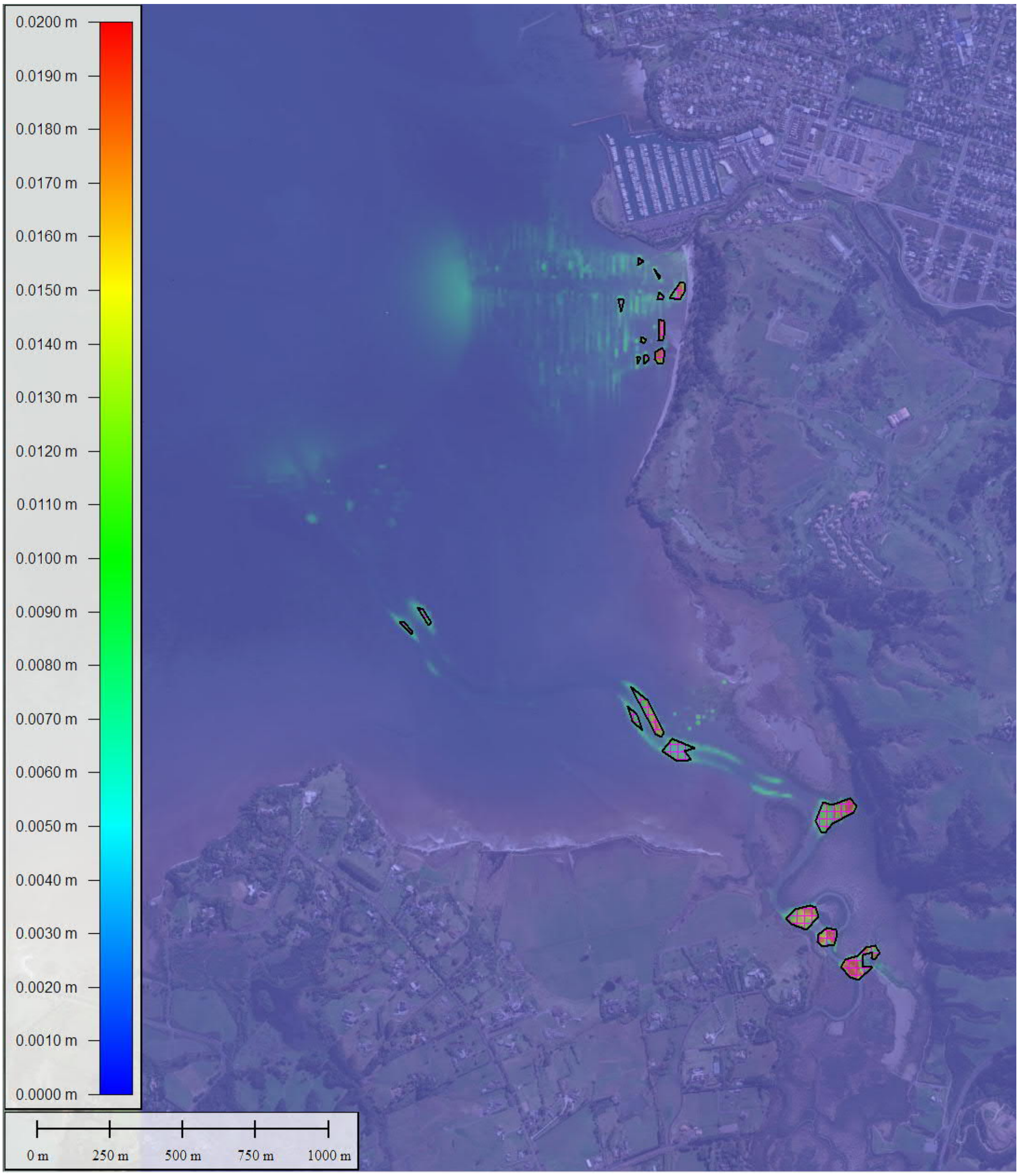

Figure 10-14 100 ARI TSS assuming Spring tide, LT peak discharge

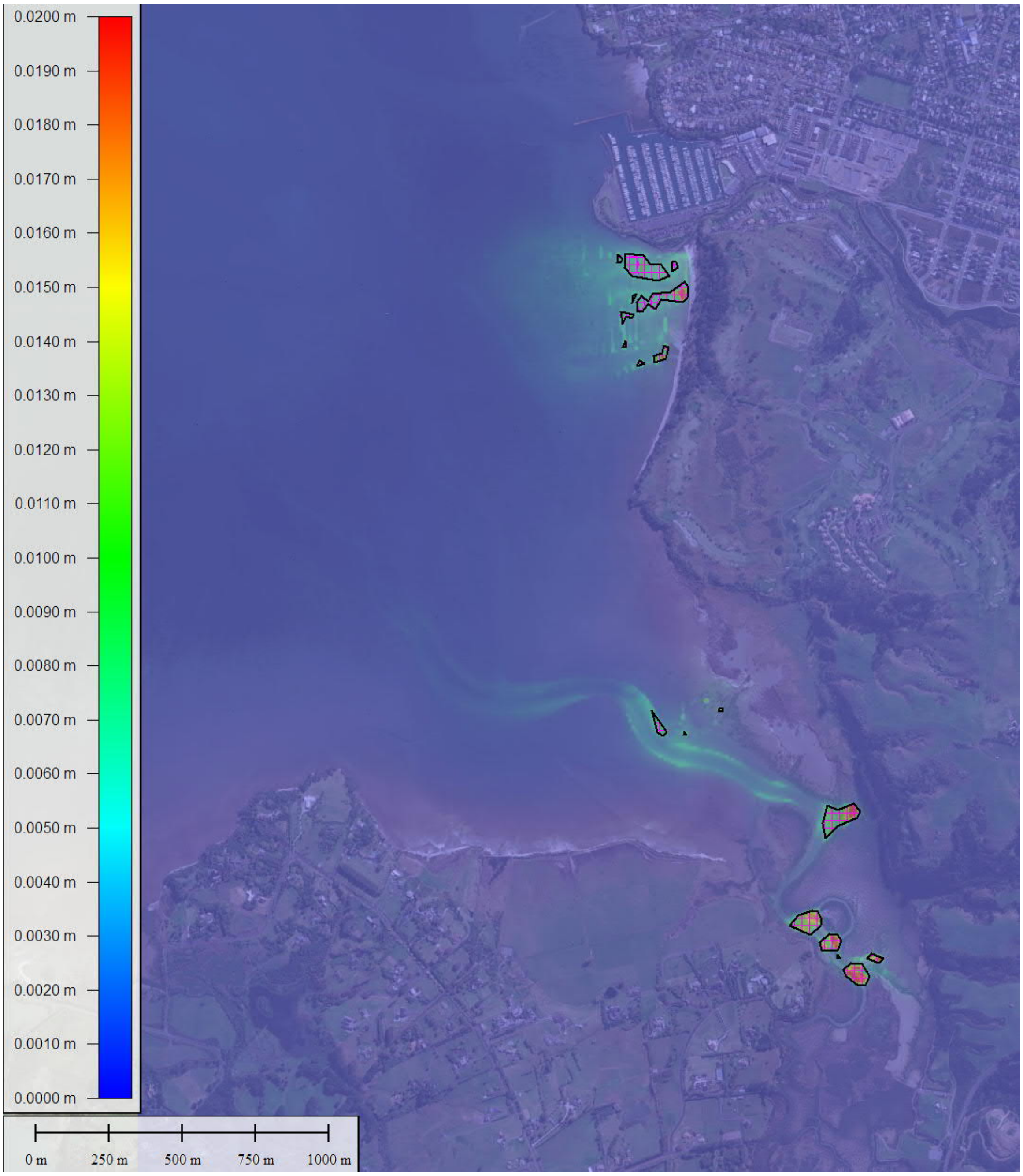

Figure 10-15 100 ARI TSS assuming Spring tide, FT peak discharge

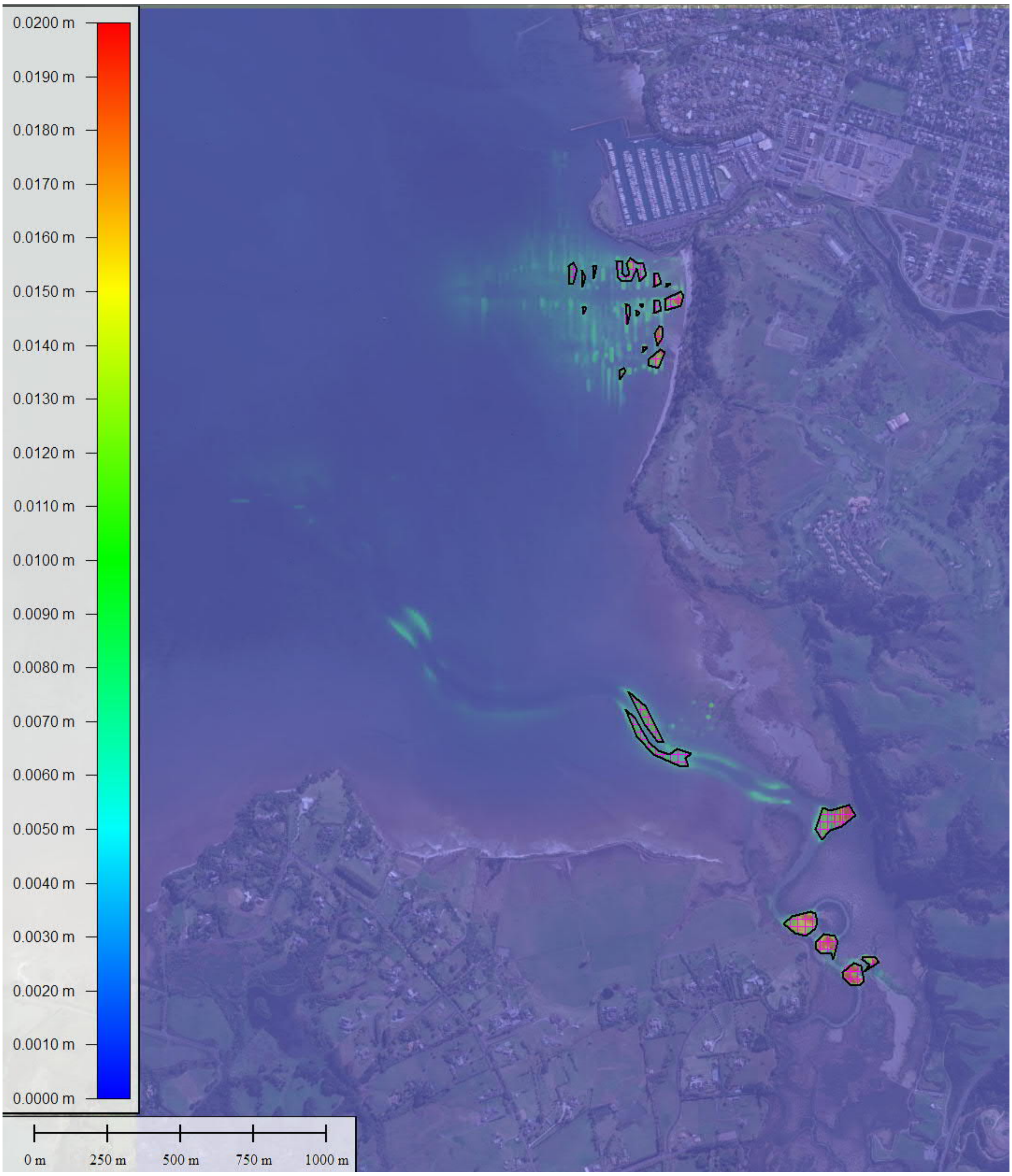

Figure 10-16 100 ARI TSS assuming Spring tide, ET peak discharge

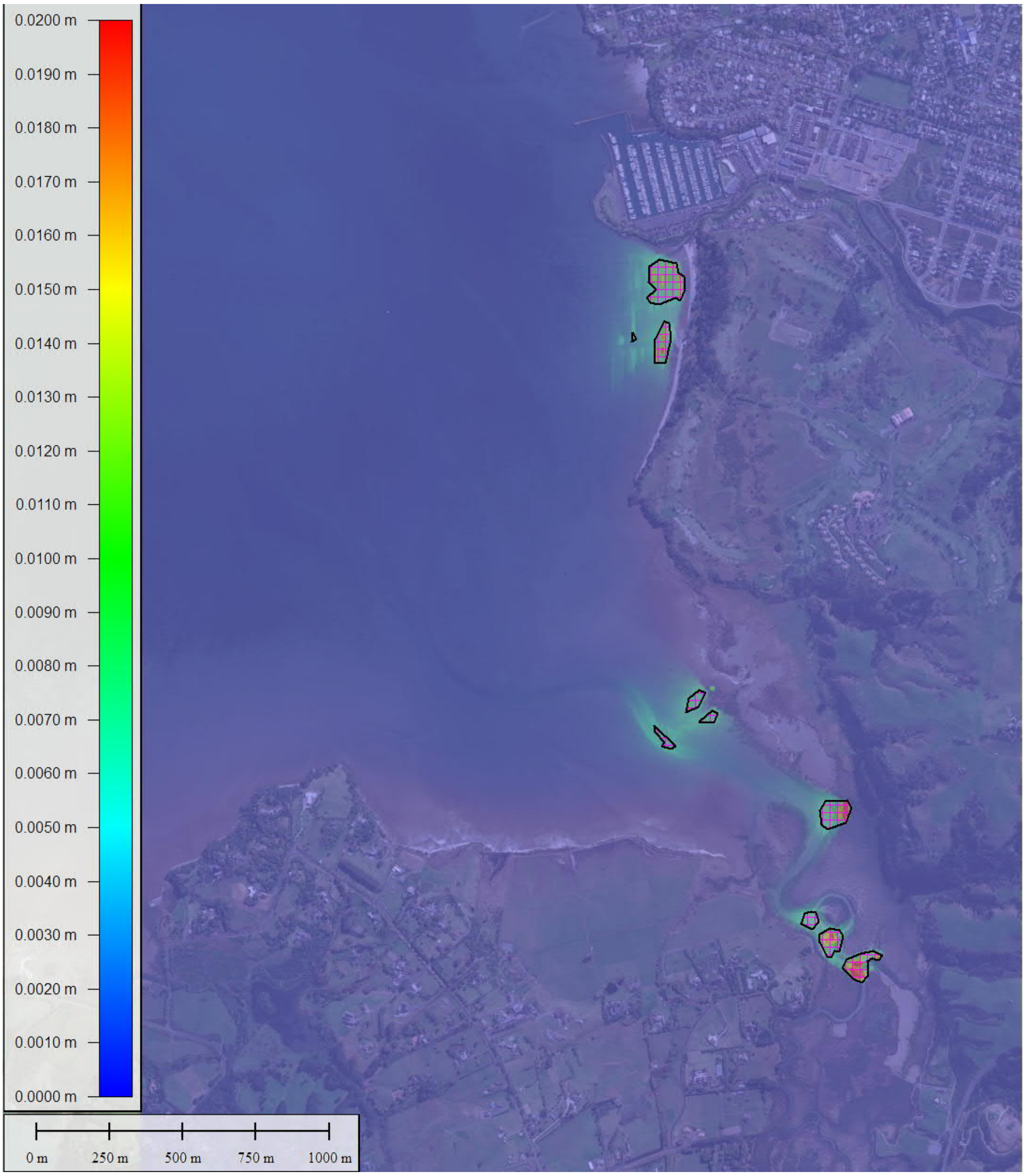

Figure 10-17 100 ARI TSS assuming Neap tide, HT peak discharge

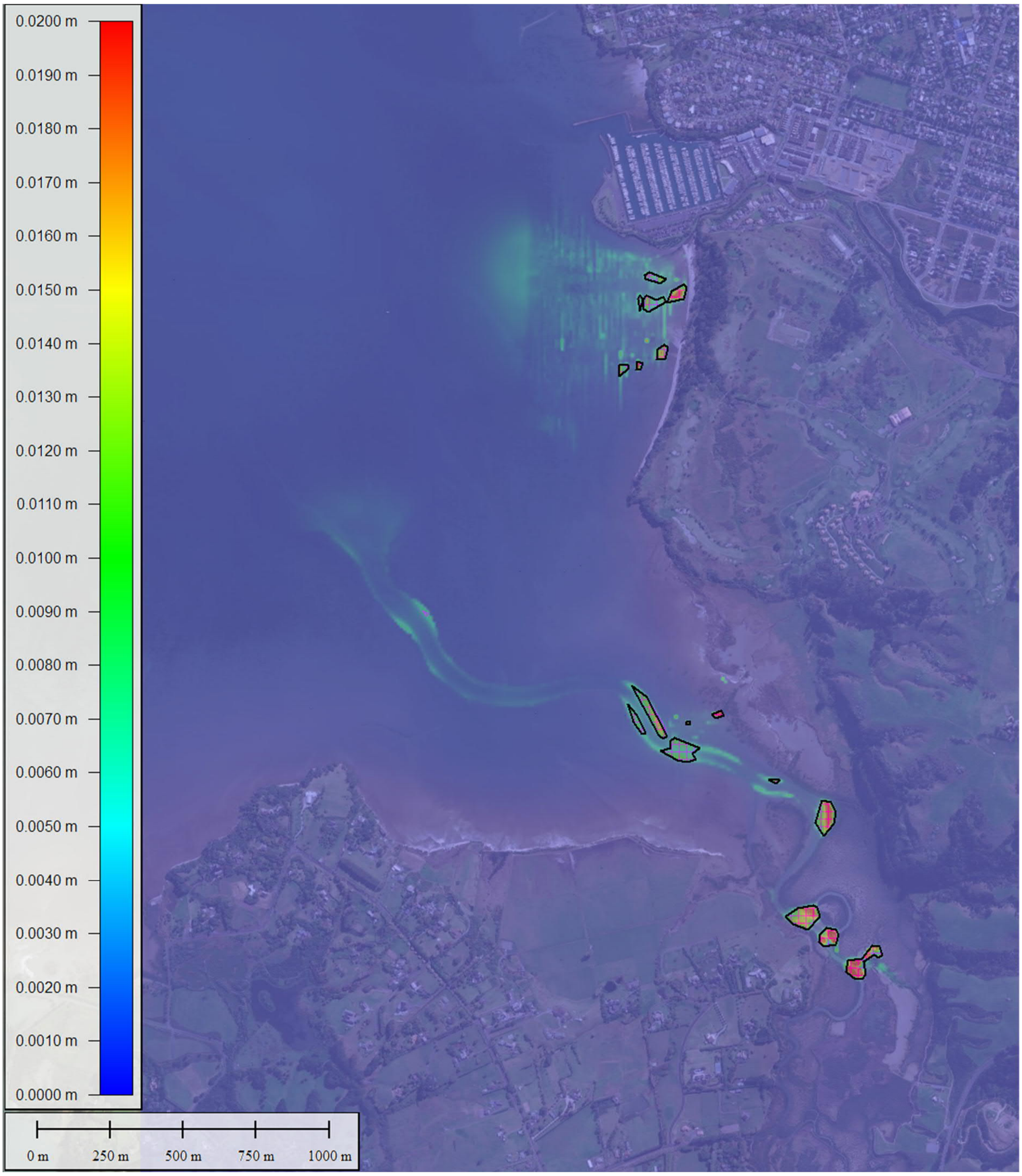

Figure 10-18 100 ARI TSS assuming Neap tide, LT peak discharge

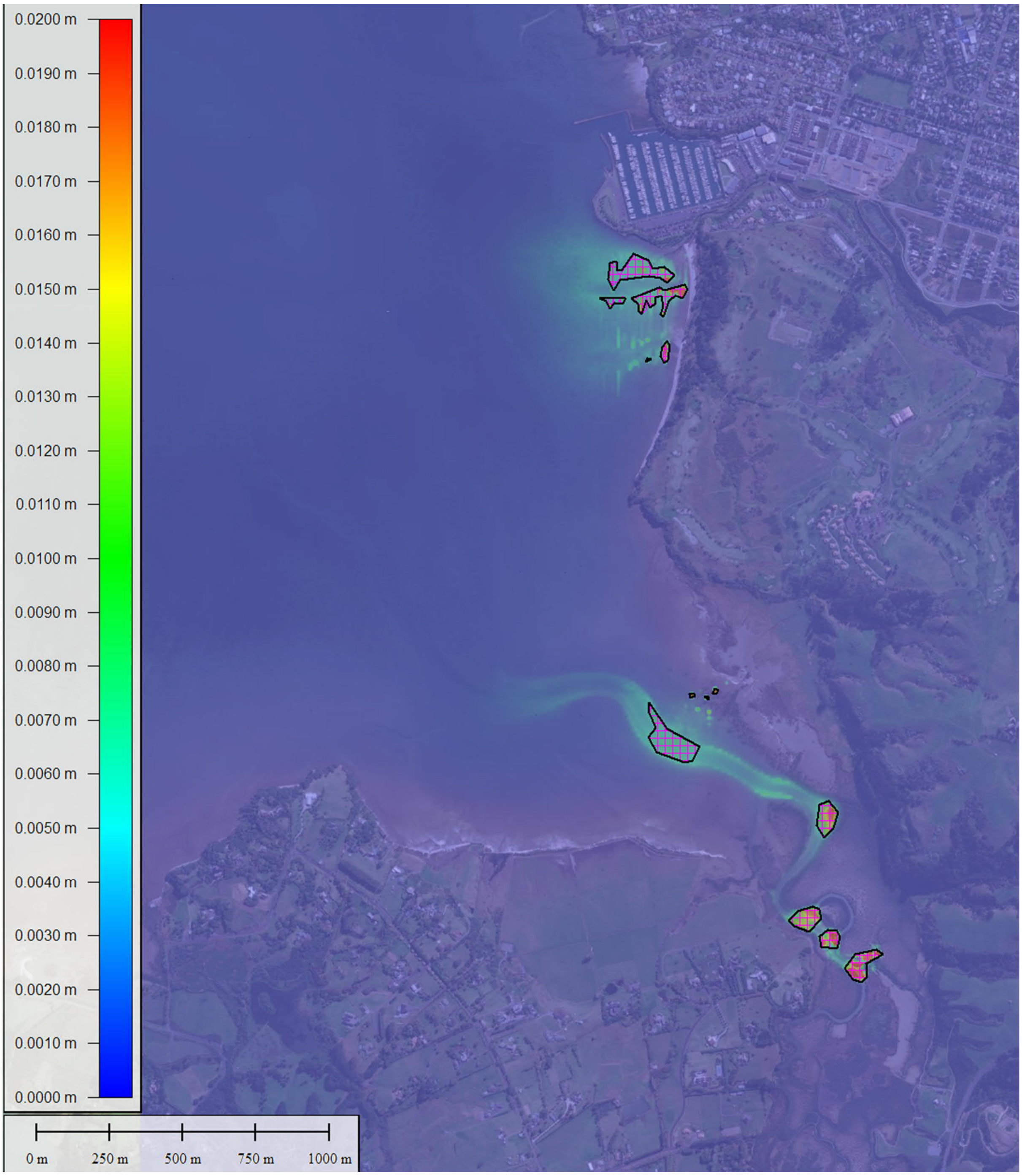

Figure 10-19 100 ARI TSS assuming Neap tide, FT peak discharge

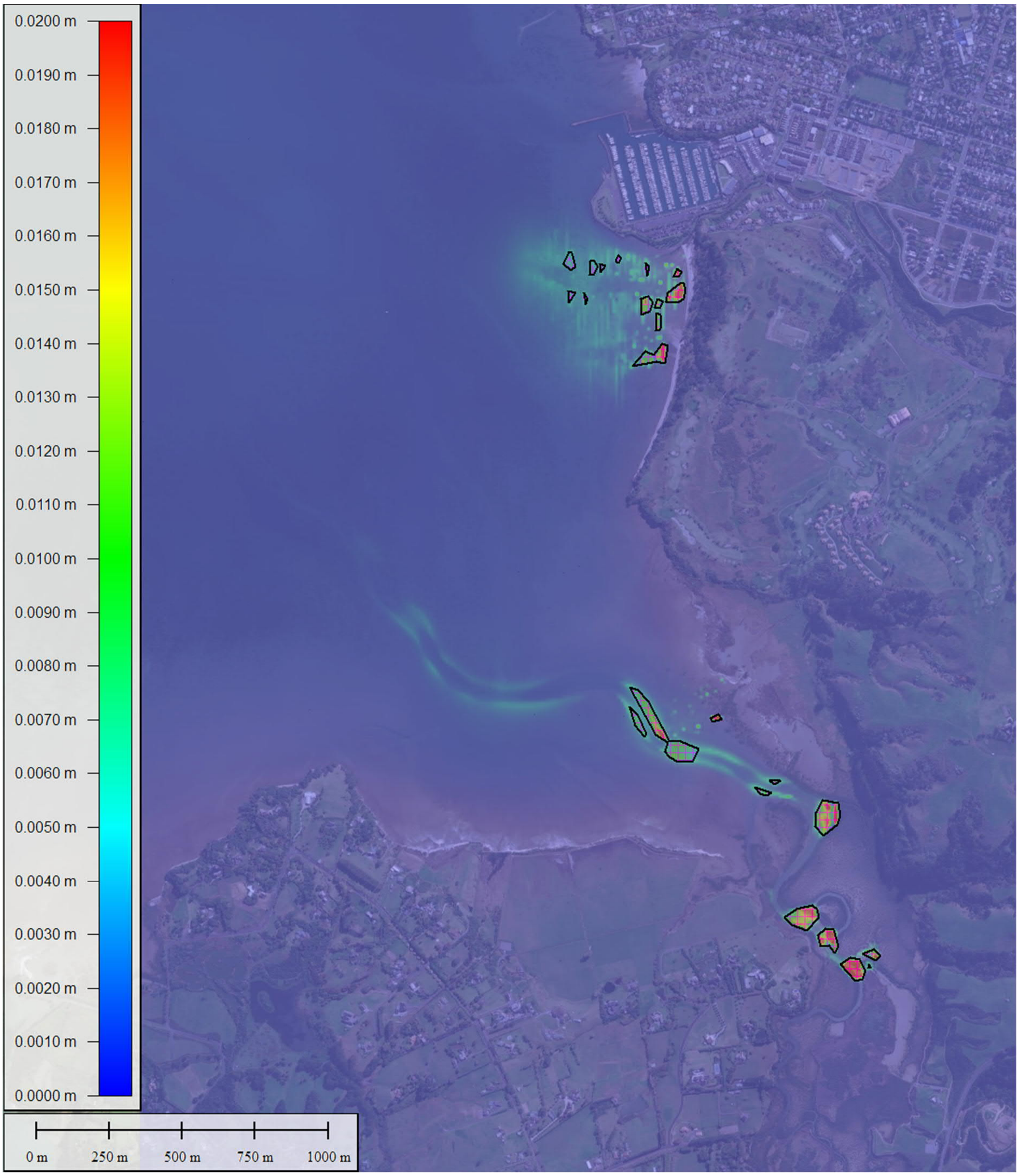

