NZ TRANSPORT AGENCY
WAKA KOTAHI

Roads of national significance

Ara Tūhono – Pūhoi to Wellsford

This document records technical and factual information used to support the NZTA's Assessment of Environmental Effects for the Pūhoi to Warkworth Project. It has been supplied to the Environmental Protection Authority by the NZTA in response to a section 149(2) Resource Management Act 1991 request. This document did not form part of the NZTA's application for the Project, which was lodged on 30 August 2013.

FURTHER NORTH

Pūhoi to Warkworth

Water Assessment Factual Report 5
Coastal Processes Modelling Report

August 2013

Pūhoi to Warkworth

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Glossary of abbreviations

Abbreviation	Definition
AC	Auckland Council
AEP	Annual Exceedence Probability
ARI	Average Recurrence Interval
Ch	Chainage
DEB	Decanting Earth Bund
ENE	East North Easterly
ESCP	Erosion and Sediment Control Plan
GIS	Geographic Information System
GLEAMS	Groundwater Loading Effects of Agricultural Management Systems
ha	Hectare(s)
kg	Kilograms
Km	Kilometre(s)
Km^2	Square Kilometres
LAT	Lowest Astronomical Tide
LiDAR	Light Detection and Ranging
m	Metre(s)
m^2	Square metre(S)
m^3	Cubic metre(s)
mg/m^3	Milligrams per cubic metre
mm	Millimetre(s)
MHWS	Mean High Water Springs
NGTR	Northern Gateway Toll Road
NIWA	National Institute of Water and Atmospheric Research
NZTA	NZ Transport Agency
RMA	Resource Management Act 1991
RoNS	Roads of National Significance
SHx	State Highway (number)
SRP	Sediment Retention Pond
SSF	Super Silt Fence
TSS	Total Suspended Solids

Glossary of defined terms

Term	Definition
Accretion	Accumulation of material within Coastal Marine Area that results in the formation of new land.
Annual Exceedance Probability Storm Event	The probability of exceeding a given storm discharge or flood level within a period of one year. For example, equivalent return period terms 1% AEP = 1 in 100 year.
Alignment	The route or position of a proposed motorway or state highway.
Average Recurrence Interval Event	The average time period between rainfall or flow events which equal or exceed a given magnitude.
Auckland Council	The unitary authority that replaced eight councils in the Auckland Region as of 1 November 2010.
Bathymetry	The measurement of the depths of bodies of water.
Benthic	Of, relating to, or occurring at the bottom of a body of water.
Bore	Any hole that has been constructed to provide access to groundwater (for example, for monitoring of ground or groundwater conditions, taking of groundwater or the discharge of stormwater).
Culvert	A pipe with an inlet from a watercourse and outlet to a watercourse, designed to convey water under a specific structure (such as a road).
Earthworks	The disturbance of land surfaces by blading, contouring, ripping, moving, removing, placing or replacing soil or earth, or by excavation, or by cutting or filling operations.
Fish Passage	The movement of fish between the sea and any river, including up-stream or downstream in that river.
Groundwater	Natural water contained within soil and rock formations below the surface of the ground.
Impervious Area	An area with a surface which either prevents or significantly retards the infiltration of water into the ground, thereby causing water to run off the ground surface in greater quantities or at an increased rate of flow than would occur under natural conditions
Intertidal	Marine habitat that occurs between high tide and low tide that is not permanently submerged
Motorway	Motorway means a motorway declared as such by the Governor-General in Council under section 138 of the PWA or under section 71 of the Government Roading Powers Act 1989.
Sediment Control	Capturing sediment that has been eroded and entrained in overland flow before it enters the receiving environment.
Sediment Generation	That sediment that is generated on the site of earthwork activity prior to treatment through any sediment retention device.

Term	Definition
Sediment Retention Pond	A detention structure that is utilised during the construction phase of earthworks activity to treat any sediment laden runoff and retain sediment.
Settlement	The gradual sinking of the ground surface as a result of the compression of underlying material.
Stormwater	Water that flows from impervious areas and completed areas of the motorway after the construction period.
Subtidal	Marine habitat that occurs below low tide and is always submerged
Terrestrial	Land-based.
Turbidity	Turbidity is a measure of water clarity or murkiness of a waterbody.
Wetland	Vegetated stormwater treatment device designed to remove a range of contaminants, providing superior water quality treatment to wetponds with increased filtering and biological treatment performance.

Contents

1. Project description

This report is intended to provide factual information for the suite of technical reports prepared for the NZ Transport Agency's (NZTA's) Ara Tūhono Road of National Significance (RoNS) Pūhoi to Wellsford, Pūhoi to Warkworth section (the Project).

The Project realigns the existing SH1 between the Northern Gateway Toll Road (NGTR) at the Johnstone's Hill tunnels and just north of Warkworth. The indicative alignment will bypass Warkworth on the western side and tie into the existing SH1 north of Warkworth. It will be a total of 18.5 km in length. The upgrade will be a new four-lane dual carriageway road, designed and constructed to motorway standards and the NZTA RoNS standards.

1.1 Project features

Subject to further refinements at the detailed design stage, key features of the Project are:

- A four lane dual carriageway (two lanes in each direction with a median and barrier dividing oncoming lanes);
- A connection with the existing NGTR at the Project's southern extent;
- A half diamond interchange providing a northbound off-ramp at Pūhoi Road and a southbound on-ramp from existing SH1 just south of Pūhoi;
- A western bypass of Warkworth;
- A roundabout at the Project's northern extent, just south of Kaipara Flats Road to tie-in to the existing SH1 north of Warkworth and provide connections north to Wellsford and Whangarei;
- Construction of seven large viaducts, five bridges (largely underpasses or overpasses and one flood bridge), and 40 culverts in two drainage catchments: the Pūhoi River catchment and the Mahurangi River catchment;
- A predicted volume of earthworks being approximately 8M m^3 cut and 6.2M m^3 fill within a proposed designation area of approximately 189 ha earthworks;

1.2 Associated reports

A number of factual and interpretative reports have been prepared as part of the Project. Where necessary the following reports have been referenced directly in this Factual Report:

- Construction Water Assessment Report (Graeme Ridley, Michelle Sands)
- Operational Water Assessment Report (Tim Fisher, Michelle Sands)
- Freshwater Ecology Assessment Report (Wayne Donovan)
- Marine Ecology Assessment Report (Sharon de Luca)
- Hydrogeology Assessment Report (Jon Williamson)
- Geotechnical Engineering Appraisal Report (Darryn Wise)
- Pūhoi – Warkworth Coastal Modelling and Field Data Collection (eCoast)
- Water Assessment Factual Report No. 3 - Pūhoi - Warkworth Road of National Significance: Estimates of Construction Sediment Loads (Prepared by NIWA for the Further North Alliance)
- Assessment of Environmental Effects (Karyn Sinclair)

1.3 Purpose of investigation and report

The coastal environment is dynamic and complex and sedimentation patterns are highly dependent on a wide range of influencing environmental factors. For this reason, this investigation has sought to identify the material environmental and construction variables and test a range of scenarios around these to support assessments of the ‘envelope’ of potential effects associated with the construction of this Project.

This report documents the investigation undertaken to identify the likely locations and magnitude of changes in deposition depths and total suspended solids (TSS) concentrations in the Mahurangi and Pūhoi Estuary environments as a result of extreme rainfall coinciding with the construction phase of the Project. This investigation includes an analysis of the probability of these changes occurring as well as the uncertainties around the findings. This report provides a foundation for the assessment of the severity and duration of additional sediment generated by the Project on the coastal ecology covered in the Marine Ecology Assessment Report. The findings in this report will also be used to support the assessment of the potential effects on navigation, contact recreation and amenity qualities in these areas. These matters are covered in the Construction Water Assessment Report.

2. Description of the coastal environments

The Project involves construction in two catchments, the Pūhoi and the Mahurangi River Catchments. These catchments feed into the Pūhoi and Mahurangi estuary environments. These two coastal areas share many similarities despite their different sizes. The catchments, the proposed designation and the indicative Project alignment are shown in Figure 1.

2.1 Mahurangi

The Mahurangi Estuary is similar to much of the coastal environment of the Hauraki Gulf featuring extensive intertidal areas, mangroves and shallow low tide channels. The estuary has an open water area of 24km^2. It is almost 14km from the mouth of the Mahurangi River to the estuary outlet to the open ocean. As it approaches the mouth the estuary deepens until near the entrance there are water depths of close to 20m.

The tidal range within the estuary was recorded as part of the field data collection for the Project. Over the spring-neap cycle the range was between 1.6 to 2.5m. Flushing time for the estuary has been estimated at approximately two days (Mead *et al*. 2007). Sediment samples from across the estuary indicate that there is not a lot of variation in sediment makeup, with the main difference being that slightly finer material is found in the upper reaches of the estuary.

The land area of the contributing catchment is 121km^2. The land-use in the surrounding catchment is primarily pasture, forestry and native bush. There is also the town of Warkworth located near the upper reaches of the estuary. The estuary is used extensively for recreational activities including boating and fishing. Most of the main low tide channels in the estuary are used to provide boating access to moorings, including as far up as the weir in Warkworth. There are also a number of aquaculture farms within the estuary. A number of studies have been undertaken for Auckland Council, then Auckland Regional Council, to understand sediment inputs and patterns within the estuary. These studies included investigation of sedimentation rates based on pollen and radiocarbon dating of cores (Swales *et al*. 2009 and Oldman *et al*. 2009). This study found that much of the sediment entering the estuary is retained and that over the last century the sedimentation rate has been in the order of 24mm/yr in the upper estuary. Sedimentation rates quickly drop the further away from the Mahurangi River mouth with rates less than 5mm/yr in the lower estuary.

2.2 Pūhoi

The Pūhoi is a much smaller estuary with an open water area of less than 10% of the Mahurangi Estuary, 1.5km^2. However the land area of the contributing catchment is about half the size of the Mahurangi at 53km^2. The land in the surrounding catchment is primarily pasture, forestry and native forest. The town of Pūhoi is located on the banks of the Pūhoi River near the upper reaches of the tidal influence. The deeper channels in the estuary are used for navigation to access moorings as far up as the township.

Much of the estuary is intertidal with a single low tide channel running to the outlet to the open ocean. During flood events the entire estuary flows as a wide river to the constriction to the mouth. Sediment samples from across the estuary indicate that there is not a lot of variation in sediment makeup. The tidal range within the estuary was recorded as part of the field data collection for the Project. Over the spring-neap cycle the range was between 1.3 to 2.3m. Flushing times for the estuary has been estimated at approximately two days (Mead *et al*. 2007).

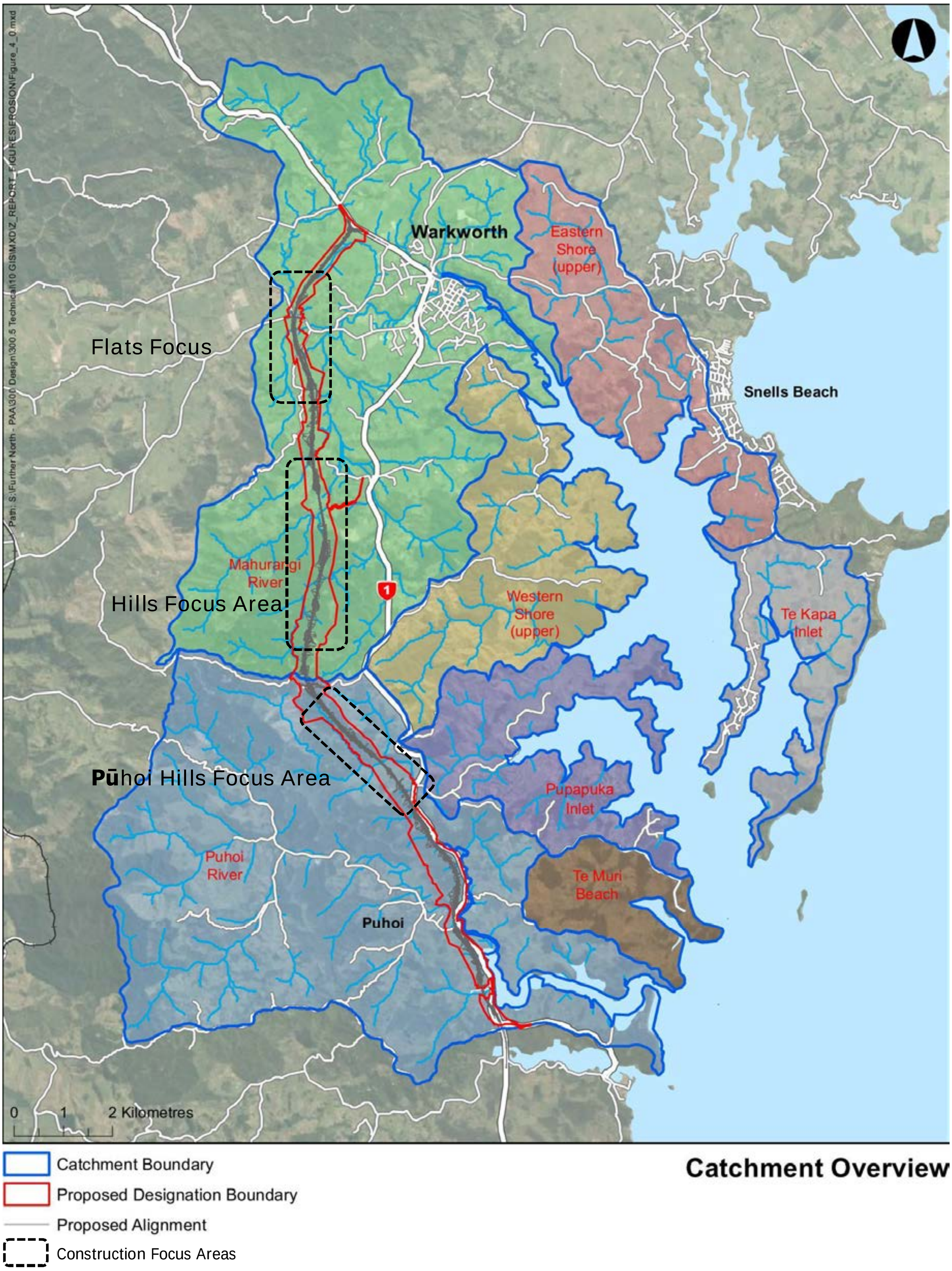

Figure 1: Catchment overview showing main catchments and the project alignment.

3. Coastal modelling scenarios

With consideration of the level of detail and purpose of this investigation, three key coincident factors were identified as having a significant influence on the fate of additional sediment entering the Mahurangi and Pūhoi Estuaries. These factors were selected based on a review of previous relevant studies in the Mahurangi Estuary, particularly the recent investigations by NIWA for Auckland Regional Council (Swales *et al*. 2009 and Oldman *et al*. 2009), combined with a sensitivity analysis of the major environmental factors that influence the sediment deposition patterns in the estuaries. These three factors are:

- The location and extent of construction earthworks in the contributing catchment;
- Extreme rainfall occurring during the construction of the project; and
- Coincident wind conditions during the release of high sediment loads into the estuaries.

Based on these three factors the coastal modelling scenarios were developed.

3.1 Earthworks location and extent

In addition to the background (pre-construction), scenario two different earthwork locations and extent scenarios were selected in the catchments contributing to the Pūhoi and Mahurangi estuarine environments. These were selected based on the indicative staging and construction methodology.

In the Mahurangi, two areas of active open earthworks were assumed. The first was in the steep hilly area near Moirs Hill Road. The second was down on the flats west of Warkworth (see Figure 1). We refer to those areas as follows:

Flats Focus Area 1 – Woodcocks Road to Perry Road Viaduct (CH 49250 to CH 53100)
Hills Focus Area 2 – Perry Road Viaduct to Moirs Hill Road (CH 53450 to CH 56800)

These two focus areas represent the two distinguishing features of the overall construction zone for the Project alignment. Their total length makes up about 40% of the total indicative alignment length. As explained in the Construction Water Assessment Report, the soil properties and geology, slopes and climate in these focus areas are also representative of those for the rest of the alignment.

In the Pūhoi Catchment, a single area of open earthworks was chosen in the steep hills area also near Moirs Hill Road (refer Figure 1). For the purposes of analysing event based sediment generation, this focus area was assumed to be equivalent to that in the Mahurangi hills area.

Based on the indicative staging and construction methodology over a 5 year period, as illustrated in the graph in Figure 2, the areas of open earthworks anticipated in January 2019 was selected as representative of the peak area of open earthworks that is likely throughout the construction of the Project. Similarly for a 10 year construction period, as illustrated in Figure 3, March 2020 was chosen as representative of the peak area of open earthworks for this longer construction scenario. These areas of open earthworks are shown in Table 1.

Table 1: Areas of peak open earthworks for the short and long project construction scenarios (ha).

	Mahurangi Catchment		Pūhoi Catchment
	Hills Area	Flats Area	Hills Area
Short (5yr) Construction Scenario	41	21	41
Long (10yr) Construction Scenario	26	9	26

The peak areas of open earthworks calculated for the long (10yr) project construction programme was found to also be representative of the average area of open earthworks for the shorter (5yr) project construction period.

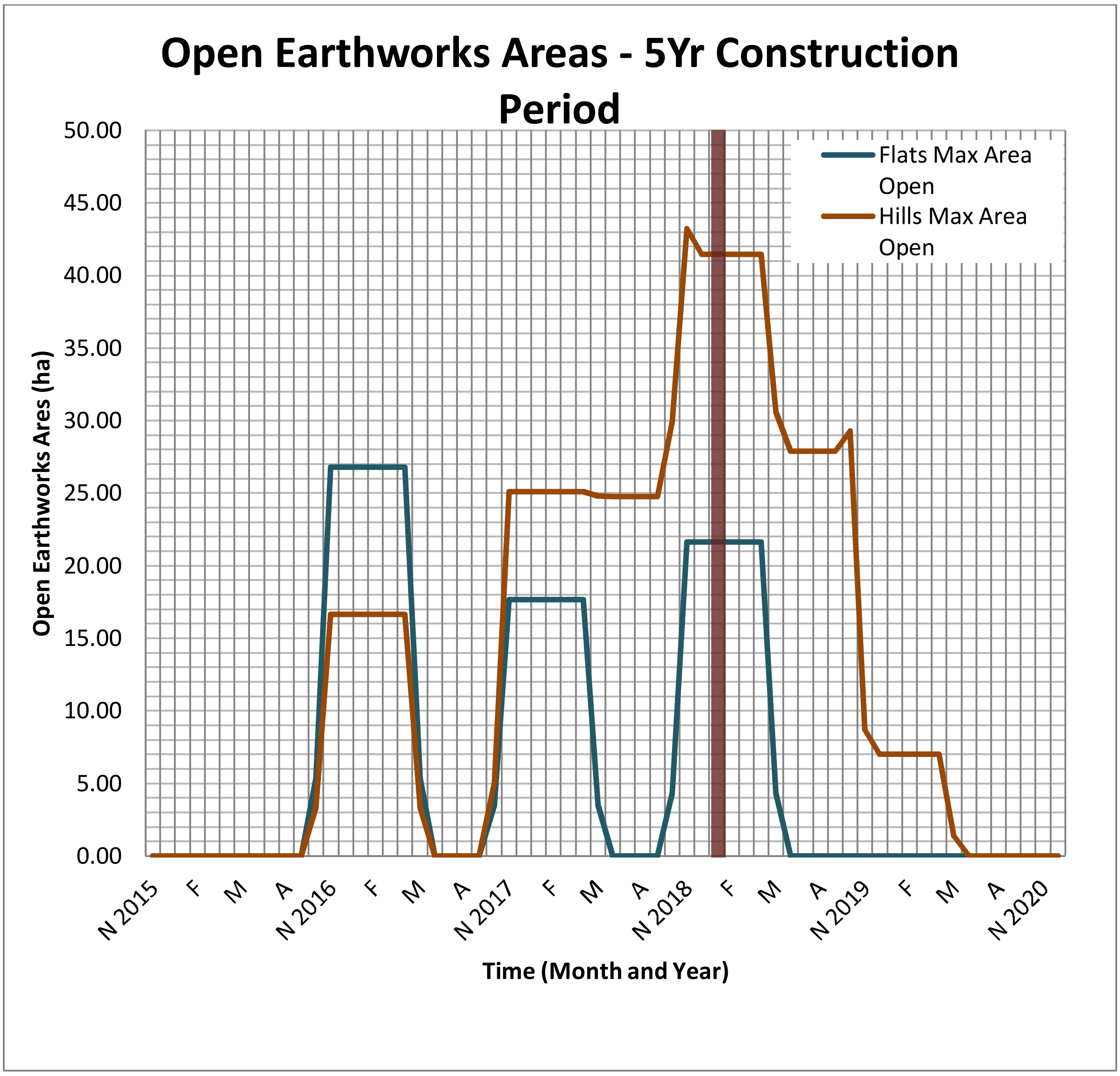

Figure 2: Areas of open earthworks in the Mahurangi Catchment based on a 5 year construction programme.

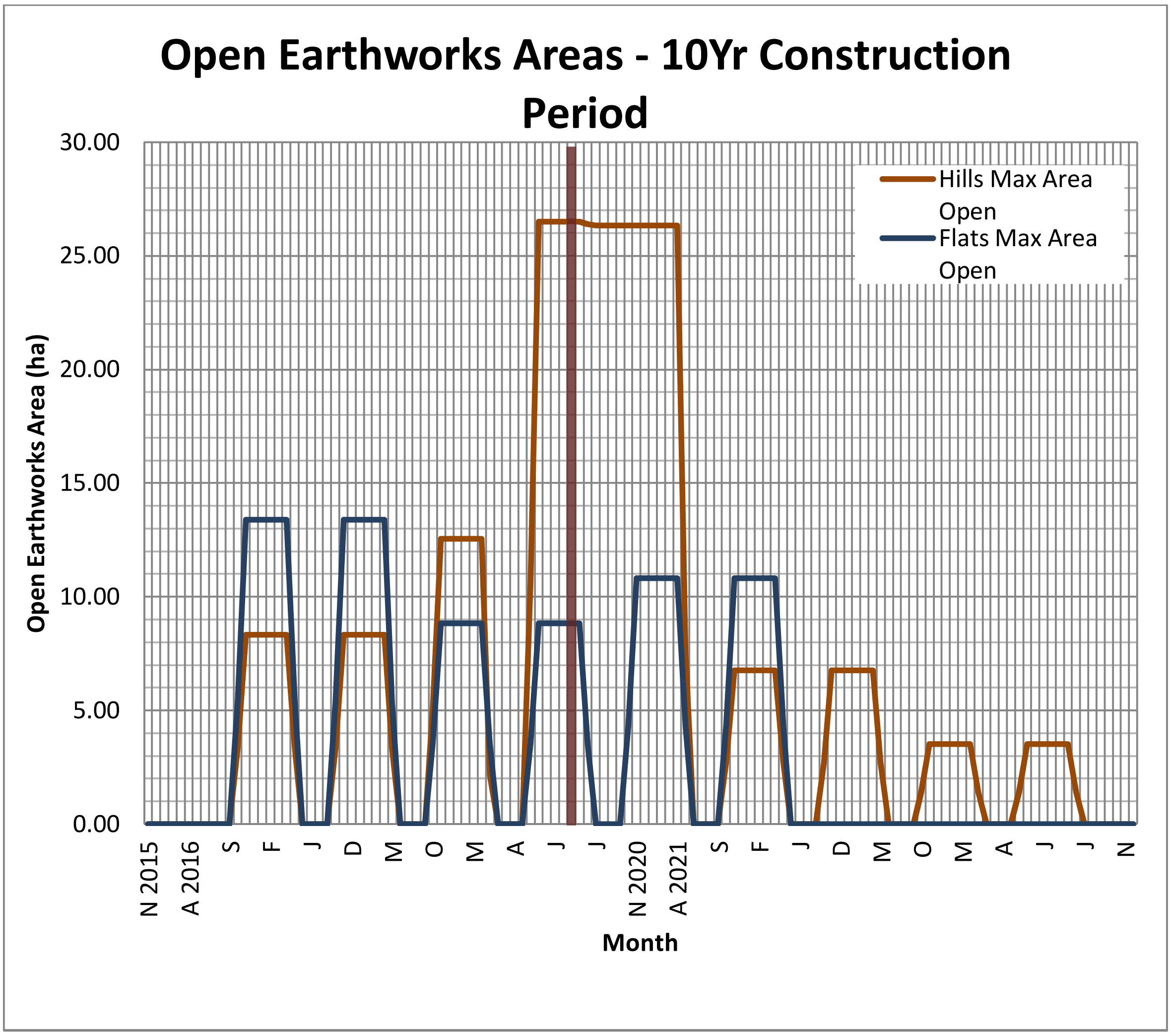

Figure 3: Areas of open earthworks in the Mahurangi Catchment based on a 10 year construction programme.

Further detail on how the peak areas of open earthworks were selected is recorded in the Construction Water Assessment Report.

3.2 Extreme rainfall scenarios

Sediment loads that are washed off from catchments are highly influenced by the intensity and depths of rainfall. In extreme rainfall events the sediment loading greatly increases above the loading typically experienced in more common rainfall events. Furthermore as rainfall runoff from construction sites increases the removal efficiency of the sediment treatment devices lowers.

For each of the areas of open earthworks a construction sequence and erosion, sediment and stabilisation methodology has been developed. This has allowed for an estimation of the sediment removal efficiency that can be achieved under various rainfall events, see Table 2. Further detail on erosion, sediment and stabilisation measures used to develop these removal efficiencies can be found in Construction Water Assessment Report.

Table 2: Sediment control device efficiencies.

Sediment Control Device Type	Sediment Removal Efficiency (%) by Rainfall Return Period		
	2yr ARI	10yr ARI	50yr ARI
Super Silt Fence (SSF)	80%	65%	50%
Decanting Earth Bund (DEB) – Chemically Treated	90%	80%	60%
Sediment Retention Pond (SRP) – Chemically Treated	95%	85%	65%

With consideration of background sediment loading and the high sediment removal rates that are anticipated in the 2 year Average Recurrence Interval (ARI) rainfall event, only the 10 and 50 year ARI rainfall events were selected as scenarios for the coastal modelling. The 10 and 50 year ARI rainfalls have an Annual Exceedance Probability (AEP) of 10% and 2% respectively. The Construction Water Assessment Report and the Water Assessment Factual Report No. 3 *Pūhoi - Warkworth Road of National Significance: Estimates of Construction Sediment Loads* (Prepared by NIWA for the Further North Alliance) describes the methodology and result for estimating the sediment loading from the construction open areas of earthworks and for the background sediment loads into the estuaries. These reports calculate the sediment generated from the open areas of earthworks in a 10 and 50 year rainfall event. This additional sediment has been added to the predicted background 10 and 50 year ARI flows and sediment loads entering the estuaries from the Pūhoi and Mahurangi Rivers.

It is important to note that while the background sediment loads predicted in the Sediment Load Models seek to account for a range of sediment losses, including sediment deposited in the streams before they get to the coast, a conservative assumption has been made that the entire additional sediment generated from the construction activities reaches the coast as a suspended sediment load.

3.2.1 Mahurangi

In the modelling of the sediment inputs into the Mahurangi Estuary an attempt was made to model a rainfall and sediment scenario reflective of reality. All the estimated additional sediment generated by the Project that enters the estuary will enter via the Mahurangi River. However only about half of the estuary catchment area is drained by the Mahurangi River, see Figure 4. It is unlikely that the same level of extreme rainfall that occurs in the Mahurangi River Catchment will also be occurring in the other areas of the estuary catchment.

To determine the magnitude of flow events in neighbouring tributaries when the Mahurangi is in flood, the bivariate log-Normal distribution approach was adopted, which is recommended for use in Australian Rainfall and Runoff Book VI (Nathan and Weinmann, 1999). This method utilises the correlation in flood peaks between the major catchment and other neighbouring catchments to understand the coincidence of design flood events.

In the Mahurangi estuary catchment flow data is sparse. As an alternative to flow, a log-Normal correlation was established between flow in the Mahurangi River and rainfall data from surrounding recorders (Orewa and Warkworth). This assumes that a rainfall event correlates to a flow event of equal Annual Exceedance Probability (AEP). The bivariate log-Normal distribution calculates that a 10 year ARI flood in the Mahurangi River coincides with much lower order events, approximately a 4 year ARI return period flood, in the neighbouring catchments.

Based on this analysis, the availability of modelling outputs from the sediment load modelling and to avoid masking the contribution of sediment from the road construction by over estimating the background sediment loads, the following scenarios were selected for the sediment modelling in the Mahurangi Estuary:

- During a 10 year sediment and flow event in the Mahurangi River, a 2 year sediment and flow event was modelled in the other catchments feeding into the estuary; and
- During a 50 year sediment and flow event in the Mahurangi River, a 10 year sediment and flow event was modelled in the other catchments feeding into the estuary.

The model results revealed that these assumptions had little influence on the event based impacts of additional sediment in the estuary as the dominant sediment loads are from the Mahurangi River and much of this sediment settles in the upper catchment near the river mouth.

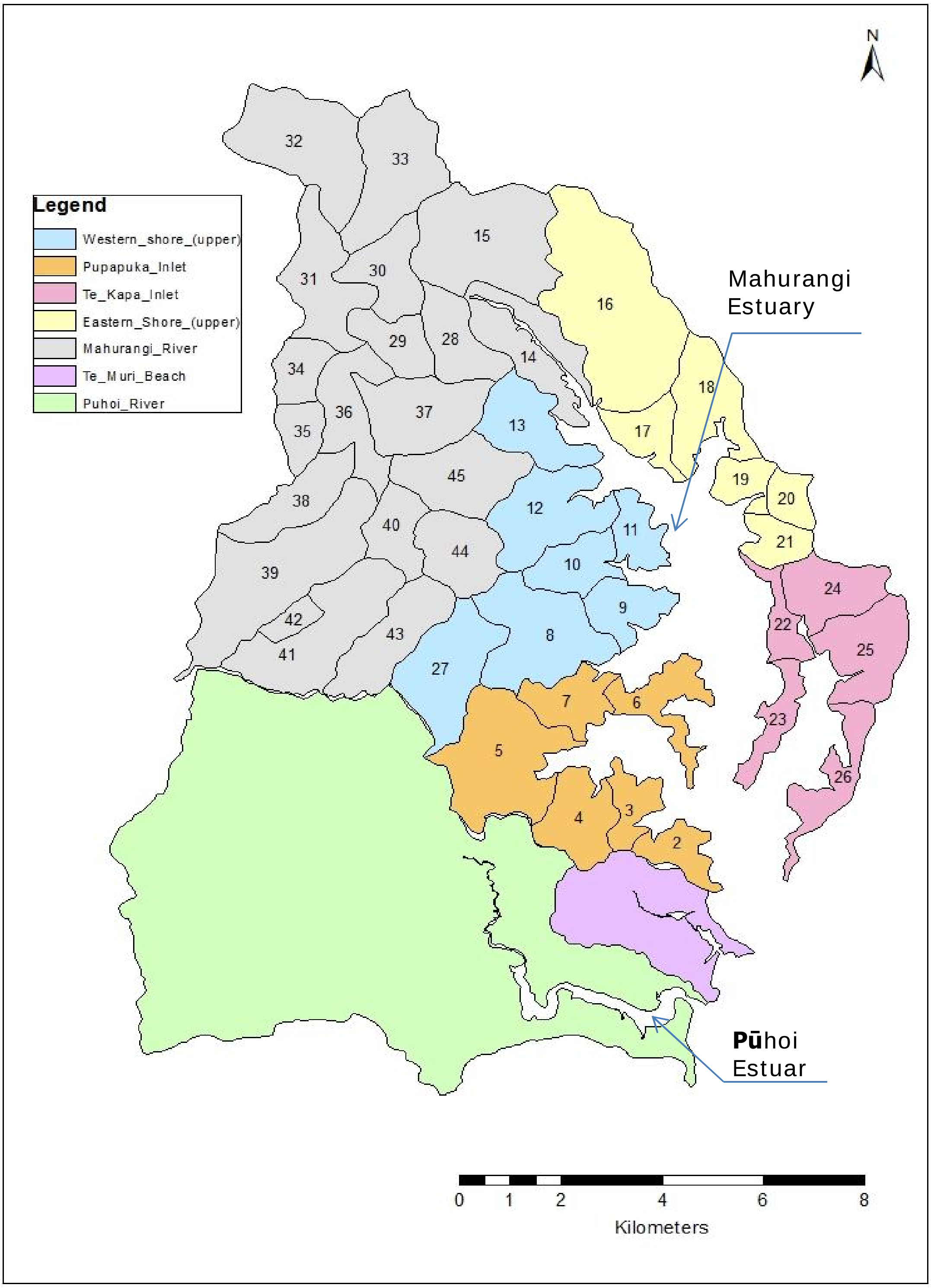

Figure 4: Catchments used in the sediment load modelling (NIWA, 2013).

3.3 Coincident wind conditions

Wind can be an important influence on the sediment deposition patterns in the estuaries and therefore the location and extent of sediment impacts. Wind induced currents can alter circulation patterns and the waves generated by wind over the estuary can keep sediment in suspension longer and can resuspend bed material. To help understand the influence of wind on the estuaries in extreme rainfall events the following analysis was undertaken.

For over 35 years there has been a wind recorder in Warkworth. The wind rose from this recorder is shown in Figure 5. The dominant wind conditions at Warkworth are the West South Westerly and the East North Easterly. As the modelling of the sediment in the estuaries is primarily concerned with extreme rainfall events the rainfall records were compared to the wind records to understand the wind conditions during heavy rain. The results of this analysis are shown in Table 3, Table 4 and Table 5.

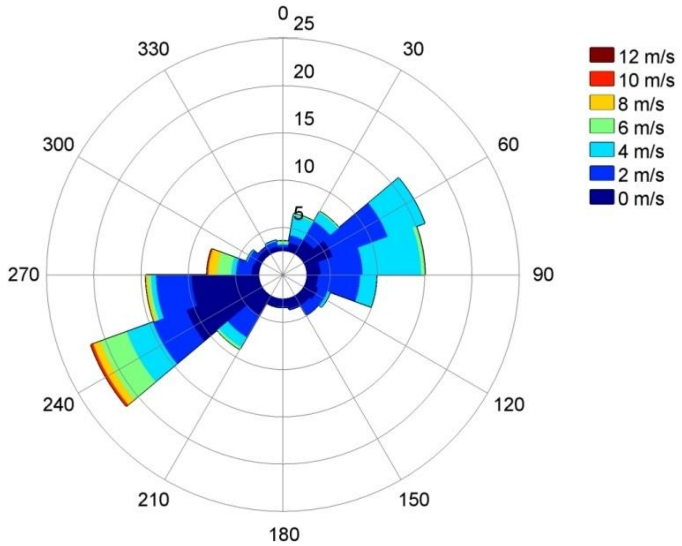

Figure 5: Wind rose of the Warkworth wind recorder data (eCoast, 2013).

Table 3: Average wind conditions during 2-10yr (ARI) rainfall events.

Date	Rainfall (mm)	Wind Direction (degrees)	Wind Direction	Wind Speed (m/s)
30/05/1975	97.60	90	East	12.4
09/08/1976	95.00	70	ENE	12.4
22/05/1977	119.60	90	East	6.7
21/06/1978	98.40	90	East	9.8
06/12/1983	114.70	75	ENE	10.6
26/03/1985	98.40	110	ESE	10.2
04/01/1986	96.10	15	NNE	3.3
22/06/1996	126.00	80	East	10.3

Date	Rainfall (mm)	Wind Direction (degrees)	Wind Direction	Wind Speed (m/s)
01/03/1997	103.30	100	East	5.7
28/06/2000	101.80	61.5	ENE	8.8
02/07/2000	93.20	81	East	5.2
04/11/2000	109.20	89	East	8.2
20/06/2002	128.60	77.5	ENE	10.1
24/04/2006	94.74	64	ENE	6
29/07/2008	94.76	88	East	4.2
03/12/2009	105.57	75	ENE	4.4
20/05/2010	113.99	116.5	ESE	3.2
22/01/2011	118.99	113.5	ESE	3.6

Table 4: Average wind conditions during 10-50yr (ARI) rainfall events.

Date	Rainfall (mm)	Wind Direction (degrees)	Wind Direction	Wind Speed (m/s)
12/01/1976	160.30	60	ENE	4.6
22/05/1985	210.30	85	East	7.7
29/03/1995	157.00	70	ENE	3.2
01/09/2001	163.40	86.5	East	4.2
29/03/2007	177.72	63.5	ENE	7.8
22/02/2008	147.32	71.5	ENE	9.2
28/01/2011	172.63	96.5	East	4.0

Table 5: Average wind conditions during >50yr (ARI) rainfall events.

Date	Rainfall (mm)	Wind Direction (degrees)	Wind Direction	Wind Speed (m/s)
22/05/1985	210.30	85	East	7.7

These results suggest that there are two dominant wind conditions that are experienced in the Warkworth area during extreme rainfall events. These are a near calm wind condition (for this study calm is considered as wind speeds less than 5m/s or 10 knots) and a wind from the East or North East. In the above tables the near calm wind conditions have been coloured orange and the winds between East and North East have been coloured green. In the last 35 years of recorded wind and rainfall records in Warkworth there has been only one instance during extreme rainfall when the wind was not either of these two wind conditions (red coloured row in Table 3). On the 26/03/1985 a heavy rainfall occurred during an East South Easterly.

Based on this analysis two wind scenarios were chosen as representative of the likely coincident wind conditions during an extreme rainfall event in the Catchments feeding into the Mahurangi and Pūhoi Estuaries. These two conditions are:

- Calm wind conditions
- 9m/s East North Easterly (67.5^{o})

3.4 Modelling scenarios

Combining the three open areas of earthworks scenarios, the two rainfall events and the two wind conditions, the Mahurangi and Pūhoi Estuary modelling scenarios were undertaken as shown in Table 6.

Table 6: Coastal modelling scenarios.

Scenario	Estuary	Construction Condition	Rainfall Condition (Annual Exceedence Probability)	Wind Condition
EM01	Mahurangi	Background	10 Year (10% AEP)	Calm
EM02	Mahurangi	Background	10 Year (10% AEP)	ENE (9 m/s)
EM03	Mahurangi	Background	50 Year (2% AEP)	Calm
EM04	Mahurangi	Background	50 Year (2% AEP)	ENE (9 m/s)
EP05	Pūhoi	Background	10 Year (10% AEP)	Calm
EP06	Pūhoi	Background	10 Year (10% AEP)	ENE (9 m/s)
EP07	Pūhoi	Background	50 Year (2% AEP)	Calm
EP08	Pūhoi	Background	50 Year (2% AEP)	ENE (9 m/s)
SM01	Mahurangi	Short (5 Year)	10 Year (10% AEP)	Calm
SM02	Mahurangi	Short (5 Year)	10 Year (10% AEP)	ENE (9 m/s)
SM03	Mahurangi	Short (5 Year)	50 Year (2% AEP)	Calm
SM04	Mahurangi	Short (5 Year)	50 Year (2% AEP)	ENE (9 m/s)
SP05	Pūhoi	Short (5 Year)	10 Year (10% AEP)	Calm
SP06	Pūhoi	Short (5 Year)	10 Year (10% AEP)	ENE (9 m/s)
SP07	Pūhoi	Short (5 Year)	50 Year (2% AEP)	Calm
SP08	Pūhoi	Short (5 Year)	50 Year (2% AEP)	ENE (9 m/s)
LM01	Mahurangi	Long (10 Year)	10 Year (10% AEP)	Calm
LM02	Mahurangi	Long (10 Year)	10 Year (10% AEP)	ENE (9 m/s)
LM03	Mahurangi	Long (10 Year)	50 Year (2% AEP)	Calm
LM04	Mahurangi	Long (10 Year)	50 Year (2% AEP)	ENE (9 m/s)
LP05	Pūhoi	Long (10 Year)	10 Year (10% AEP)	Calm
LP06	Pūhoi	Long (10 Year)	10 Year (10% AEP)	ENE (9 m/s)
LP07	Pūhoi	Long (10 Year)	50 Year (2% AEP)	Calm
LP08	Pūhoi	Long (10 Year)	50 Year (2% AEP)	ENE (9 m/s)

In addition to these scenarios, a range of sensitivity tests were also carried out to further understand and quantify the variability and uncertainty in the outputs.

3.5 Modelling sediment and flow inputs

The sediment concentrations and associated fluvial flows that are used as inputs into the coastal process model were developed for the Further North Alliance by NIWA. Details of the methodology used to develop the inputs are discussed in the Water Assessment Factual Report No. 3: *Pūhoi -*

Warkworth Road of National Significance: Estimates of Construction Sediment Loads (Prepared by NIWA for the Further North Alliance). The following is a brief summary of this process which is illustrated in Figure 6.

The background sediment inputs were developed using a BNZ Model. This model was run for 50 years of rainfall data and a sediment load rating curve developed for the catchments feeding into the estuaries. Based on these rating curves the event based sediment loads that would arrive at the coast were estimated. These loads formed the background sediment loads.

A GLEAMS model was constructed by NIWA to assess the additional sediment that would be generated by the construction of the Project. The GLEAMS model estimated the additional sediment that could be expected to be generated for the peak area of open earthworks as predicted by the early assessment of construction staging for both a 5 year (short) and 10 year (long) construction programme. In the modelling of the construction scenarios this additional sediment was added to the background sediment inputs assuming that there were no losses in the fluvial environment.

For the 10 and 50 year event based modelling of the estuaries NIWA developed representative inflow hydrographs for each major stream and river. In some locations where stream mouths are close together the sediment loads have been combined to a single input. The shapes of the hydrographs were chosen based on observed data from the flow gauge at Warkworth. To provide TSS concentrations these sediment loads were distributed across the hydrograph. In the modelling of the 10 and 50 year events in the Mahurangi River catchment the timing of all other input hydrographs were adjusted to coincide with the peak of the inflows in the Mahurangi River.

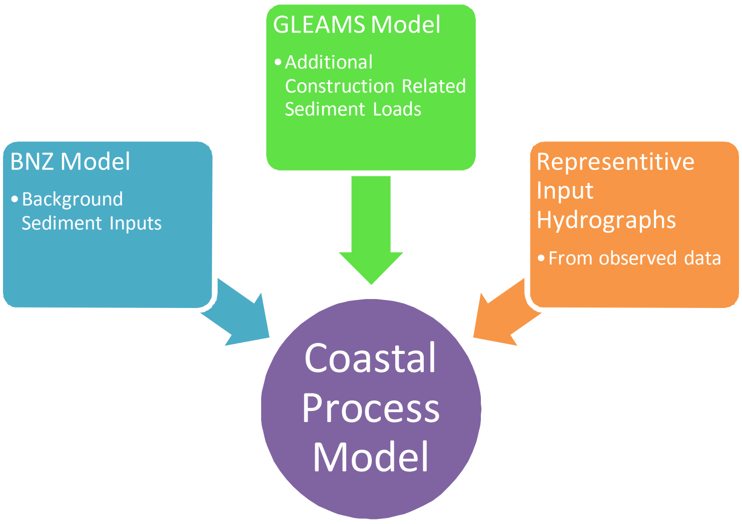

Figure 6: Input sediment and flows to the estuary models.

The hydrograph inputs are shown in Figure 7 and Figure 8 while the TSS loading is shown in Table 7 and Table 8. In the modelling of the 10 and 50 year events in the Mahurangi River, smaller coincident rainfall and associated sediment load events were used in the modelling of the other catchments feeding into the estuary to avoid the masking of potential sediment contributions and to account for rainfall variability across the catchments.

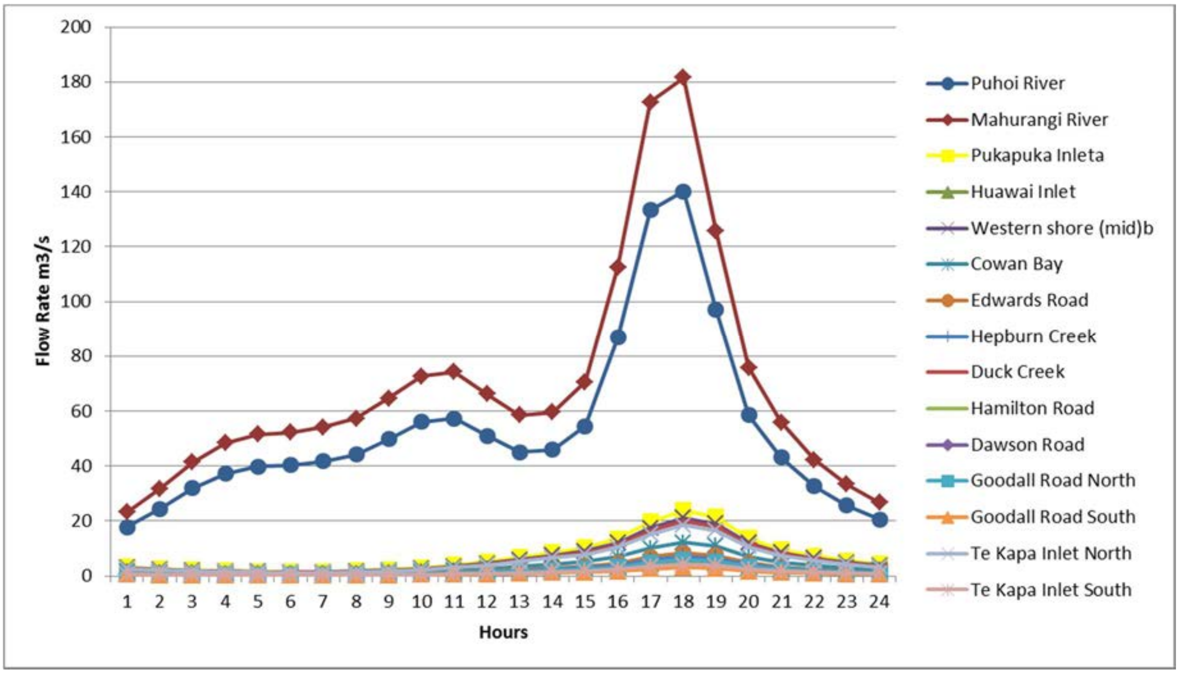

Figure 7: Hydrograph used as inputs for the 10 year (ARI) rainfall event scenario.

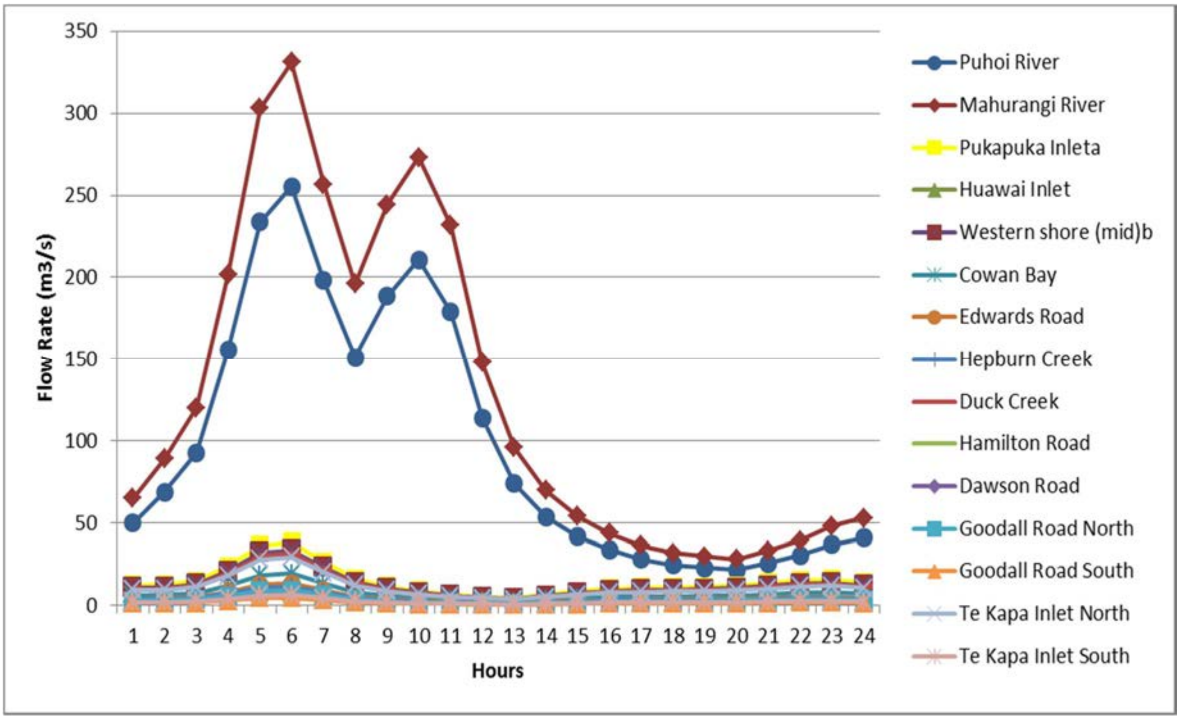

Figure 8: Hydrograph used as inputs for the 50 year (ARI) rainfall event scenario.

Table 7: Sediment loads and peak hourly TSS for the inputs into the coastal process models for the 10 year ARI rainfall event scenario.

Waterway	NIWA catchments	Coordinates (NZTM)		Background		Short (5yr) Construction Programme		Long(10yr) Construction Programme	
		X location	Y location	Total Sediment Load (T)	Peak Hourly TSS (g/m^3)	Total Sediment Load (T)	Peak Hourly TSS (g/m^3)	Total Sediment Load (T)	Peak Hourly TSS (g/m^3)
Pūhoi River	-	**1749520**	**5957680**	**10740**	**3943**	**11635**	**4275**	**11126**	**4086**
Mahurangi River	-	**1749137**	**5970700**	**7152**	**2048**	**8249**	**2363**	**7555**	**2164**
Pukapuka Inlet	4,5,7	1751070	5961350	1216	3588	1216	3588	1216	3588
Huawai Inlet	2,3	1752620	5959880	364	4227	364	4227	364	4227
Western shore	6,8,27	1752320	5963340	800	2699	800	2699	800	2699
Cowan Bay	9,10,11	1752560	5965090	750	4102	750	4102	750	4102
Edwards Road	12	1752220	5967070	546	4661	546	4661	546	4661
Hepburn Creek	13	1751840	5967950	326	3241	326	3241	326	3241
Duck Creek	16	1751570	5968500	650	2220	650	2220	650	2220
Hamilton Road	17	1752990	5966820	132	2387	132	2387	132	2387
Dawson Road	18	1753790	5966700	110	1824	110	1824	110	1824
Goodall Road North	19,20	1754250	5966340	151	1626	151	1626	151	1626
Goodall Road South	21	1754610	5965860	94	1940	94	1940	94	1940
Te Kapa Inlet North	22,23,24,25	1755855	5962614	1414	5305	1414	5305	1414	5305
Te Kapa Inlet South	26	1756220	5960784	370	5963	370	5963	370	5963

Table 8: Sediment loads and peak hourly TSS for the inputs into the coastal process models for the 50 year ARI rainfall event scenario.

Waterway	NIWA catchments	Coordinates (NZTM)		Background		Short (5yr) Construction Programme		Long(10yr) Construction Programme	
		X location	Y location	Total Sediment Load (T)	Peak Hourly TSS (g/m^3)	Total Sediment Load (T)	Peak Hourly TSS (g/m^3)	Total Sediment Load (T)	Peak Hourly TSS (g/m^3)
Pūhoi River	-	**1749520**	**5957680**	**27489**	**4856**	**30079**	**5314**	**28871**	**5101**
Mahurangi River	-	**1749137**	**5970700**	**18304**	**2498**	**21844**	**2981**	**19875**	**2712**
Pukapuka Inlet	4,5,7	1751070	5961350	3476	5544	3476	5544	3476	5544
Huawai Inlet	2,3	1752620	5959880	1042	7376	1042	7376	1042	7376
Western shore	6,8,27	1752320	5963340	2286	3926	2286	3926	2286	3926
Cowan Bay	9,10,11	1752560	5965090	2146	6839	2146	6839	2146	6839
Edwards Road	12	1752220	5967070	1559	7435	1559	7435	1559	7435
Hepburn Creek	13	1751840	5967950	932	5204	932	5204	932	5204
Duck Creek	16	1751570	5968500	1858	3188	1858	3188	1858	3188
Hamilton Road	17	1752990	5966820	378	4018	378	4018	378	4018
Dawson Road	18	1753790	5966700	314	3037	314	3037	314	3037
Goodall Road North	19,20	1754250	5966340	432	2812	432	2812	432	2812
Goodall Road South	21	1754610	5965860	268	3343	268	3343	268	3343
Te Kapa Inlet North	22,23,24,25	1755855	5962614	4040	8633	4040	8633	4040	8633
Te Kapa Inlet South	26	1756220	5960784	1056	9895	1056	9895	1056	9895

The percentage increase in sediment in the Pūhoi and Mahurangi Rivers predicted if an extreme rainfall was to occur during the peak of construction is shown in Table 9.

Table 9: Predicted maximum percentage increase in total sediment load reaching the **Pūhoi** and Mahurangi River mouths under the two construction programmes for the 10 and 50 Year ARI rainfall events.

	Increase in total sediment loads in the Pūhoi River		Increase in total sediment loads in the Mahurangi River	
	10yr ARI	50yr ARI	10yr ARI	50yr ARI
Short (5 Year) Construction Programme	8%	9%	15%	19%
Long (10 Year) Construction Programme	4%	5%	6%	9%

3.6 Probabilities

The risk of the Project contributing additional sediment loads that could result in adverse effects in the estuaries requires an understanding of the likelihood of the event occurring as well as quantifying the consequences. The scenarios developed in this modelling investigation have been designed to assist in the assessment of the ecological, visual, commercial and amenity impacts. These impacts are assessed in the Construction Water Assessment Report and the Marine Ecology Assessment Report. The likelihood of the scenarios occurring can be quantified by combining the probability of an extreme rainfall occurring during the construction of the project and the duration of construction earthworks in the contributing catchment.

The probability of any Annual Recurrence Interval (ARI) rainfall event occurring at least once over the construction period is calculated using the formula below:

$$P_T = 1 - (1-P_f)^n$$

Where:

- P_T is the probability of occurrence for the entire construction period;
- P_f is the probability of occurrence of the rainfall event in any single year; and
- n is the total time period in years

Using this formula the probability of the 10 and 50 year rainfalls occurring at least once during the two construction periods are shown in Table 10. The table also includes the likelihood rating category from the NZTA's *Risk Management Process Manual*, 2004.

Table 10: Probability of extreme rainfall occurring during the two construction programmes.

	Rainfall Event	
	10yr ARI	50yr ARI
Short (5 Year) Construction Programme	39% (Quite Common)	10% (unusual)
Long (10 Year) Construction Programme	63% (likely)	18% (unlikely)

It is important to note that the modelling scenarios have been developed on the basis of the predicted peak area of open earthworks predicted in the 5 and 10 year construction staging programmes. Over the construction period the average area of open earthworks is likely to be significantly lower. However, focusing on the consequences of extreme rainfall occurring during the peak areas of open earthworks allows for maximum allowable area of open earthworks limits to be developed.

A sediment rating curve was used in the calculation of the return period of sediment loads. For the purposes of this Report, we have assumed that a 10 and 50 year sediment load is generated by a 10 and 50 year rainfall.

4. Estuary modelling

The modelling of the Mahurangi and Pūhoi Estuaries was undertaken by eCoast Limited. The model was constructed using the 3DD software suite and included hydrodynamic, wave and sediment transportation modelling. The scope of eCoast's work included three phases: field data collection for the purposes of model construction and calibration; calibrated hydrodynamic model construction; and sediment dispersion and deposition modelling. A detailed account of the modelling undertaken for this Project is contained in the report *Pūhoi Warkworth Coastal Modelling and Field Data Collection*, 2013, prepared by eCoast for the Further North Alliance. A brief summary of the modelling construction and calibration is documented in this report along with a detailed analysis of the modelling outputs.

4.1 Field data collection

Instruments to measure current speed, current direction, water levels and turbidity were deployed at 2 locations in the Mahurangi Estuary and at 2 locations in the Pūhoi Estuary. A further turbidity meter was deployed in the Mahurangi River, downstream from the Warkworth weir. Data was collected for a 4 week period between 1st and 28th March 2013.

In addition to the instrumentation, water sample collection was undertaken at two transects across each estuary as well as temperature strings to help understand the thermal structure of the water column during rainfall events. 38 sediment samples were also collected from across the estuaries to further understand sediment movement and particle sizes across the estuary.

4.2 Calibrated hydrodynamic model construction

Two depth-averaged models were developed to simulate the sediment dispersion and deposition within the Mahurangi and Pūhoi estuaries. The models were used to quantify the changes in deposition and concentration patterns due to additional sediment generated by earthworks during the construction of the Project. The models build on the previous work undertaken by Oldman *et al*. (2009) and increase the resolution. The Mahurangi is modelled at 25 by 25m and Pūhoi is modelled at 10 by 10 m. Bathymetry for the models was developed from a range of sources including bathymetric charts, LiDAR and aerial photographs.

In addition to the stream and river inflows from the simulated rainfall events, the models were driven by sea level boundaries on the open coast that were extracted from a wider model of the Hauraki Gulf. The model also includes the influences of wind using a 2-dimensional numerical wave refraction model. This model applies an iterative, finite-difference solution of the wave action equations to solve for wave height, wave period and mean bottom orbital currents.

Hydrodynamic calibration of the models was undertaken using the measured data collected for this Project. A good calibration was achieved for water levels in both Mahurangi and Pūhoi Models. The modelled currents in the Mahuragi also matched closely with the observed data. In the Pūhoi the model only achieved a partial match to the measured currents due to the location of the recorder being in a channel narrower than the resolution of the model. The hydrodynamic calibration of both models is suitable for the purposes of this investigation.

4.3 Sediment dispersion and deposition modelling

As well as the hydrodynamic and wave model a cohesive sediment transport model was used for simulating the settlement and re-suspension of sediments. Initial calibration of this model was undertaken using the measured data. However this calibration largely focused on the relatively low concentrations of resuspended sediment as there was no significant rainfall during the data collection period. As this investigation is focussed on understanding the sediment patterns in the estuaries generated by extreme (10 year and 50 year ARI) rainfall events, verification of the sediment transport models relied on comparison of the model results with historical sediment rates in the estuaries. In addition to this a sensitivity analysis was undertaken on a range of modelling factors to understand the variability in the results.

Previous studies in the Mahurangi had calculated annual average sedimentation rates based on pollen and radiocarbon dating of cores (Swales *et al*., 2009 and Oldman *et al*. 2009). This study found that over the last century the sedimentation rates approximately 3km downstream of the Warkworth weir were 24mm/yr. However these rates quickly drop further out into the estuary, with sedimentation rates of less than 5mm/yr being observed approximately 6km from the weir. These findings match well with the model results which indicate that much of the sediment from the Mahurangi River deposits in the upper estuary, with very little deposition occurring more than 6km from the weir.

Our sensitivity analysis revealed that the deposition in all the scenarios runs is dominated by the TSS that is delivered to the estuaries by the rivers. Therefore changes to factors such as the erosion threshold, threshold for deposition, bulk density and changes to the coincident neap-spring tidal cycle had little influence on the extent of deposition or accretion. In all cases the general pattern of deposition and concentration was consistent despite the changes made to parameters. The results of the sensitivity analysis are contained in Appendix E.

Both the comparisons to historical data and the sensitivity analysis give us confidence that the models are appropriate tools to assess the event based changes in sediment patterns within the estuaries as a result of extreme rainfall coinciding with earthworks associated with this Project.

5. Modelling results

5.1 Modelling Results

The models were run for the scenarios described in Section 3.4, for each model the following results were extracted and mapped:

- Peak TSS during the event;
- Deposition depths 1 day following the peak of the input hydrograph;
- TSS 1 day following the peak of the input hydrograph;
- Deposition depths 3 days following the peak of the input hydrograph; and
- TSS 3 days following the peak of the input hydrograph.

These results were used to understand the event based consequences that the additional sediment generated by the construction of the Project would have on deposition patterns in the two estuaries. Plans of the results are shown in Appendix A-D.

5.2 Mahurangi Estuary

Plots of the peak TSS anticipated in the 10 year and 50 year event scenario are shown in Figure 9. These results show that the high concentrations of sediment discharging from the Mahurangi River are largely confined to the upper reaches of the estuary. The high concentrations are clearly observed in the model results to be following the low tide channels where the increased velocities carry the sediment further out into the estuary.

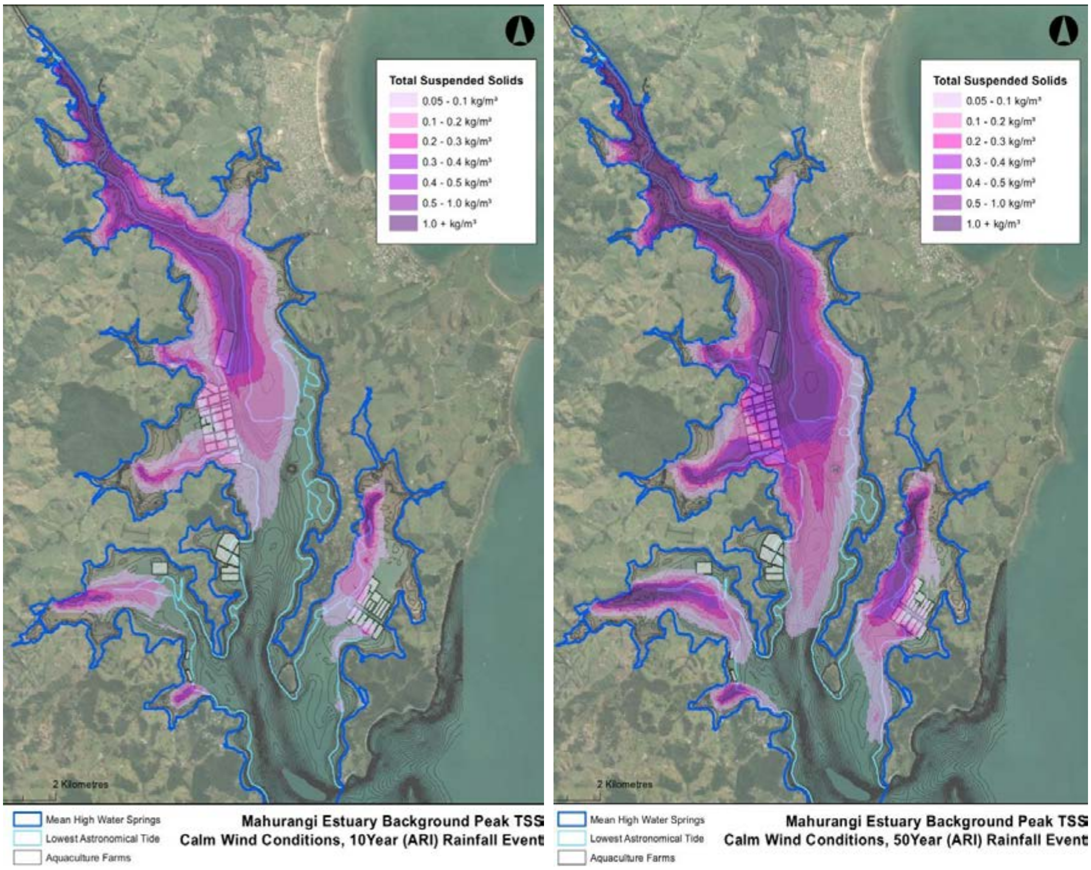

Figure 9: Background peak total suspended sediment in the Mahurangi Estuary in the 10 and 50 year sediment load scenarios.

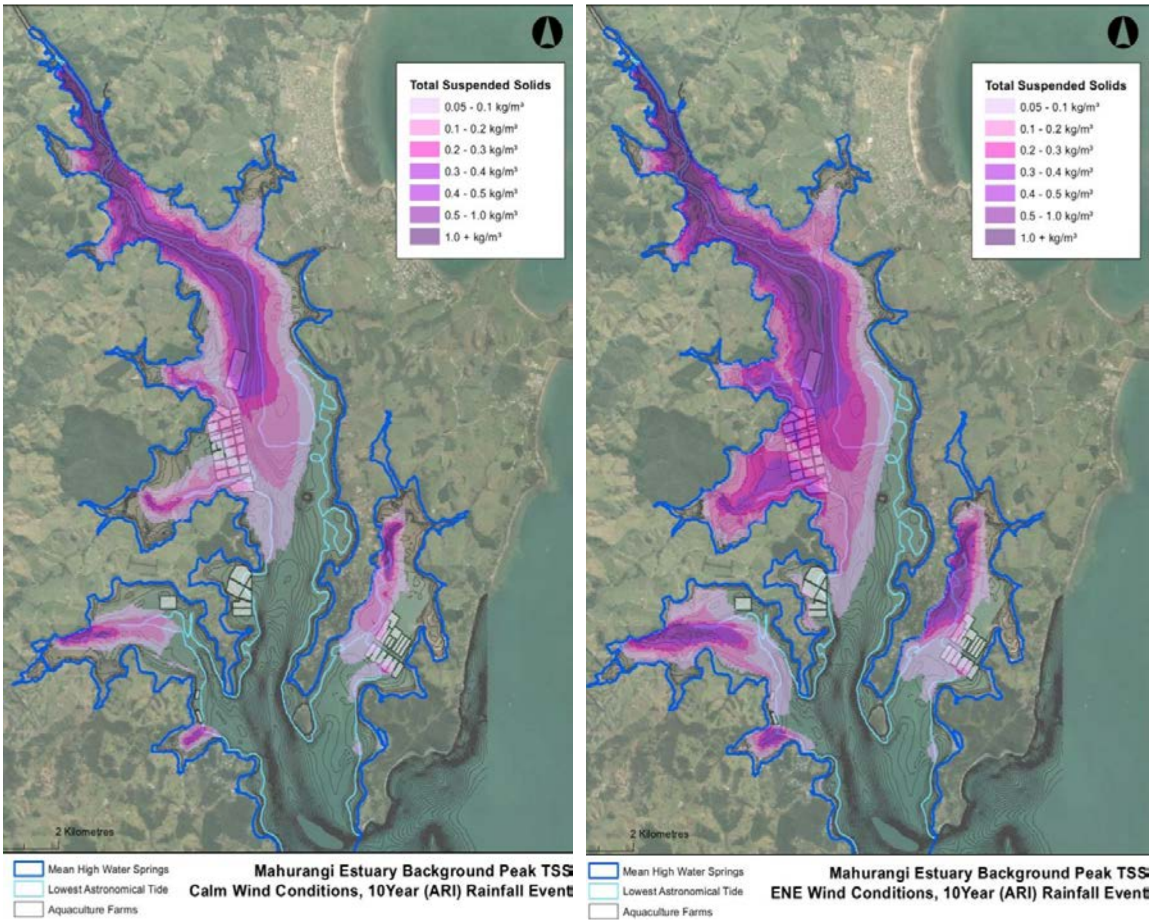

Figure 10: Comparison of background peak total suspended sediment in the Mahurangi Estuary in the 10 year sediment load scenario under the two different wind conditions.

Figure 10 illustrates the impact that the inclusion of the 9m/s East North Easterly (ENE) wind condition had on the TSS patterns in the Mahurangi. The sediment in suspension is forced towards the western edge of the estuary. There are also higher concentrations seen due to wave induced re-suspension of the sediment on the bed. The waves also help keep the sediment in suspension for longer resulting in the sediment travelling further into the estuary.

Even in the scenarios with wind the model predicts that the majority of the sediment will quickly deposit on the bed and concentrations in suspension will quickly drop following a heavy rainfall event. Figure 11 shows the drop in concentrations 1 day and 3 days following the peak of the 50 year sediment loads being released into the estuary. After 3 days, even with the 9m/s ENE wind there is almost no sediment in concentrations greater than 50 g/m^3.

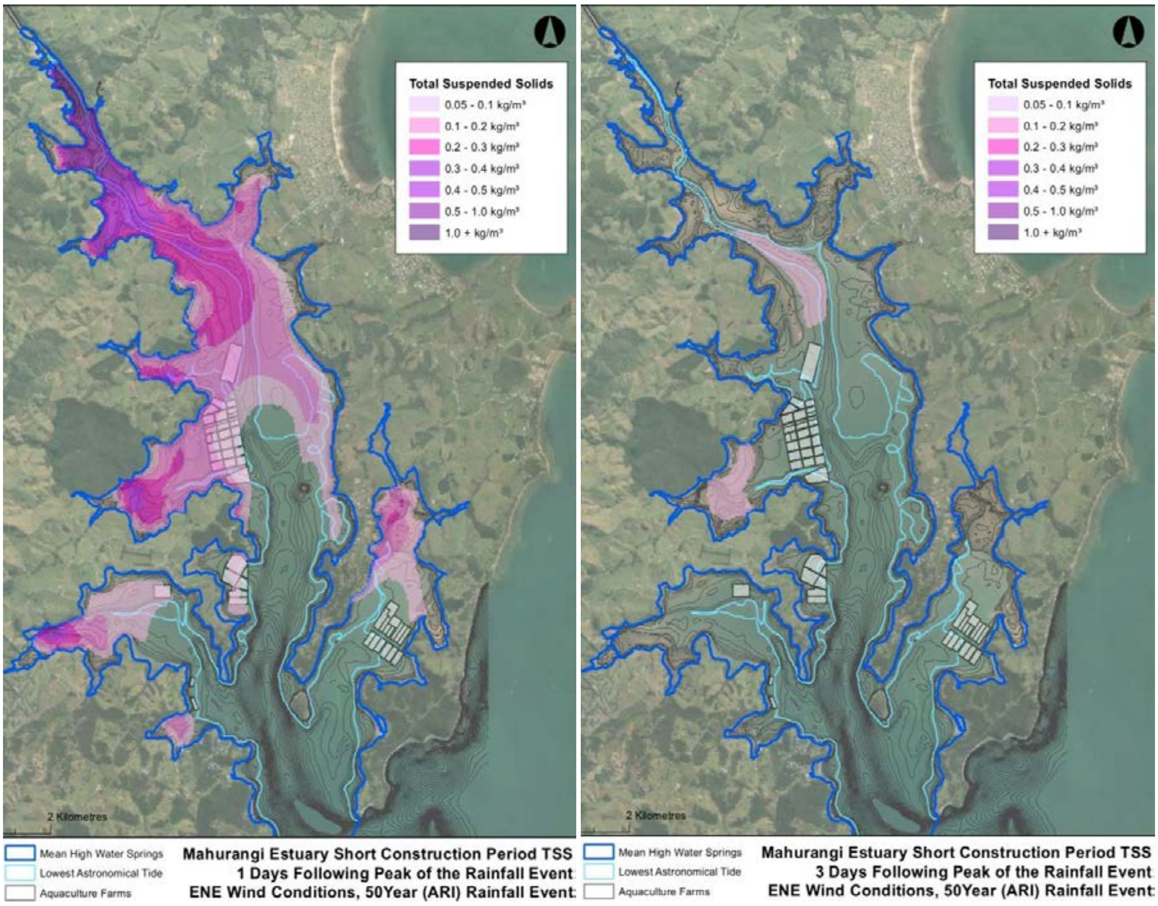

Figure 11: TSS after 1 day and 3 days in the Mahurangi Estuary in the 50 year sediment load scenario including the 9m/s ENE wind.

With the inclusion of the construction related sediment loads there is very little influence on the extent of TSS in the model results. Even in the 50 year sediment load scenario there is typically only a 30-40 g/m^3 increase 1 day following the peak of the sediment event. There was almost no observable influence 3 days after the peak of the sediment event.

5.2.1 Deposition

Sediment deposition in the scenarios modelled match closely the locations of long term historical sedimentation in the upper estuary (Swales *et al*., 2009 and Oldman *et al*. 2009). Figure 12 illustrates the deposition patterns found in the modelled 10 and 50 year sediment load scenarios. Much of the sediment is deposited over approximately 100Ha downstream of the river mouth. This thin layer of sediment is deposited ranging in typical thickness of up to 10mm. As expected the deepest deposits are found on the mangrove fringes where velocities rapidly drop. The model also indicates deeper deposits in the intertidal areas in comparison to the low tide channels. The 50 year sediment scenarios show a much larger extent of deposition than in the 10 year sediment scenario, due to the greatly increased sediment loads. However the sediment is still largely contained within the upper estuary in the days following heavy rainfall.

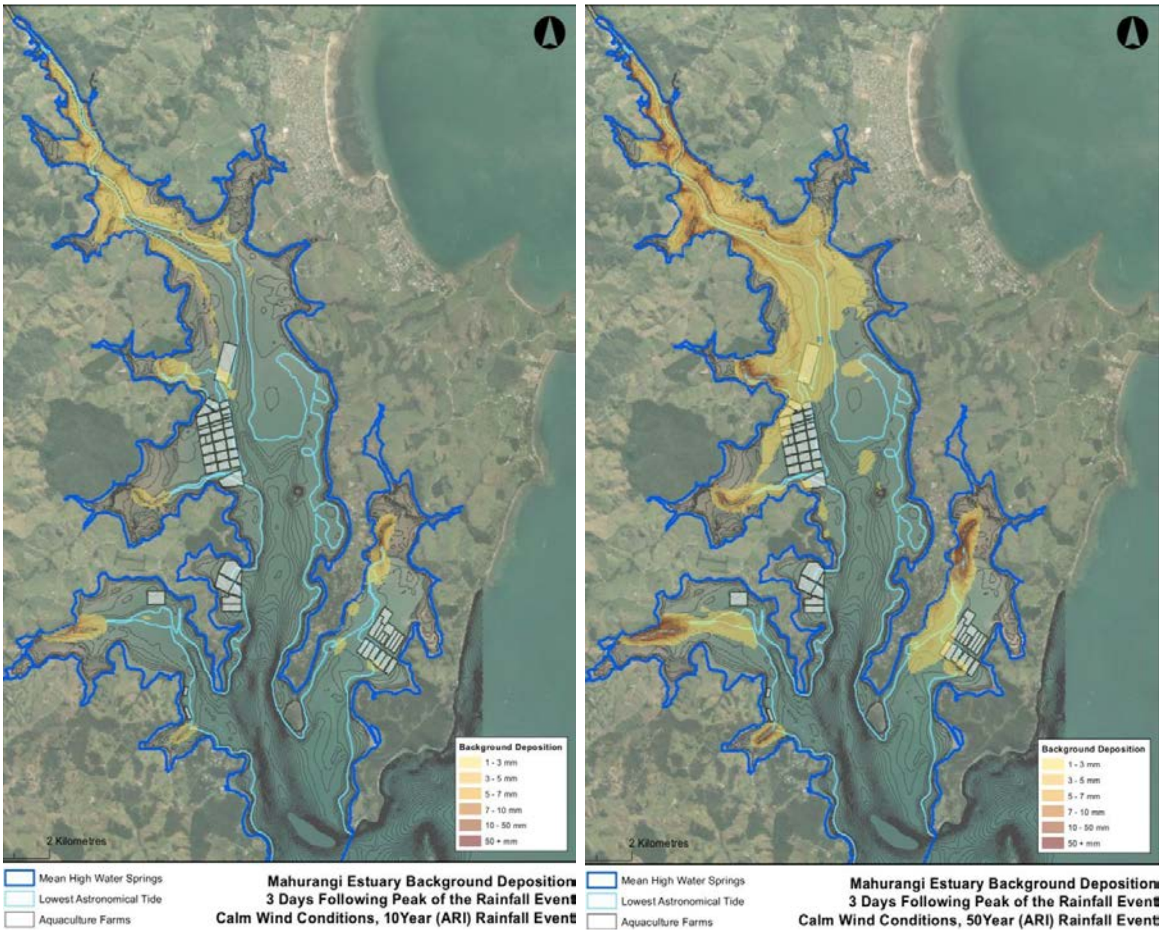

Figure 12: Background deposition in the Mahurangi Estuary in the 10 and 50 year sediment load scenarios.

The inclusion of the ENE wind has little influence on the extent of deposition, as shown in Figure 13. The most notable influence of the wind are slightly deeper deposits in the upper reaches of the estuary and less deep deposits of sediment on the intertidal areas on the western side of the estuary, as the wind induced waves help keep sediment in suspension longer.

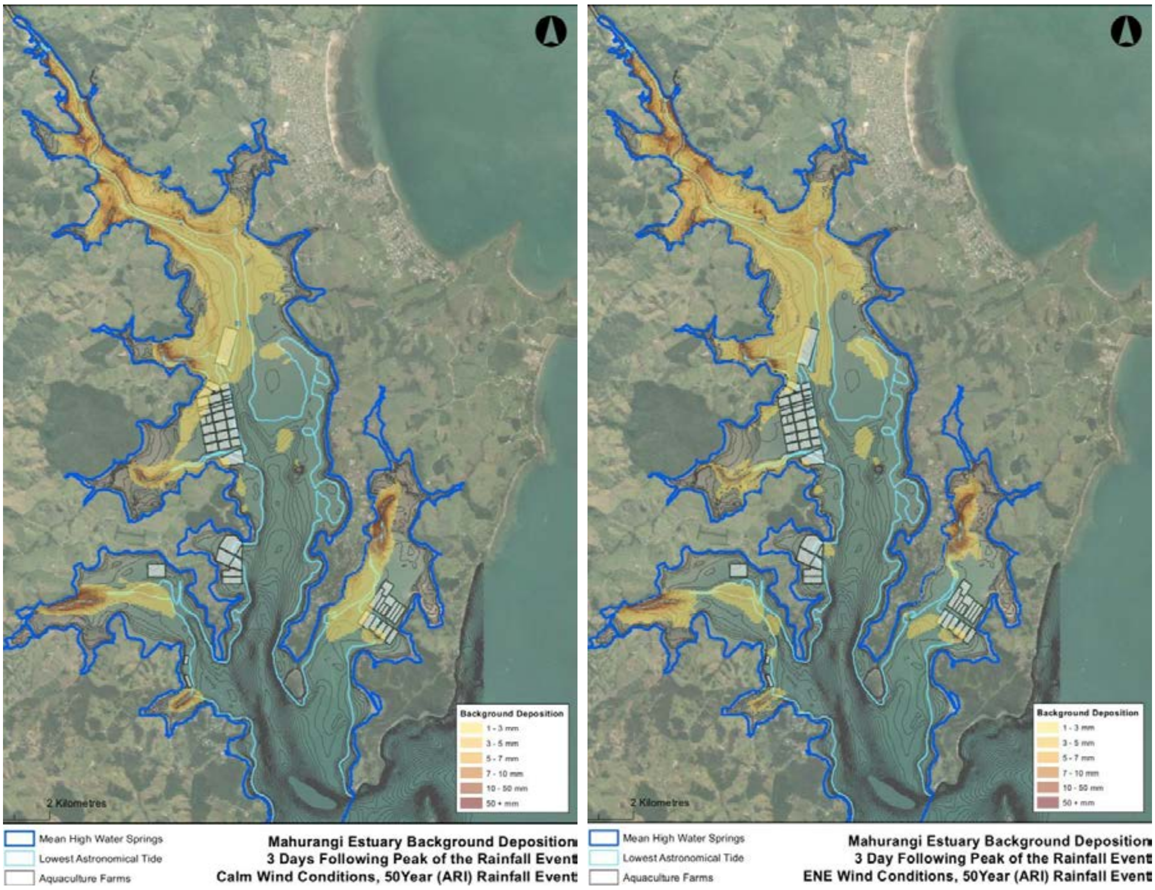

Figure 13: Background deposition in the Mahurangi Estuary in the 50 year sediment load scenario under calm and ENE wind conditions.

With the inclusion of the additional sediment associated with the peak areas of open earthworks in the short construction period the model results were compared with the results from the background sediment loads to identify the location and magnitude of the impacts.

In the 10 year ARI rainfall event the impacts were found to be largely contained to the intertidal area in the very upper reaches of the estuary. The inclusion of the ENE wind had little influence on the location and extent of the sediment, see Figure 14.

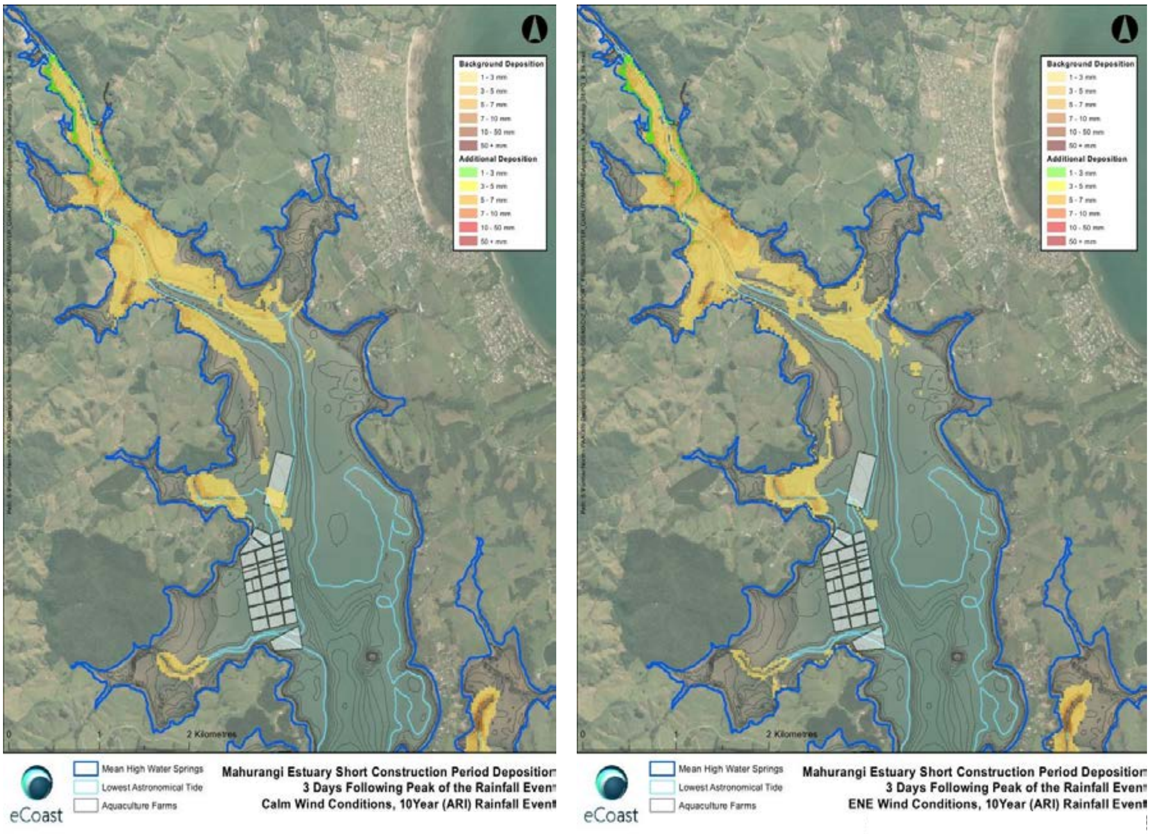

Figure 14: Predicted impacts of the additional sediment associated with the peak open earthworks in the short construction programme in the Mahurangi Estuary during a 10 year ARI sediment load scenario under calm and ENE wind conditions.

In the 50 year ARI sediment event the impacts were found to be much more widely spread but still largely contained within the intertidal areas of the upper estuary, refer Figure 15. The inclusion of the ENE wind had a little impact on the extent of the impacts, causing more of the additional sediment to drop out closer to the river mouth. Even in the 50 year ARI sediment load scenarios the increase in deposition is largely less than 3mm.

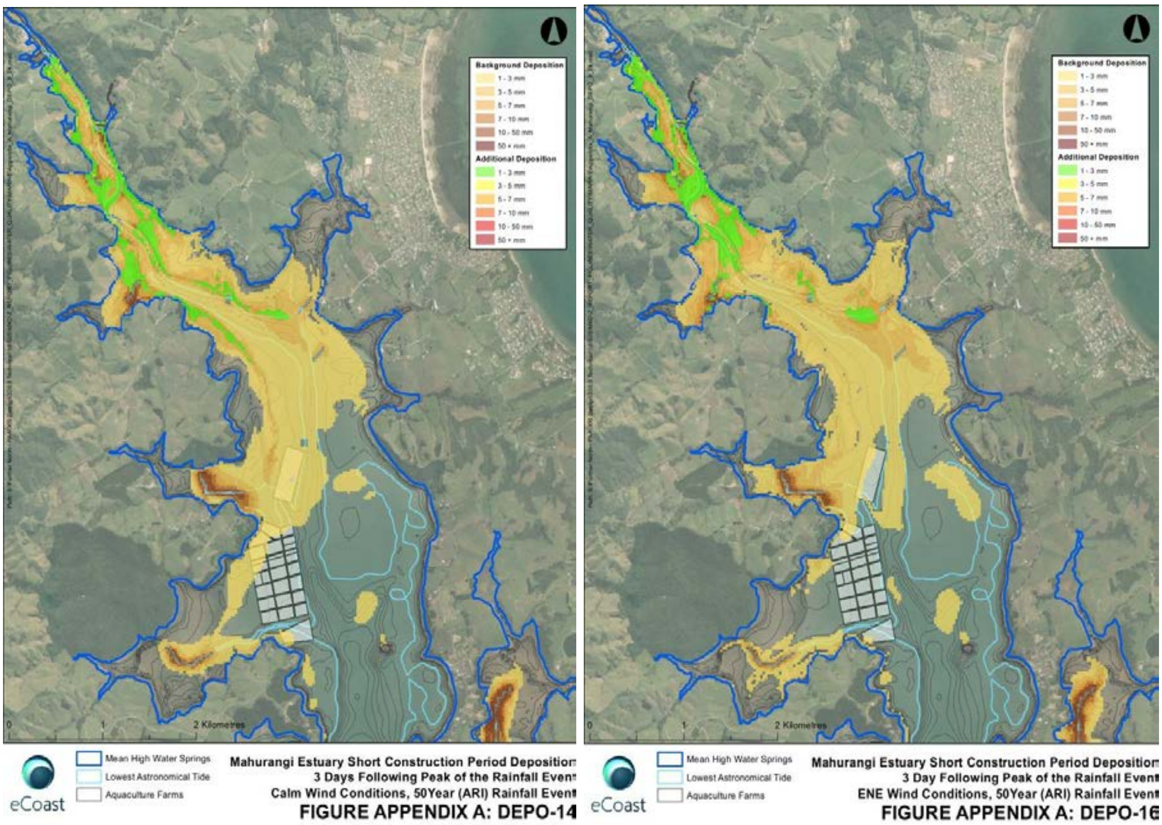

Figure 15: Predicted impacts of the additional sediment associated with the peak open earthworks in the short construction programme in the Mahurangi Estuary during a 50 year ARI sediment load scenario under calm and ENE wind conditions.

The model results of the longer 10 year construction programme with reduced areas of peak open earthworks showed that the impacts were much smaller. Figure 16: illustrates that the impacts in the days following heavy rain are largely contained to the intertidal areas near the mouth of the Mahurangi River.

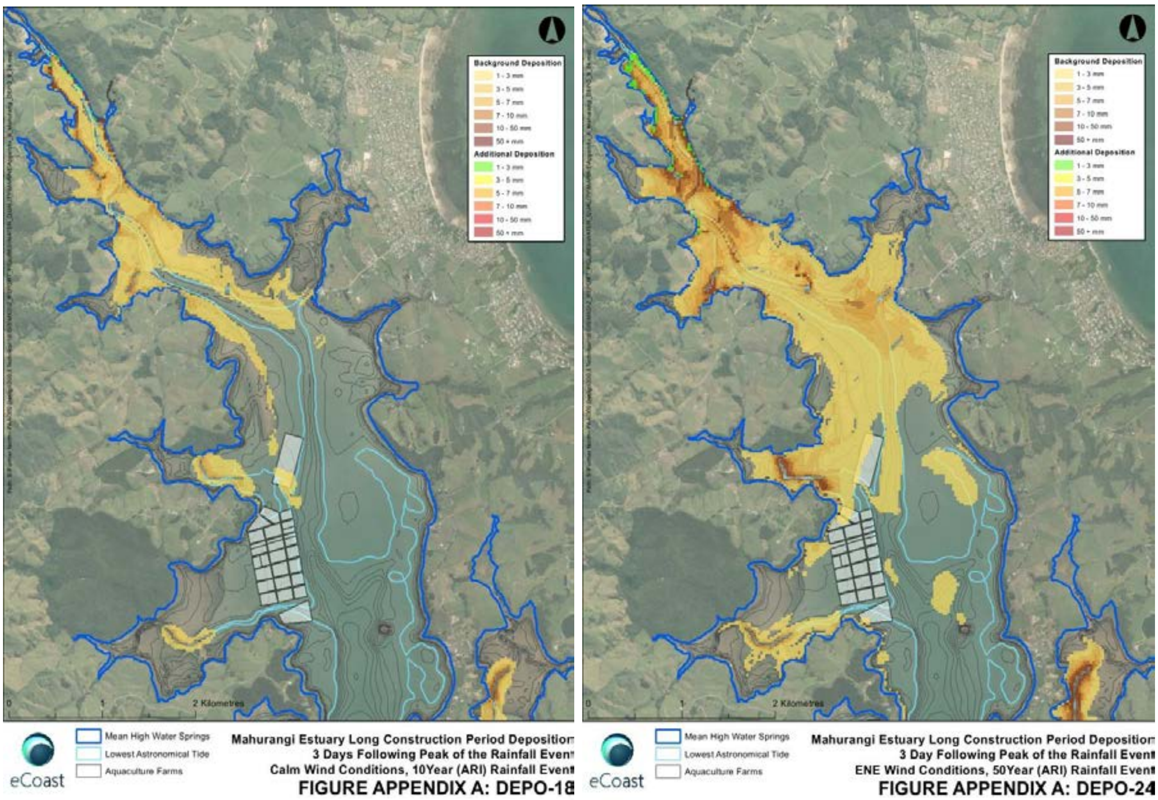

Figure 16: Predicted impacts of the additional sediment associated with the peak open earthworks in the long construction programme in the Mahurangi Estuary in the 10 and 50 year ARI sediment load scenarios.