Figure 10-20 100 ARI TSS assuming Neap tide, ET peak discharge

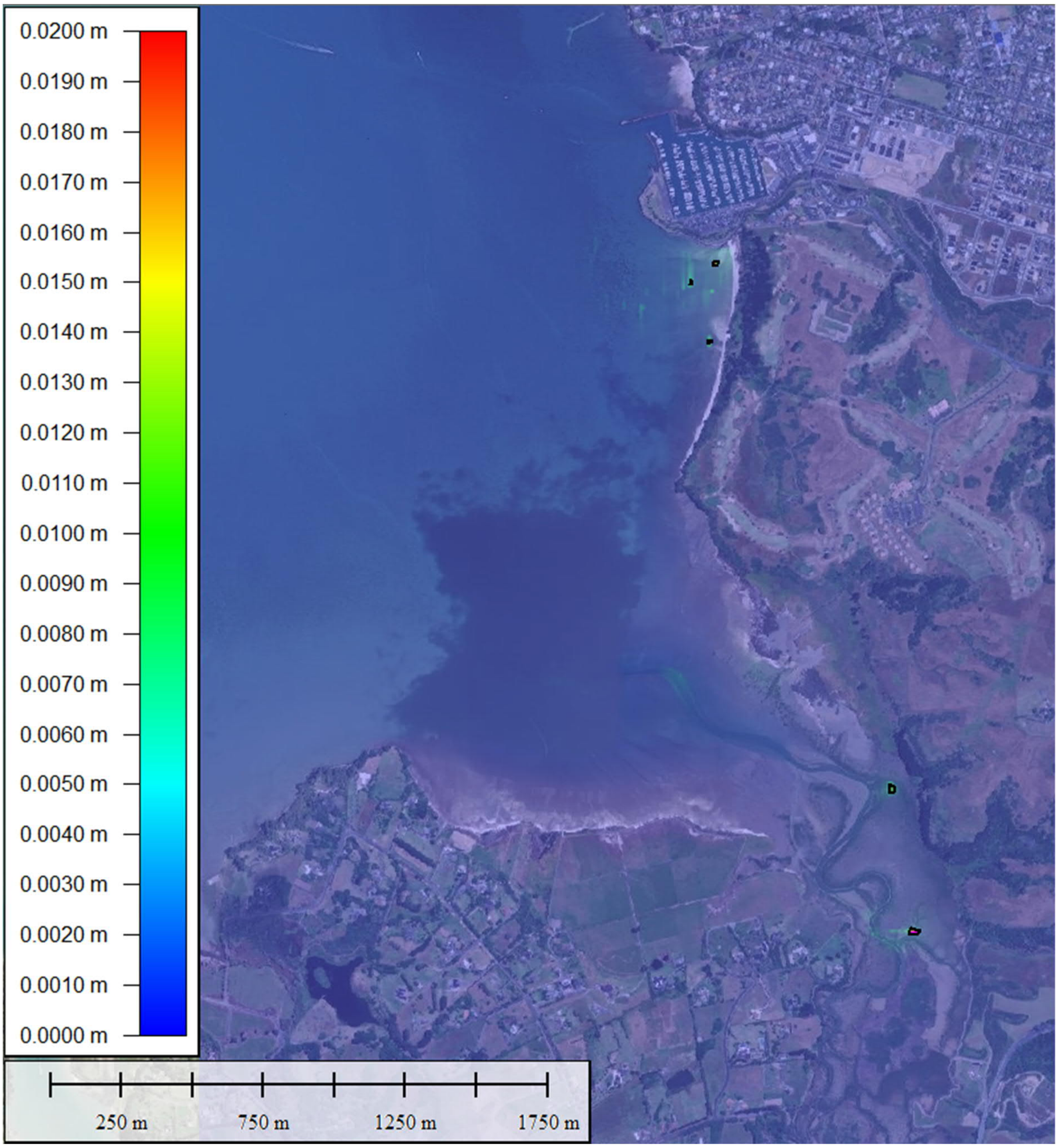

Figure 10-21 10 ARI TSS assuming Spring tide, HT peak discharge

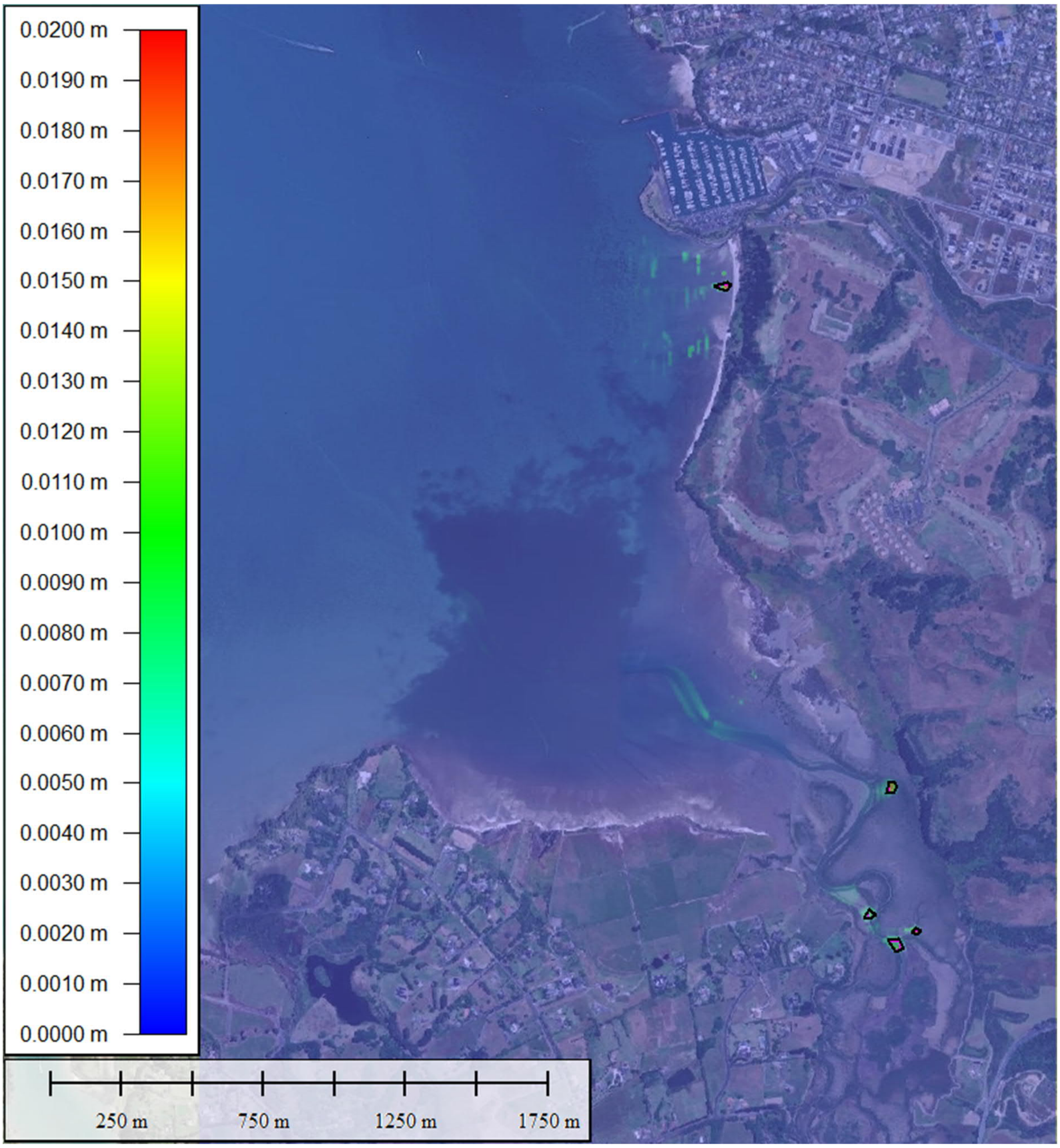

Figure 10-22 10 ARI TSS assuming Spring tide, LT peak discharge

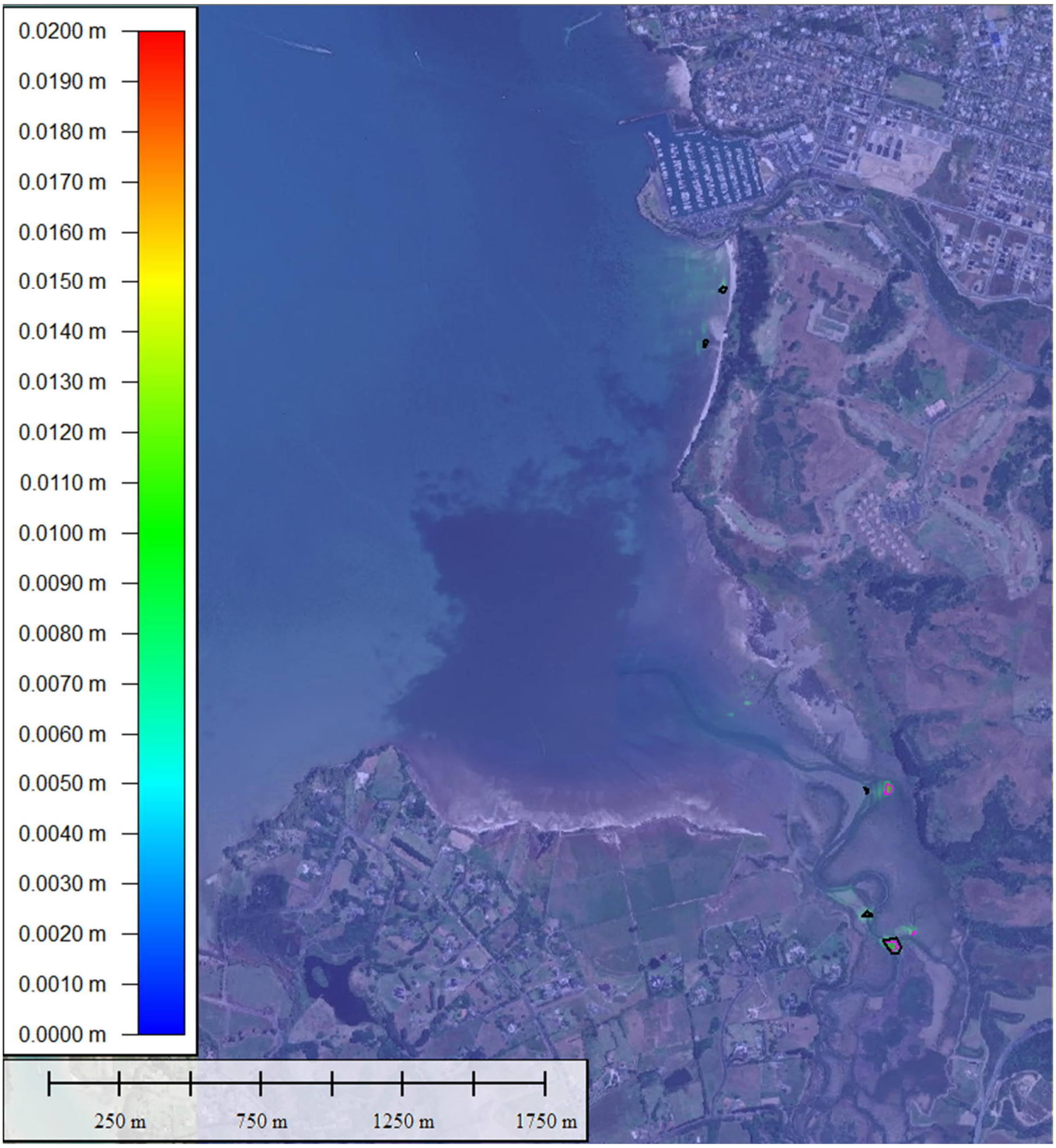

Figure 10-23 10 ARI TSS assuming Spring tide, FT peak discharge

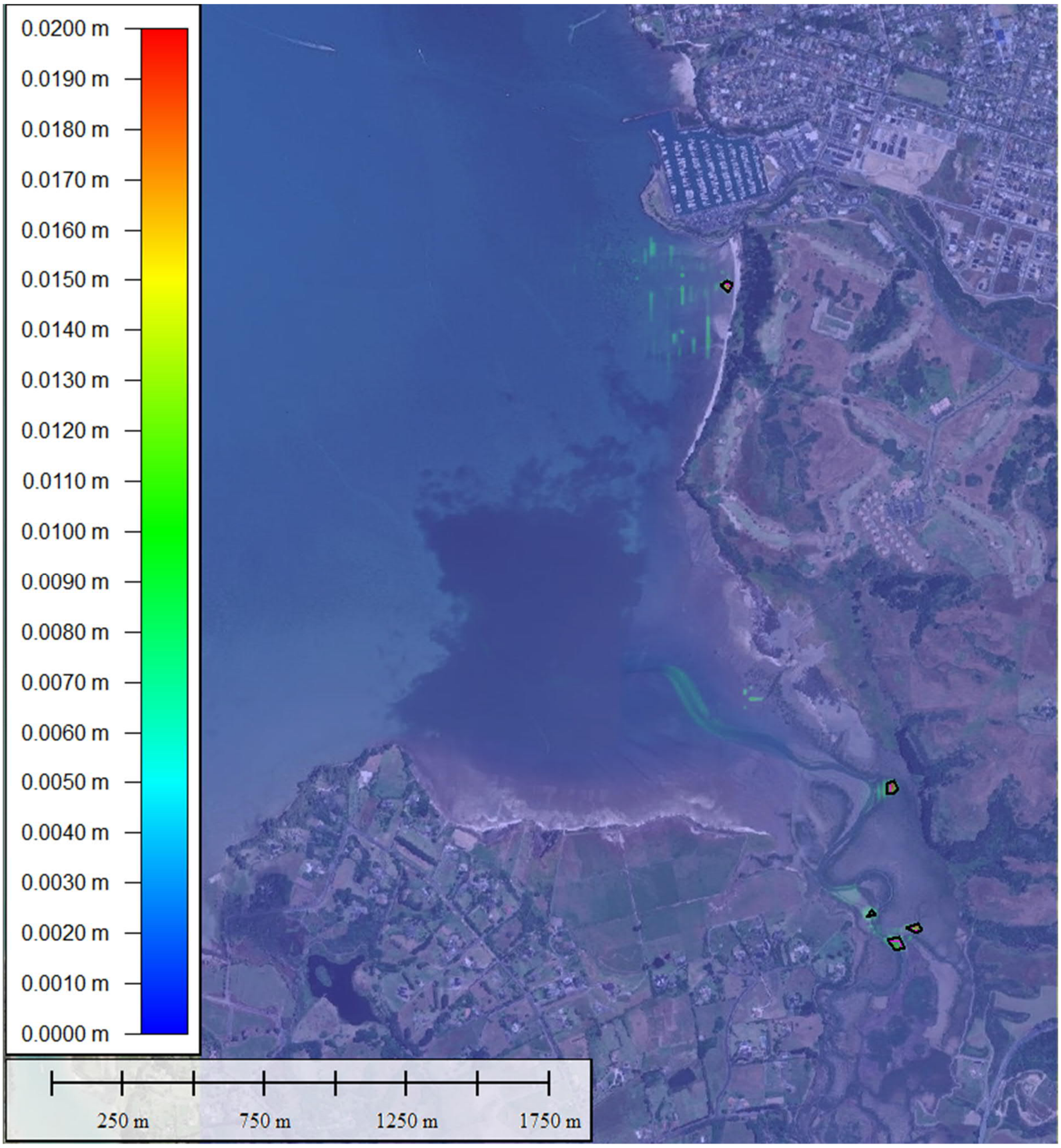

Figure 10-24 10 ARI TSS assuming Spring tide, ET peak discharge

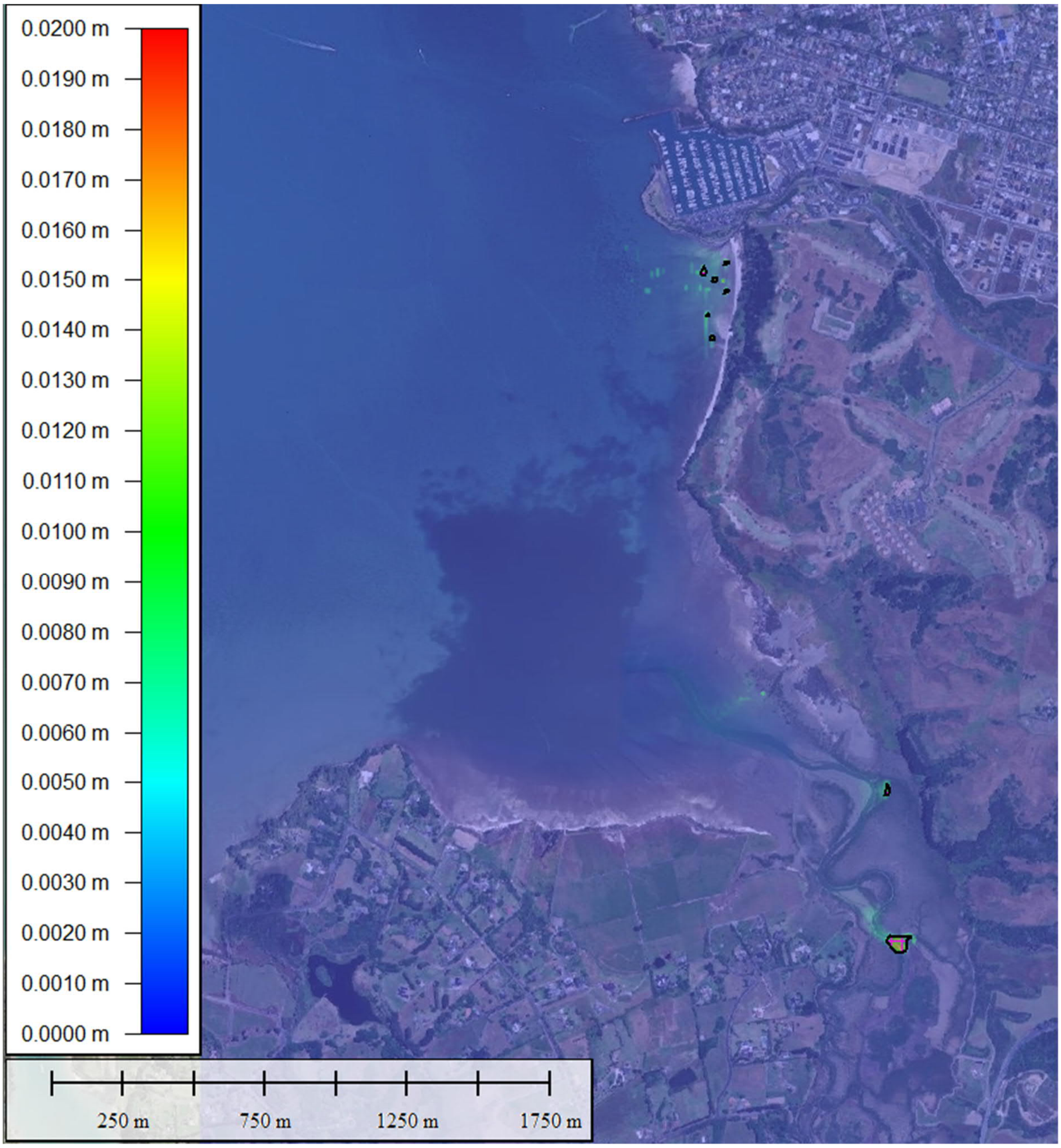

Figure 10-25 10 ARI TSS assuming Neap tide, HT peak discharge

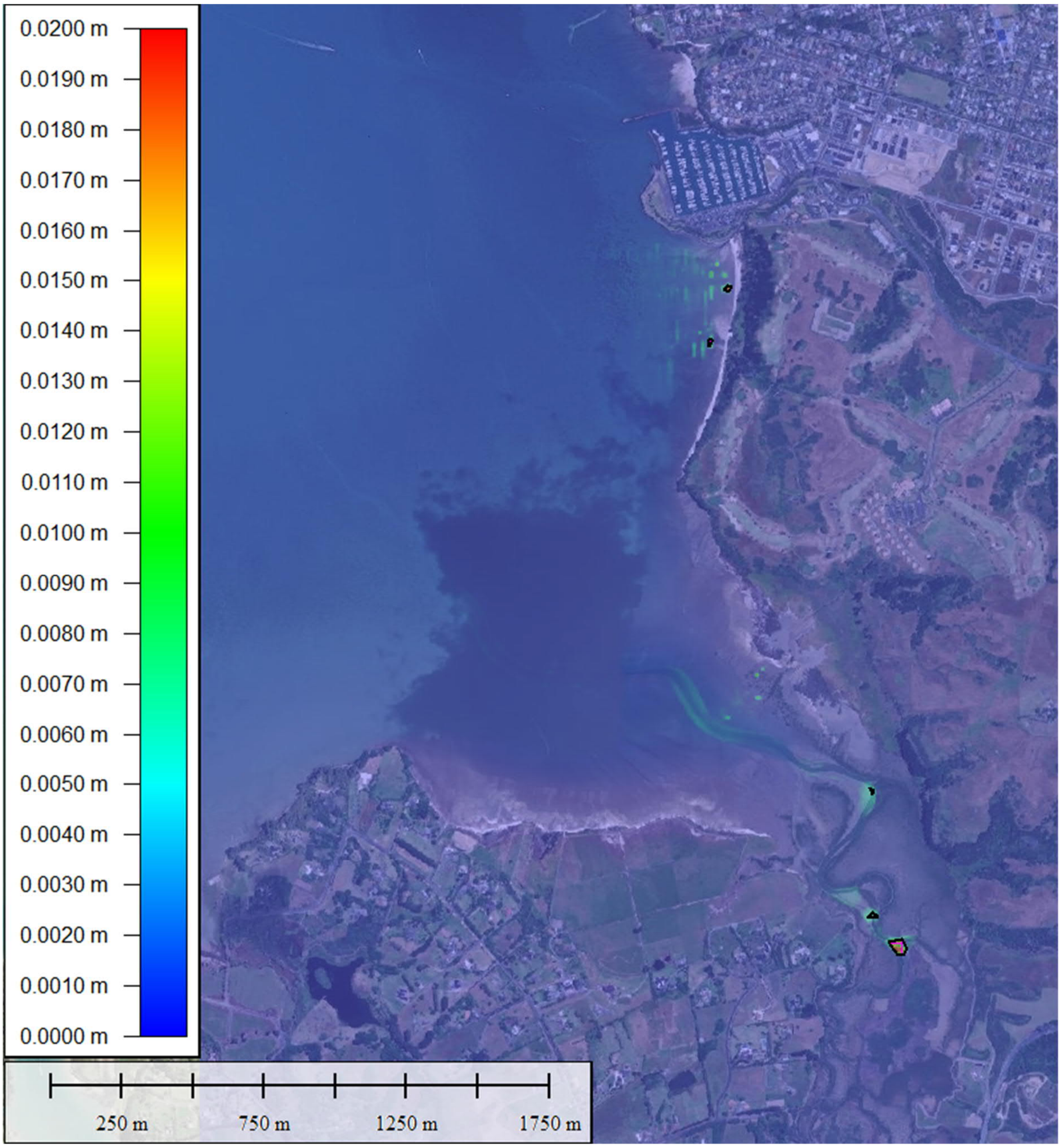

Figure 10-26 10 ARI TSS assuming Neap tide, LT peak discharge