5.2.2 Mahurangi threshold analysis

To help quantify the impacts that the additional sediment generated by the Project could have on ecology a threshold analysis was undertaken. The areas within the estuary that are predicted to be impacted by deposition depths of between 5-10mm and greater than 10mm have been identified for the background sediment scenarios. These areas were then compared to the scenarios with the inclusion of the additional sediment predicted to be generated by the project to identify the change in extents, see Table 11 and Table 12.

Table 11: Areas of deposition between 5-10mm and greater than 10mm in the Mahurangi Estuary under background sediment load conditions for the scenarios modelled (ha).

Scenario	Construction Condition	Rainfall Condition (ARI)	Wind Condition	Areas of high background deposition (ha)					
				5-10mm Total (ha)	5-10mm Sub-Tidal (ha)	5-10mm Inter-tidal (ha)	10mm+ Total (ha)	10mm+ Sub-Tidal (ha)	10mm+ Intertidal (ha)
EM01	Background	10yr	Calm	19.7	0.7	18.9	4.6	0.1	4.5
EM02	Background	10yr	ENE (9 m/s)	20.9	1.9	19.0	5.4	0.3	5.2
EM03	Background	50yr	Calm	90.5	10.3	80.2	40.2	1.8	38.4
EM04	Background	50yr	ENE (9 m/s)	90.7	14.9	75.8	37.5	4.5	33.0

Table 12: Increase in areas experiencing deposition between 5-10mm and greater than 10mm in the Mahurangi Estuary under the two construction programmes for the scenarios modelled (ha).

Scenario	Construction Condition	Rainfall Condition (AEP)	Wind Condition	Deposition Increase in Areas experiencing high deposition above background (ha)					
				5-10mm Total	5-10mm Sub-Tidal	5-10mm Inter-tidal	10mm+ Total	10mm+ Sub-Tidal	10mm+ Inter-tidal
SM01	Short (5 Year)	10yr	Calm	3.1	0.2	2.8	0.8	0.1	0.7
SM02	Short (5 Year)	10yr	ENE (9 m/s)	5.0	0.5	4.5	1.1	0.1	1.0
SM03	Short (5 Year)	50yr	Calm	20.5	3.6	16.9	5.2	0.3	4.9
SM04	Short (5 Year)	50yr	ENE (9 m/s)	22.6	5.0	17.6	5.7	0.7	5.0
LM01	Long (10 Year)	10yr	Calm	1.0	0.2	0.9	0.3	0.0	0.3
LM02	Long (10 Year)	10yr	ENE (9 m/s)	1.8	0.2	1.6	0.3	0.0	0.3
LM03	Long (10 Year)	50yr	Calm	7.4	0.9	6.5	1.7	0.1	1.6
LM04	Long (10 Year)	50yr	ENE (9 m/s)	9.7	1.0	8.7	2.3	0.6	1.7

This threshold analysis confirms that there is very little difference between the areas impacted in the calm and the ENE wind scenarios. The analysis also shows the increase in impacts between the 10 and 50 year (ARI) sediment load scenarios, with almost a fourfold increase in the threshold areas impacted in the larger event.

In comparison with background levels of deposition the increase observed in the areas of the estuary impacted by between 5-10mm of deposition, in the short construction scenarios, is almost 25%. However this is only a very small proportion of the total intertidal areas of the estuary, less than 2%, see Table 13. In the longer, 10 year, construction scenarios the increase in area experiencing 5-10mm of deposition is approximately 10%.

Table 13: Total areas of the Mahurangi Estuary.

Intertidal Areas (ha)	1610
Subtidal Areas (ha)	916

5.3 Pūhoi

Plots of the peak TSS anticipated in the 10 year and 50 year event scenario are shown in Figure 17. In comparison with the calm wind scenarios there was little difference in the peak TSS results with the inclusion of the 9m/s ENE wind. Unlike the Mahurangi estuary the much smaller Pūhoi estuary has high concentrations of sediment all the way to the mouth. During flood events the Pūhoi Estuary acts like a wide river. The model suggests that after 3 days almost 30% of the sediment released into the estuary escapes to the open ocean in a 10 year flood event and almost 40% in a 50 year flood event. The rest of the sediment is deposited within the estuary.

Previous modelling of the hydrodynamics of the areas outside of these estuaries has been undertaken (Mead *et al*., 2011). Dr Shaw Mead was contacted by the author to provide comment on the fate of sediments exiting the estuaries based on his previous studies and his knowledge of oceanographic principles. The following is taken from his email response (S. Mead, pers. comm, 21/5/2013):

> *Suspended sediments that are flushed from these estuaries during a 10 or 50 year event are unlikely to settle and persist in the nearshore zone for extended periods. The results of tidal and wave modelling, considering peak tidal currents and seabed orbital velocities generated by average wave conditions in the Hauraki Gulf (i.e. 1 m high waves at 10 second periods from the northeast) indicate that only small areas of the coast to the north and south of Pūhoi Estuary mouth (less than 1km in each direction) experience seabed velocities of less than 0.1 m/s (i.e. the threshold of sediment transport for fine sediments is ~0.1 m/s). Therefore, if some fraction of the sediment load settled in the nearshore zone along this coast during calm conditions, they would be re-suspended and distributed into deeper waters during the next wind/wave event, as is the normal process of sediment sorting on the coast. Indeed, much of the subtidal area in the lee of Kawau and Motuora Islands is comprised of fine sediment. It is notable that the 10 and 50 year return period rain events most often occur during periods of northeasterly winds and associated waves. Impacts of additional sediment inputs during 10 and 50 year return periods (pulse events) during construction are likely to be insignificant on the coast outside the estuaries.*

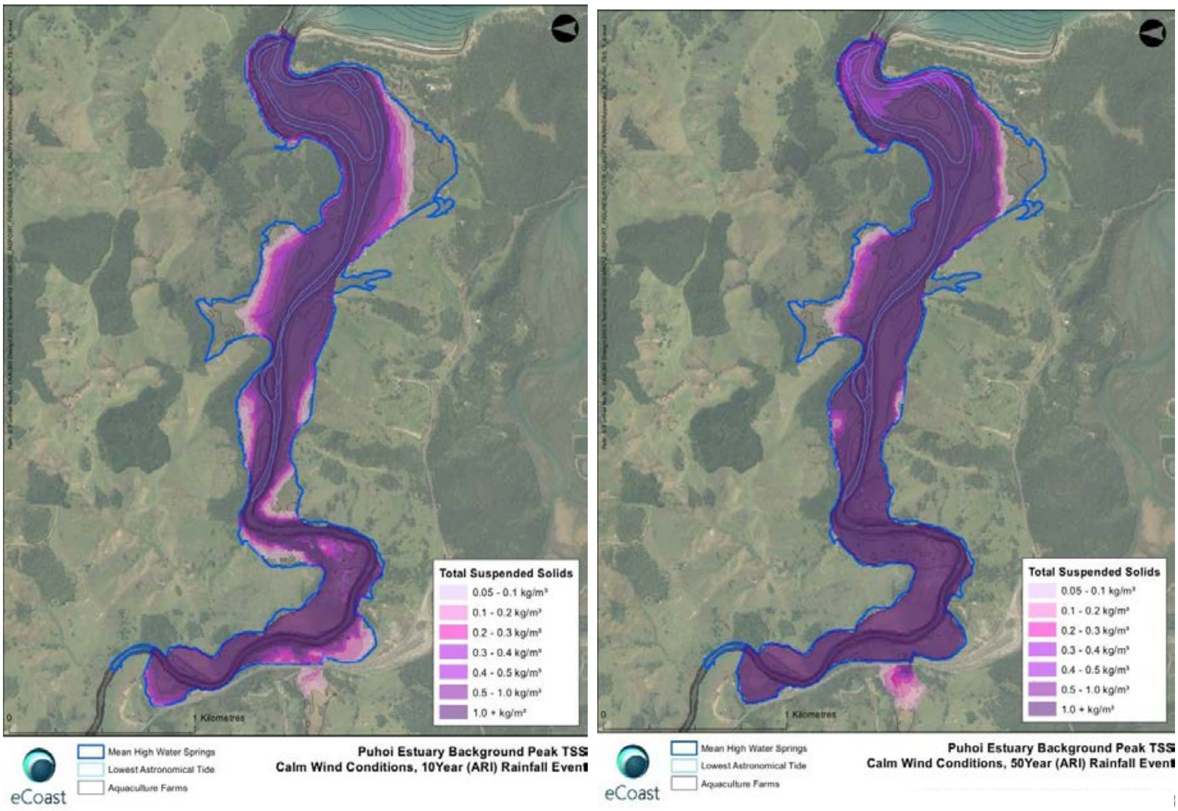

Figure 17: Background peak total suspended sediment in the Pūhoi Estuary in the 10 and 50 year sediment load scenarios.

The model indicates that the suspended sediment loads are quickly deposited or escape to open ocean, even in the scenarios with wind. Figure 18 shows the concentration predicted by the model 1 day following the peak of the 50 year sediment loads being released into the estuary. After 3 days, even with the 9m/s ENE wind, the model predicted that there was no sediment in concentrations greater than 50 g/m^3.

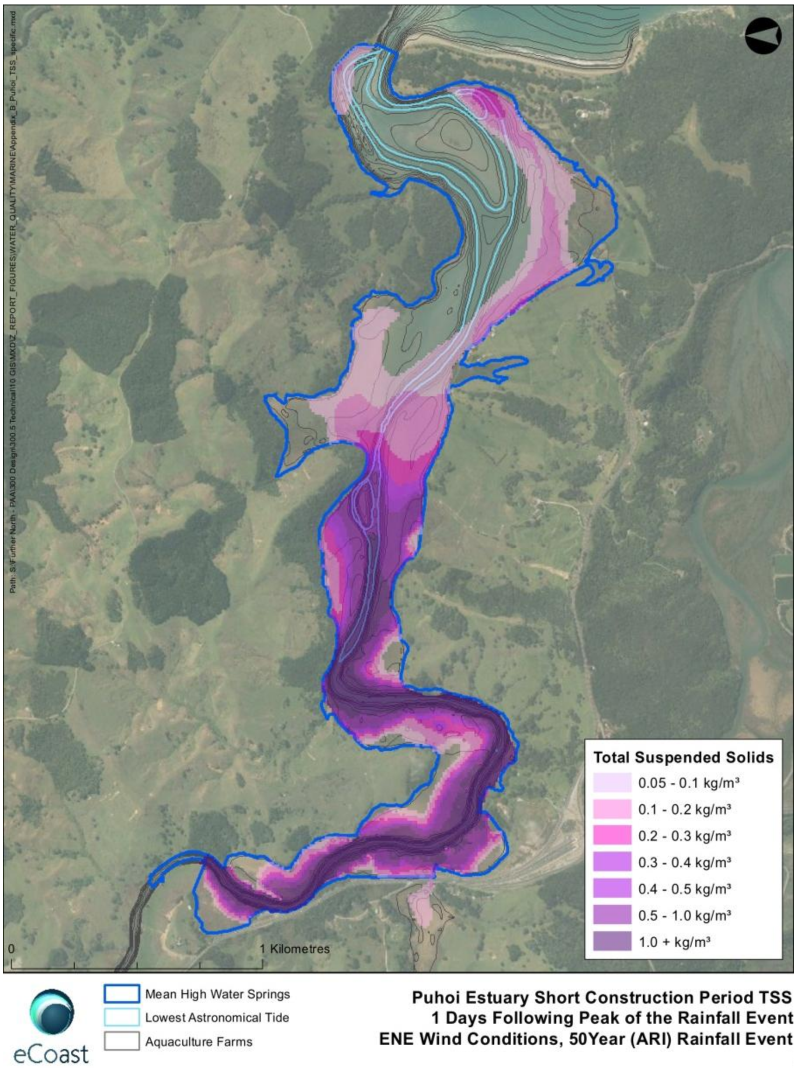

Figure 18: Background total suspended sediment in the Pūhoi Estuary 1 day after peak of the 50 year sediment load scenario including the 9m/s ENE wind.

Like the results from the Mahurangi the inclusion of the construction related sediment loads was found to make very little impact on the TSS concentrations in the model results. Even in the 50 year sediment load scenario there is typically only a 20-30 g/m^3 increase in concentrations 1 day following the peak of the sediment event. In the confined, narrow upper reaches of the estuary the difference in TSS concentrations are more pronounced with up to 150 g/m^3 increases being predicted 1 day following the peak of the 50 year short construction period event. However these concentrations were found to quickly dissipate or settle with almost no observable change being detected 3 days.

Figure 19 illustrates the modelled deposition patterns found in the 10 and 50 year sediment load scenarios. While sediment is deposited throughout the 150ha of estuary the areas of greatest deposition are in the intertidal areas at the river end of the estuary and in the area near the mouth. The deeper deposits near the mouth occur due to a combination of reductions in velocity and mixing with more saline water from the incoming tide.

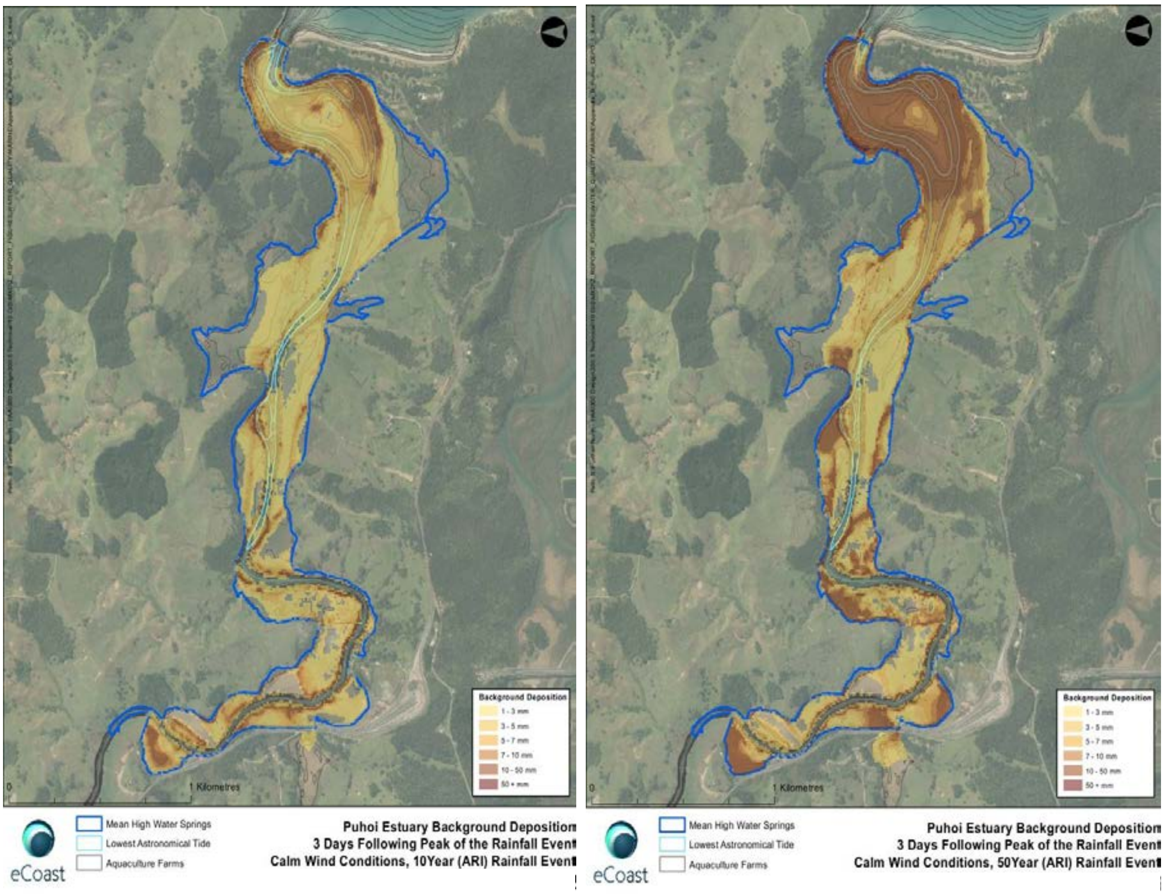

Figure 19: Background deposition in the Pūhoi Estuary in the 10 and 50 year sediment load scenarios.

The inclusion of the ENE wind has little impact on the location and extent of deposition in the days following a heavy rainfall event, as shown in Figure 20. The results suggest that the ENE holds some of the sediment back within the upper estuary increasing the areas of the deeper deposits.

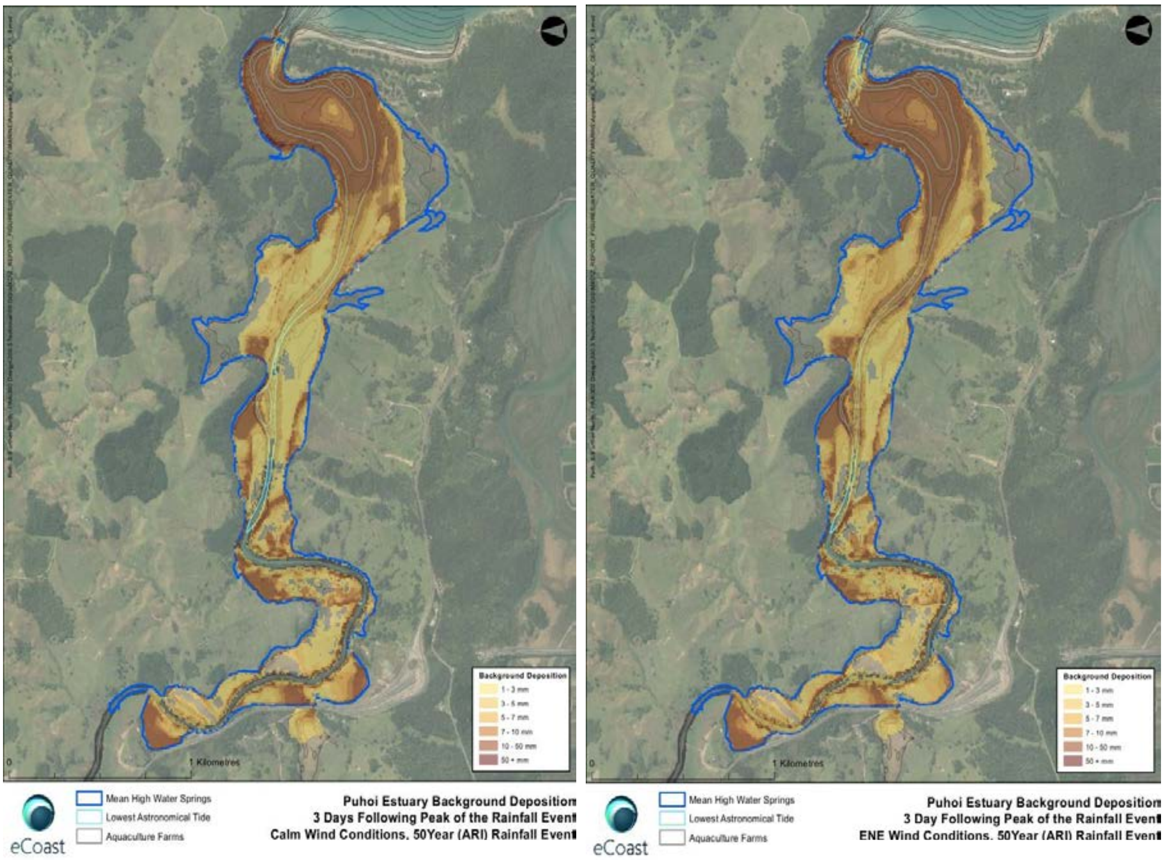

Figure 20: Background deposition in the Pūhoi Estuary in the 50 year sediment load scenario under calm and ENE wind conditions.

With the inclusion of the additional sediment associated with the peak areas of open earthworks in the short construction period the model results were compared with the results from the background sediment loads to identify the location and magnitude of the impacts.

In the 10 year (ARI) sediment event the impacts were found to be in pockets throughout the intertidal areas of the estuary. Two locations containing larger areas of impacts were found to be near the river end of the model where the sediment enters and in the intertidal areas near the mouth. The inclusion of the ENE wind was found to exacerbate these areas but not significantly change the locations, see Figure 21.

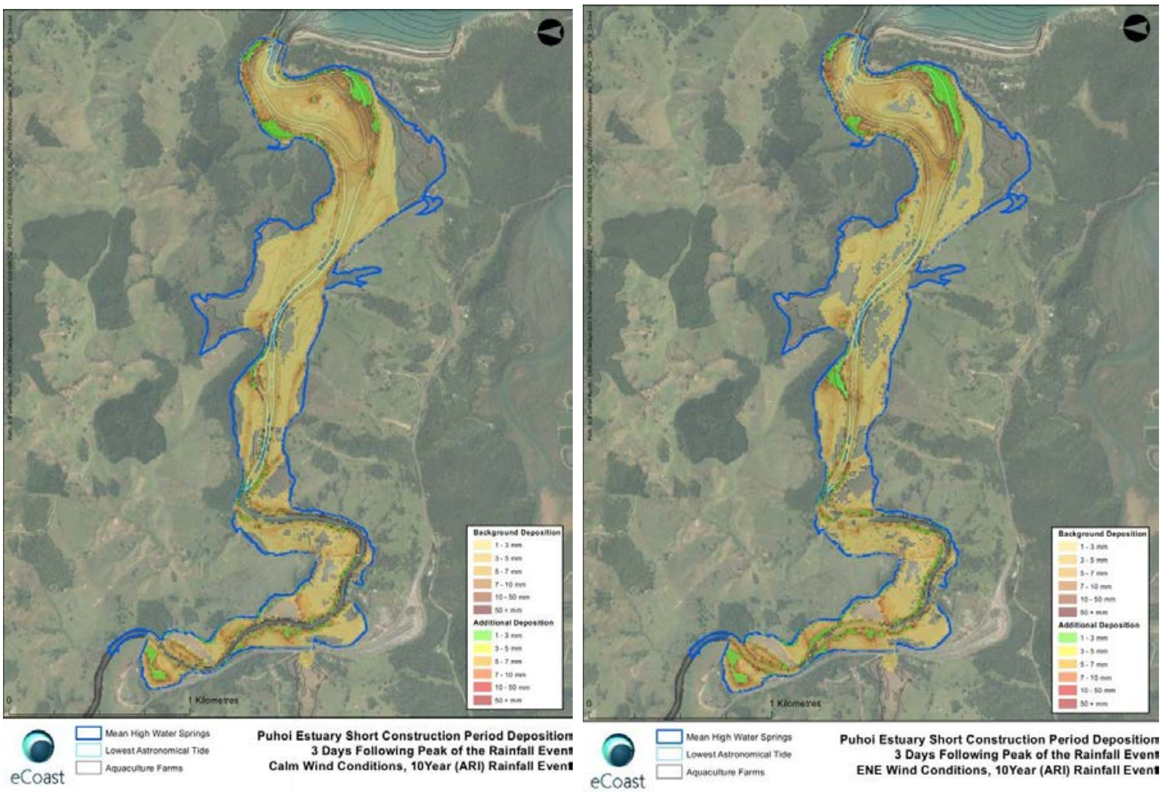

Figure 21: Predicted impacts of the additional sediment associated with the peak open earthworks in the short construction programme in the Pūhoi Estuary during a 10 year (ARI) sediment load scenario under calm and ENE wind conditions.

In the 50 year (ARI) sediment event the impacts were found to be much more widely spread, and also included much of the sub-tidal area near the mouth. Deeper additional deposits were also observed however much of the additional sediment is deposited in thin layers typically less than 3mm. The inclusion of the ENE wind had only a minor influence on the extent and location of the impacts, see Figure 22.

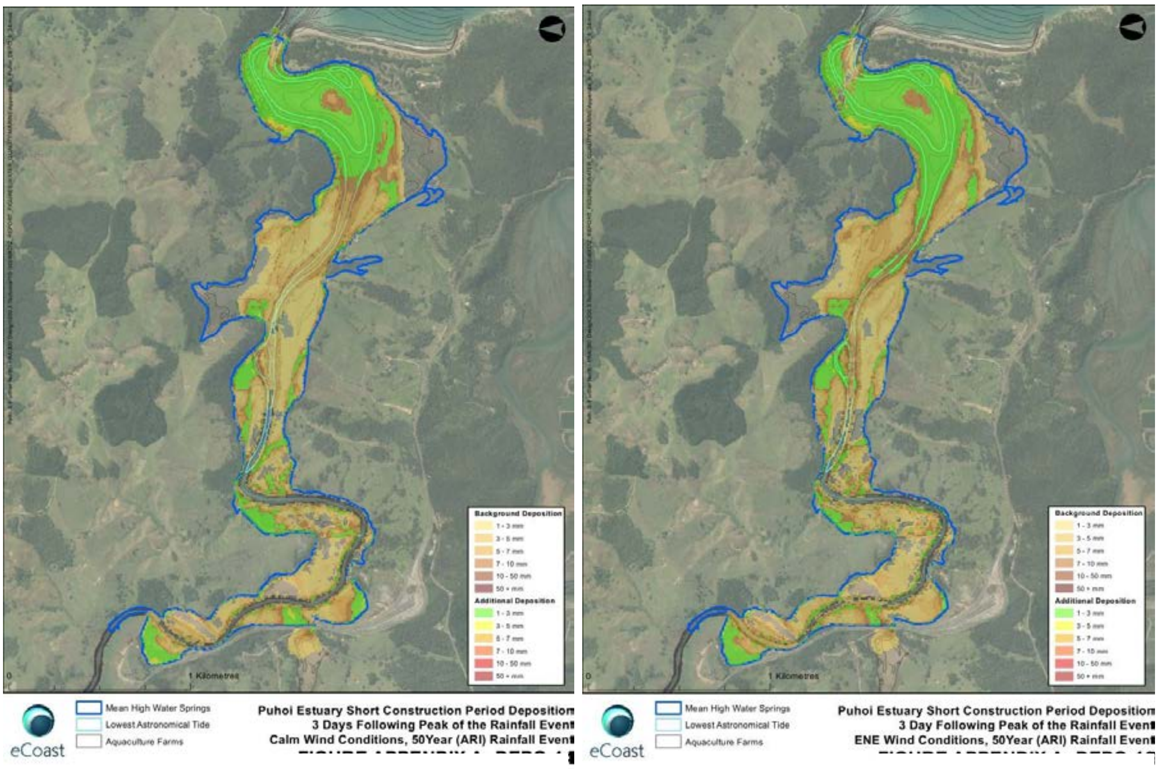

Figure 22: Predicted impacts of the additional sediment associated with the peak open earthworks in the short construction programme in the Pūhoi Estuary during a 50 year (ARI) sediment load scenario under calm and ENE wind conditions.

The model results of the longer 10 year construction programme with reduced areas of peak open earthworks showed that the impacts in the Pūhoi Estuary were much smaller. Figure 23 shows almost no impacts in the 10 year sediment load event and much smaller areas of impact in the 50 year sediment load event.

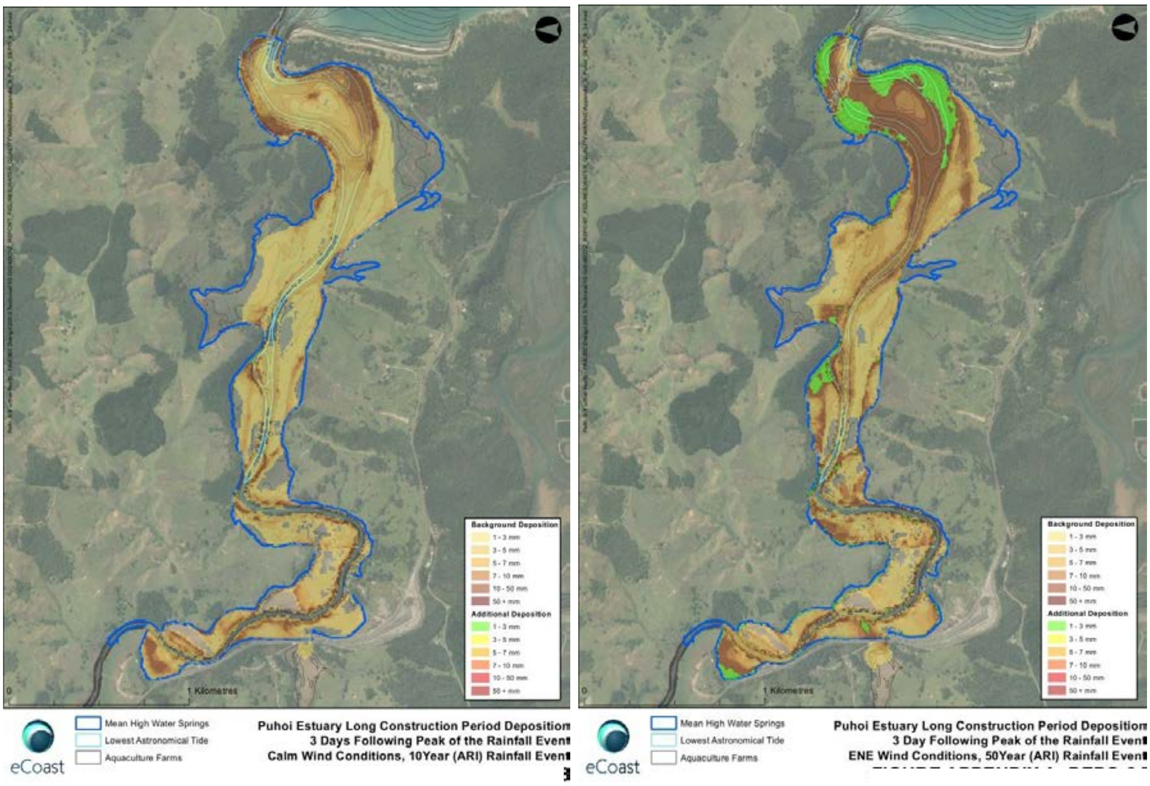

Figure 23: Predicted impacts of the additional sediment associated with the peak open earthworks in the long construction programme in the Pūhoi Estuary in the 10 and 50 year (ARI) sediment load scenarios.

5.3.1 Pūhoi threshold analysis

As with the Mahurangi results, a threshold analysis was undertaken to help quantify the impacts that the additional sediment generated by the Project could have on ecology in the Pūhoi Estuary. The areas within the estuary that are predicted to be impacted by deposition between 5-10mm and greater than 10mm have been found in the background sediment modelling scenarios. These areas were then compared to the scenarios including the additional sediment predicted to be generated by the Project to identify the change in extents. The results are recorded in Table 14 and 15.

Table 14: Areas of deposition between 5-10mm and greater than 10mm in the Pūhoi Estuary under background sediment load conditions for the scenarios modelled (ha).

Scenario	Construction Condition	Rainfall Condition (AEP)	Wind Condition	5-10mm Total	5-10mm Sub-Tidal	5-10mm Inter-tidal	10mm+ Total	10mm+ Sub-Tidal	10mm+ Inter-tidal
EP05	Background	10yr	Calm	26.9	4.7	22.2	10.3	1.3	9.0
EP06	Background	10yr	ENE (9 m/s)	28.2	6.3	21.9	13.0	2.3	10.7
EP07	Background	50yr	Calm	30.9	2.6	28.3	49.3	8.8	40.5
EP08	Background	50yr	ENE (9 m/s)	39.3	3.3	36.0	46.6	9.9	36.7

Table 15: Increase in areas experiencing deposition between 5-10mm and greater than 10mm in the Pūhoi Estuary under the two construction programmes for the scenarios modelled (ha).

Scenario	Construction Condition	Rainfall Condition (AEP)	Wind Condition	Increase in Areas (ha) above background					
				5-10mm Total	5-10mm Sub-Tidal	5-10mm Inter-tidal	10mm+ Total	10mm+ Sub-Tidal	10mm+ Inter-tidal
SP05	Short (5 Year)	10yr	Calm	4.2	0.6	3.6	1.8	0.4	1.5
SP06	Short (5 Year)	10yr	ENE (9 m/s)	3.4	0.4	3.1	2.3	0.6	1.7
SP07	Short (5 Year)	50yr	Calm	4.5	0.3	4.2	3.7	0.3	3.4
SP08	Short (5 Year)	50yr	ENE (9 m/s)	5.2	0.2	5.0	5.2	0.8	4.4
LP05	Long (10 Year)	10yr	Calm	1.9	0.2	1.7	0.7	0.1	0.6
LP06	Long (10 Year)	10yr	ENE (9 m/s)	1.4	0.2	1.3	1.0	0.3	0.8
LP07	Long (10 Year)	50yr	Calm	2.2	0.2	2.0	2.0	0.2	1.8
LP08	Long (10 Year)	50yr	ENE (9 m/s)	2.7	0.1	2.6	2.6	0.3	2.3

This threshold analysis confirms that the likely coincident wind conditions make very little difference to the area of deposition impacts. The analysis also shows the impacts in the 50 year (ARI) sediment load scenarios are more pronounced in the 10mm+ threshold band than in the 5-10mm threshold indicating the deeper deposits in parts of this estuary. The analysis also indicates that the short construction period results contain approximately double the threshold impacts of the longer construction scenario.

In comparison with background levels of deposition, the increase observed in the areas of the estuary experiencing between 5-10mm of deposition are almost 15%. However this is only a small proportion of the intertidal areas of the estuary, approximately 3%, (see Table 13). In the long, 10 year, construction scenarios there is less than a 10% increase in the area experiencing 5-10mm of deposition.

Table 16: Total areas of the Pūhoi Estuary.

Intertidal Area (ha)	158
Subtidal Area (ha)	15

6. Conclusions

The Mahurangi and Pūhoi Estuaries are important coastal environments in the Hauraki Gulf. Both are used for recreational activities including boating and fishing. Most of the main low tide channels are used to provide boating access to moorings. There are also a number of aquaculture farms within the Mahurangi Estuary.

The investigation documented in this report has been undertaken to quantify the rainfall event based impacts of additional sediment generated by the Project reaching the coastal environment. The results in this report have been used to assess the effects on coastal ecology (see the Marine Ecology Assessment Report), and on water quality, recreation, navigation, commercial and amenity values (see the Construction Water Assessments Report).

The consequences of the additional sediment entering the estuaries will also need to be considered in conjunction with the probability of this occurring. There is a 39% probability of a 10 year ARI rainfall event occurring during a short, 5 year, construction programme and a 10% probability of a 50 year ARI rainfall event occurring over this time frame. In the, 10 year, construction scenario these probabilities increase to 63% for a 10 year ARI rainfall and 18% for a 50 year ARI event.

The catchments feeding into the Pūhoi and Mahurangi Estuaries share similar land-uses and have experienced high event based sediment loads over the last century. Historical sediment rates in the upper Mahurangi Estuary have been measured in the order of 24mm/yr. Location wise the modelling results reflect these historical findings, with much of the modelled deposition predicted to also be retained in the upper Mahurangi Estuary. The impacts of coincident wind on deposition and suspended sediment patterns in the estuary were found to be minor.

The calibration and comparison with the findings in previous studies together with a sensitivity analysis have confirmed that the calibrated hydrodynamic and wave model and the coupled sediment transport model are appropriate tools to assess the event based sediment impacts of the additional sediment entering the estuaries as a result of The Project.

In the days following heavy rain the impacts of the additional sediment generated by the peak areas of open earthworks were found to be largely contained to the upper Mahurangi Estuary. In the 10 year ARI event scenario the additional sediment was observed to largely deposit in the intertidal areas close to the mouth of the Mahurangi River. In the 50 year ARI sediment event the impacts were found to be more widely spread but still largely contained within the upper estuary. The increase in deposition is typically less than 3mm.

The threshold analysis indicates that in the short, 5 year, construction scenario there will be an increase above background areas of almost 25% in the 5-10mm deposition range, however this is only a very small proportion of the intertidal areas of the estuary, less than 2%. In the long, 10 year, construction scenarios the impacts were found to be greatly reduced.

The background modelling results of the much smaller Pūhoi Estuary reveal that there will be high concentrations of sediment all the way to the mouth, however, this will quickly settle or escape the estuary to the open ocean. The modelling suggests that within 3 days almost 30%-40% of the sediment released into the estuary in an extreme rainfall event will pass out to the open ocean. The rest of the sediment is deposited within the estuary.

With the inclusion of the predicted additional sediment generated by the Project the increase in deposition depths was found to be in pockets throughout the intertidal areas of the estuary typically in locations already experiencing deposition. In the 50 year ARI sediment event in the short, 5 year, construction scenario the impacts were found to be widely spread, and also included much of the sub-tidal area near the mouth. While there are isolated areas of deeper additional deposits much of the additional sediment is deposited in thin layers typically less than 3mm deep. The model results of the longer 10 year construction programme with reduced areas of peak open earthworks showed almost no impacts in the 10 year sediment load event and much smaller areas of impact in the 50 year sediment load event.

The threshold analysis on the Pūhoi model results show that the short, 5 year, construction period results contain approximately double the threshold impacts of the longer, 10 year construction scenario. In comparison with background levels of deposition the increases observed in the areas of the estuary experiencing between 5-10mm of deposition are almost 15% in the short construction scenario. This is however only 3% of the total intertidal area of the estuary.

7. References

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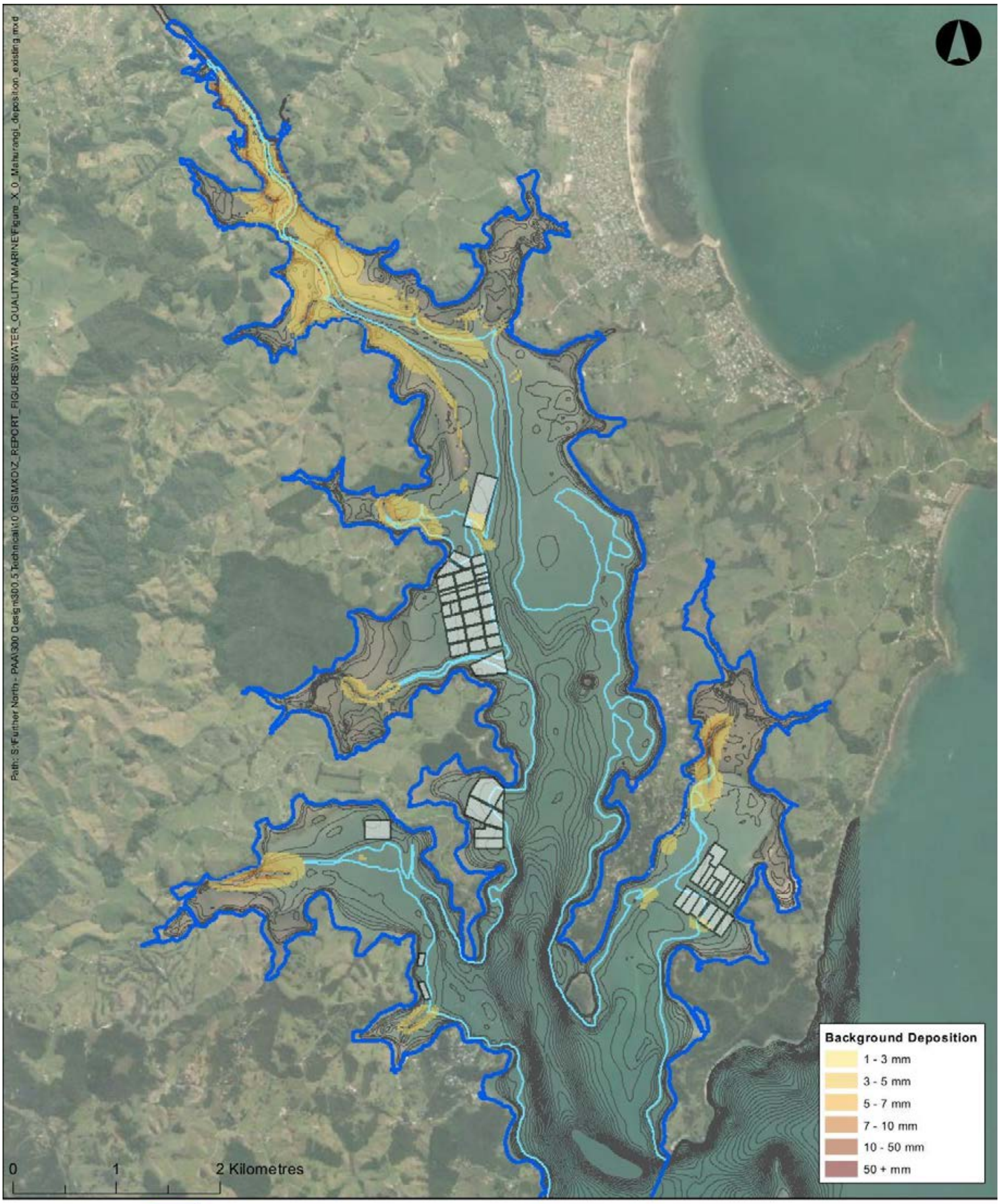
Appendix A Mahurangi deposition plans

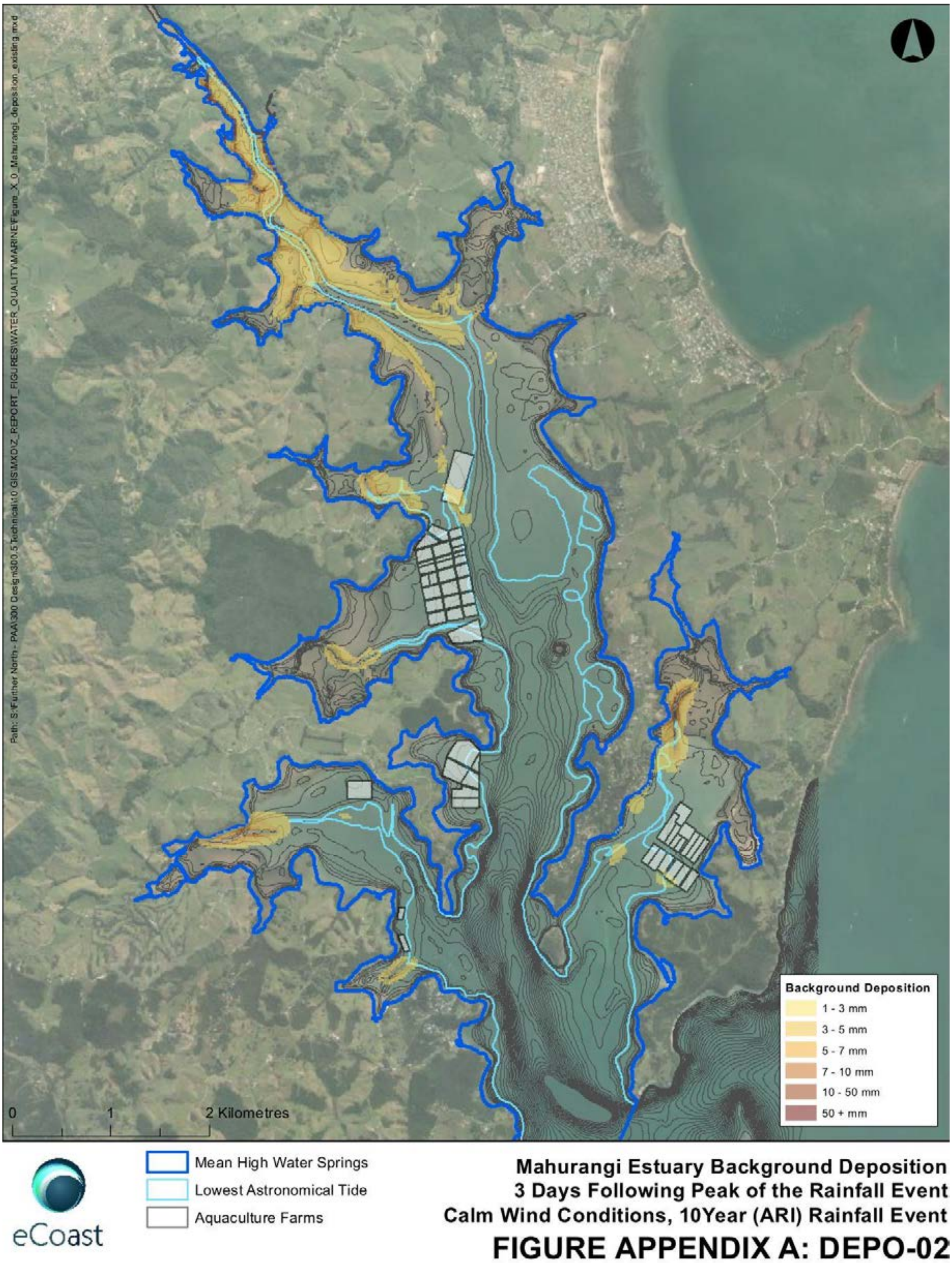


eCoast

Mean High Water Springs
Lowest Astronomical Tide
Aquaculture Farms

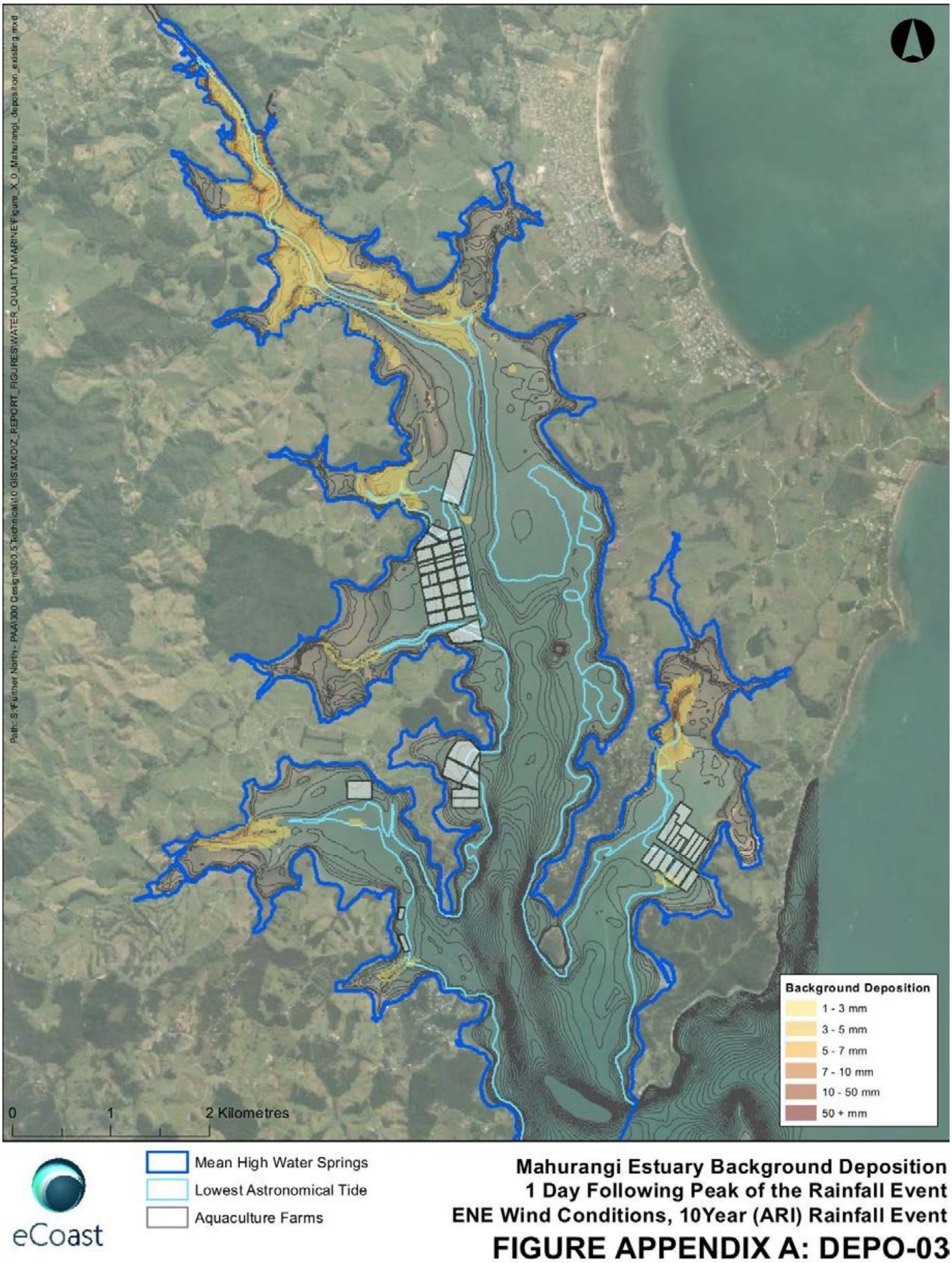
Mahurangi Estuary Background Deposition
1 Day Following Peak of the Rainfall Event
Calm Wind Conditions, 10Year (ARI) Rainfall Event

FIGURE APPENDIX A: DEPO-01



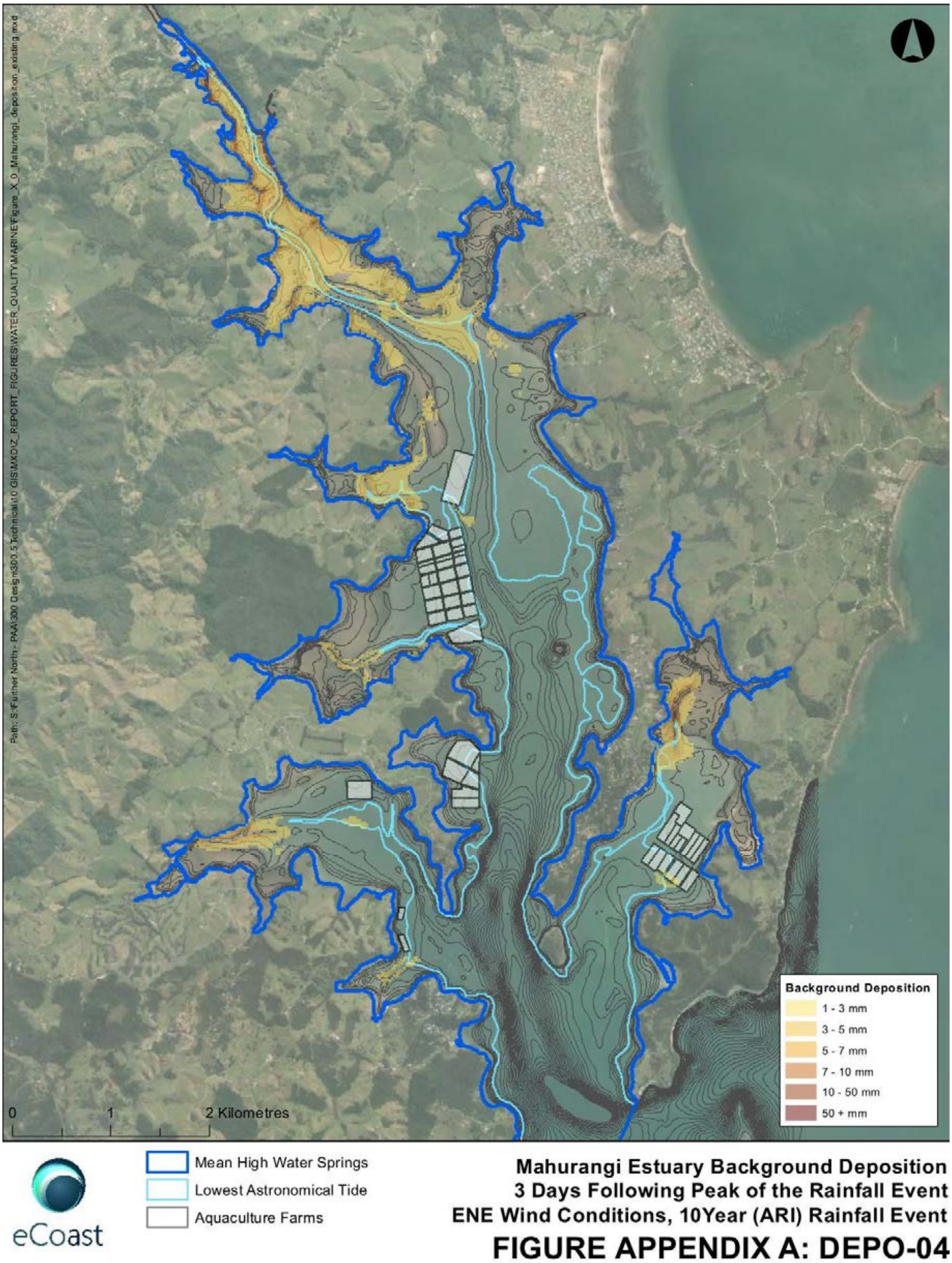
Mahurangi Estuary Background Deposition
3 Days Following Peak of the Rainfall Event
Calm Wind Conditions, 10Year (ARI) Rainfall Event

FIGURE APPENDIX A: DEPO-02



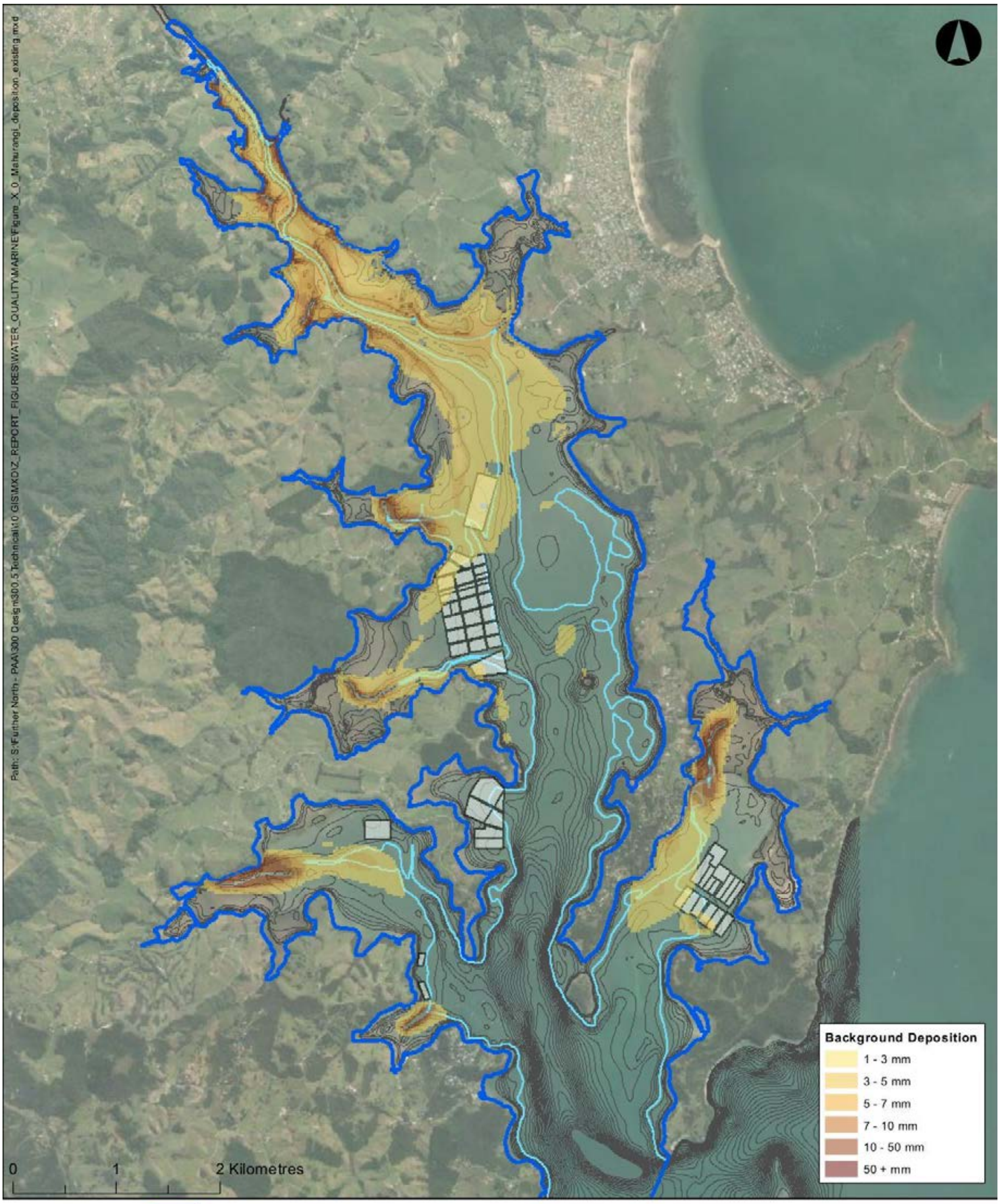
Mahurangi Estuary Background Deposition
1 Day Following Peak of the Rainfall Event
ENE Wind Conditions, 10Year (ARI) Rainfall Event

FIGURE APPENDIX A: DEPO-03



Mahurangi Estuary Background Deposition
3 Days Following Peak of the Rainfall Event
ENE Wind Conditions, 10Year (ARI) Rainfall Event

FIGURE APPENDIX A: DEPO-04

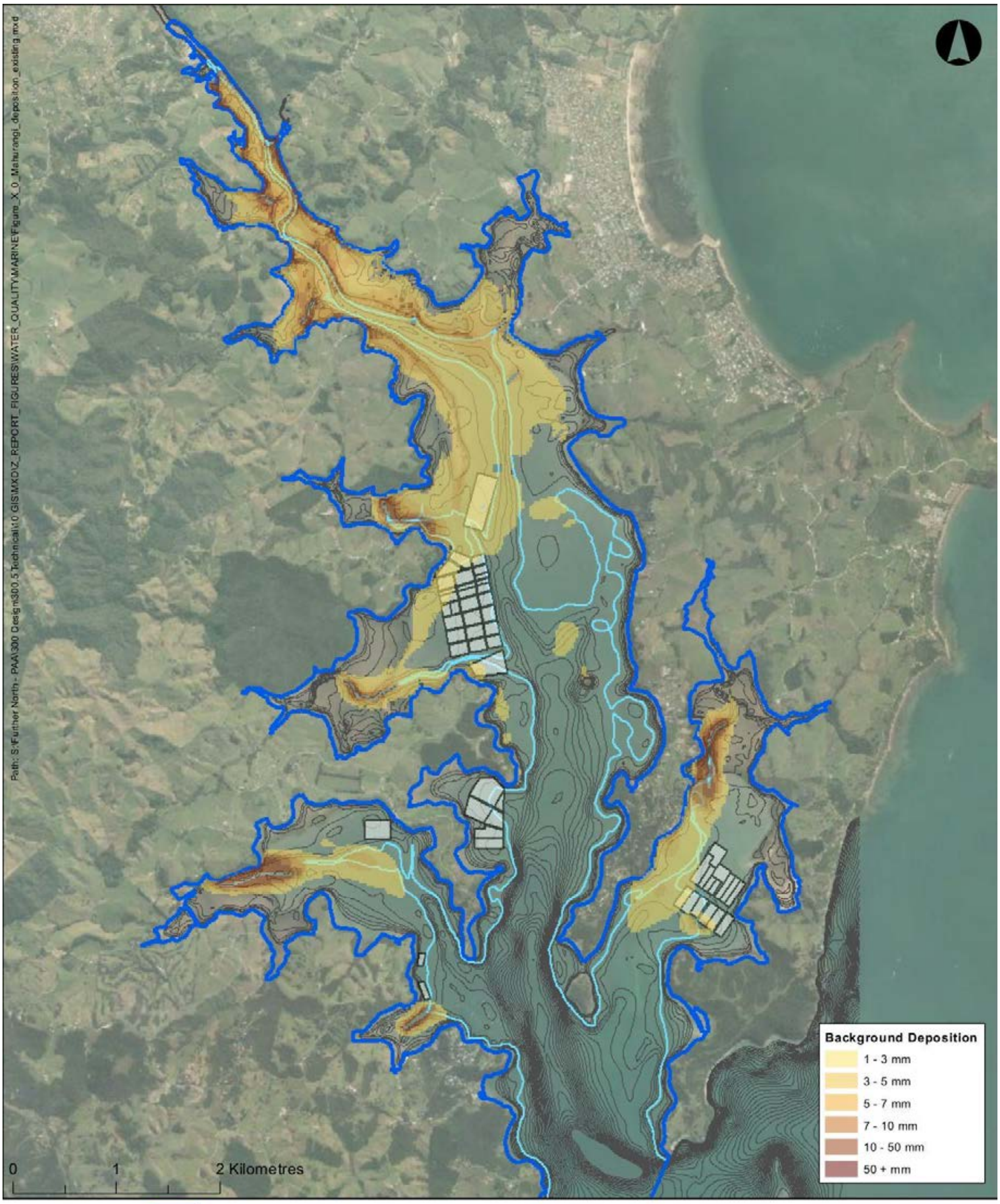


eCoast

Mean High Water Springs
Lowest Astronomical Tide
Aquaculture Farms

Mahurangi Estuary Background Deposition
1 Day Following Peak of the Rainfall Event
Calm Wind Conditions, 50Year (ARI) Rainfall Event

FIGURE APPENDIX A: DEPO-05

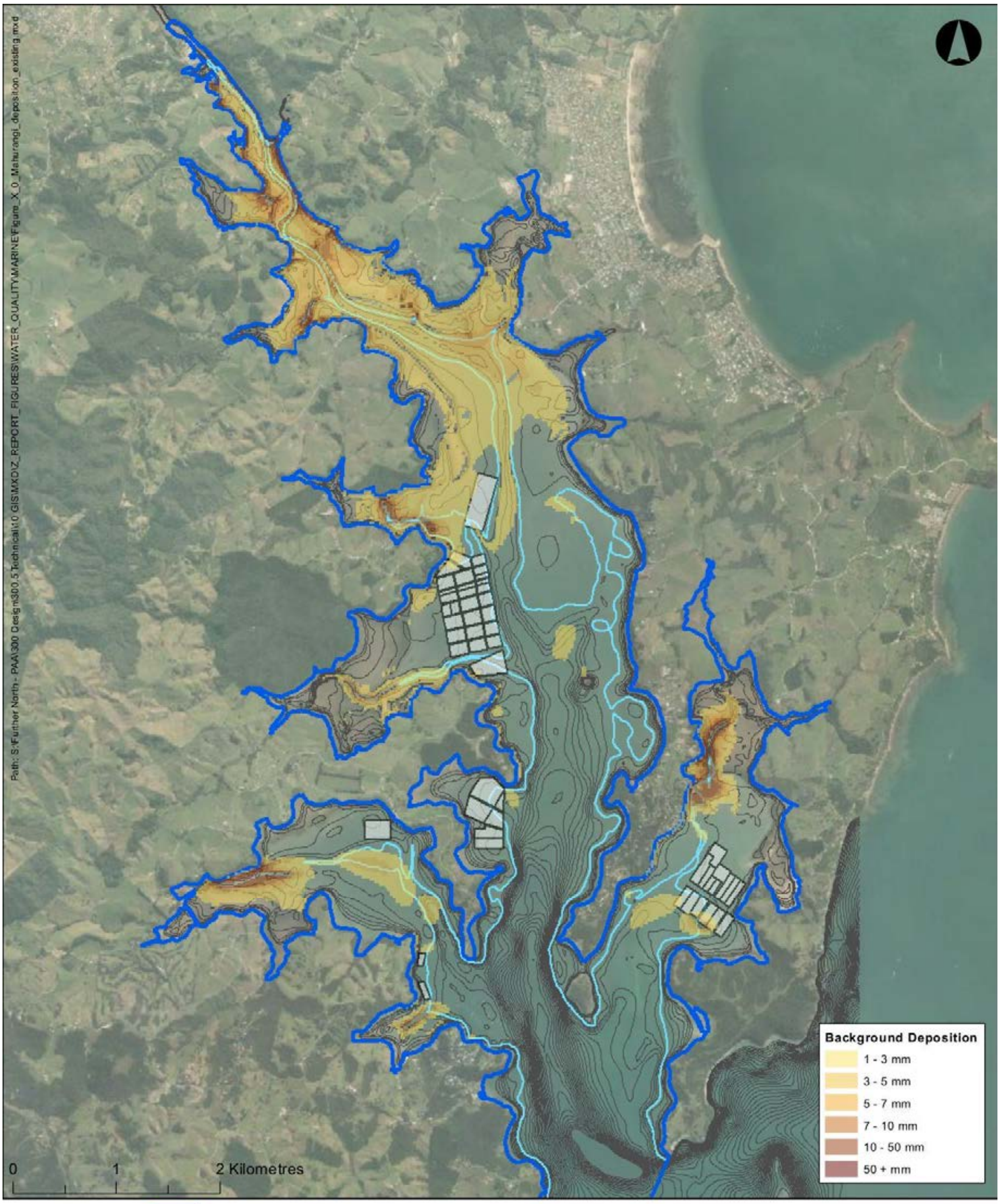


eCoast

Mean High Water Springs
Lowest Astronomical Tide
Aquaculture Farms

Mahurangi Estuary Background Deposition
3 Days Following Peak of the Rainfall Event
Calm Wind Conditions, 50Year (ARI) Rainfall Event

FIGURE APPENDIX A: DEPO-06

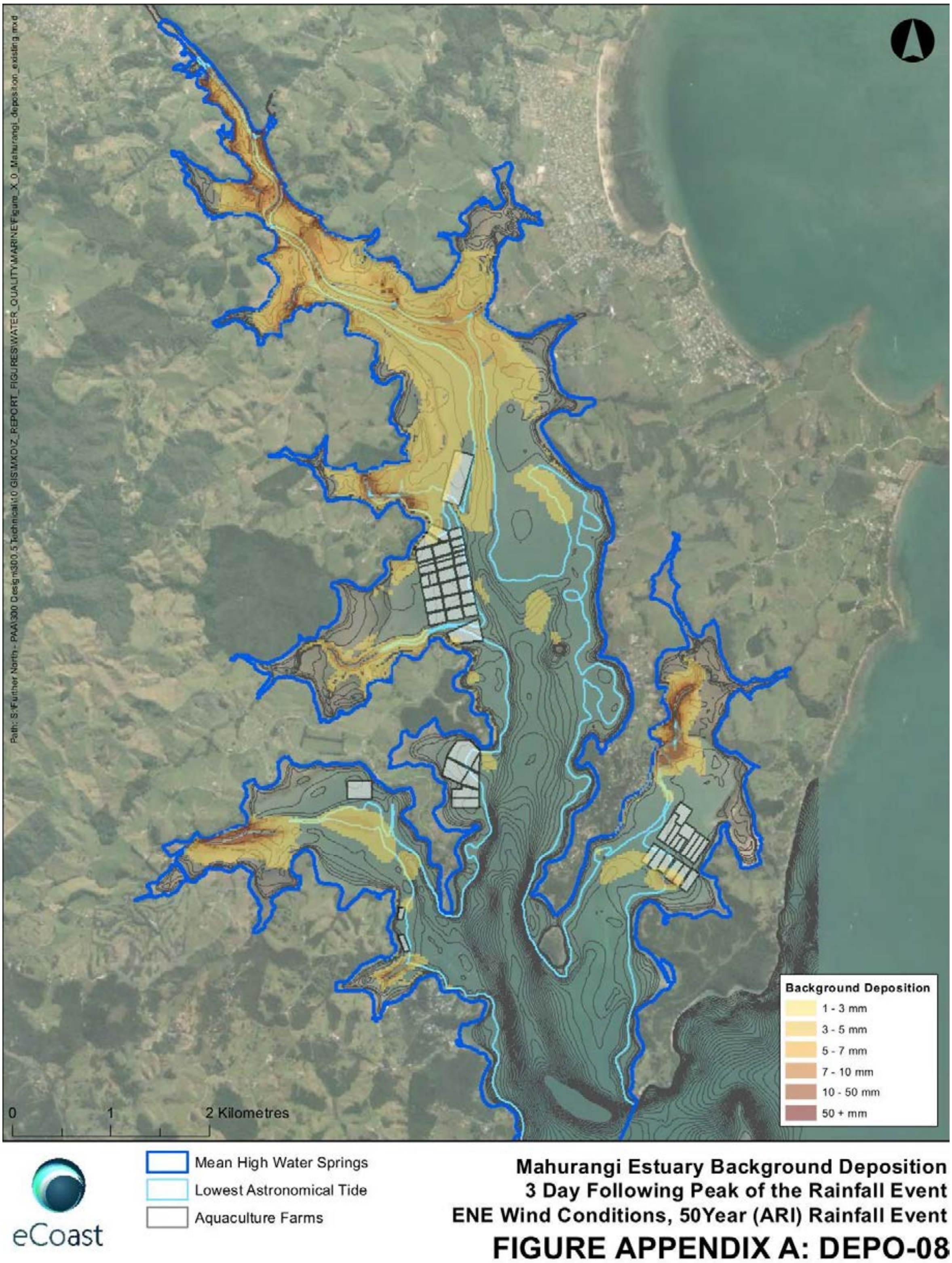


Mean High Water Springs
Lowest Astronomical Tide
Aquaculture Farms

eCoast

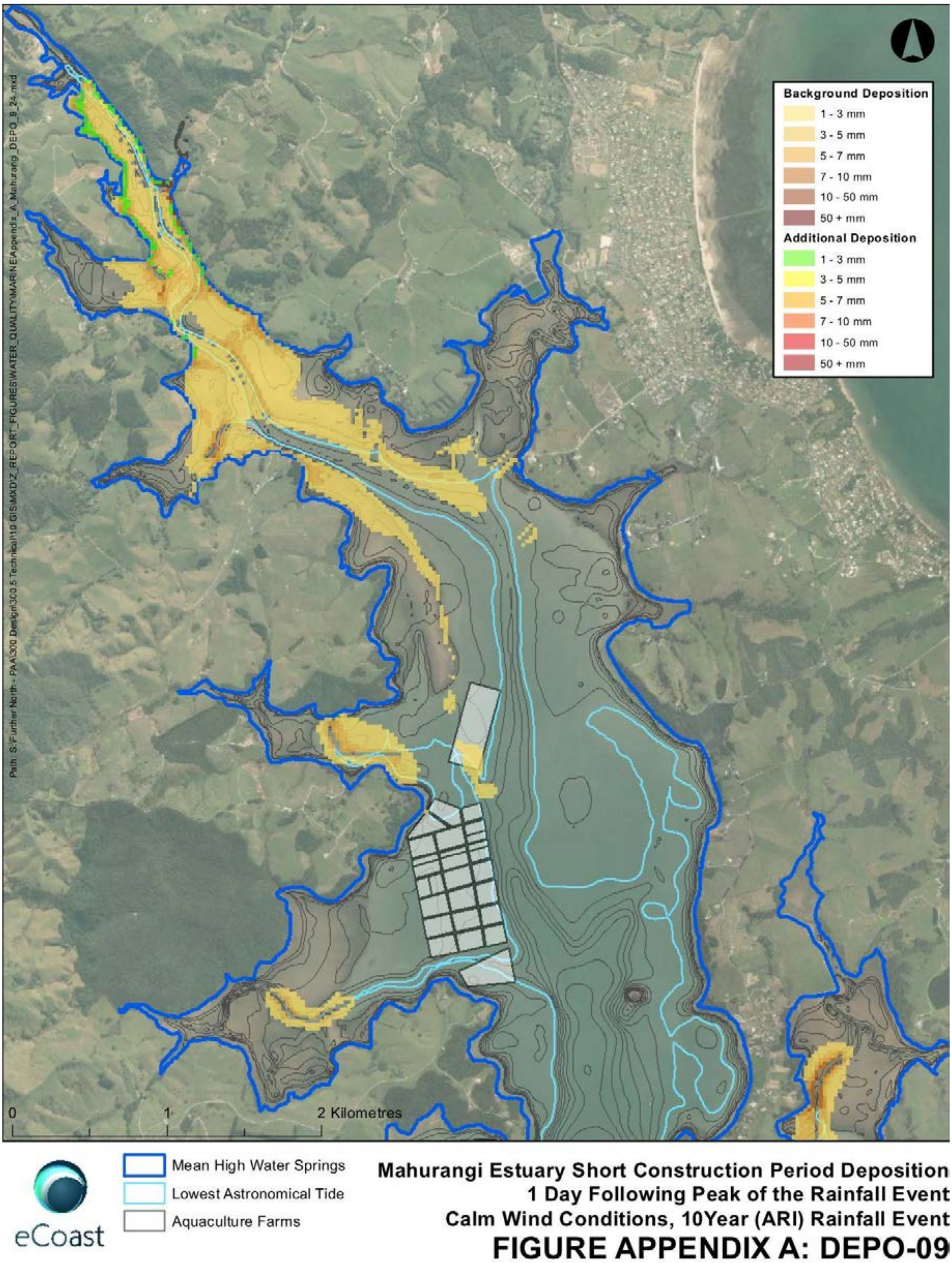
Mahurangi Estuary Background Deposition
1 Day Following Peak of the Rainfall Event
ENE Wind Conditions, 50Year (ARI) Rainfall Event

FIGURE APPENDIX A: DEPO-07



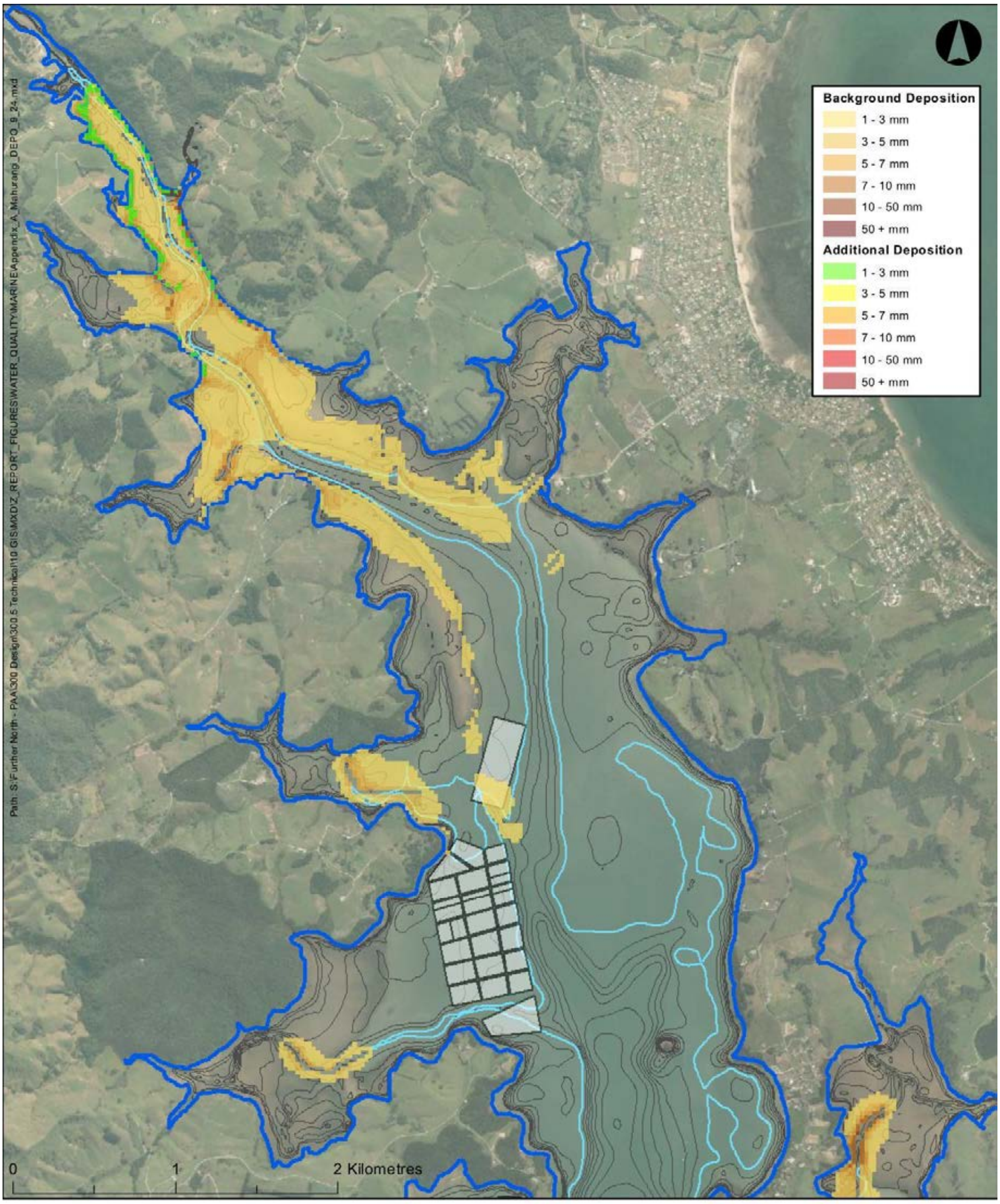
Mahurangi Estuary Background Deposition
3 Day Following Peak of the Rainfall Event
ENE Wind Conditions, 50Year (ARI) Rainfall Event

FIGURE APPENDIX A: DEPO-08



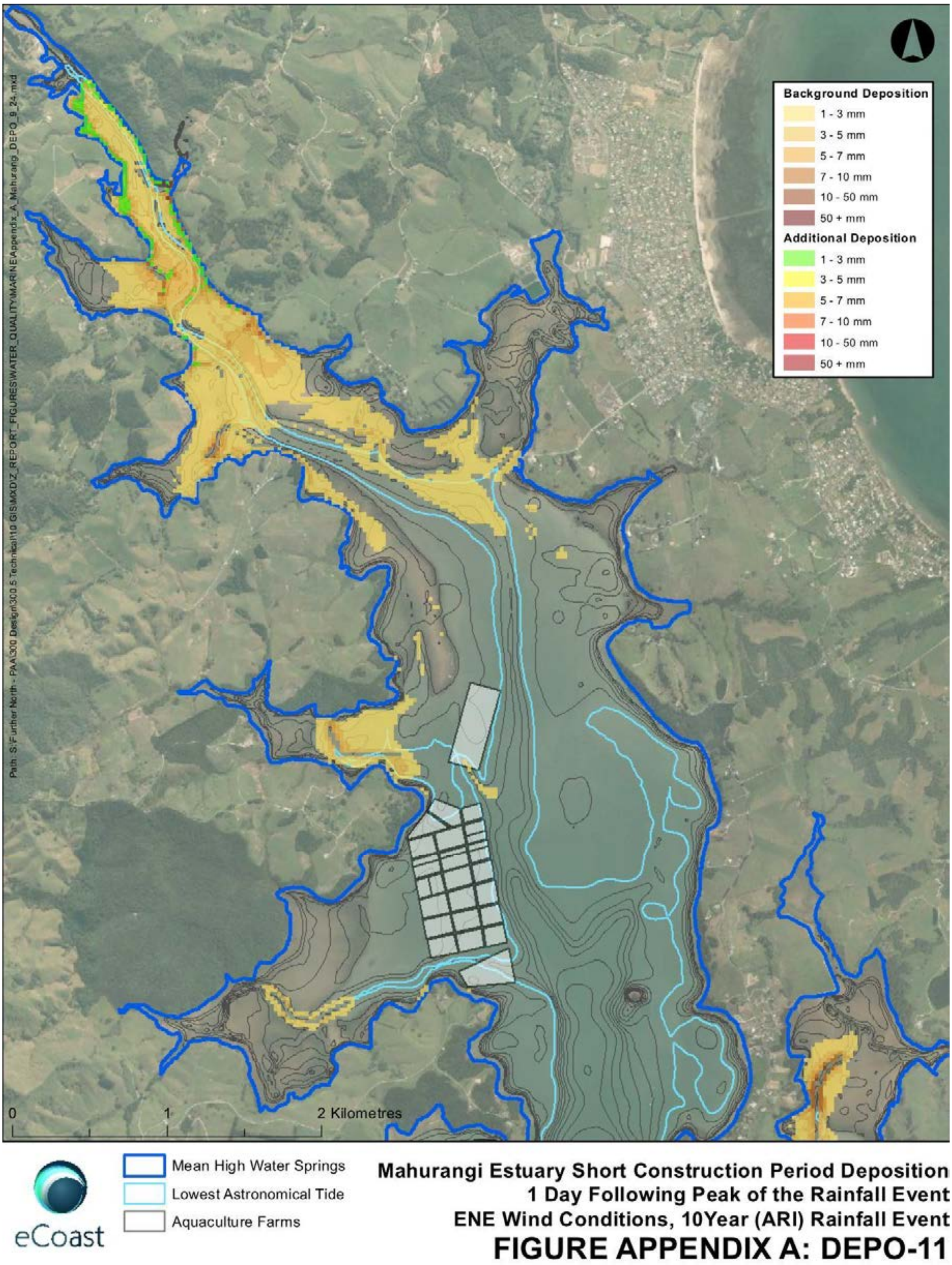
Mahurangi Estuary Short Construction Period Deposition
1 Day Following Peak of the Rainfall Event
Calm Wind Conditions, 10Year (ARI) Rainfall Event

FIGURE APPENDIX A: DEPO-09



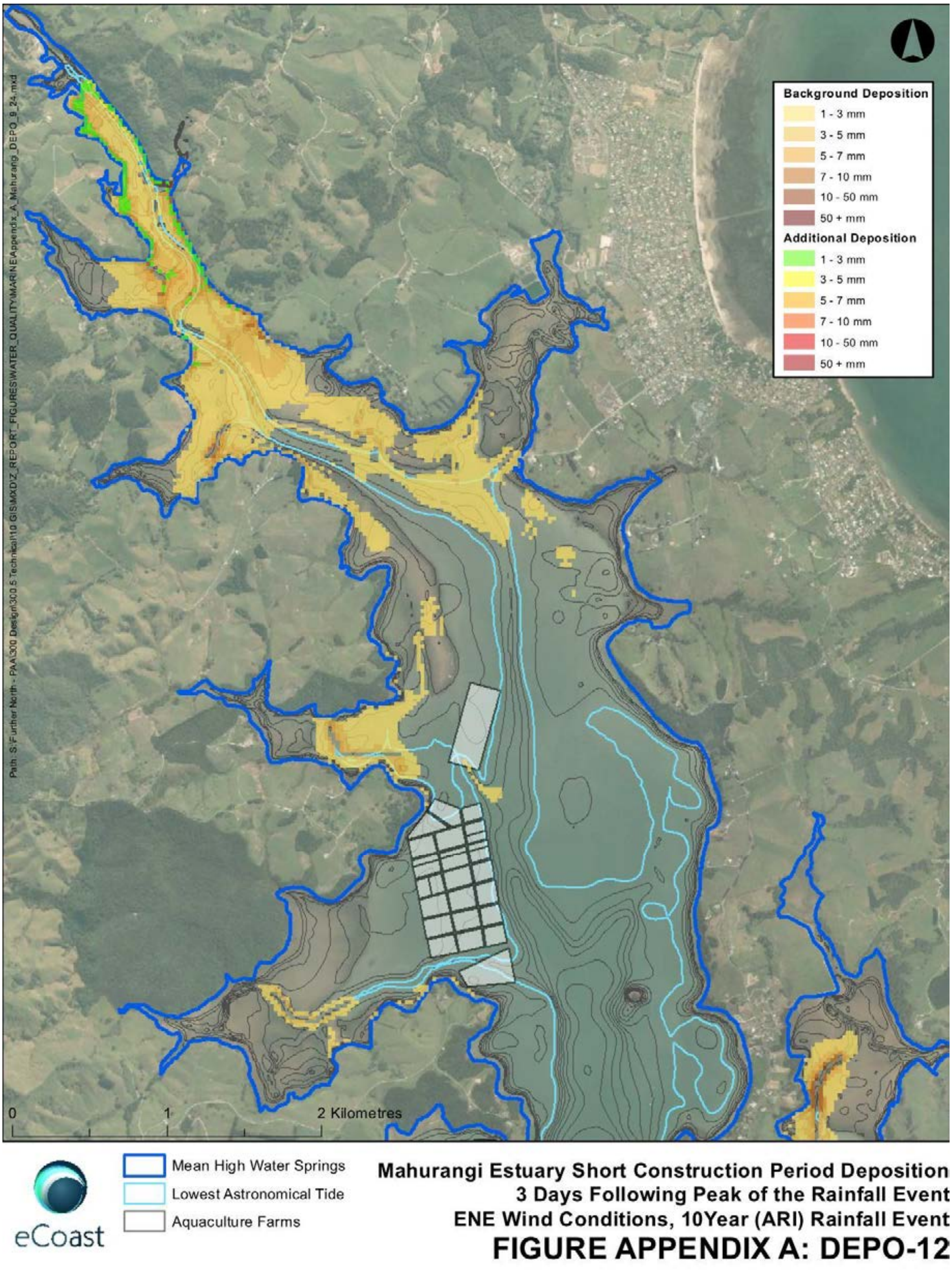
Mahurangi Estuary Short Construction Period Deposition
3 Days Following Peak of the Rainfall Event
Calm Wind Conditions, 10Year (ARI) Rainfall Event

FIGURE APPENDIX A: DEPO-10



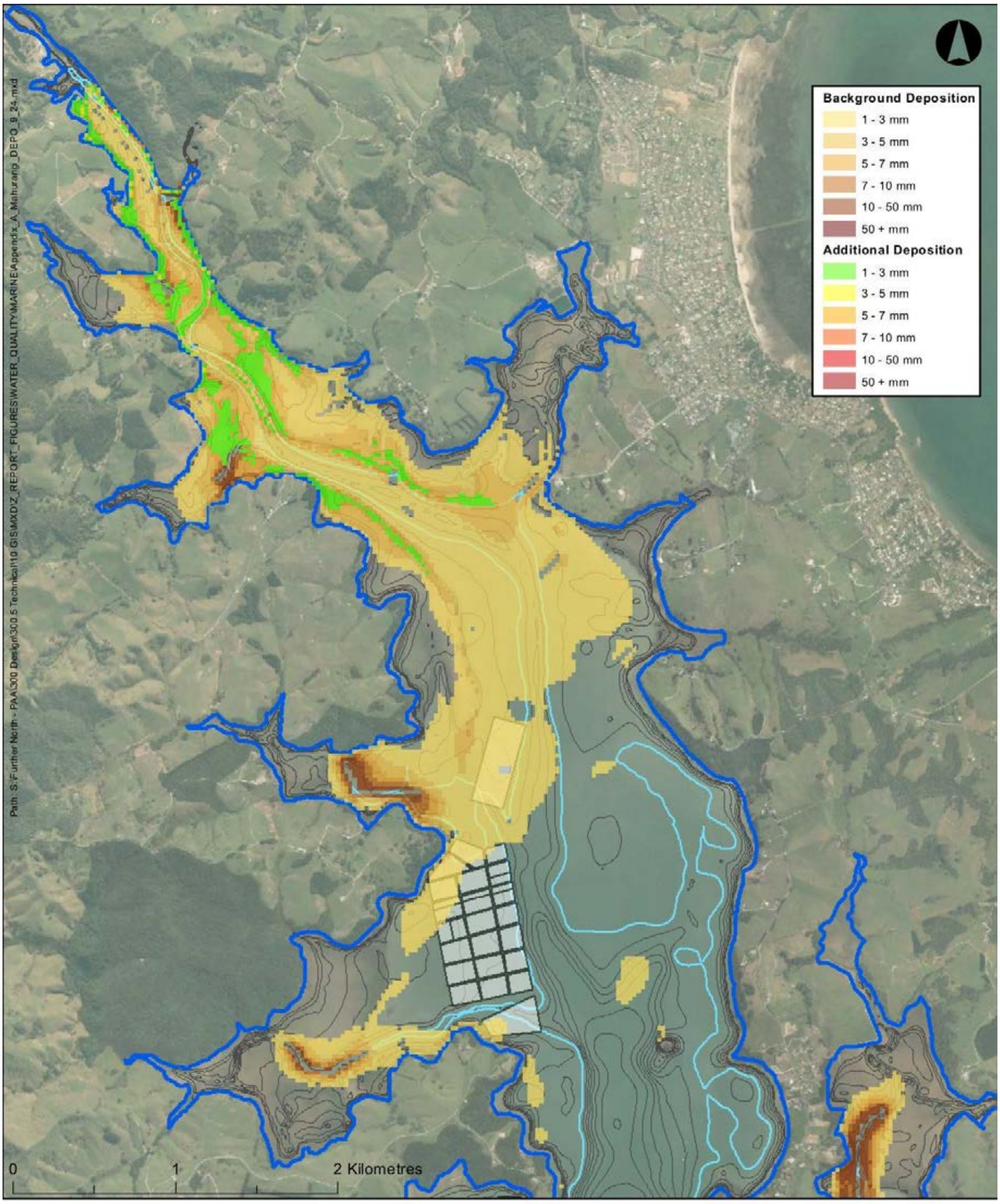
Mahurangi Estuary Short Construction Period Deposition
1 Day Following Peak of the Rainfall Event
ENE Wind Conditions, 10Year (ARI) Rainfall Event

FIGURE APPENDIX A: DEPO-11



Mahurangi Estuary Short Construction Period Deposition
3 Days Following Peak of the Rainfall Event
ENE Wind Conditions, 10Year (ARI) Rainfall Event