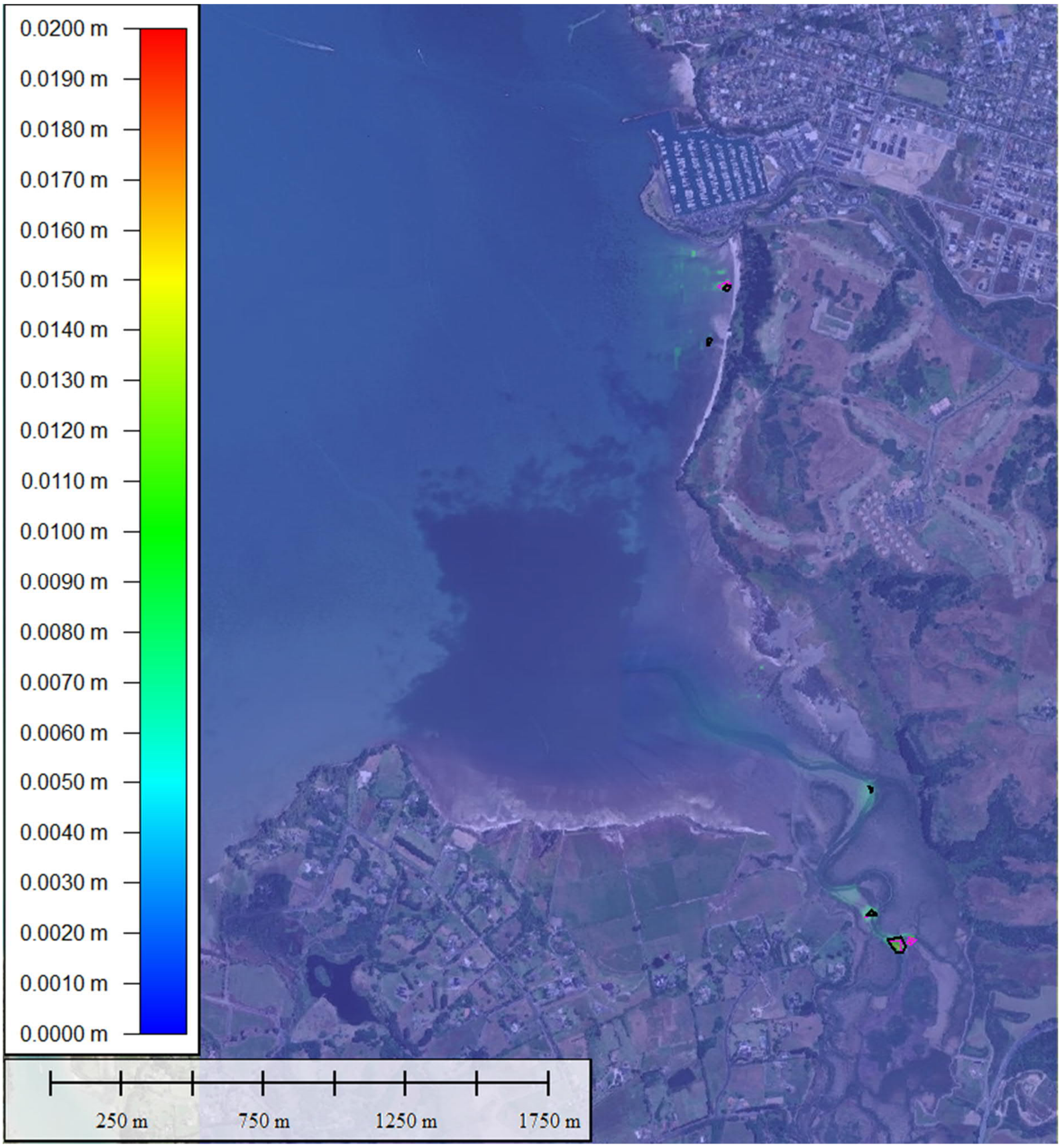

Figure 10-27 10 ARI TSS assuming Neap tide, FT peak discharge

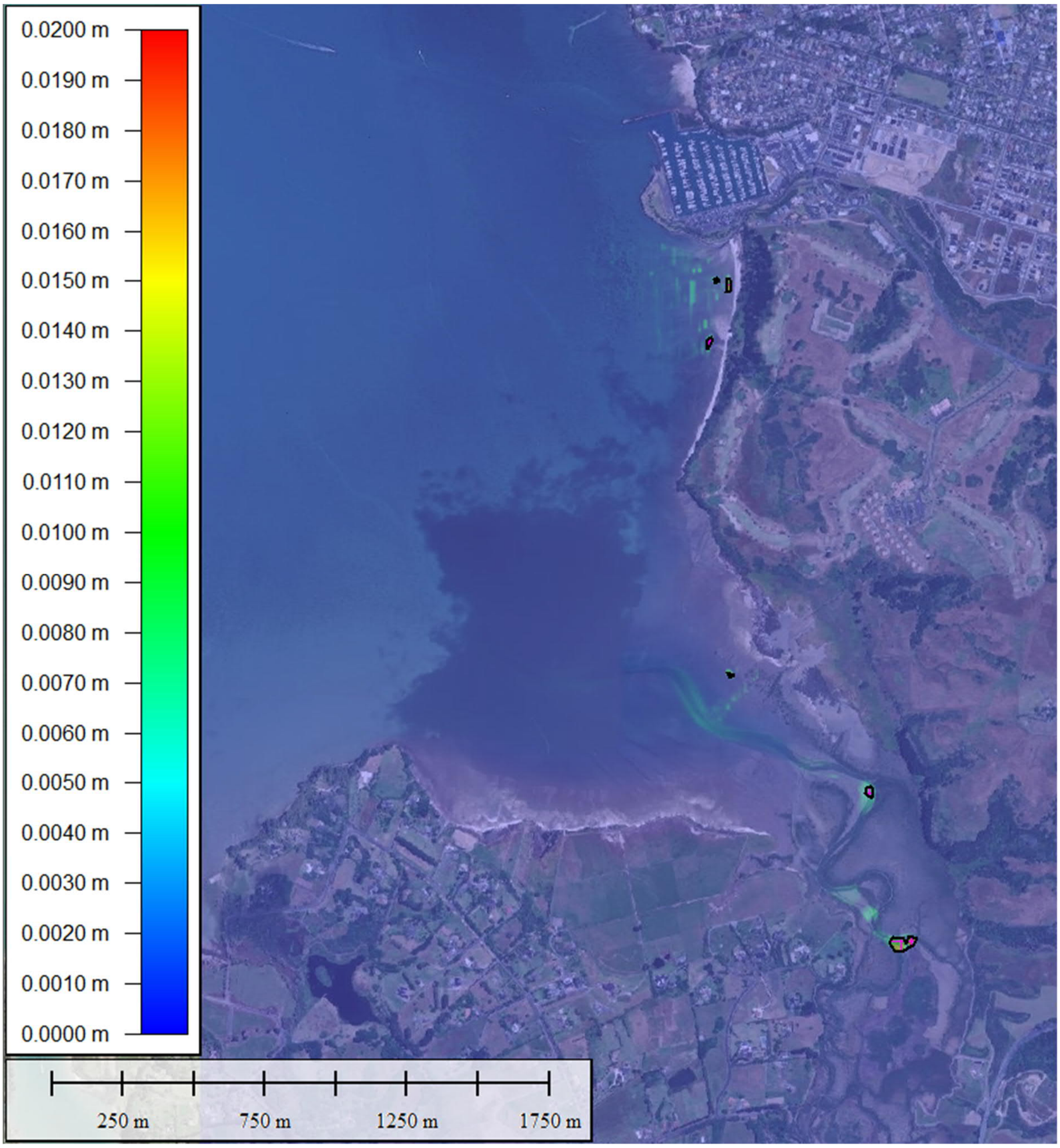

Figure 10-28 10 ARI TSS assuming Neap tide, ET peak discharge

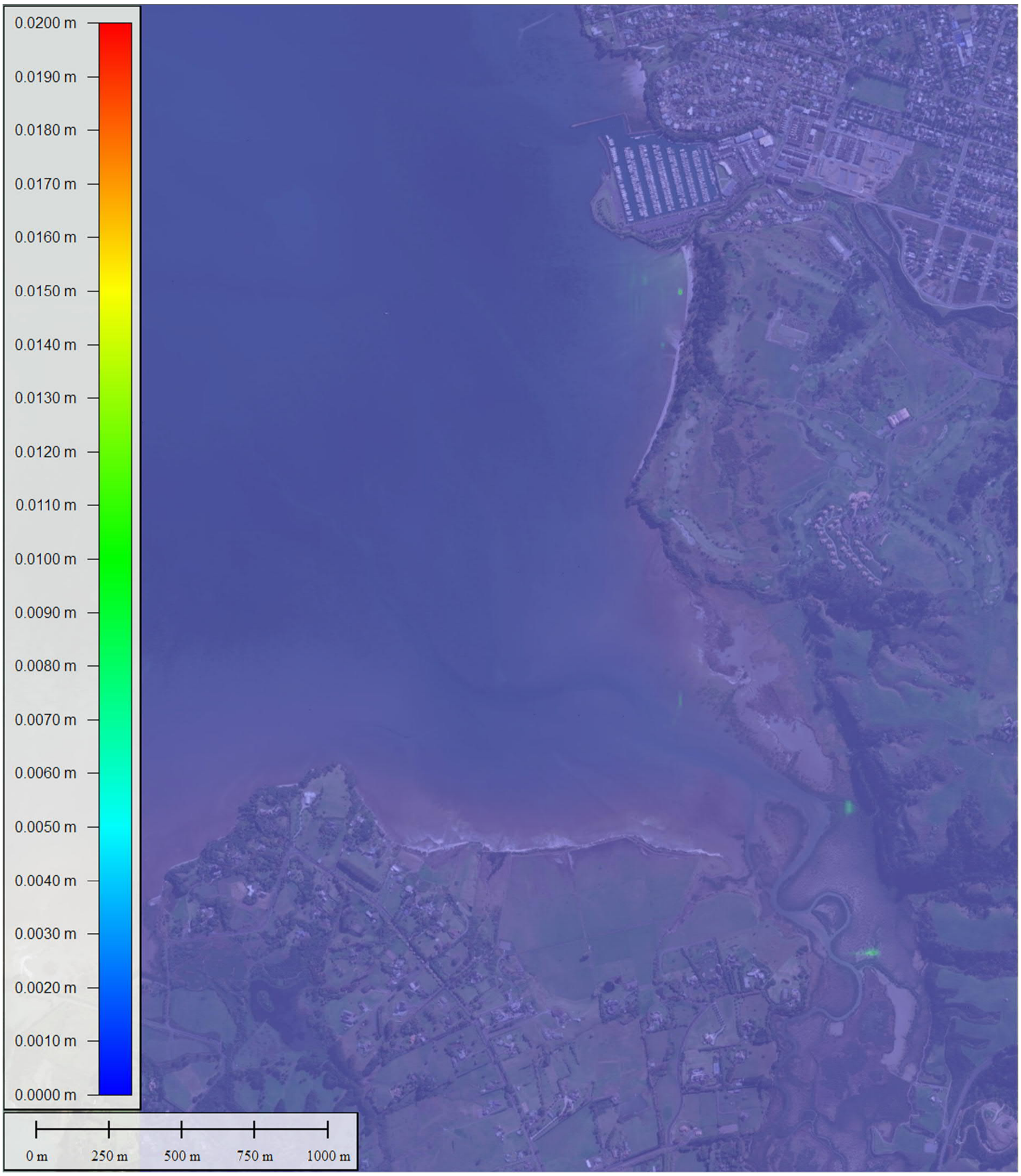

Figure 10-29 2 ARI TSS assuming Spring tide, HT peak discharge

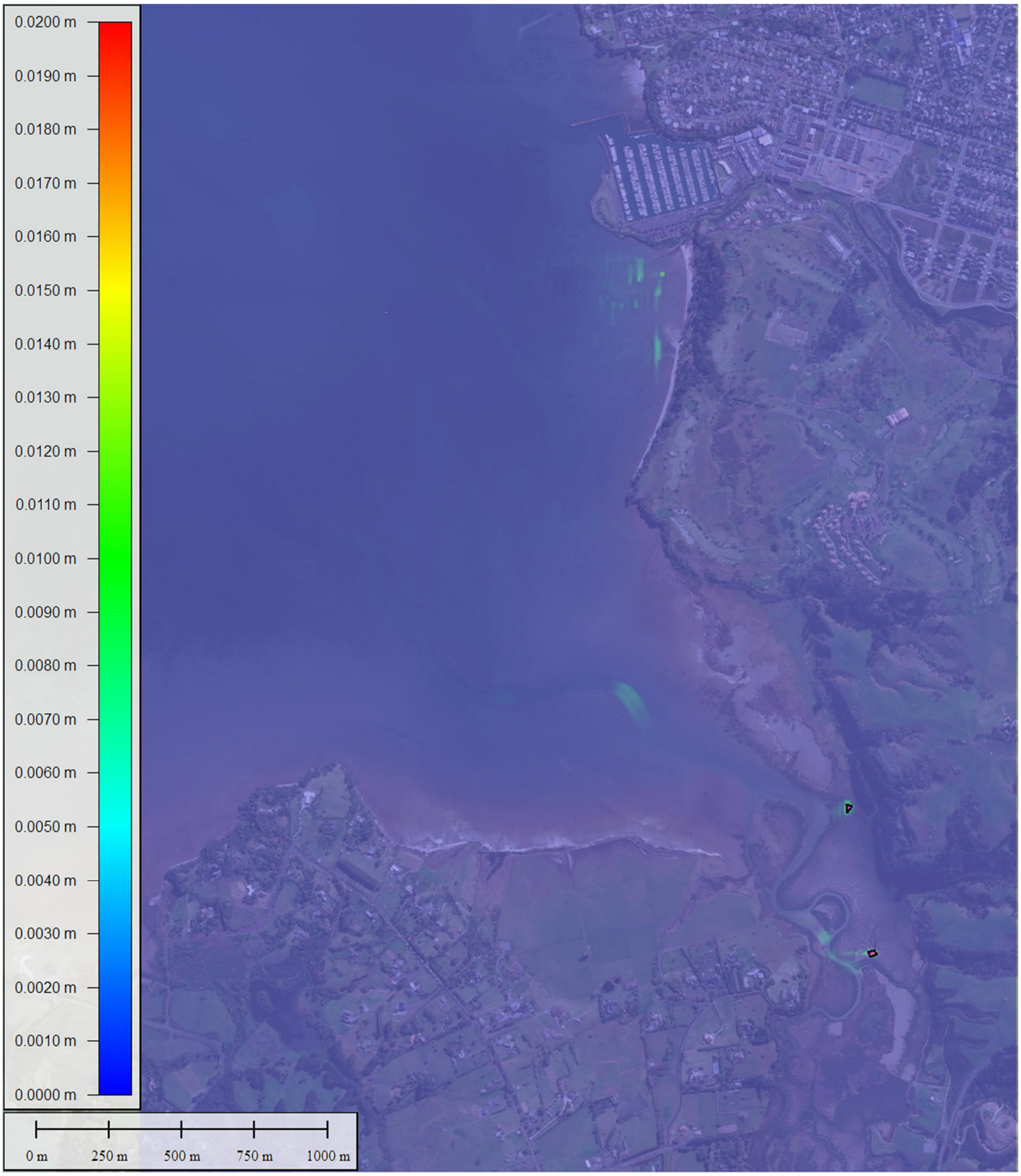

Figure 10-30 2 ARI TSS assuming Spring tide, LT peak discharge

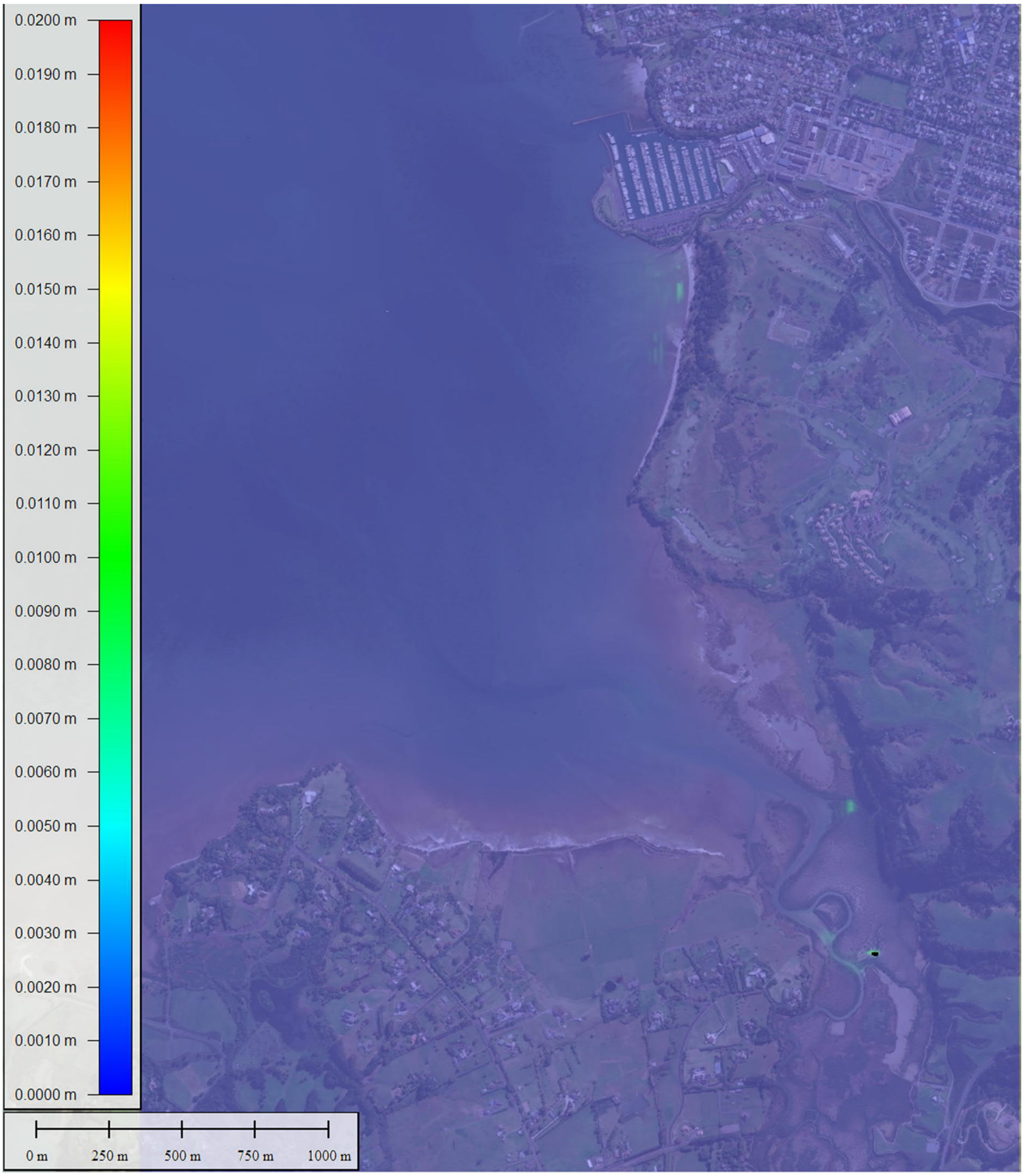

Figure 10-31 2 ARI TSS assuming Spring tide, FT peak discharge

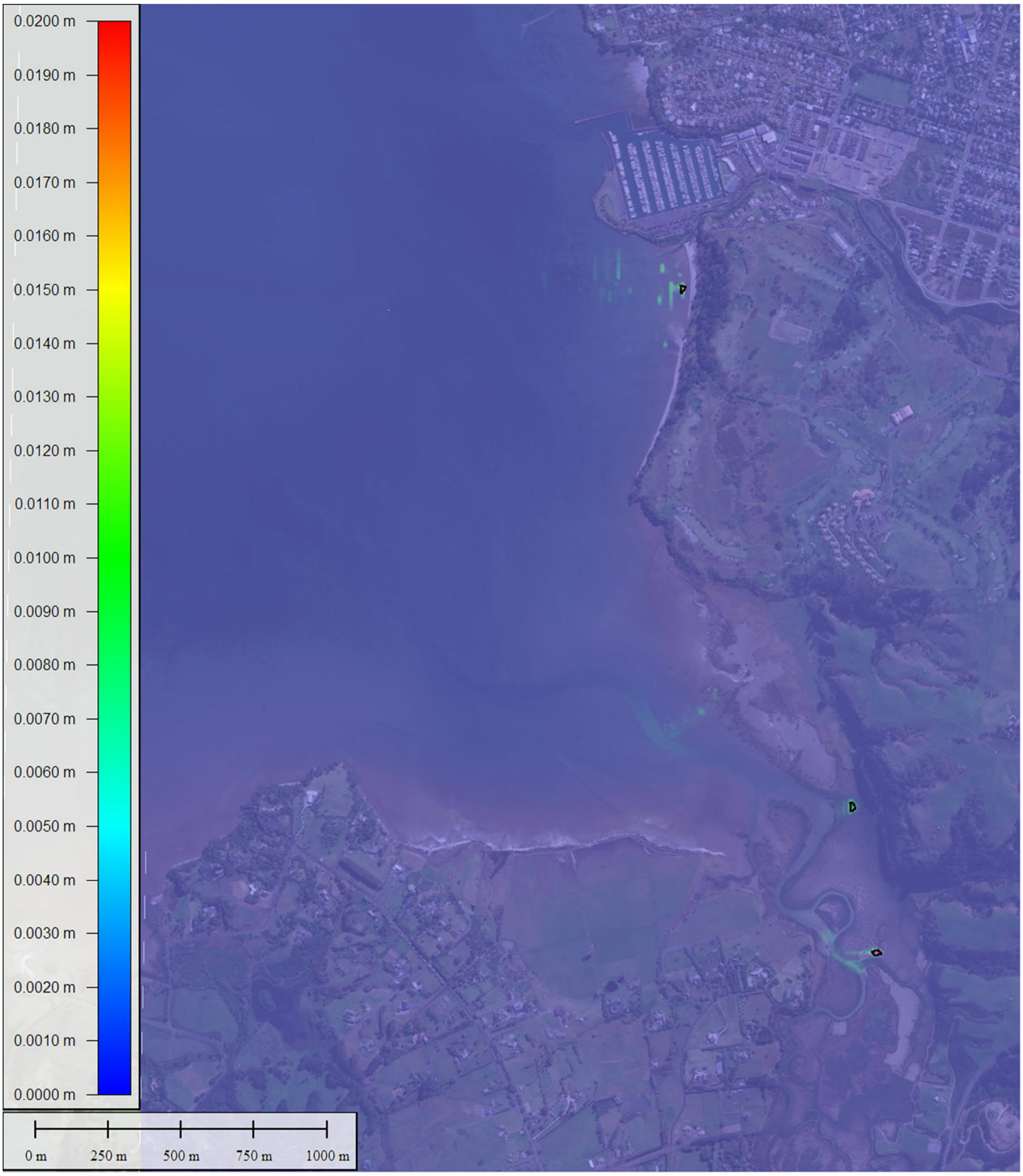

Figure 10-32 2 ARI TSS assuming Spring tide, ET peak discharge

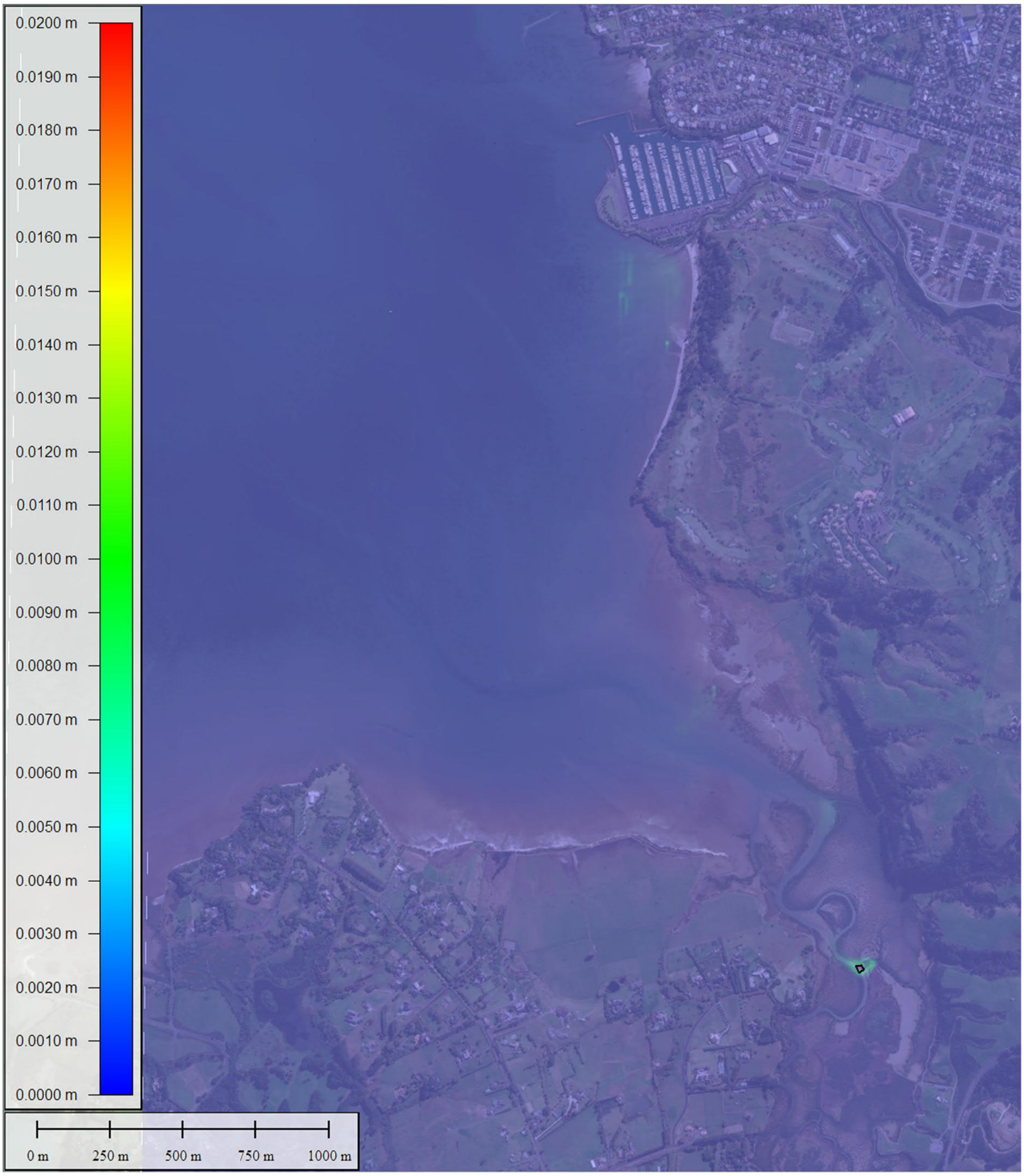