FIGURE APPENDIX A: DEPO-12

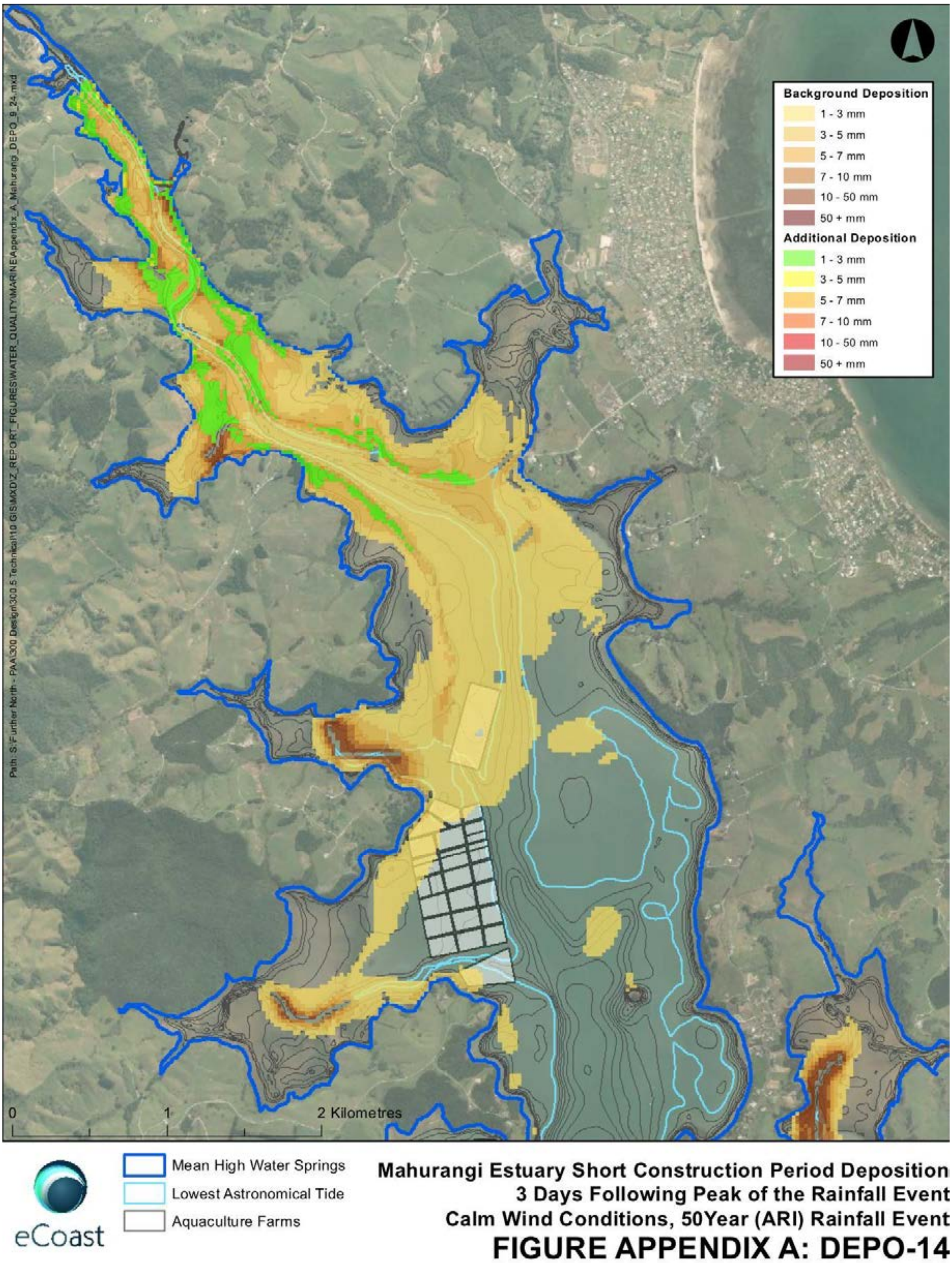


Mean High Water Springs
Lowest Astronomical Tide
Aquaculture Farms

eCoast

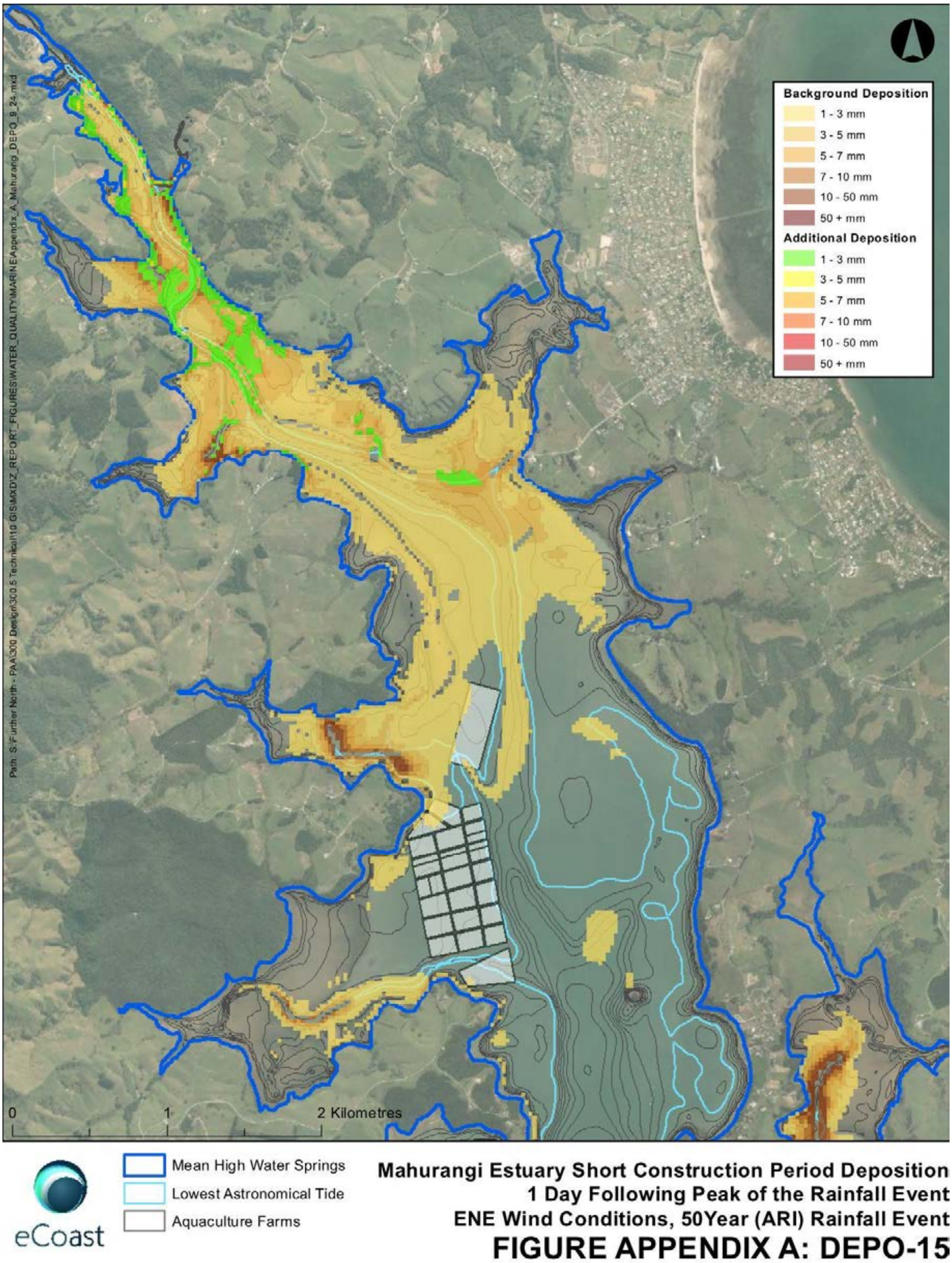
Mahurangi Estuary Short Construction Period Deposition
1 Day Following Peak of the Rainfall Event
Calm Wind Conditions, 50Year (ARI) Rainfall Event

FIGURE APPENDIX A: DEPO-13



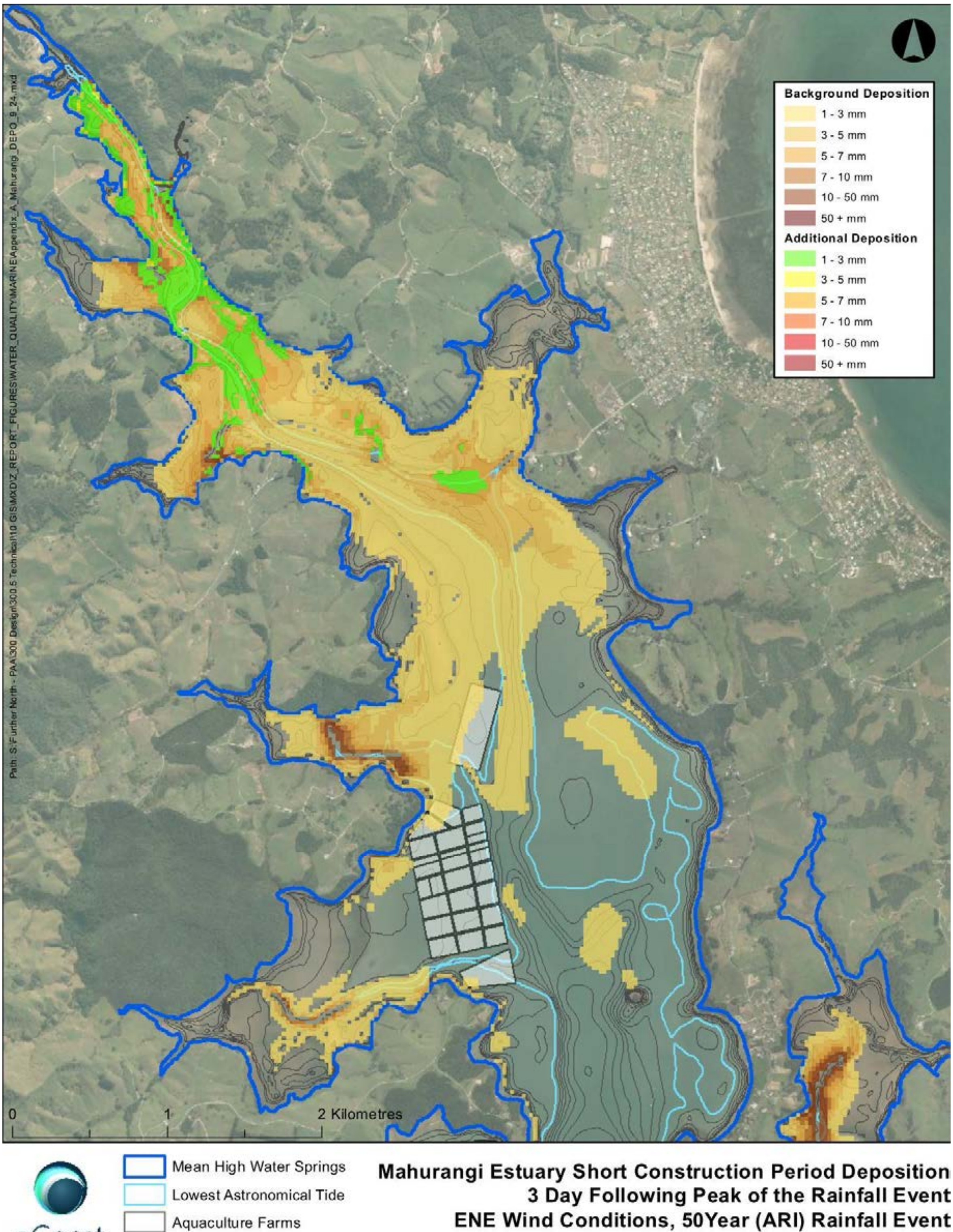
Mahurangi Estuary Short Construction Period Deposition
3 Days Following Peak of the Rainfall Event
Calm Wind Conditions, 50Year (ARI) Rainfall Event

FIGURE APPENDIX A: DEPO-14



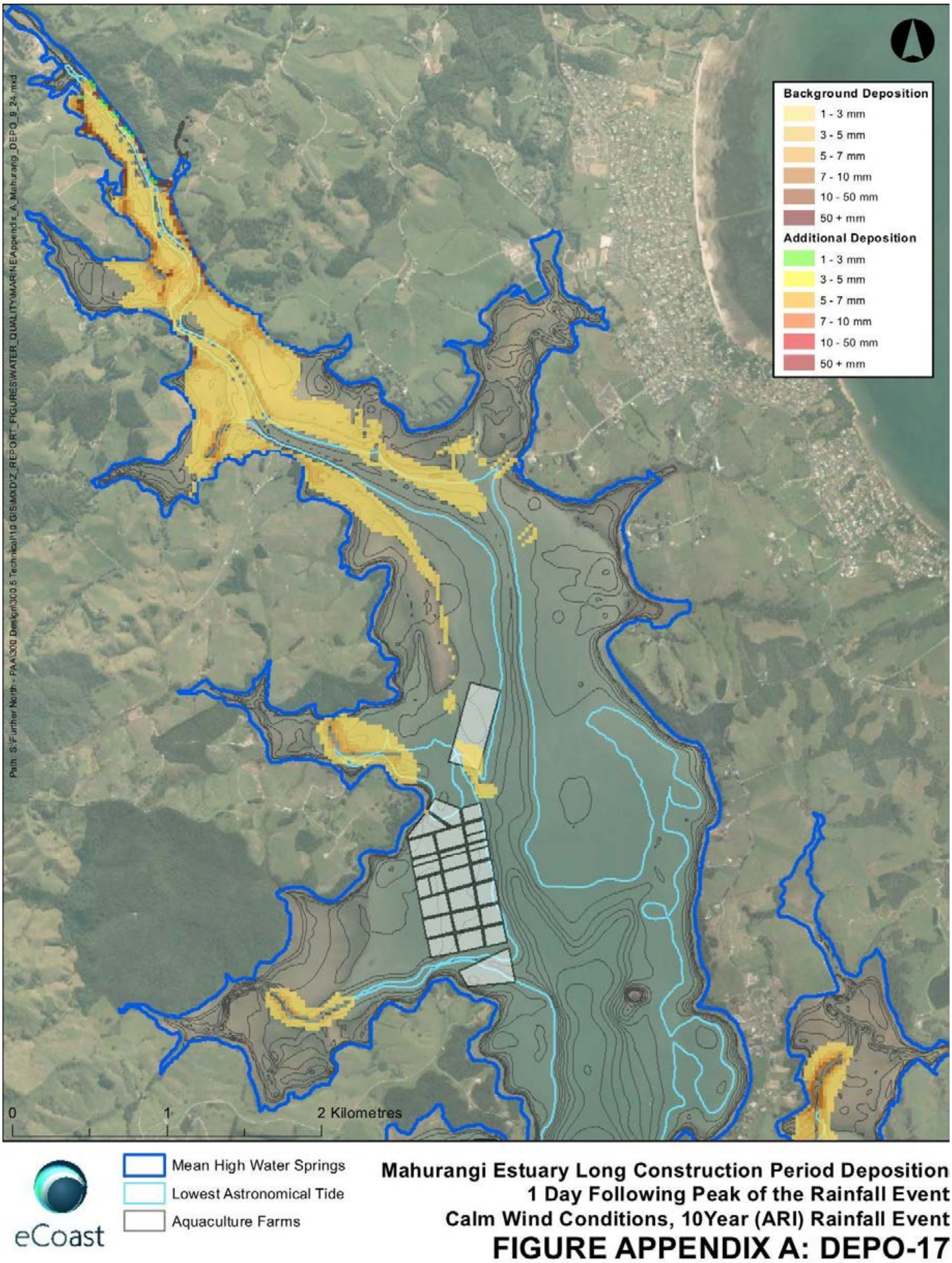
Mahurangi Estuary Short Construction Period Deposition
1 Day Following Peak of the Rainfall Event
ENE Wind Conditions, 50Year (ARI) Rainfall Event

FIGURE APPENDIX A: DEPO-15



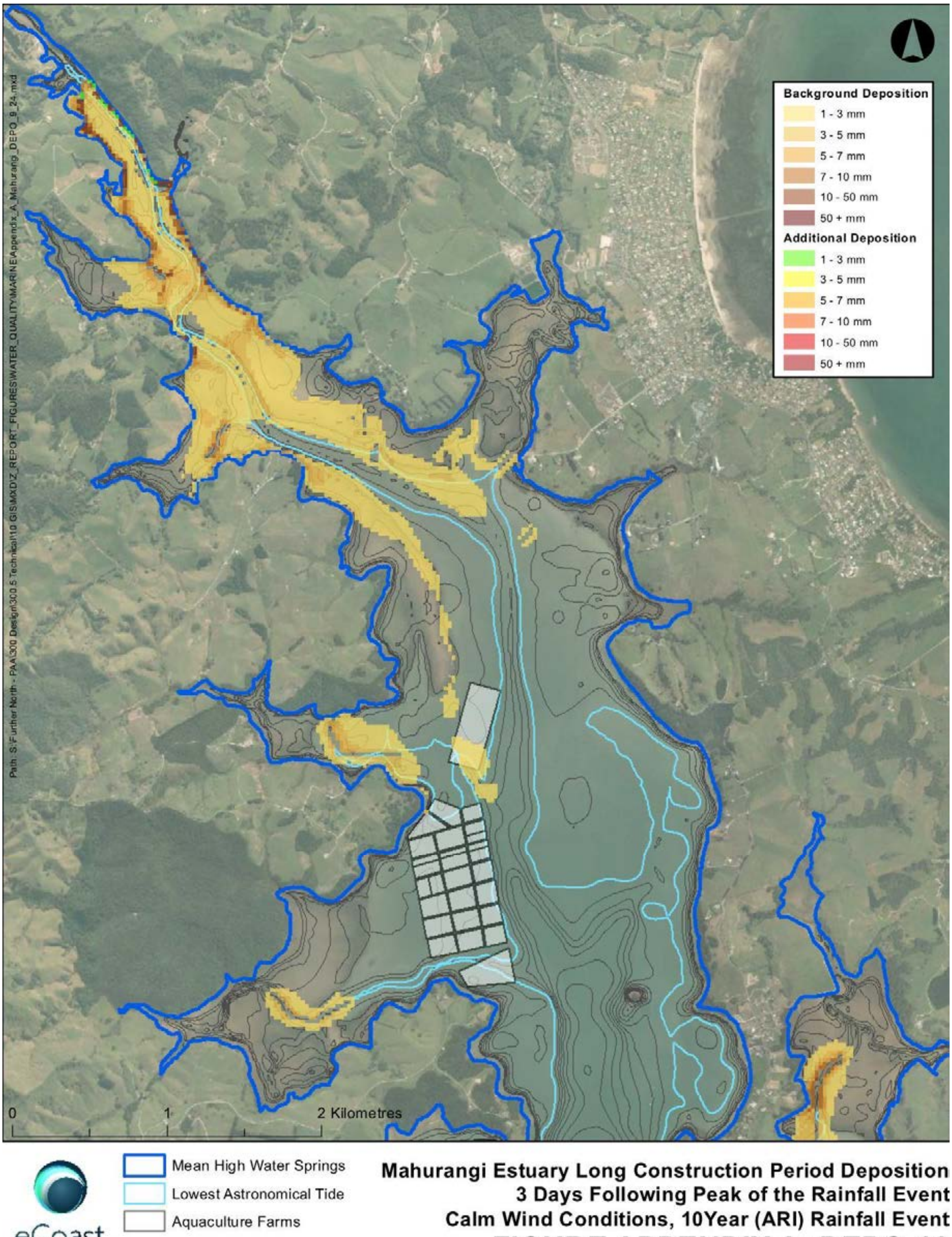
Mahurangi Estuary Short Construction Period Deposition
3 Day Following Peak of the Rainfall Event
ENE Wind Conditions, 50Year (ARI) Rainfall Event

FIGURE APPENDIX A: DEPO-16



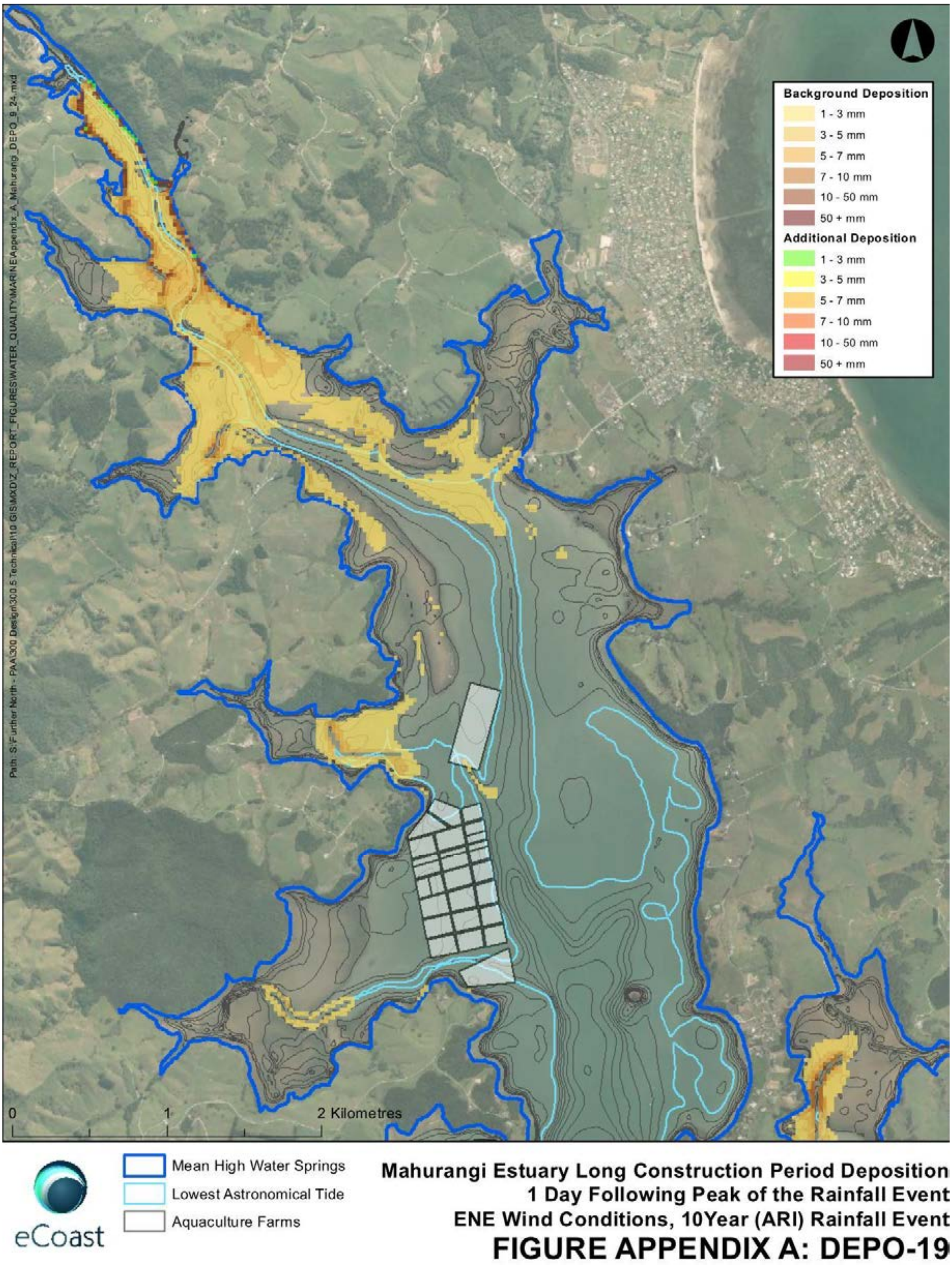
Mahurangi Estuary Long Construction Period Deposition
1 Day Following Peak of the Rainfall Event
Calm Wind Conditions, 10Year (ARI) Rainfall Event

FIGURE APPENDIX A: DEPO-17



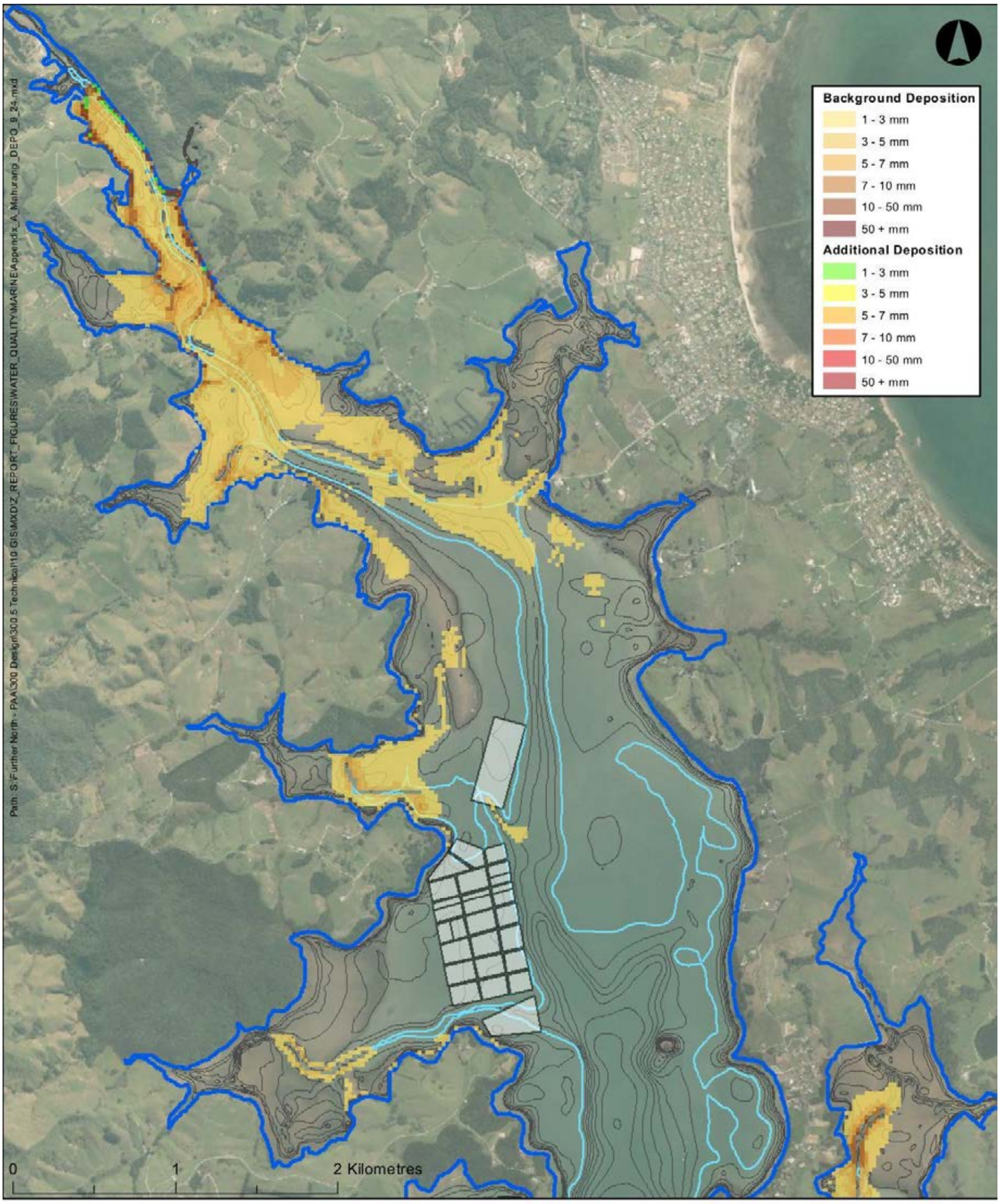
Mahurangi Estuary Long Construction Period Deposition
3 Days Following Peak of the Rainfall Event
Calm Wind Conditions, 10Year (ARI) Rainfall Event

FIGURE APPENDIX A: DEPO-18



Mahurangi Estuary Long Construction Period Deposition
1 Day Following Peak of the Rainfall Event
ENE Wind Conditions, 10Year (ARI) Rainfall Event

FIGURE APPENDIX A: DEPO-19

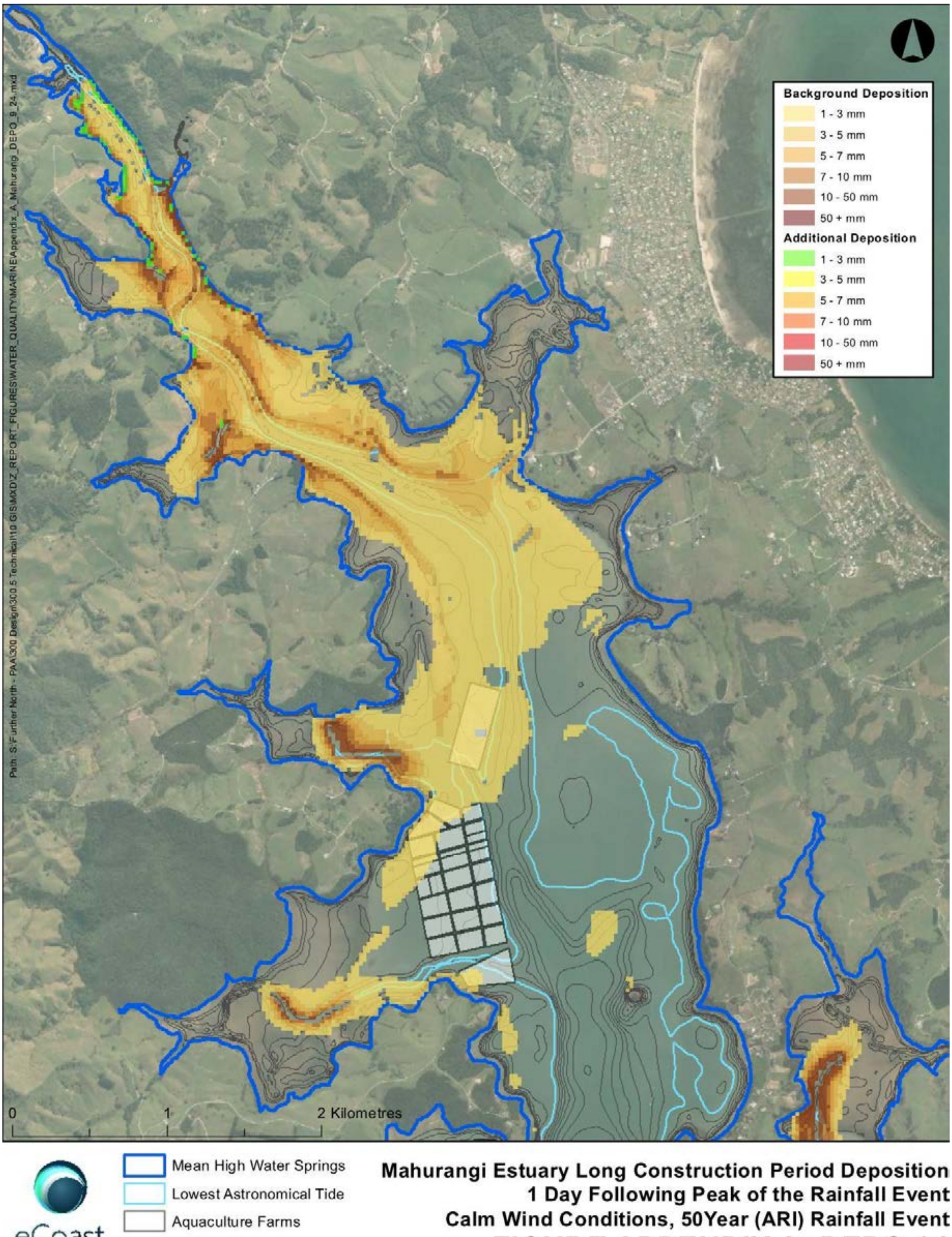


Mean High Water Springs
Lowest Astronomical Tide
Aquaculture Farms

eCoast

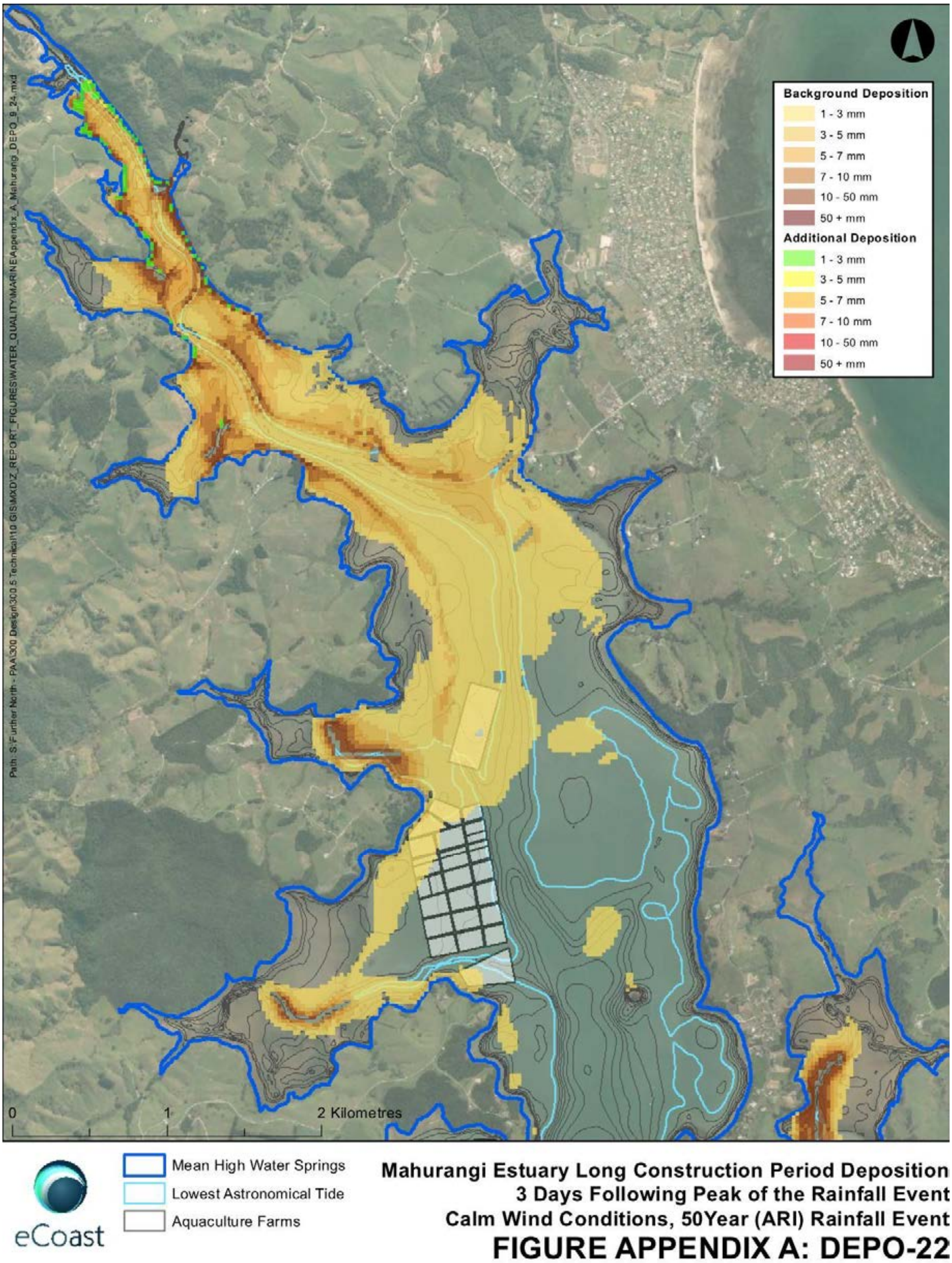
Mahurangi Estuary Long Construction Period Deposition
3 Days Following Peak of the Rainfall Event
ENE Wind Conditions, 10Year (ARI) Rainfall Event

FIGURE APPENDIX A: DEPO-20



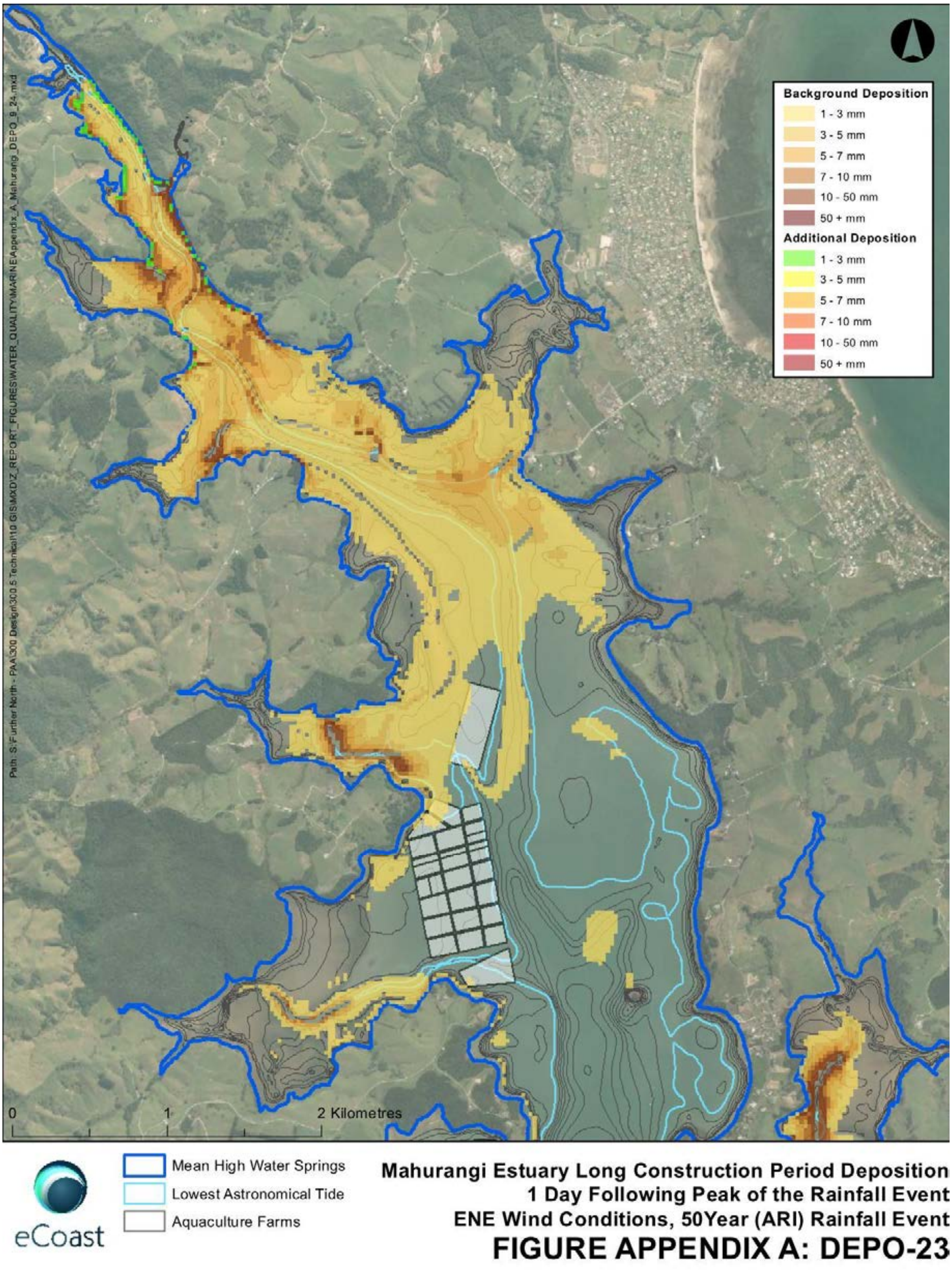
Mahurangi Estuary Long Construction Period Deposition
1 Day Following Peak of the Rainfall Event
Calm Wind Conditions, 50Year (ARI) Rainfall Event

FIGURE APPENDIX A: DEPO-21



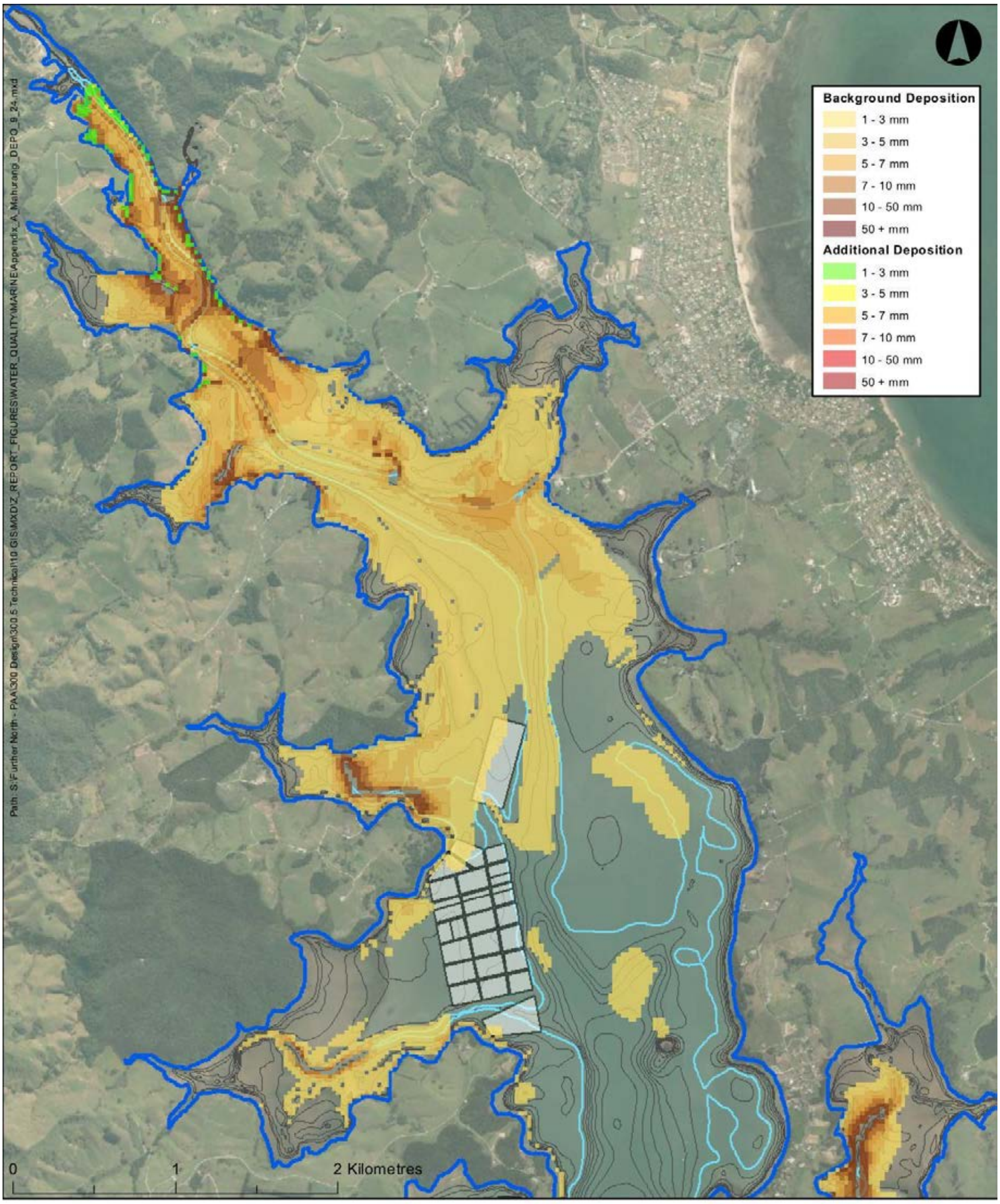
Mahurangi Estuary Long Construction Period Deposition
3 Days Following Peak of the Rainfall Event
Calm Wind Conditions, 50Year (ARI) Rainfall Event

FIGURE APPENDIX A: DEPO-22



Mahurangi Estuary Long Construction Period Deposition
1 Day Following Peak of the Rainfall Event
ENE Wind Conditions, 50Year (ARI) Rainfall Event

FIGURE APPENDIX A: DEPO-23

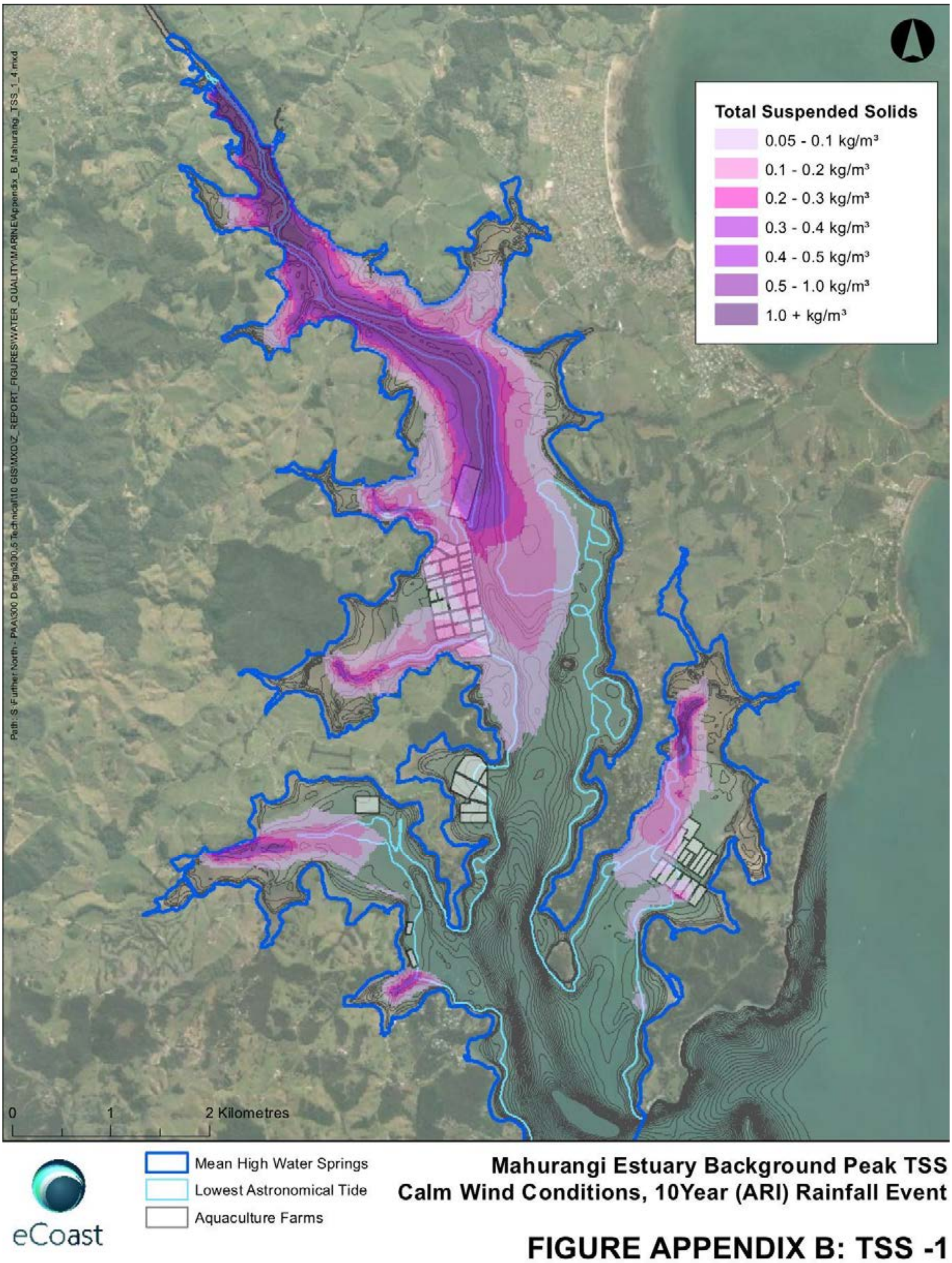


eCoast

Mean High Water Springs
Lowest Astronomical Tide
Aquaculture Farms

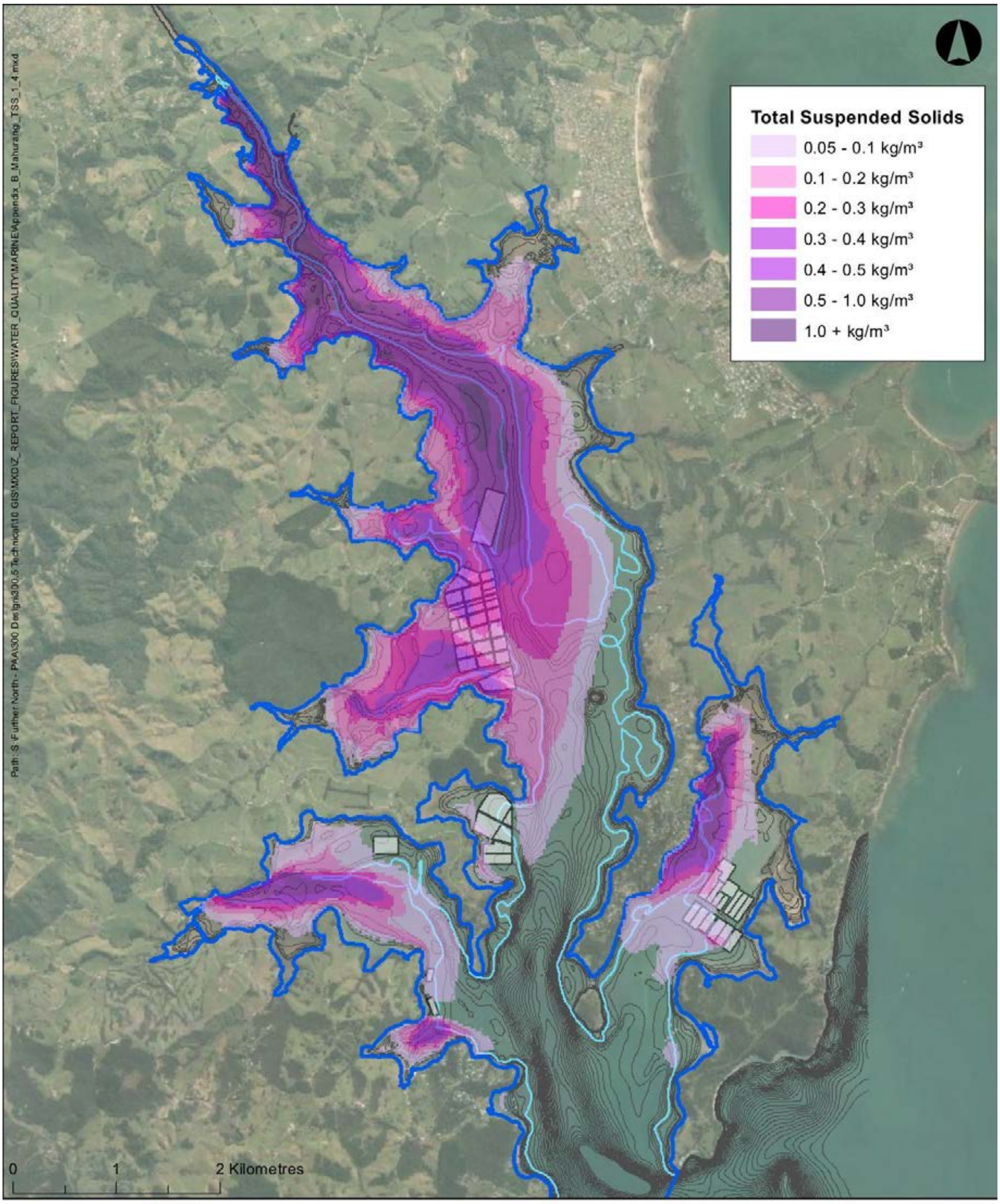
Mahurangi Estuary Long Construction Period Deposition
3 Day Following Peak of the Rainfall Event
ENE Wind Conditions, 50Year (ARI) Rainfall Event
FIGURE APPENDIX A: DEPO-24

Appendix B Mahurangi TSS plans



Mahurangi Estuary Background Peak TSS
Calm Wind Conditions, 10Year (ARI) Rainfall Event

FIGURE APPENDIX B: TSS -1

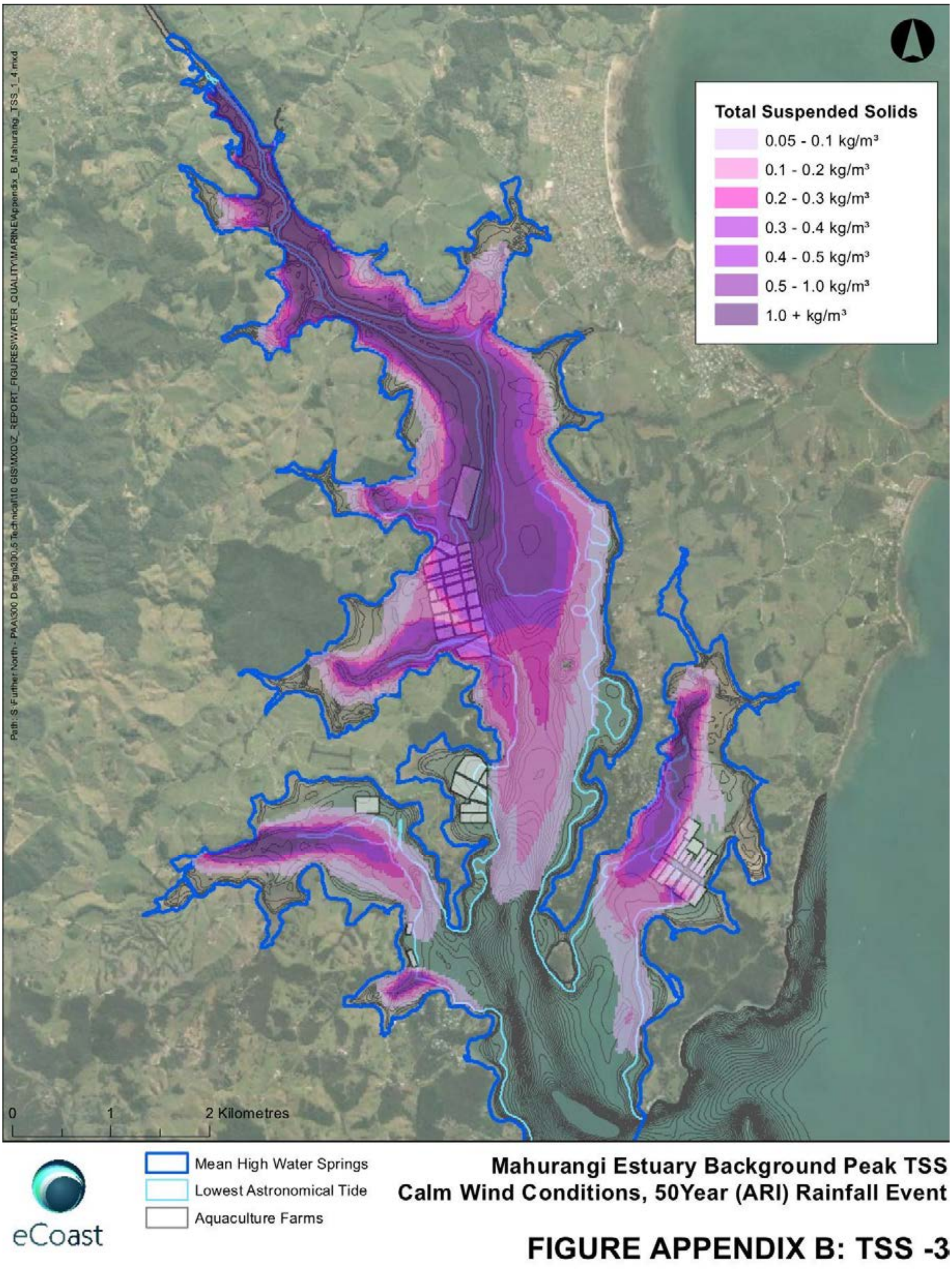


Mean High Water Springs
Lowest Astronomical Tide
Aquaculture Farms

eCoast

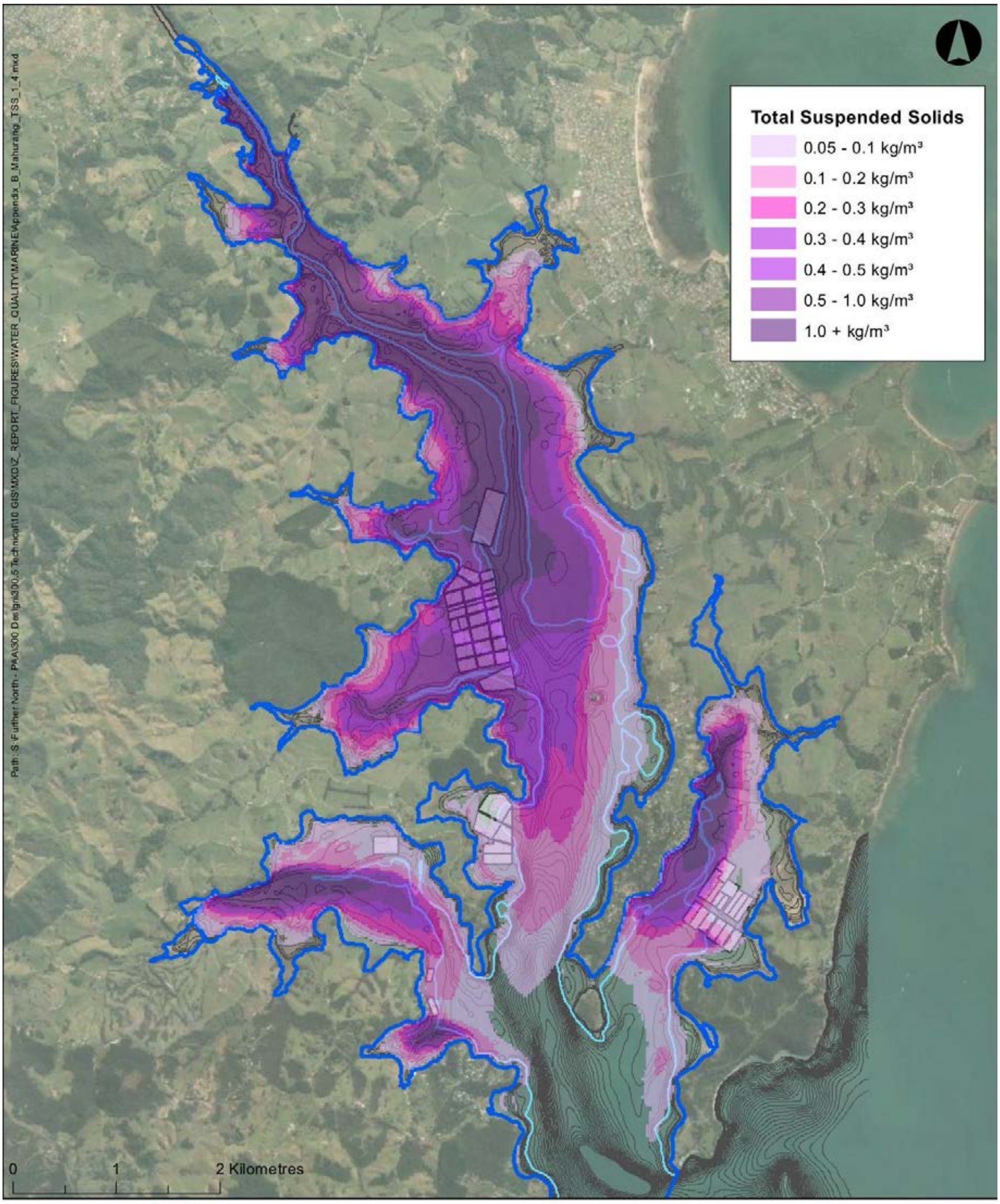
Mahurangi Estuary Background Peak TSS
ENE Wind Conditions, 10Year (ARI) Rainfall Event

FIGURE APPENDIX B: TSS -2



Mahurangi Estuary Background Peak TSS
Calm Wind Conditions, 50Year (ARI) Rainfall Event

FIGURE APPENDIX B: TSS -3

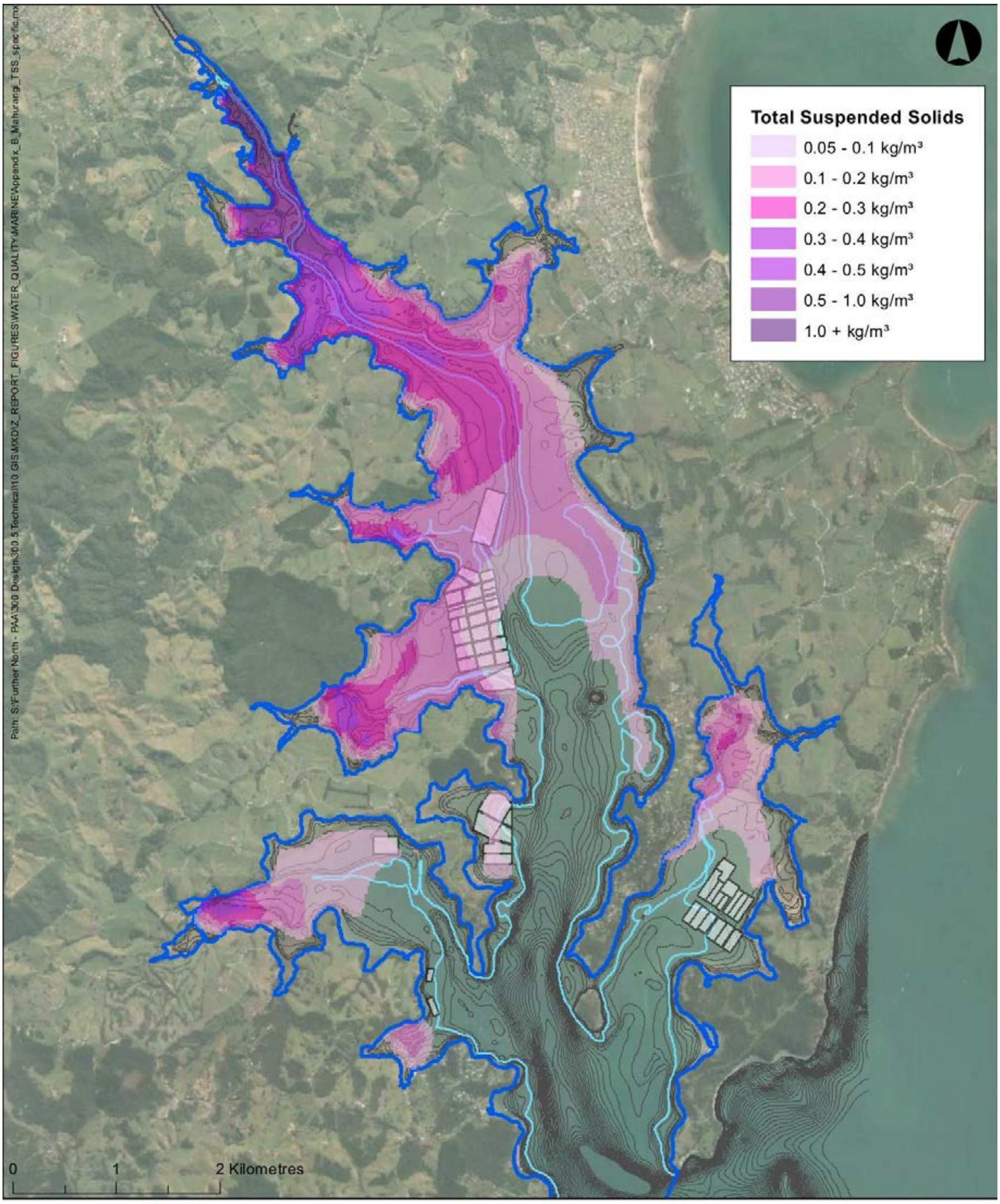


eCoast

Mean High Water Springs
Lowest Astronomical Tide
Aquaculture Farms

Mahurangi Estuary Background Peak TSS
ENE Wind Conditions, 50Year (ARI) Rainfall Event

FIGURE APPENDIX B: TSS -4

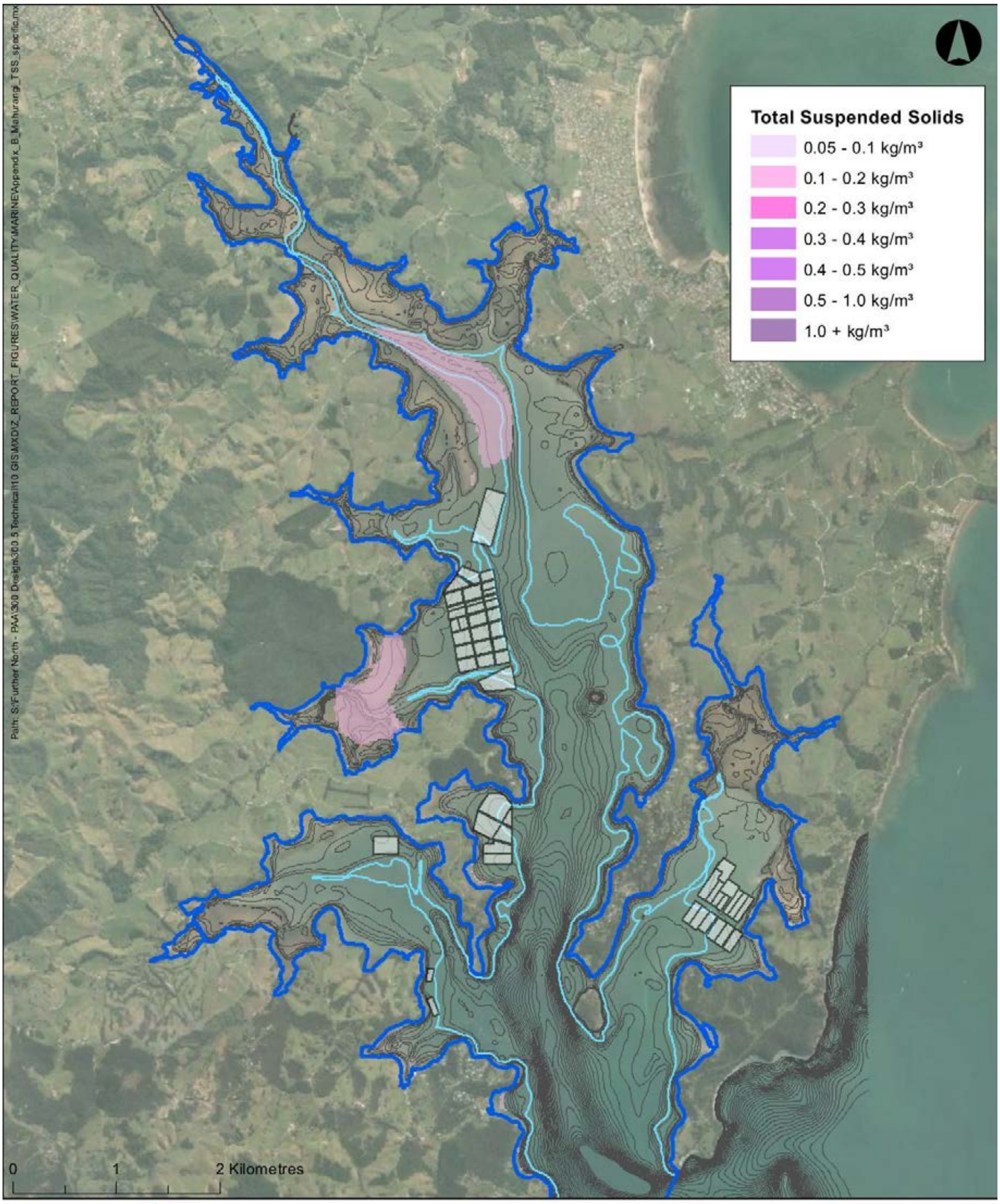


Mean High Water Springs
Lowest Astronomical Tide
Aquaculture Farms

eCoast

Mahurangi Estuary Short Construction Period TSS
1 Days Following Peak of the Rainfall Event
ENE Wind Conditions, 50Year (ARI) Rainfall Event

FIGURE APPENDIX B: TSS -5



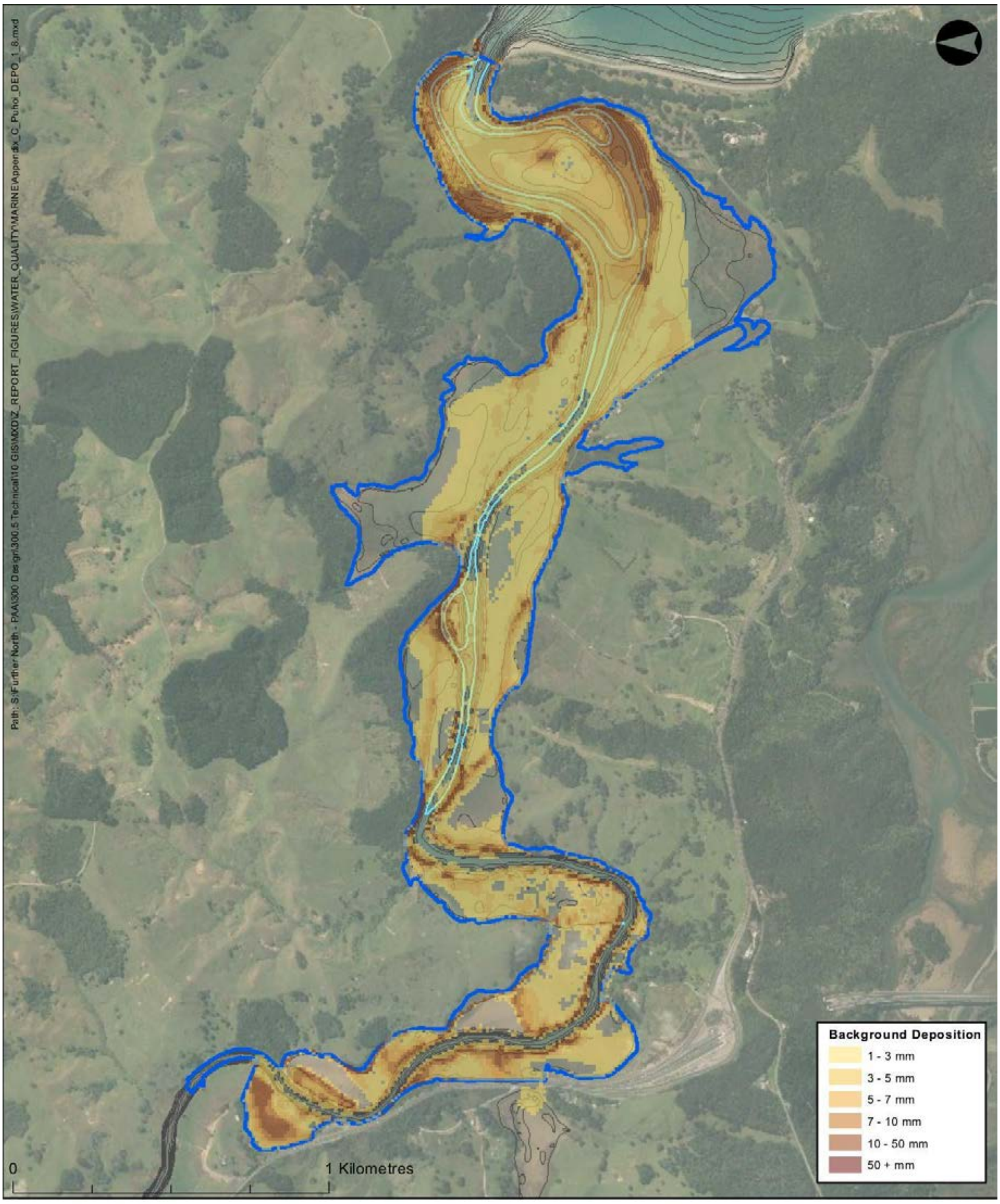
eCoast

Mean High Water Springs
Lowest Astronomical Tide
Aquaculture Farms

Mahurangi Estuary Short Construction Period TSS
3 Days Following Peak of the Rainfall Event
ENE Wind Conditions, 50Year (ARI) Rainfall Event

FIGURE APPENDIX B: TSS -6

Appendix C Pūhoi deposition plans

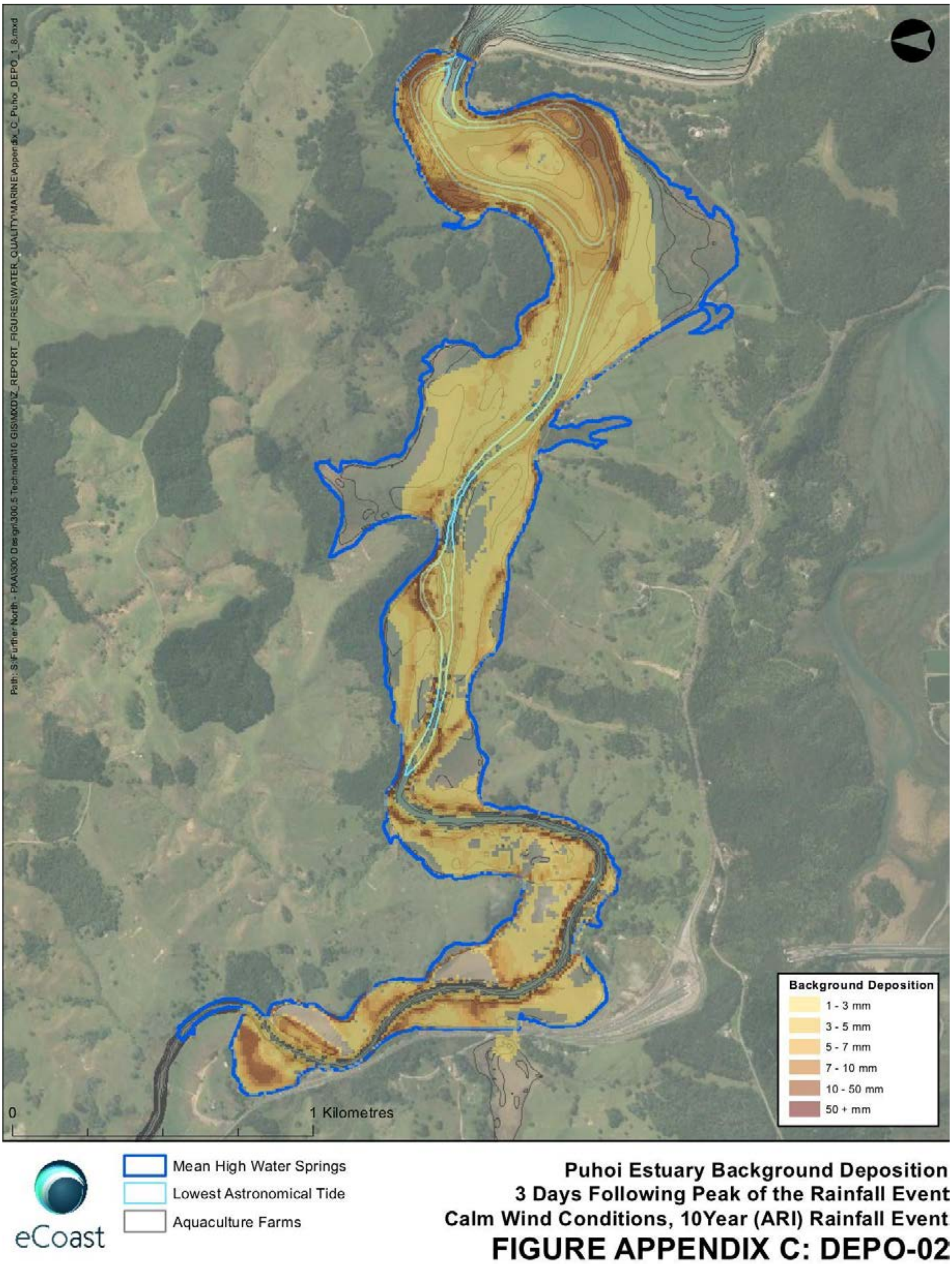


Mean High Water Springs
Lowest Astronomical Tide
Aquaculture Farms

eCoast

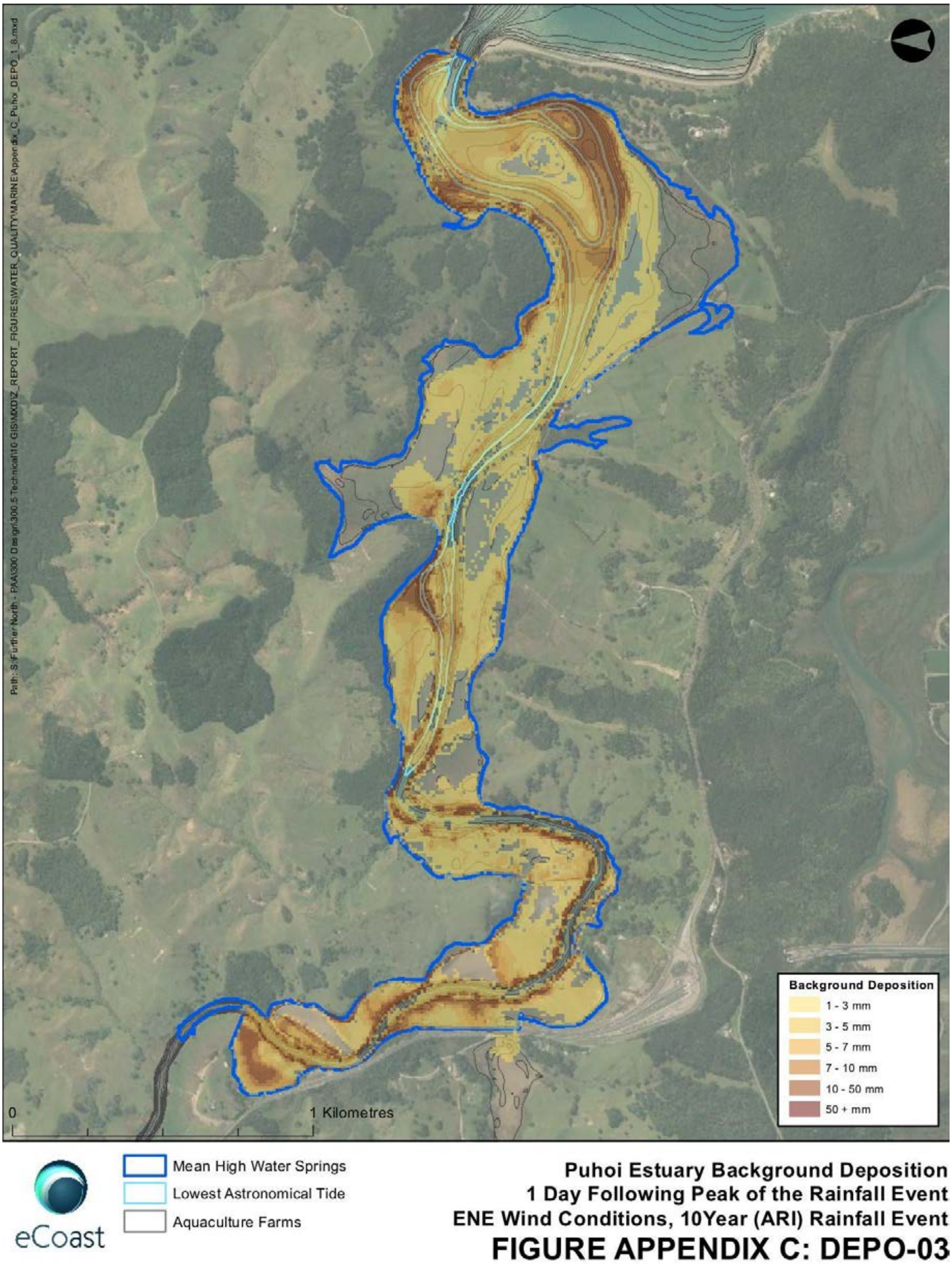
Puhoi Estuary Background Deposition
1 Day Following Peak of the Rainfall Event
Calm Wind Conditions, 10Year (ARI) Rainfall Event

FIGURE APPENDIX C: DEPO-01

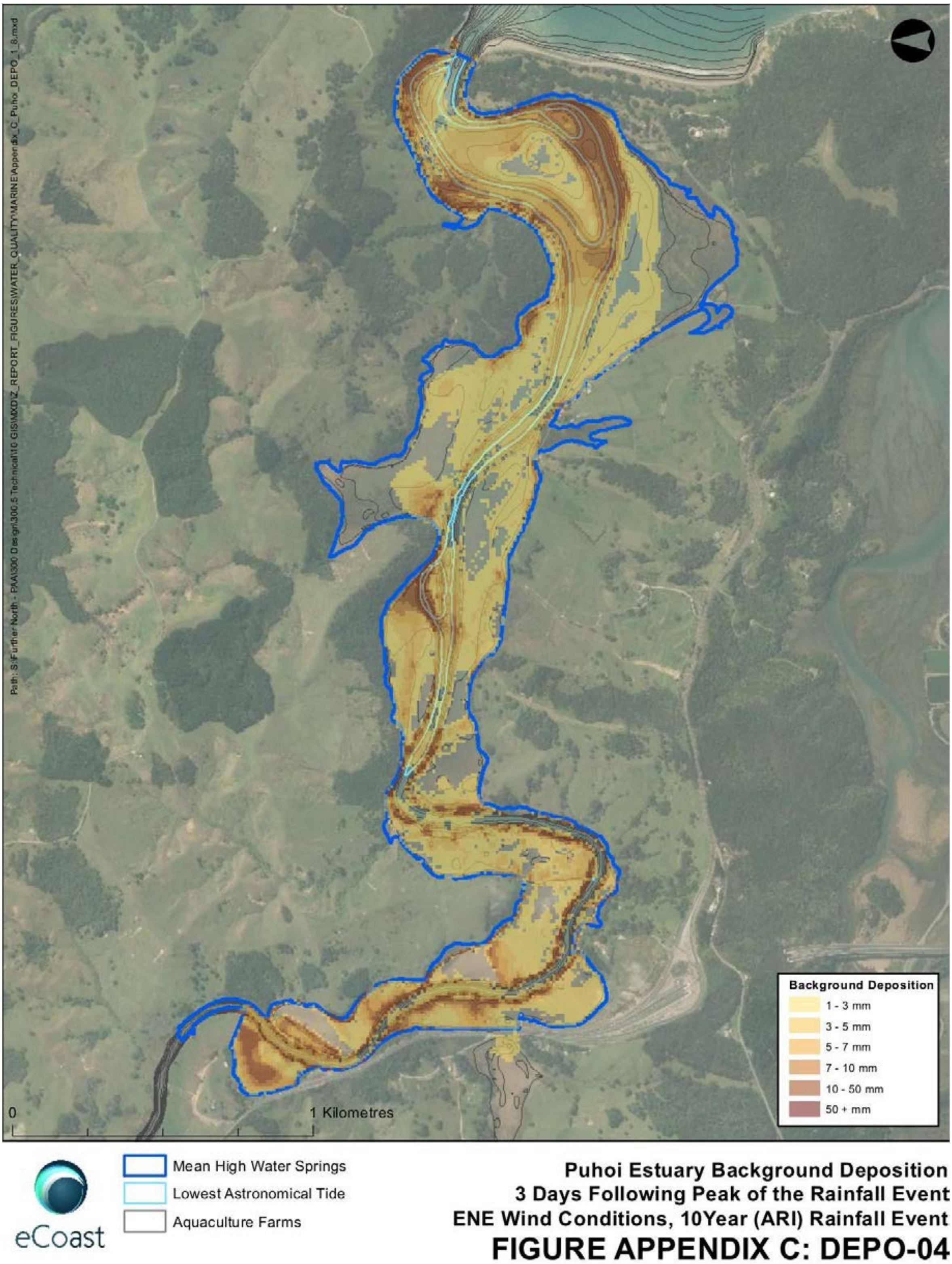


Puhoi Estuary Background Deposition
3 Days Following Peak of the Rainfall Event
Calm Wind Conditions, 10Year (ARI) Rainfall Event

FIGURE APPENDIX C: DEPO-02

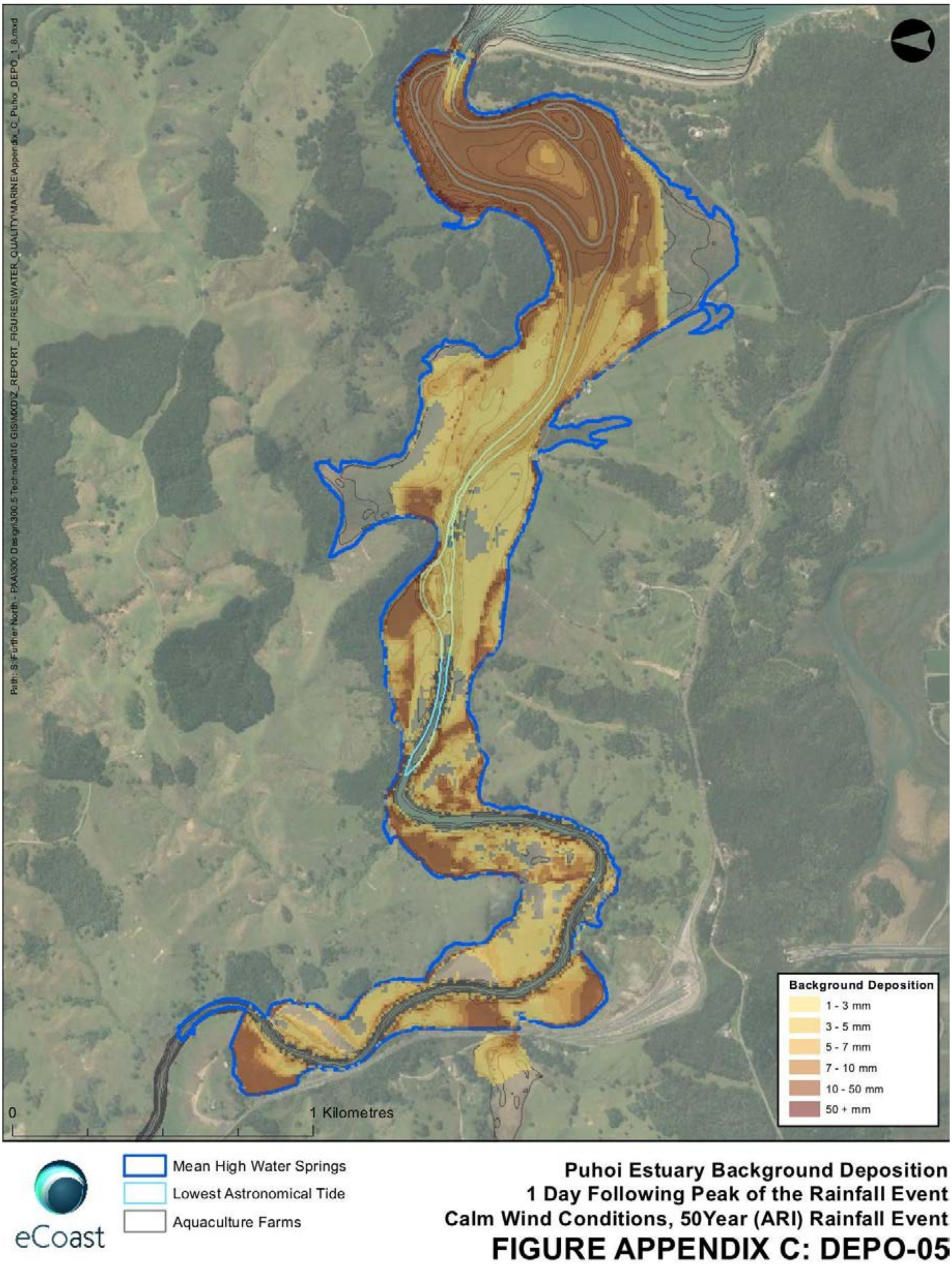


Puhoi Estuary Background Deposition
1 Day Following Peak of the Rainfall Event
ENE Wind Conditions, 10Year (ARI) Rainfall Event
FIGURE APPENDIX C: DEPO-03