Figure 10-33 2 ARI TSS assuming Neap tide, HT peak discharge

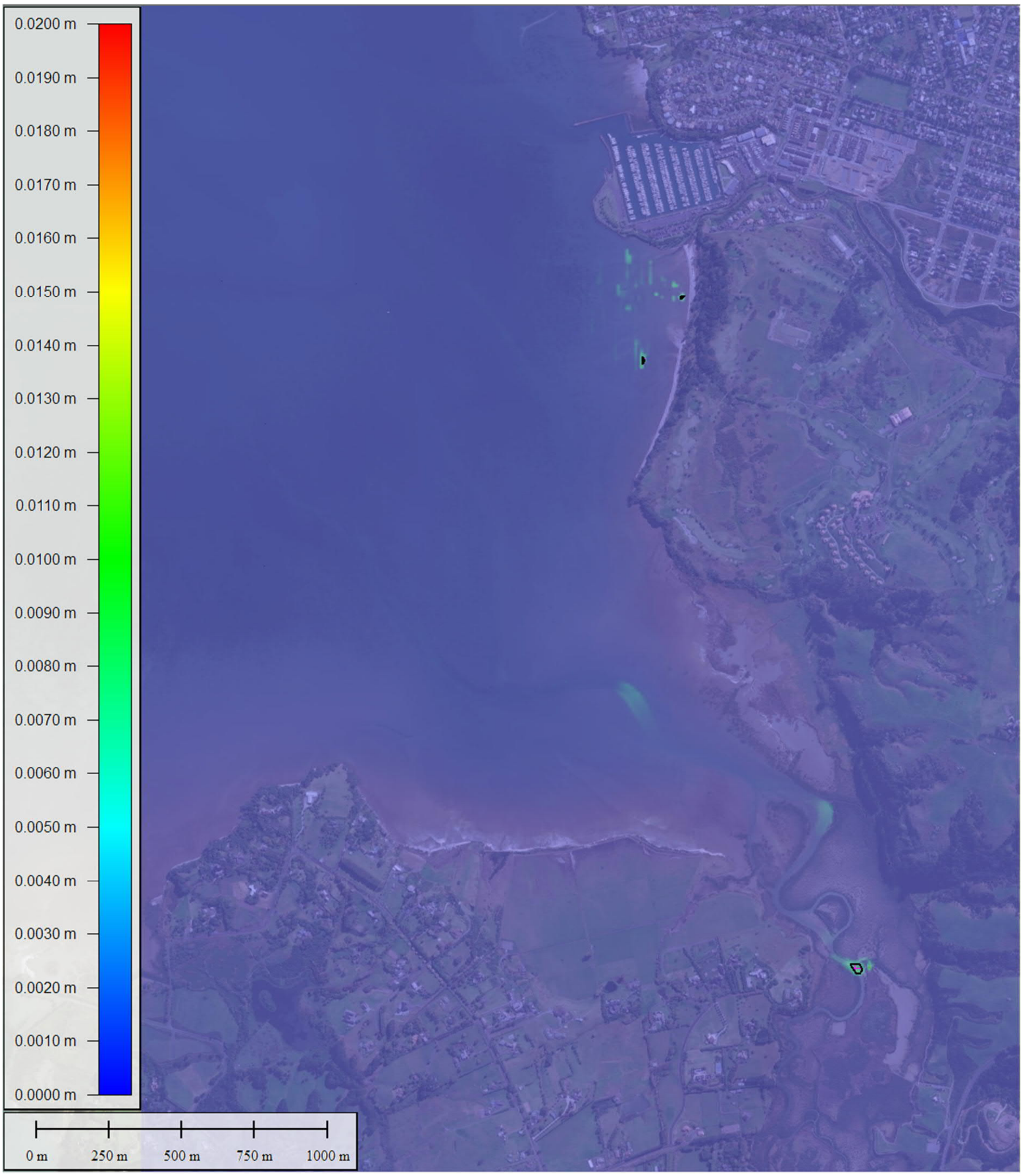

Figure 10-34 2 ARI TSS assuming Neap tide, LT peak discharge

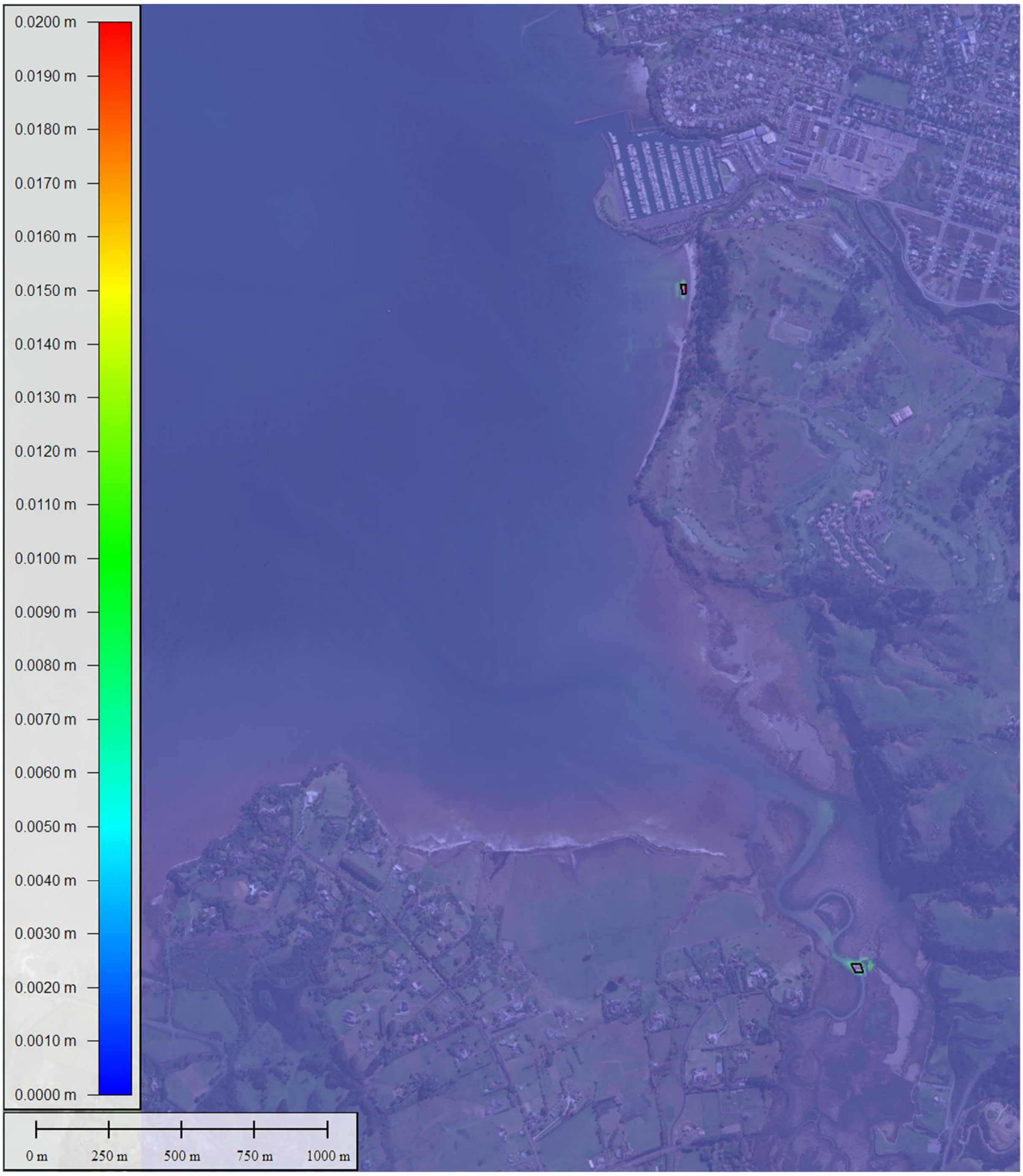

Figure 10-35 2 ARI TSS assuming Neap tide, FT peak discharge

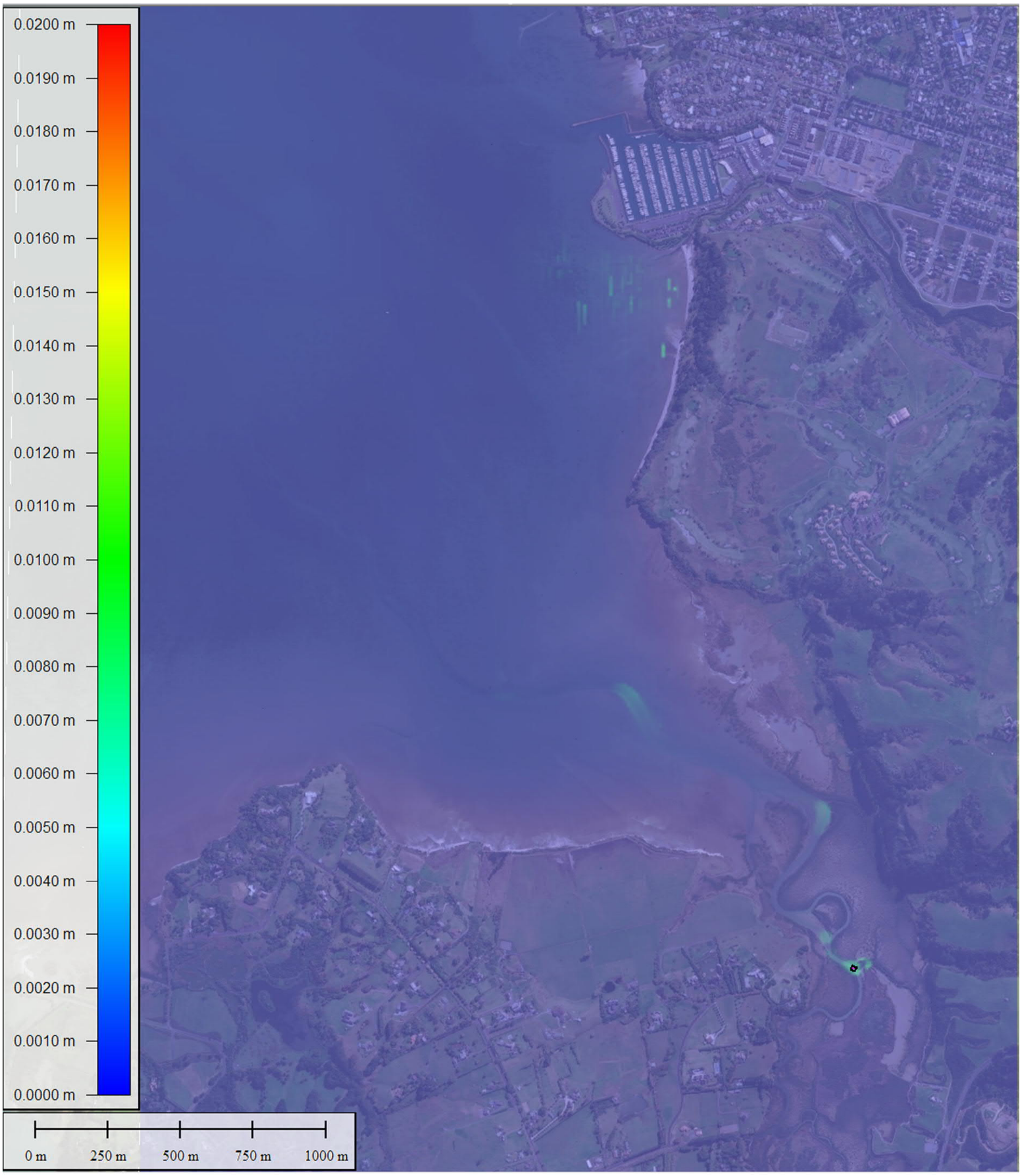

Figure 10-36 2 ARI TSS assuming Neap tide, ET peak discharge

Appendix F: Metal-Accumulation Model

The metal-accumulation model is based on the methodology developed by Green (2015). Sediment with attached metal is deposited and mixed with pre-existing bed sediment to a characteristic depth to form a surface mixed layer (SML). If the deposited sediment holds sediment at a greater concentration