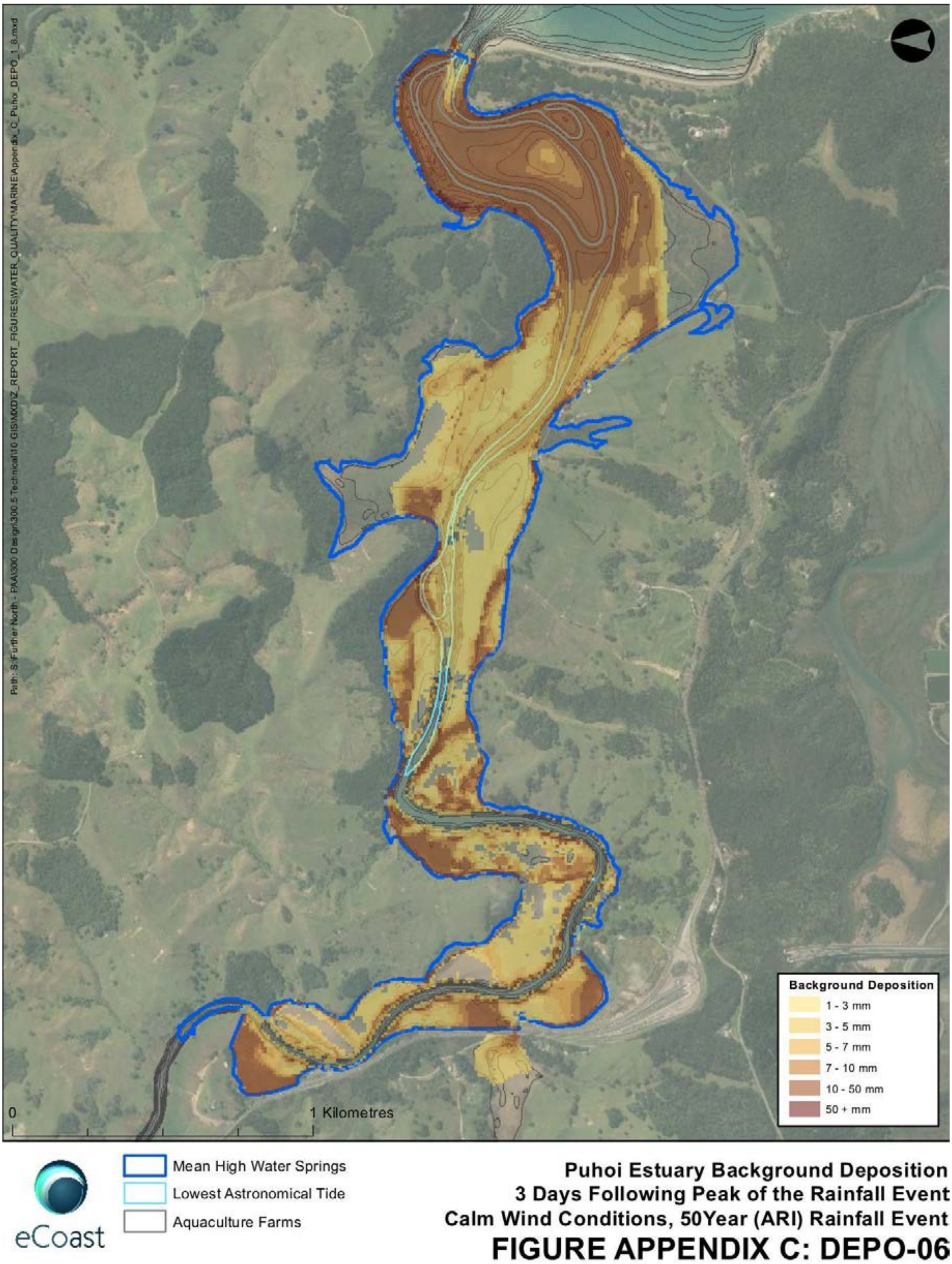


Puhoi Estuary Background Deposition
3 Days Following Peak of the Rainfall Event
ENE Wind Conditions, 10Year (ARI) Rainfall Event

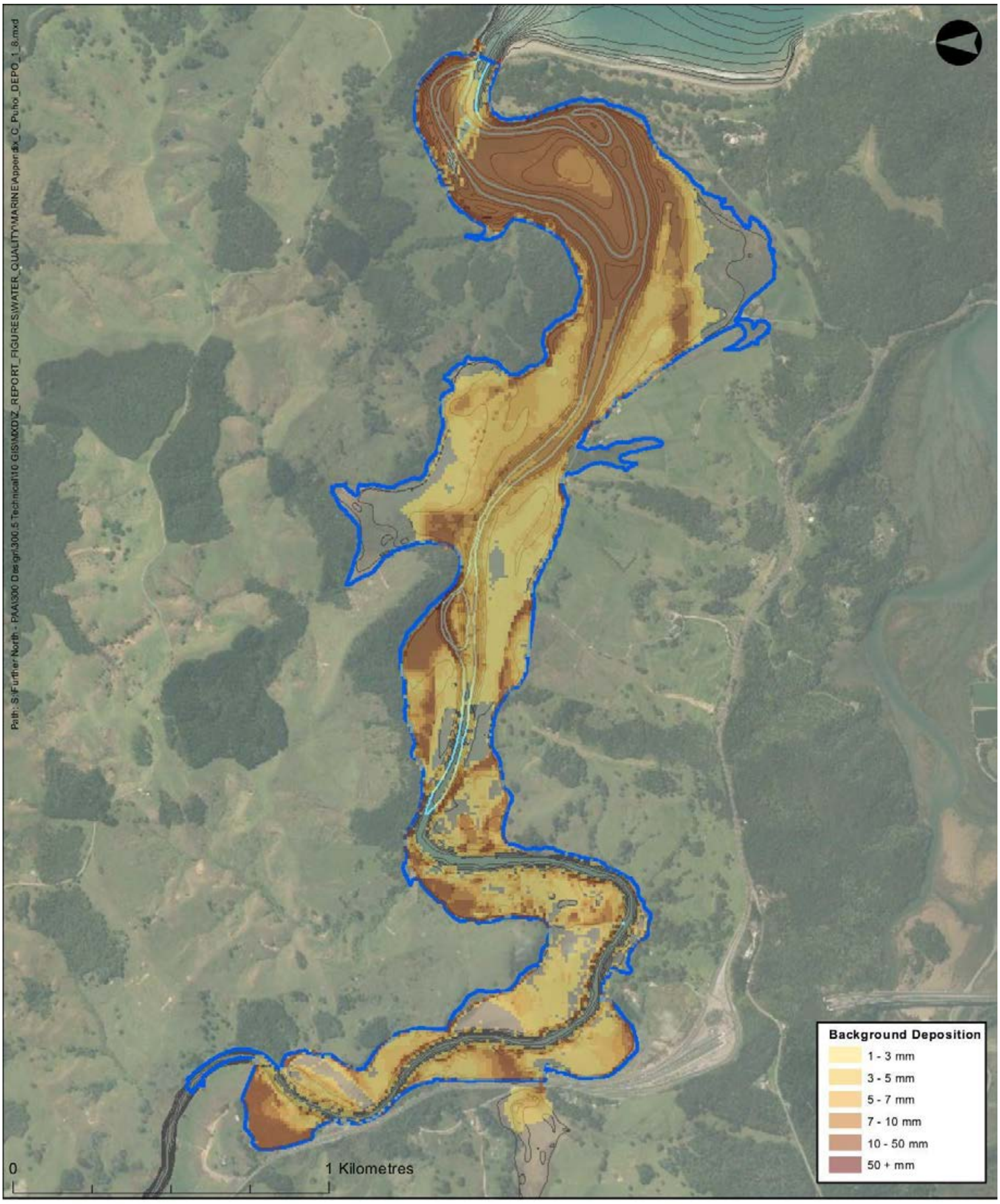
FIGURE APPENDIX C: DEPO-04



Puhoi Estuary Background Deposition
1 Day Following Peak of the Rainfall Event
Calm Wind Conditions, 50Year (ARI) Rainfall Event
FIGURE APPENDIX C: DEPO-05



Puhoi Estuary Background Deposition
3 Days Following Peak of the Rainfall Event
Calm Wind Conditions, 50Year (ARI) Rainfall Event
FIGURE APPENDIX C: DEPO-06

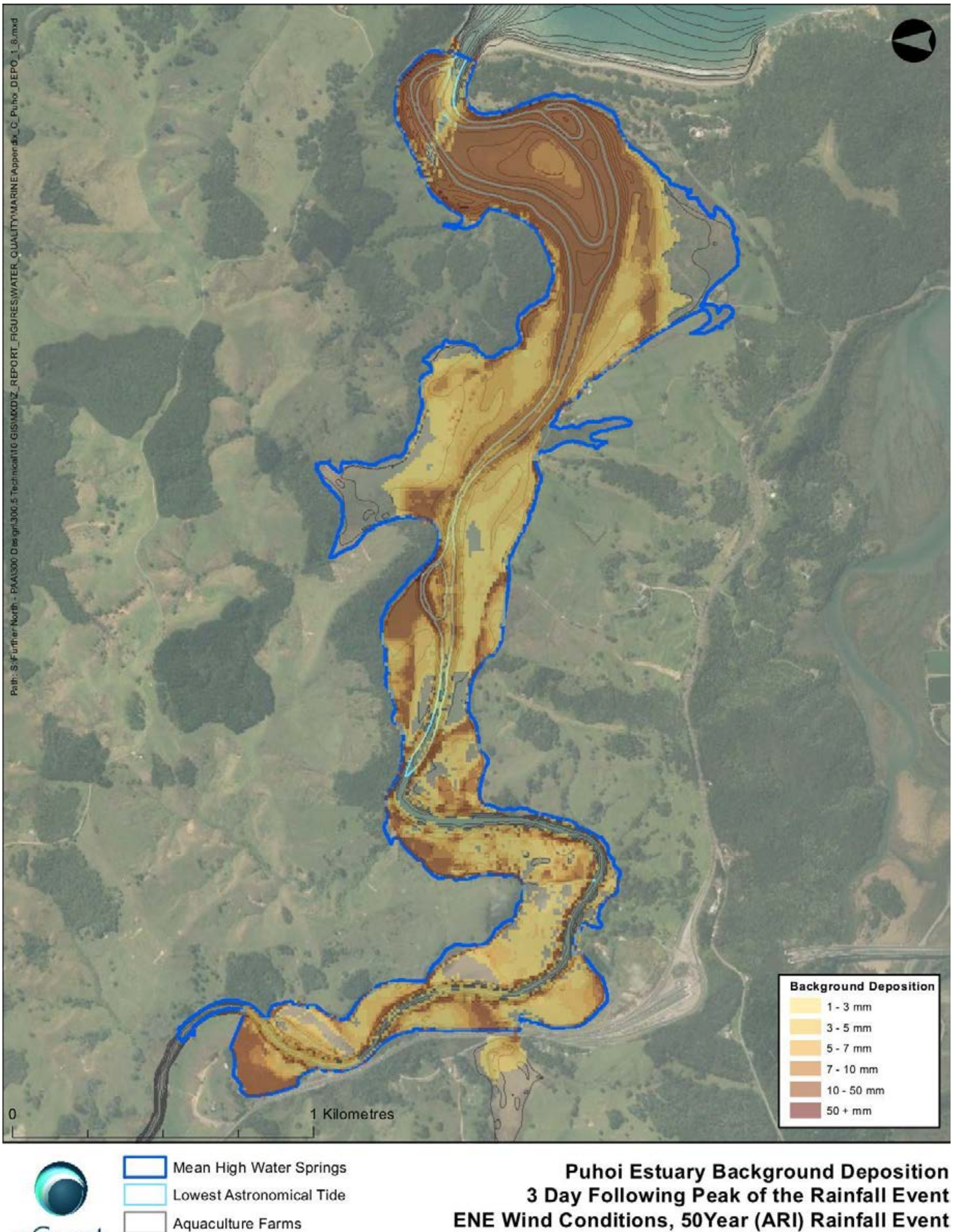


eCoast

Mean High Water Springs
Lowest Astronomical Tide
Aquaculture Farms

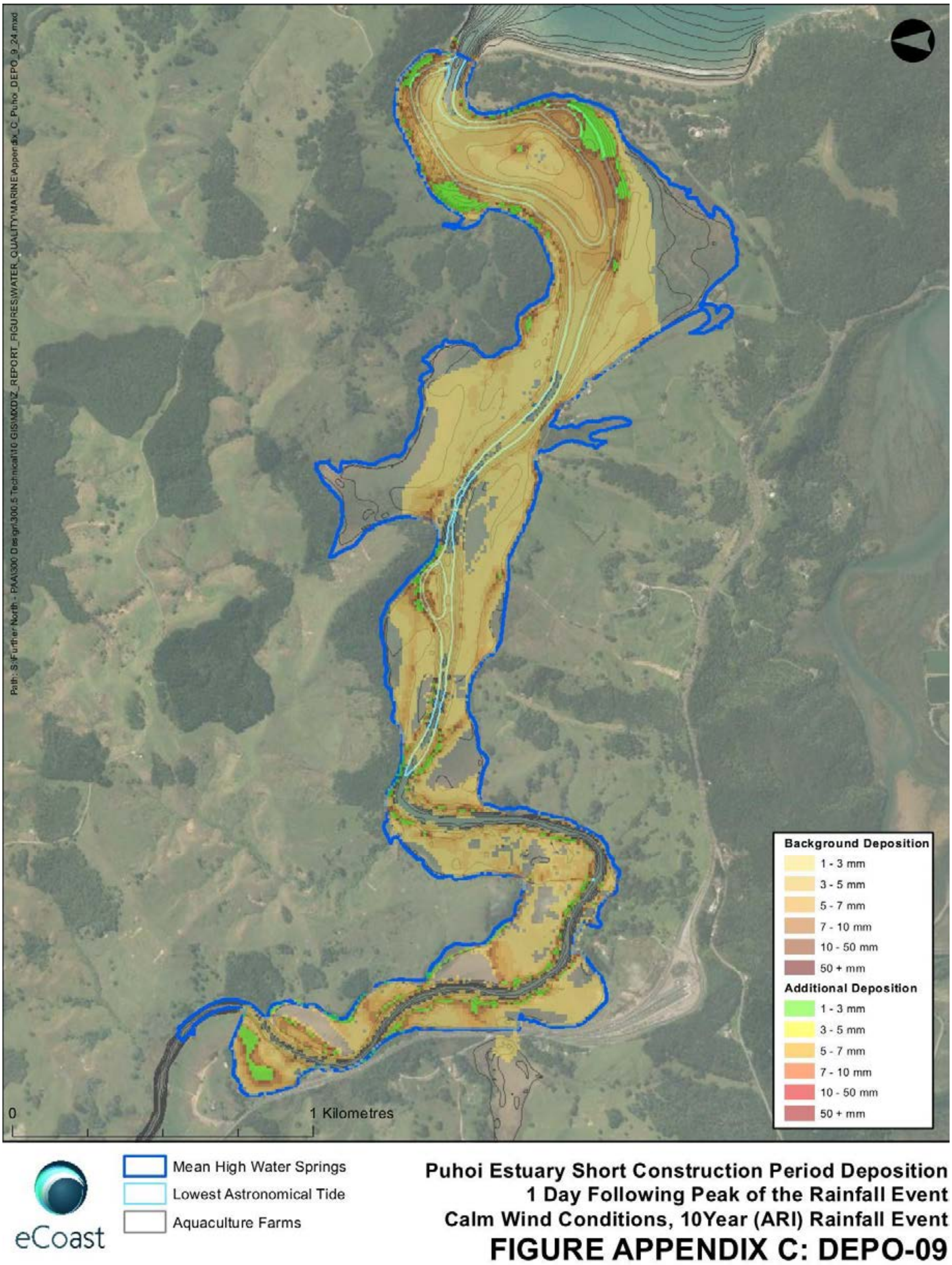
Puhoi Estuary Background Deposition
1 Day Following Peak of the Rainfall Event
ENE Wind Conditions, 50Year (ARI) Rainfall Event

FIGURE APPENDIX C: DEPO-07



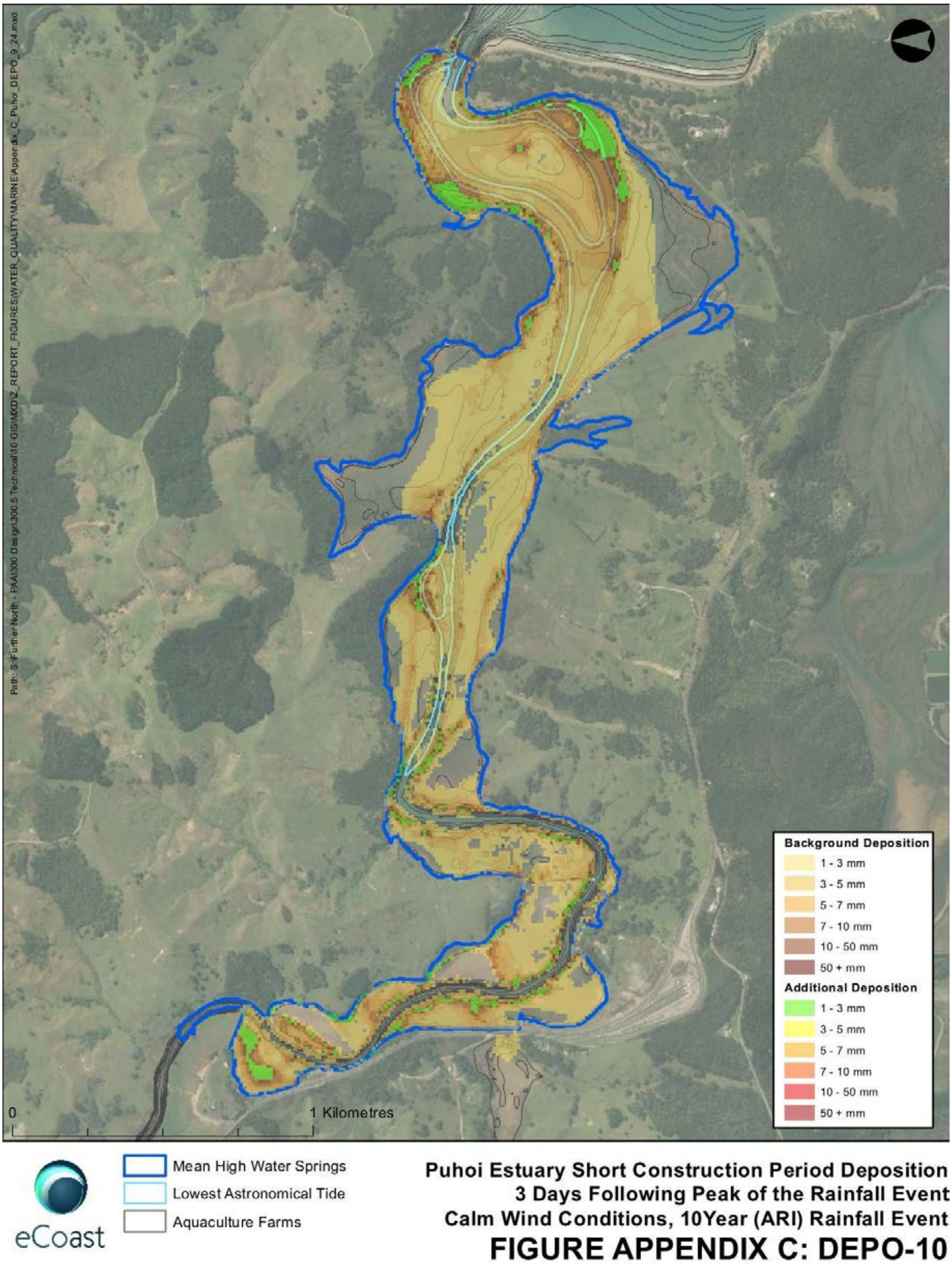
Puhoi Estuary Background Deposition
3 Day Following Peak of the Rainfall Event
ENE Wind Conditions, 50Year (ARI) Rainfall Event

FIGURE APPENDIX C: DEPO-08



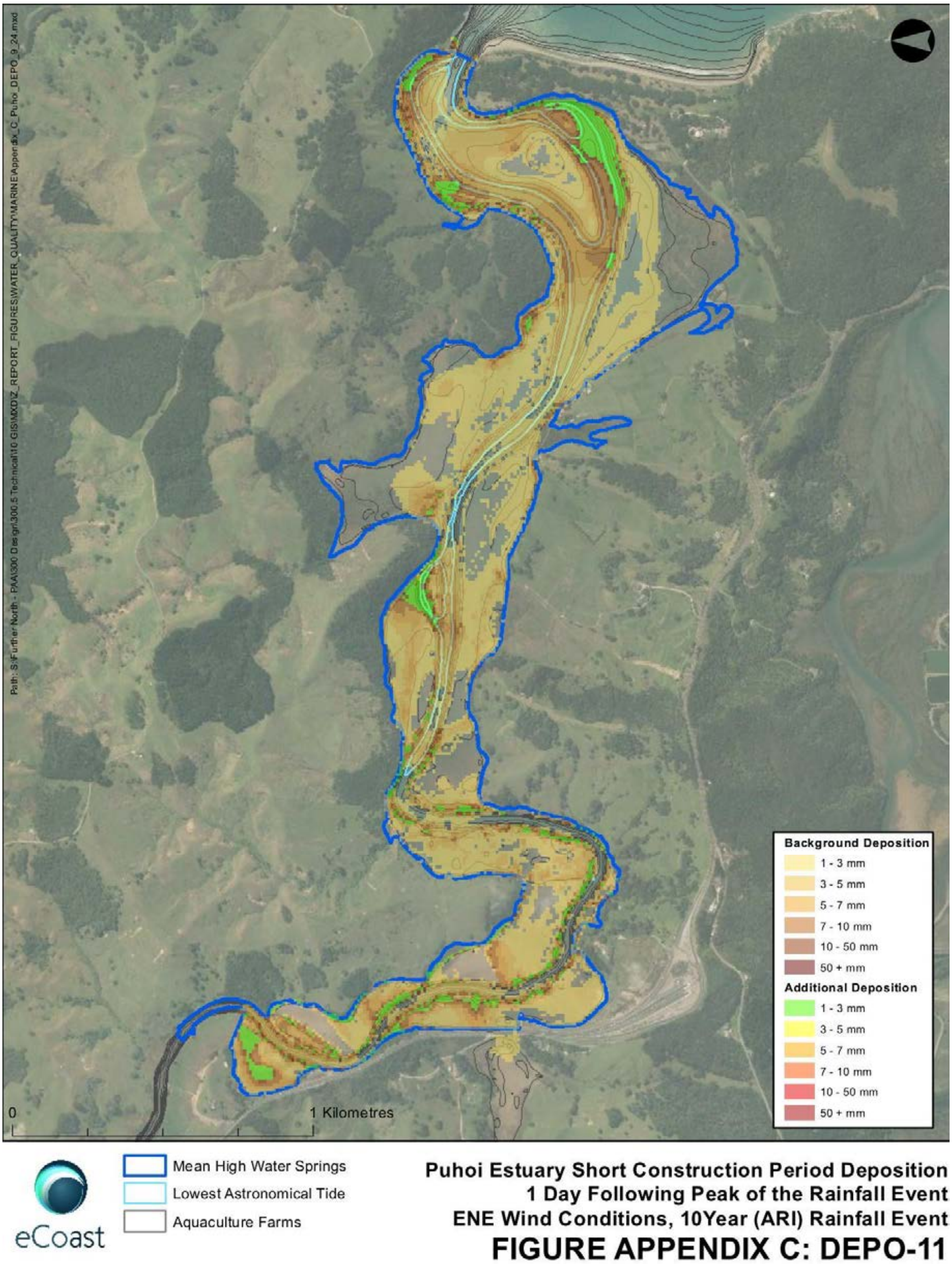
Puhoi Estuary Short Construction Period Deposition
1 Day Following Peak of the Rainfall Event
Calm Wind Conditions, 10Year (ARI) Rainfall Event

FIGURE APPENDIX C: DEPO-09



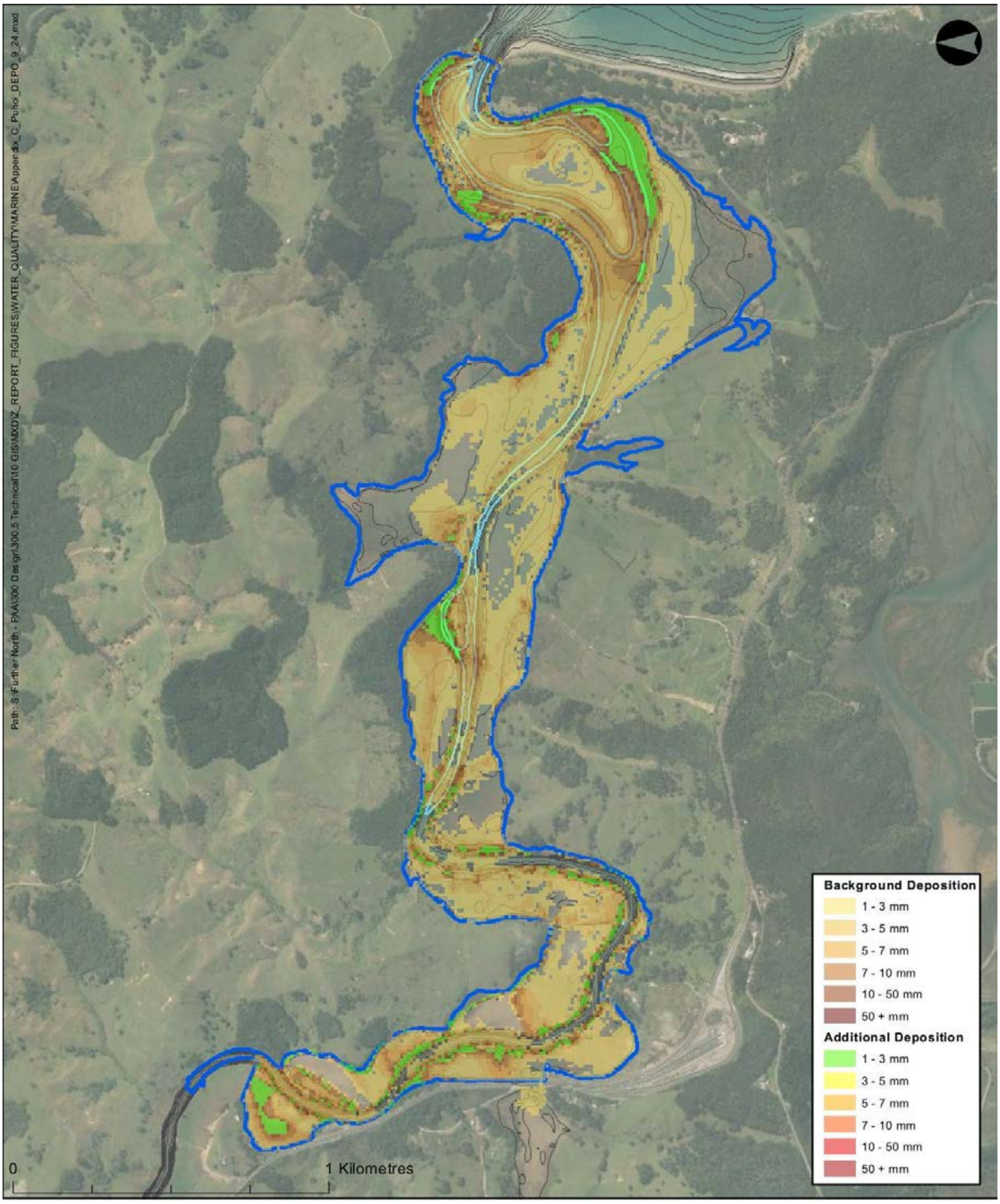
Puhoi Estuary Short Construction Period Deposition
3 Days Following Peak of the Rainfall Event
Calm Wind Conditions, 10Year (ARI) Rainfall Event

FIGURE APPENDIX C: DEPO-10



Puhoi Estuary Short Construction Period Deposition
1 Day Following Peak of the Rainfall Event
ENE Wind Conditions, 10Year (ARI) Rainfall Event

FIGURE APPENDIX C: DEPO-11

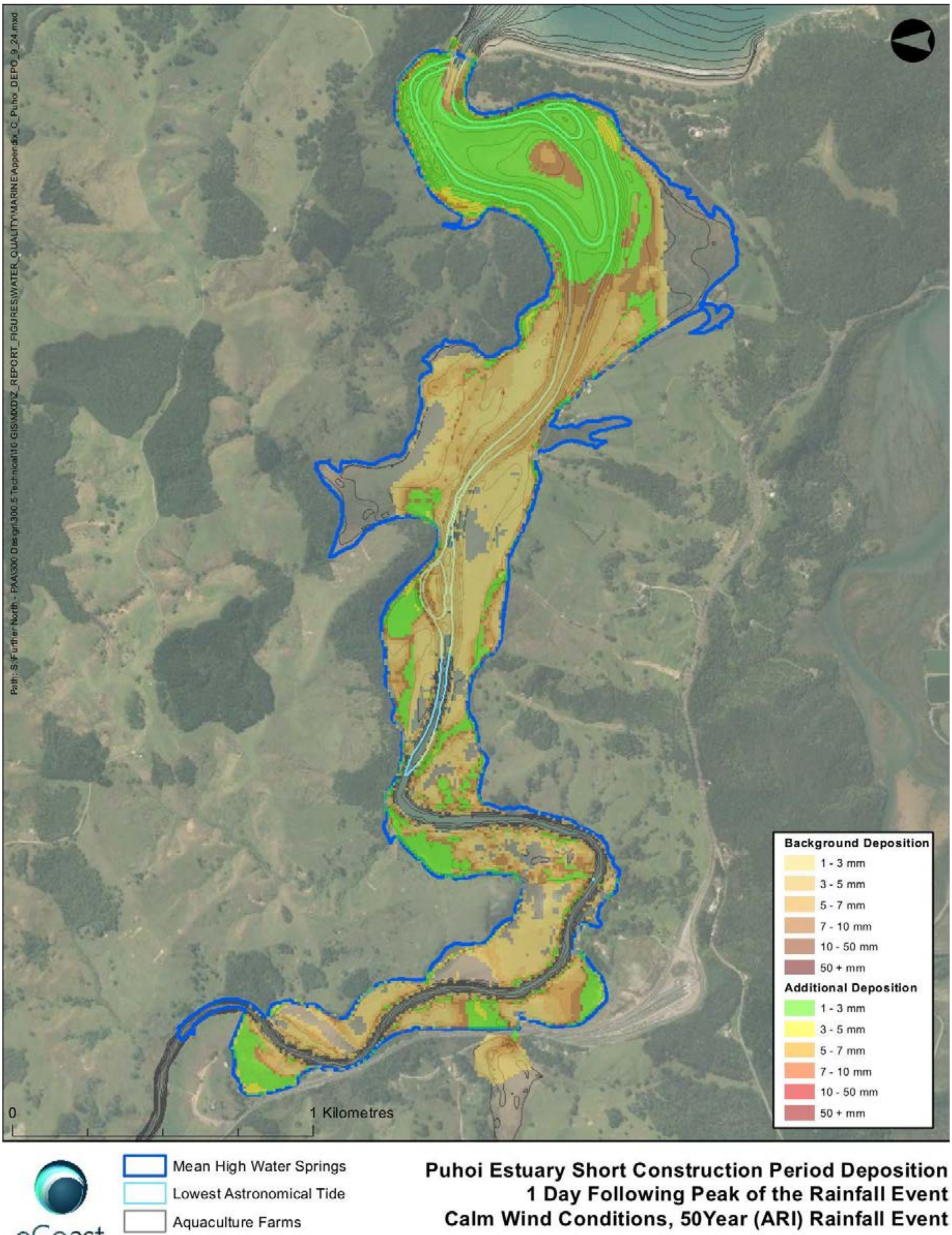


eCoast

Mean High Water Springs
Lowest Astronomical Tide
Aquaculture Farms

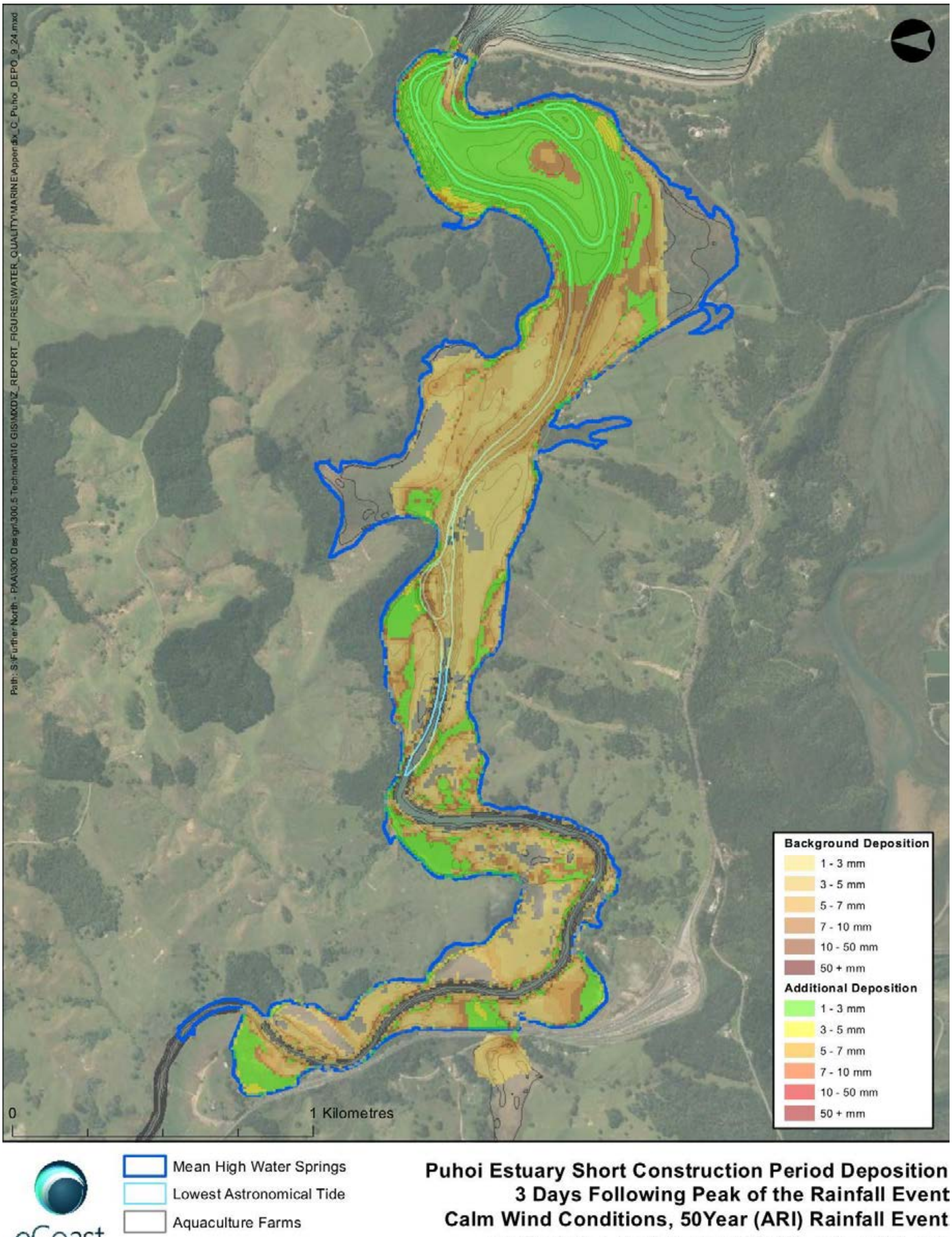
Puhoi Estuary Short Construction Period Deposition
3 Days Following Peak of the Rainfall Event
ENE Wind Conditions, 10Year (ARI) Rainfall Event

FIGURE APPENDIX C: DEPO-12



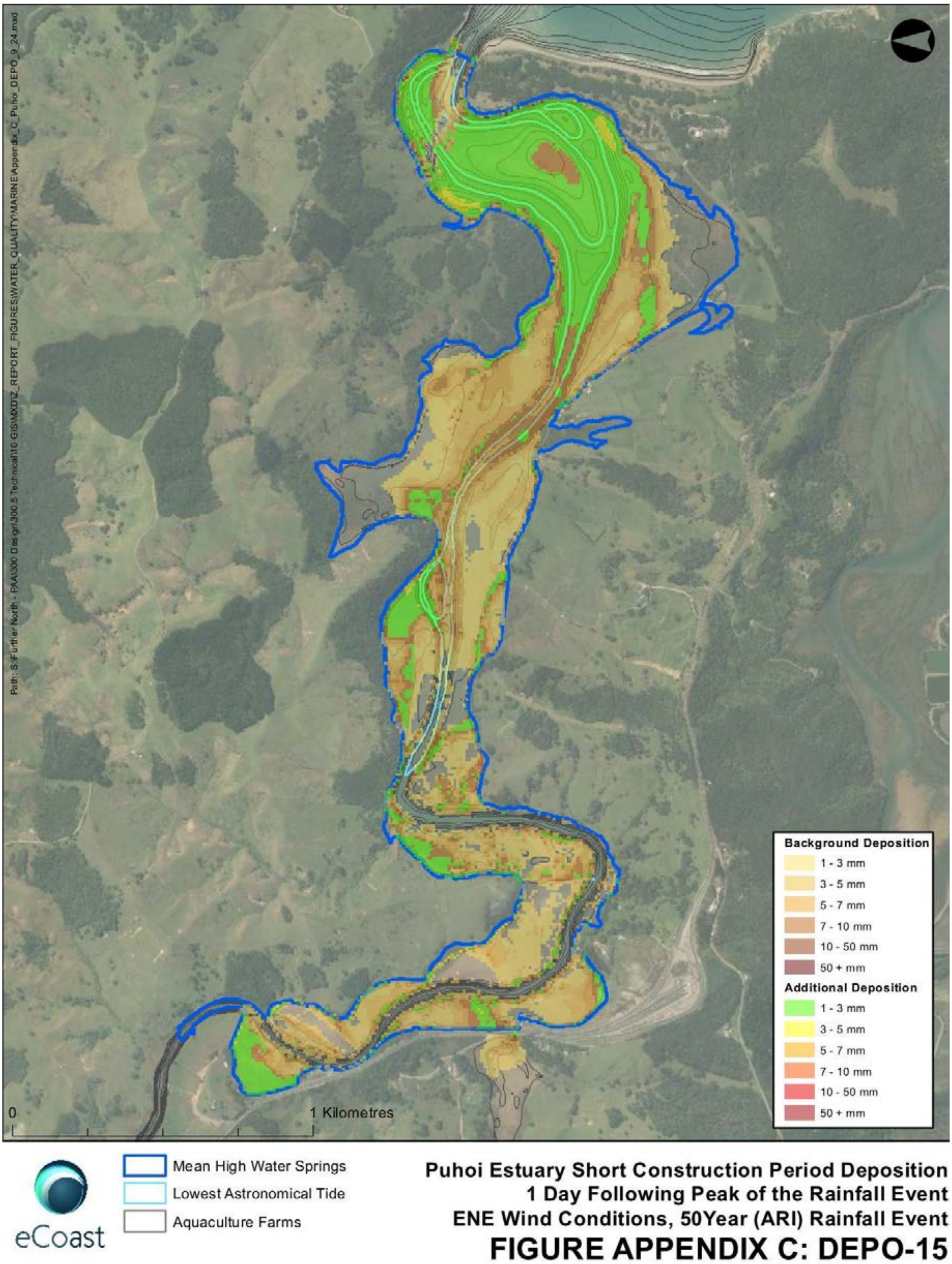
Puhoi Estuary Short Construction Period Deposition
1 Day Following Peak of the Rainfall Event
Calm Wind Conditions, 50Year (ARI) Rainfall Event

FIGURE APPENDIX C: DEPO-13



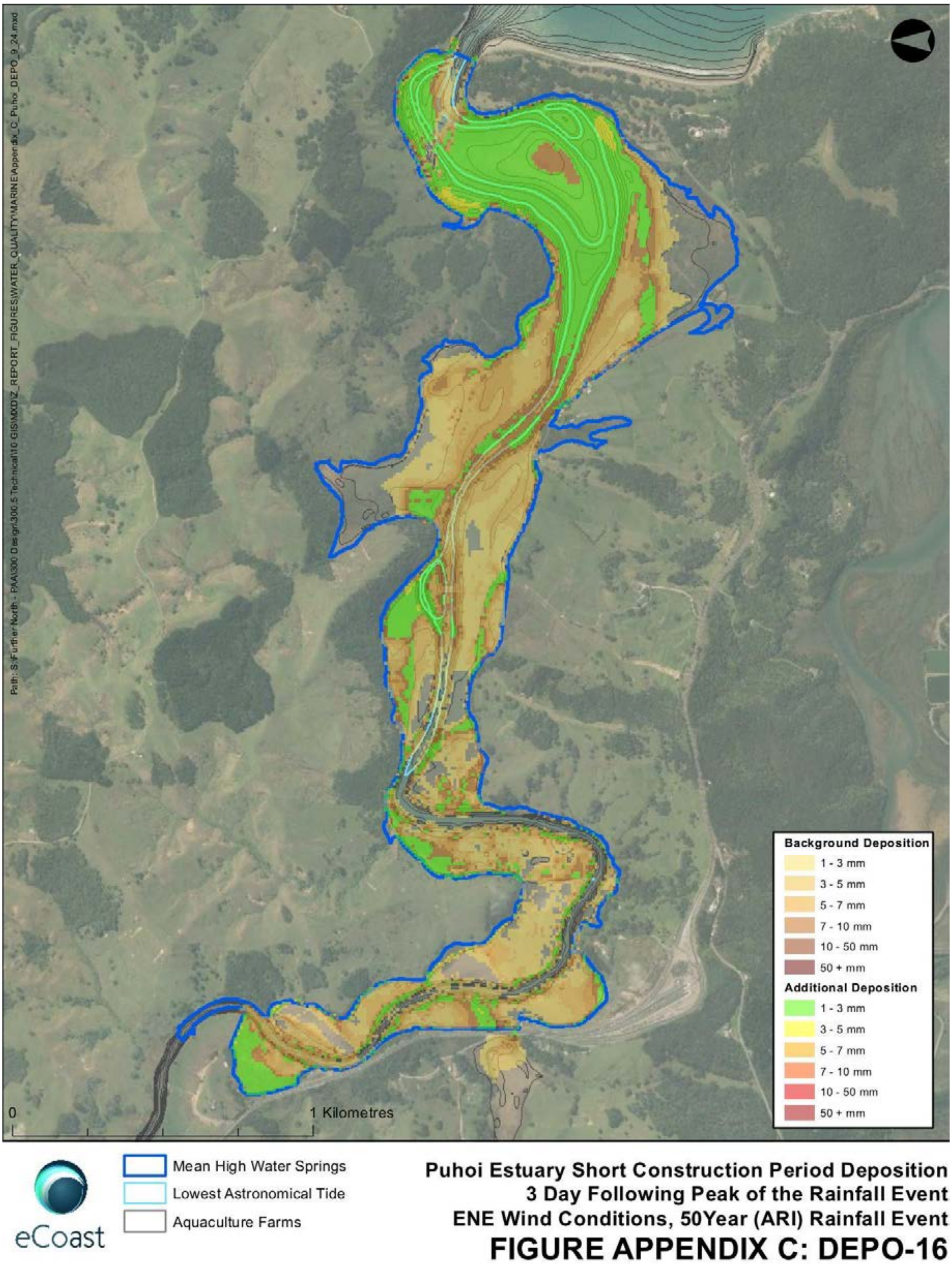
Puhoi Estuary Short Construction Period Deposition
3 Days Following Peak of the Rainfall Event
Calm Wind Conditions, 50Year (ARI) Rainfall Event

FIGURE APPENDIX C: DEPO-14

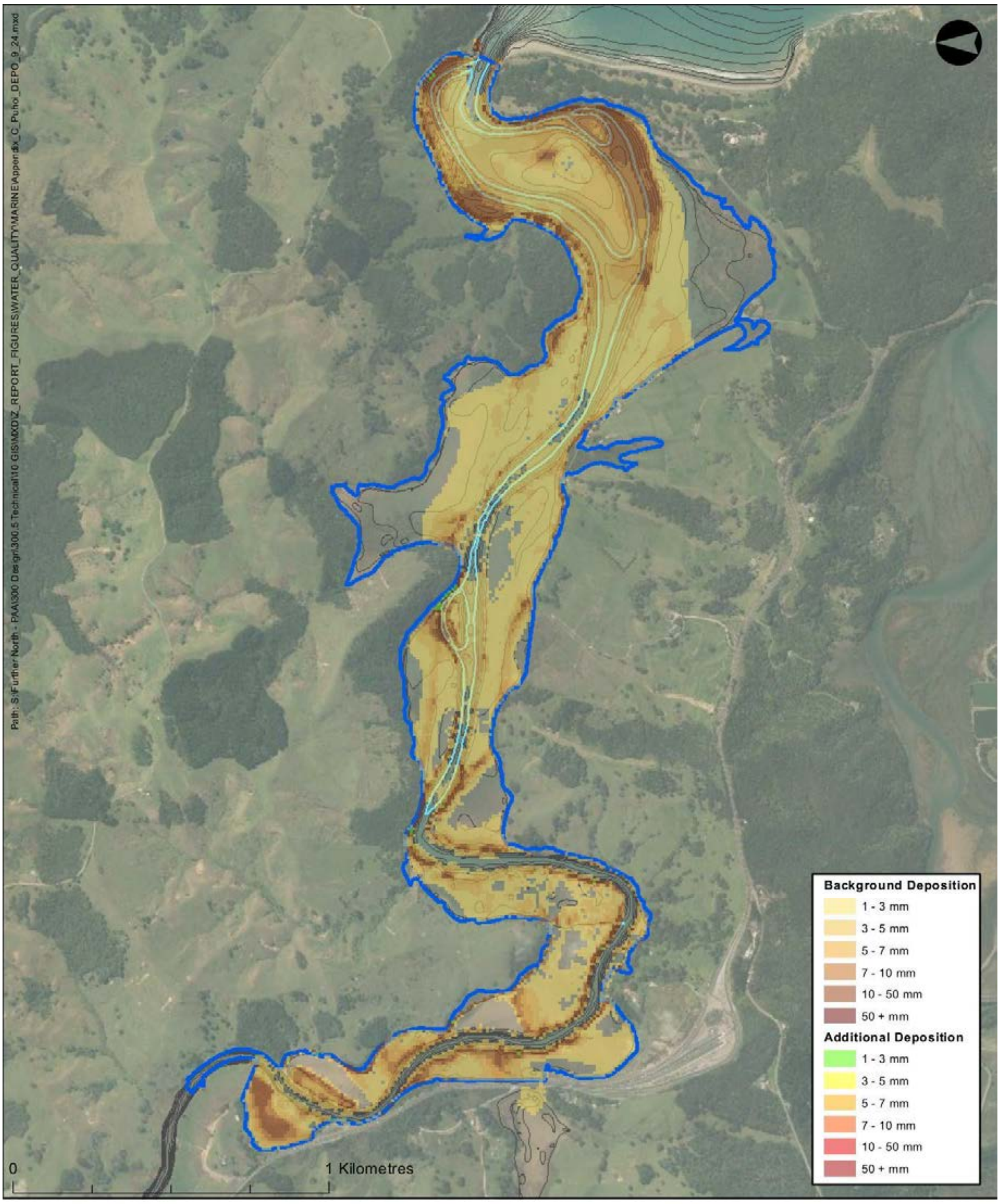


Puhoi Estuary Short Construction Period Deposition
1 Day Following Peak of the Rainfall Event
ENE Wind Conditions, 50Year (ARI) Rainfall Event