than the concentration of metal in the pre-existing bed sediment, then the metal concentration in the SML will increase over time until a m long-term equilibrium concentration is reached (Figure 10-37)

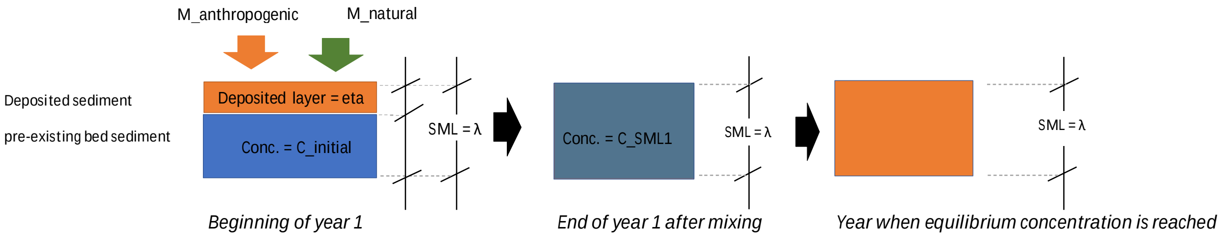

Figure 10-37 Conceptualisation of metal accumulation showing mixing of annual anthropogenic metal loads (M_anthropogenic) and natural (M_natural) metal loads

Figure 10-37 shows that the SML thickness remains constant and that the concentration in the SML will eventually approach the equilibrium concentration over time. The mass of metals that eventually ends up in the SML layer with depth, λ, is a mixture of the metals mass deposited in the layer with depth (eta) and the metals mass in the rest of the of the SML layer (λ – eta). This metals mass is associated with the mass of sediment that would be present in the SML.

In this study the annual metals loads were assumed constant (although they do not have to be) but allows for the bed metals concentration to increase with time. Subsequent years can be conceptualised in a similar way, noting that that the pre-existing bed sediment in year *n+1* would be C_SML*n*.

For a detailed explanation of the theory for this approach as well as enhancements made refer to Green (2016)[10]. As an overview, the section below presents a summary of the pertinent equations as well as some of enhancements that were made.

The mean annual sediment load from a discharge point (Ls) is a user input. The determination of this value is described in a separate report prepared by NIWA in Appendix B. The amount of sediment deposited over the area of interest can then be defined as:

$$L_D = \eta \rho_{bed} A_D \tag{1}$$

where L_D (kg TSS/y) is the total mass of sediment deposited over the area of interest, A_D (m^2), η is the average deposition rate (mm/y) and ρ_{bed} is the density (kg/m^3) at which sediment deposits on the bed.

The concentration (mg metal/kg TSS) of the layer deposited each year is given by:

$$C_{layer} = \frac{(M_{Natural} + M_{Anthropogenic})}{L_D} \tag{2}$$

where $M_{Natural}$ and $M_{Anthropogenic}$ are the masses of natural and anthropogenic metal, respectively, deposited each year.

The mass of metal (in mg) in the SML, after mixing, is therefore defined as:

$$M_{SMLn} = \frac{C_{SML(n-1)}\, L_D(\lambda - eta)\, \rho_{bed} A_D}{100} + \frac{C_{layer}\, (eta) \rho_{bed}\, A_D}{100} \quad (3)$$

where C_{SMLn} is the pre-existing bed concentration (mg/kg) in year (*n-1)*, λ is the thickness (in cm) of the SML and eta is the thickness of C_{layer} that mixes with $C_{SML(n-1)}$. M_{SMLn} is then divided by the mass of sediment (kg) in the SML.

An enhancement for the dissolution of zinc has also been included in the model.