FIGURE APPENDIX C: DEPO-15



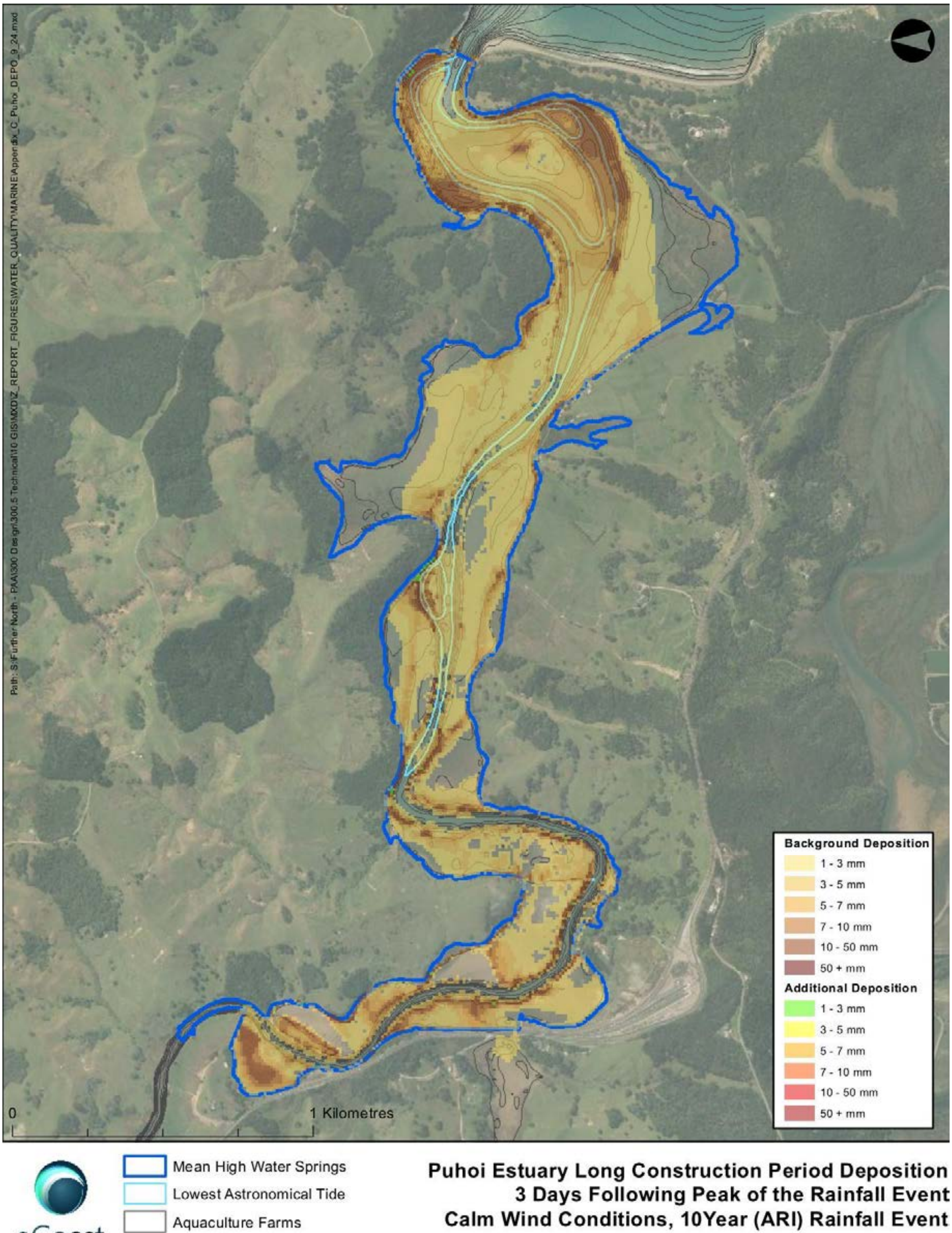
Puhoi Estuary Short Construction Period Deposition
3 Day Following Peak of the Rainfall Event
ENE Wind Conditions, 50Year (ARI) Rainfall Event
FIGURE APPENDIX C: DEPO-16



Mean High Water Springs
Lowest Astronomical Tide
Aquaculture Farms

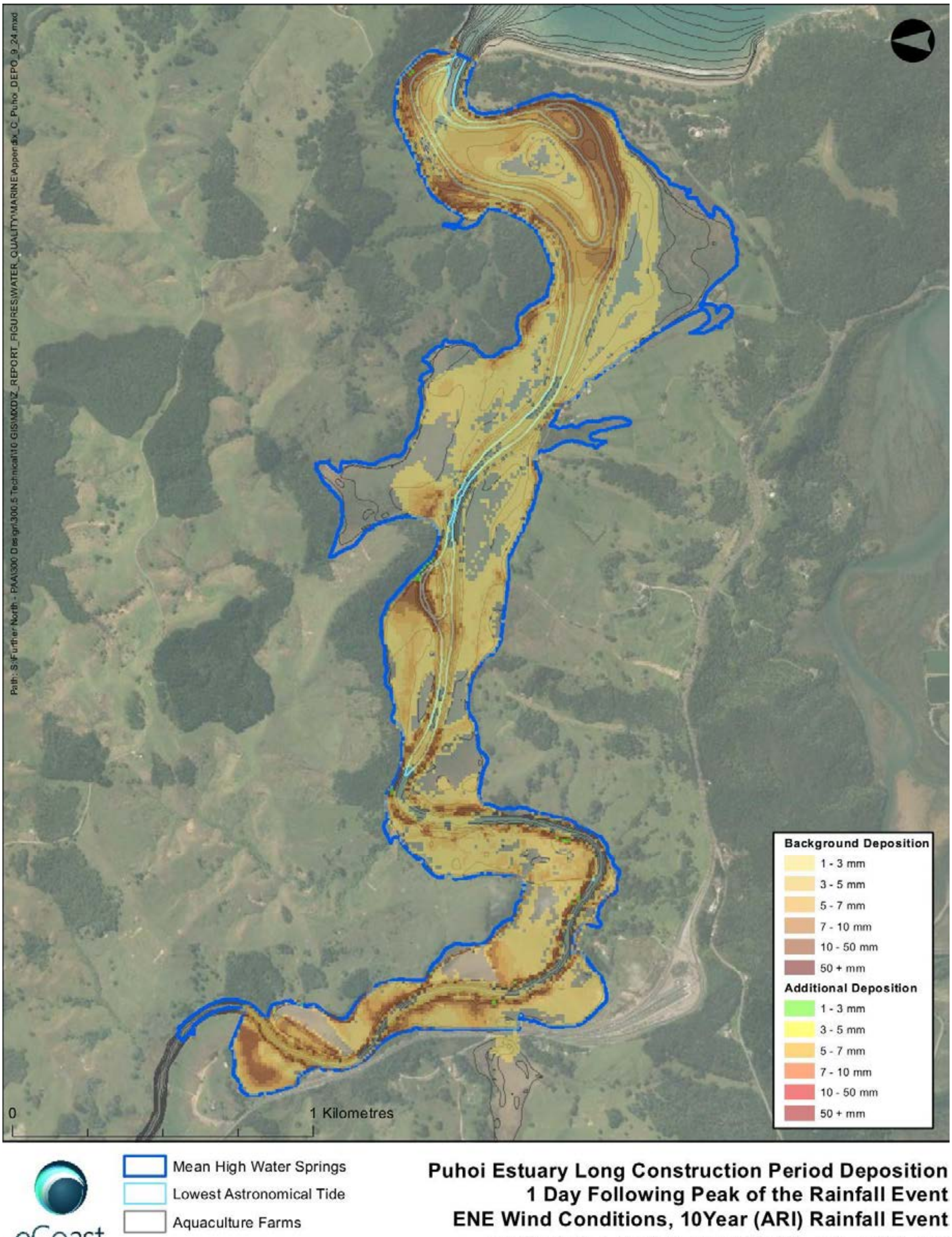
Puhoi Estuary Long Construction Period Deposition
1 Day Following Peak of the Rainfall Event
Calm Wind Conditions, 10Year (ARI) Rainfall Event

FIGURE APPENDIX C: DEPO-17



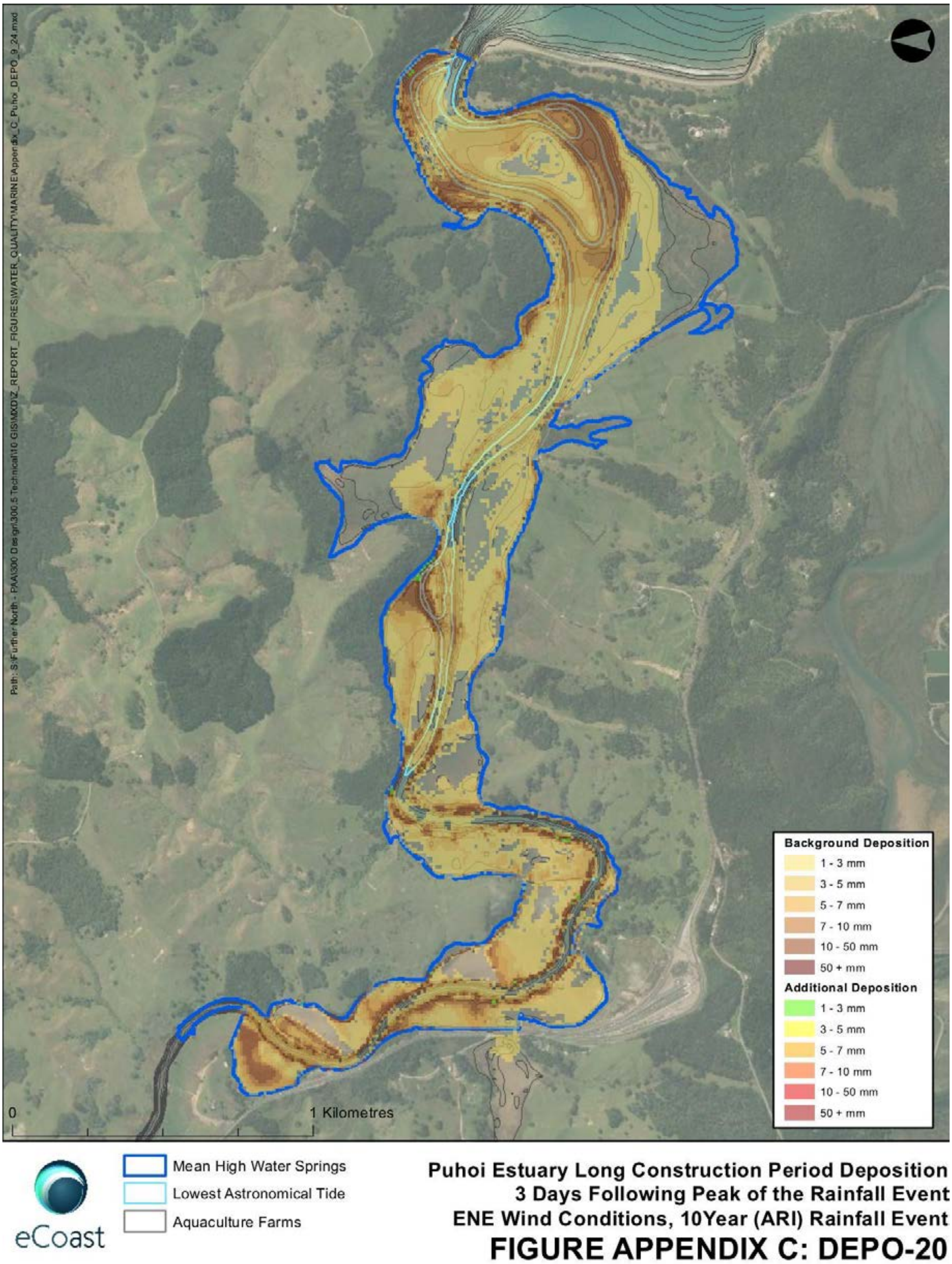
Puhoi Estuary Long Construction Period Deposition
3 Days Following Peak of the Rainfall Event
Calm Wind Conditions, 10Year (ARI) Rainfall Event

FIGURE APPENDIX C: DEPO-18



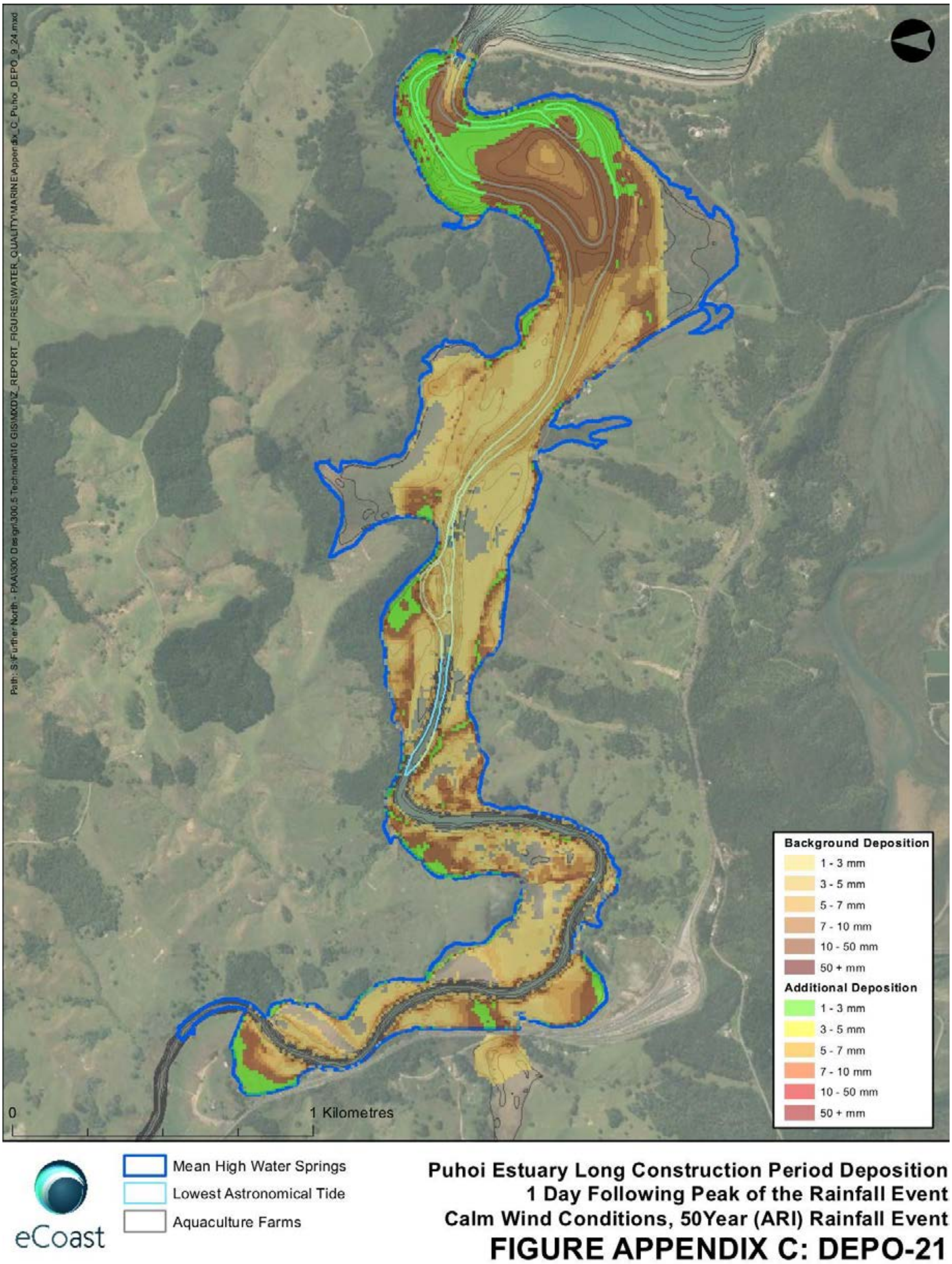
Puhoi Estuary Long Construction Period Deposition
1 Day Following Peak of the Rainfall Event
ENE Wind Conditions, 10Year (ARI) Rainfall Event

FIGURE APPENDIX C: DEPO-19



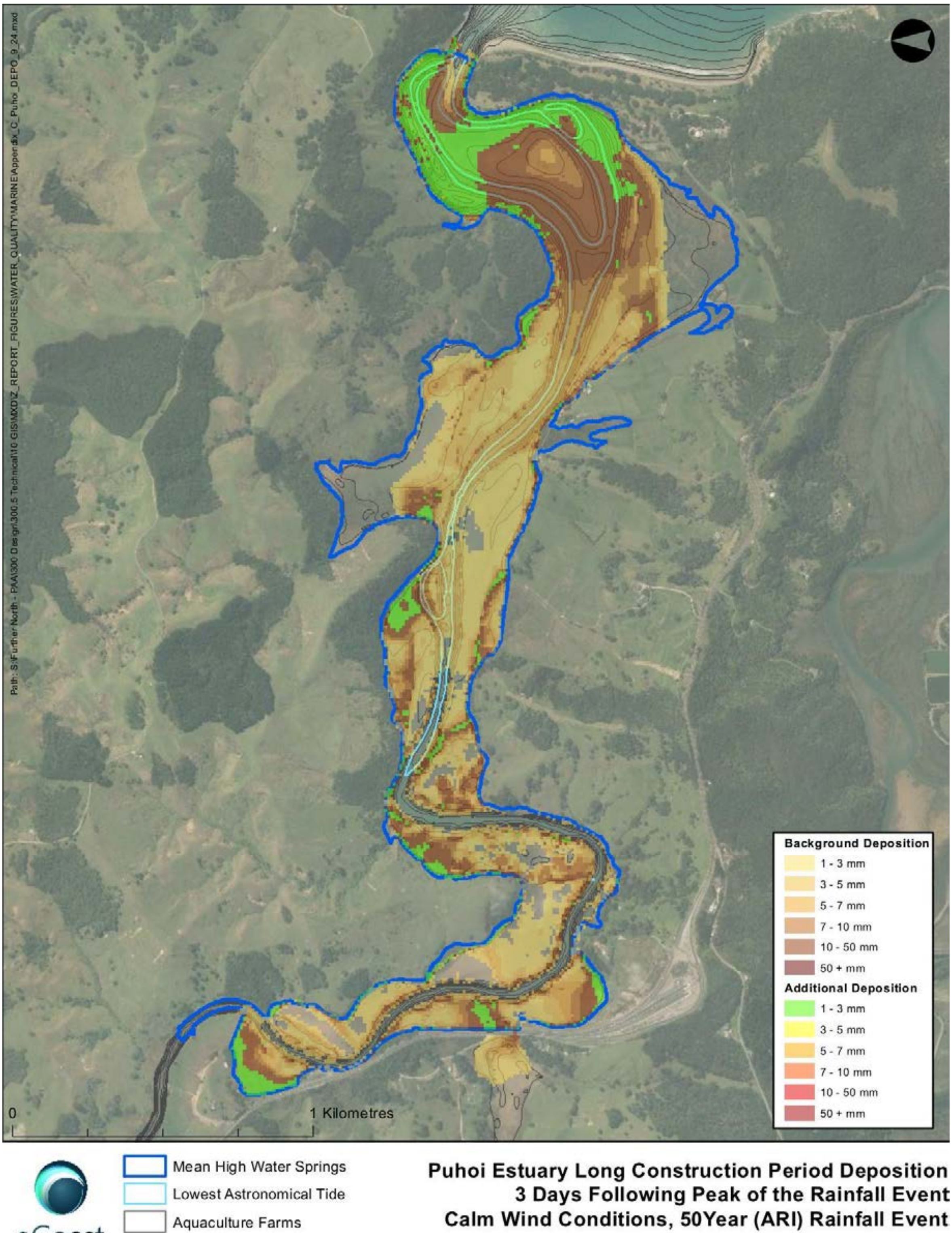
Puhoi Estuary Long Construction Period Deposition
3 Days Following Peak of the Rainfall Event
ENE Wind Conditions, 10Year (ARI) Rainfall Event

FIGURE APPENDIX C: DEPO-20



Puhoi Estuary Long Construction Period Deposition
1 Day Following Peak of the Rainfall Event
Calm Wind Conditions, 50Year (ARI) Rainfall Event

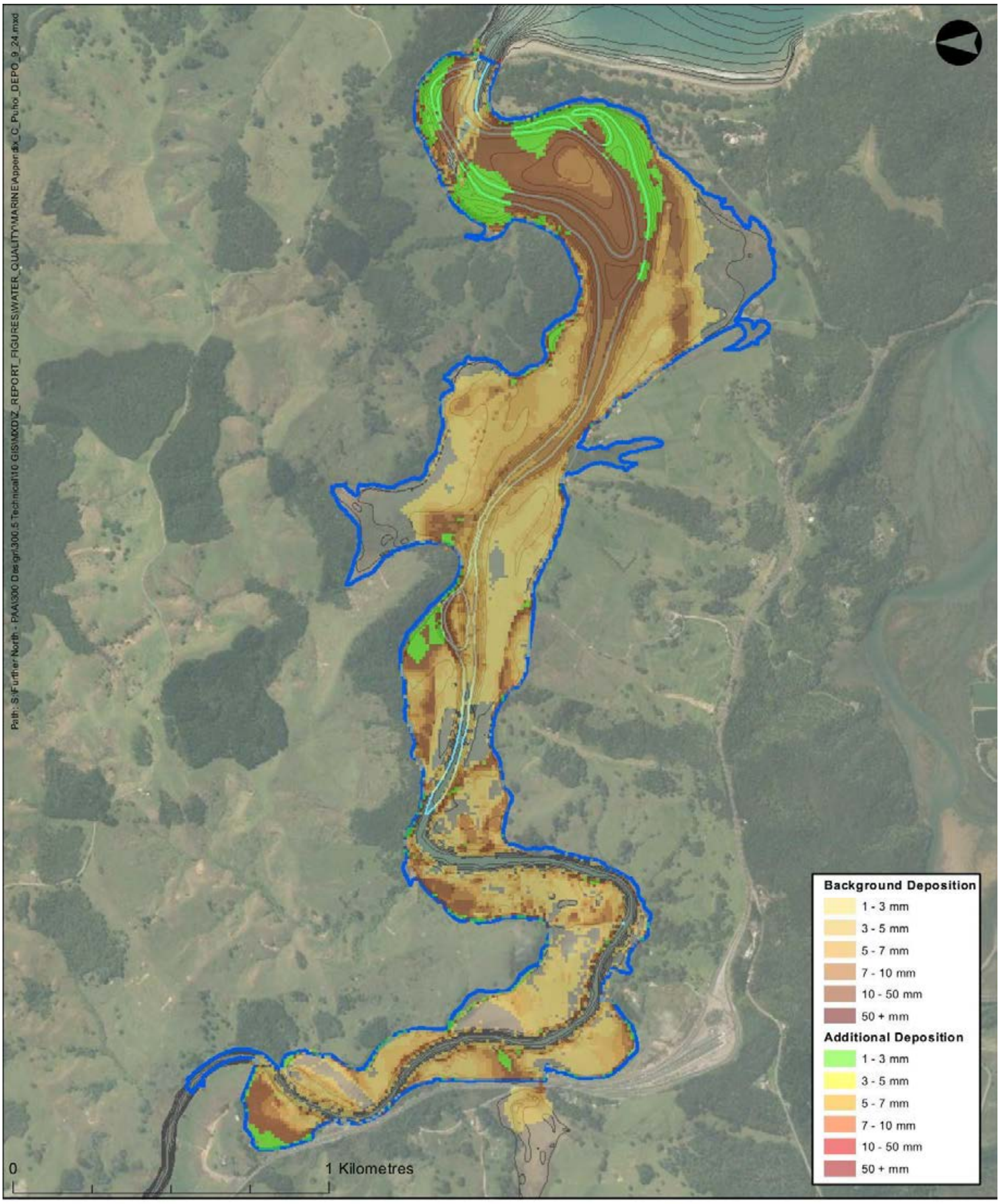
FIGURE APPENDIX C: DEPO-21



eCoast

**Puhoi Estuary Long Construction Period Deposition
3 Days Following Peak of the Rainfall Event
Calm Wind Conditions, 50Year (ARI) Rainfall Event**

FIGURE APPENDIX C: DEPO-22

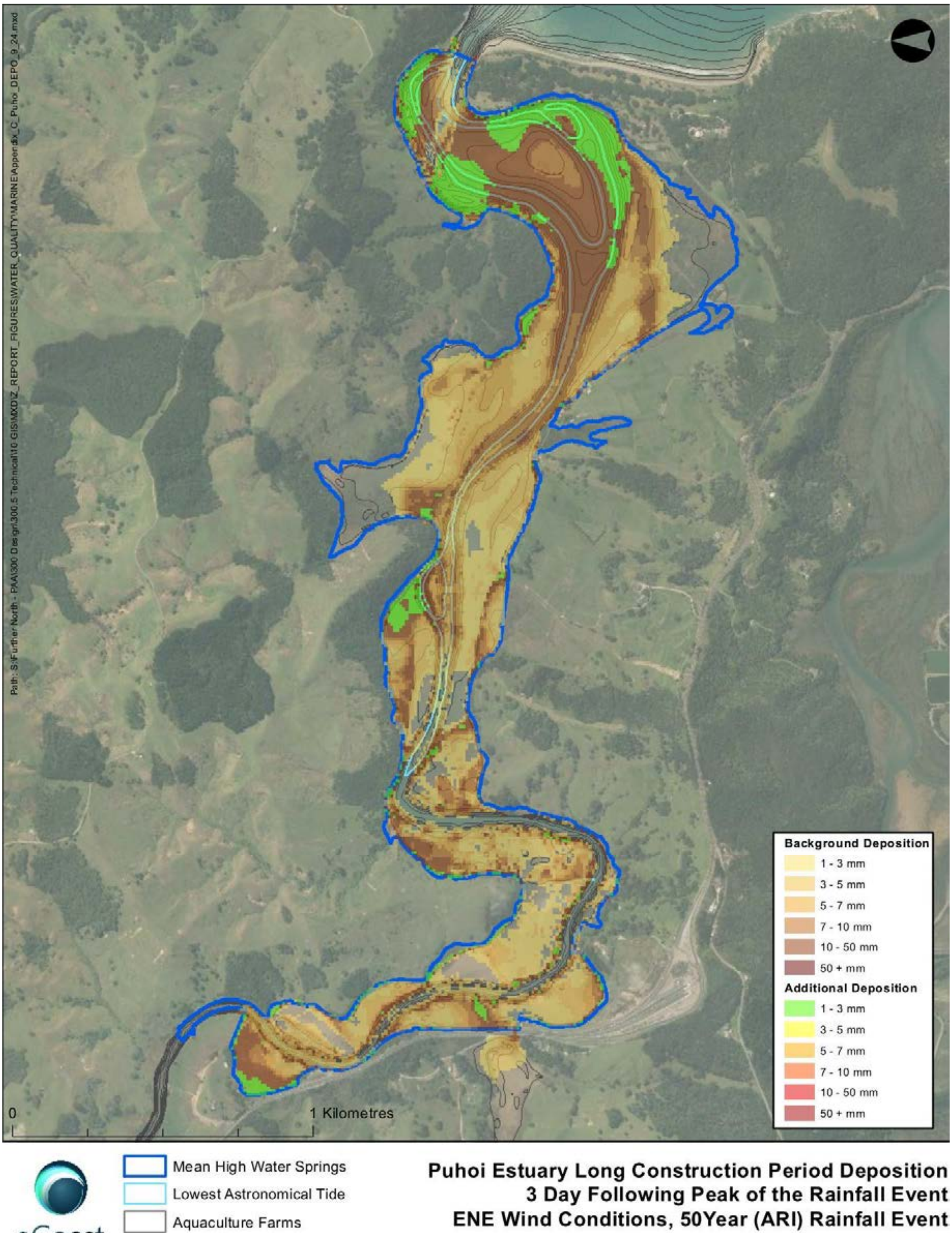


Mean High Water Springs
Lowest Astronomical Tide
Aquaculture Farms

eCoast

Puhoi Estuary Long Construction Period Deposition
1 Day Following Peak of the Rainfall Event
ENE Wind Conditions, 50Year (ARI) Rainfall Event

FIGURE APPENDIX C: DEPO-23

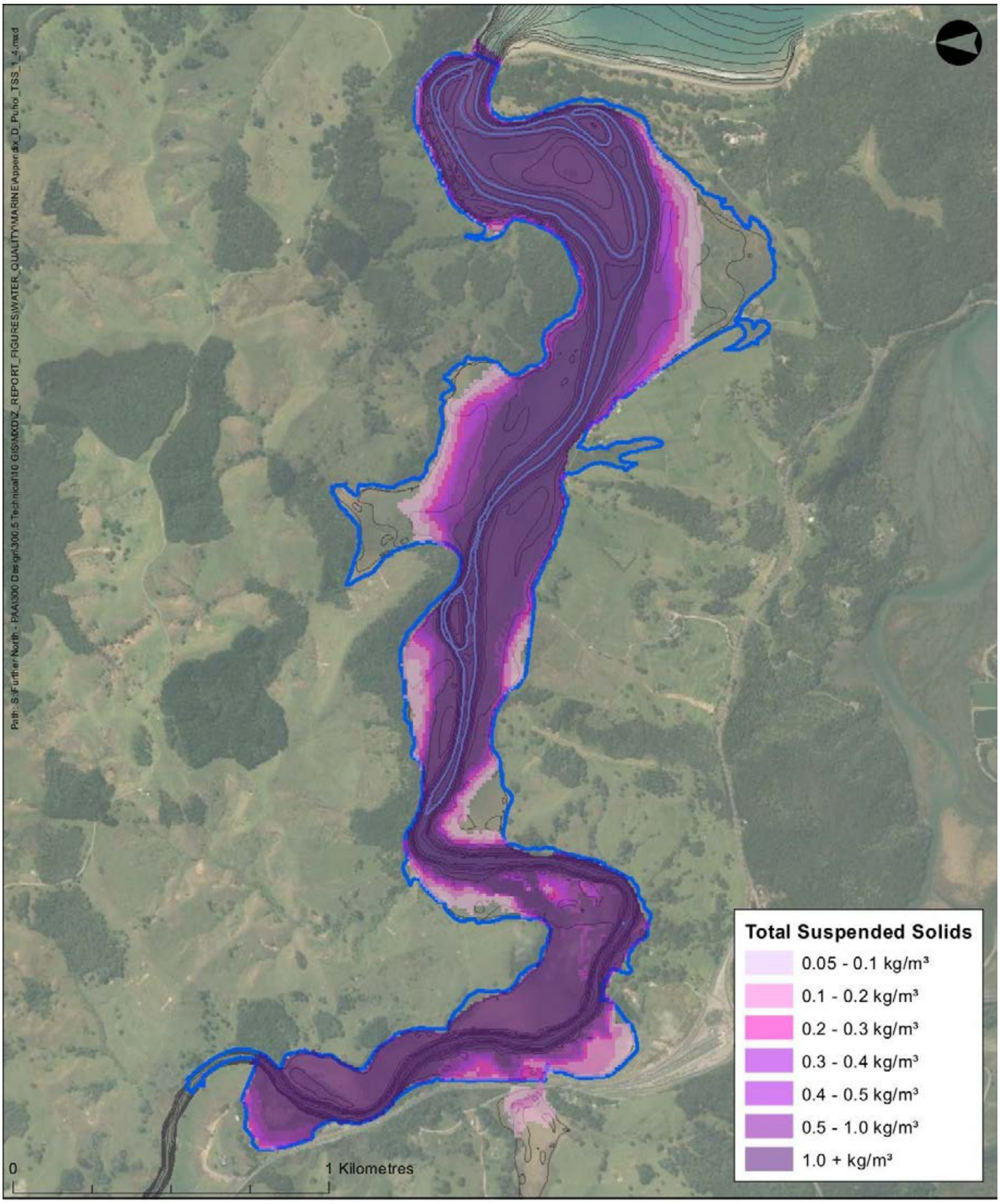


eCoast

Puhoi Estuary Long Construction Period Deposition
3 Day Following Peak of the Rainfall Event
ENE Wind Conditions, 50Year (ARI) Rainfall Event

FIGURE APPENDIX C: DEPO-24

Appendix D Pūhoi TSS plans

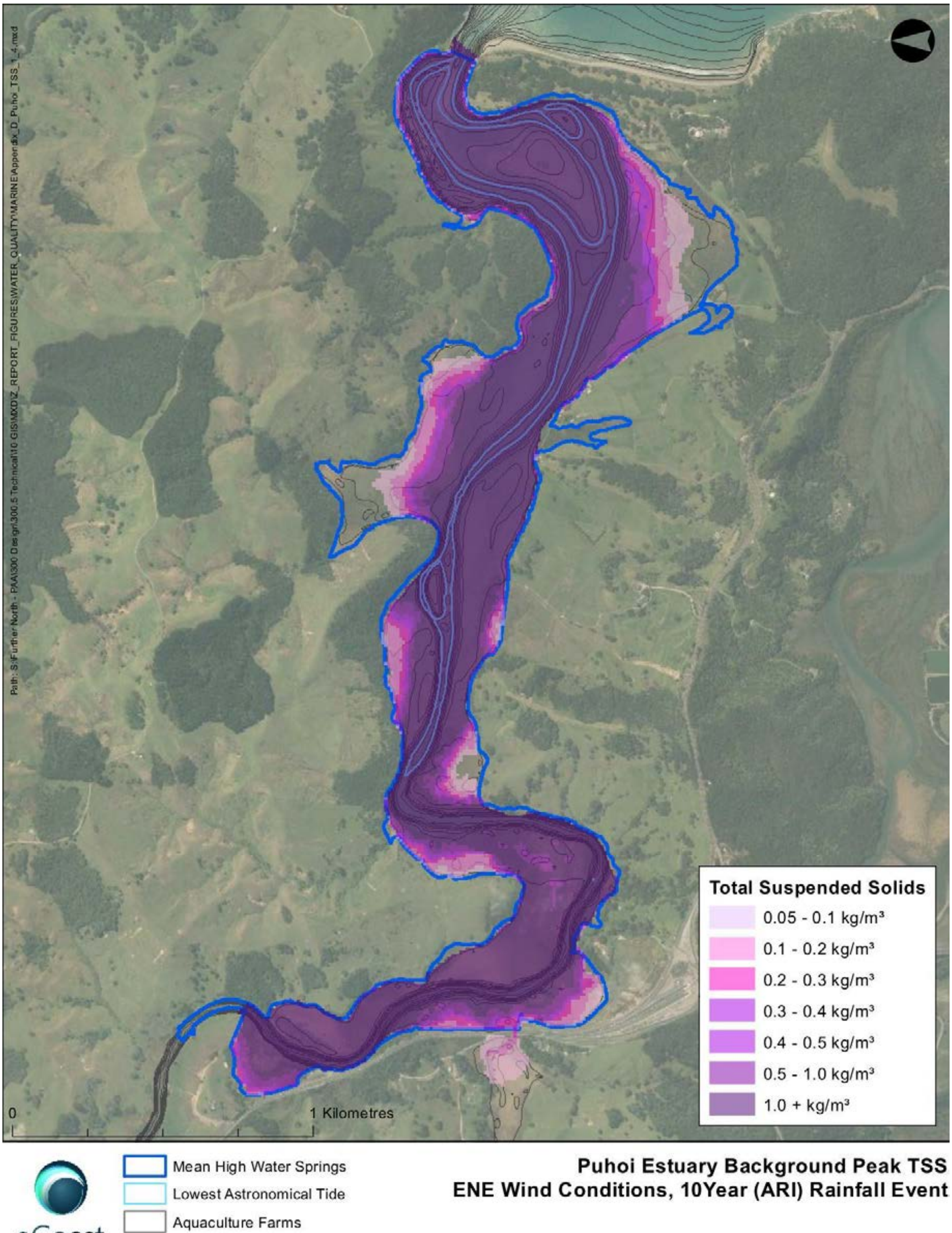


eCoast

Mean High Water Springs
Lowest Astronomical Tide
Aquaculture Farms

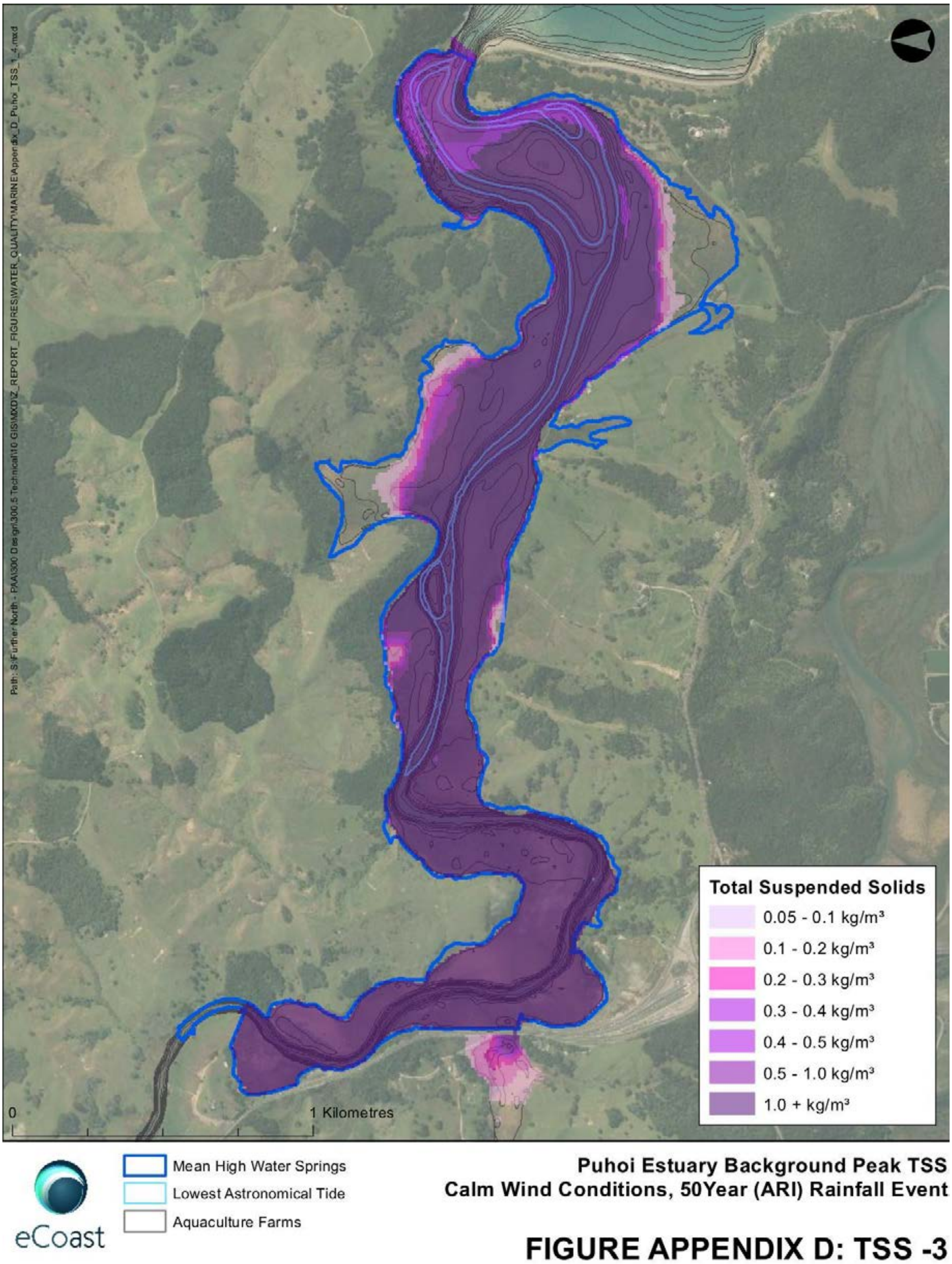
Puhoi Estuary Background Peak TSS
Calm Wind Conditions, 10Year (ARI) Rainfall Event

FIGURE APPENDIX D: TSS -1



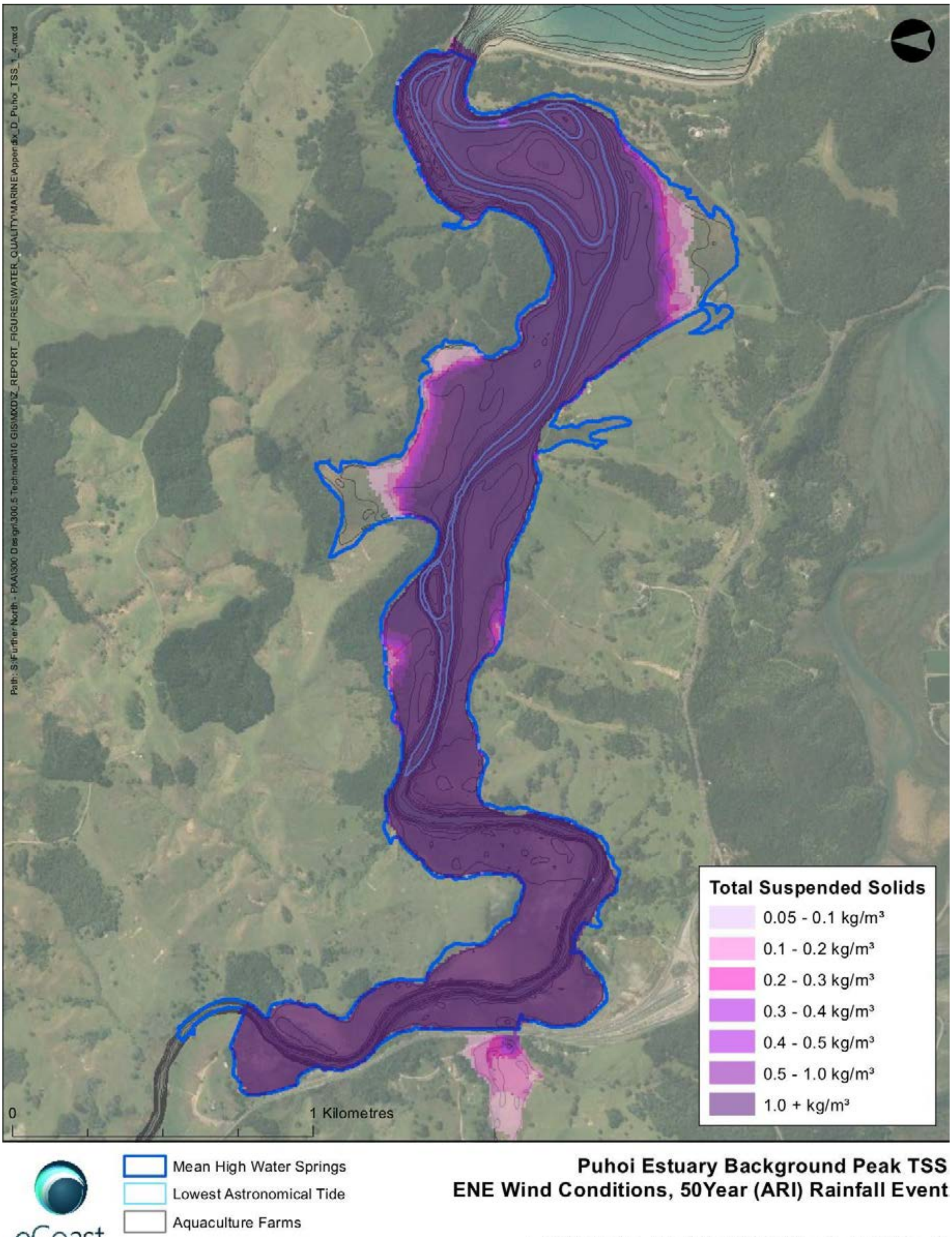
Puhoi Estuary Background Peak TSS
ENE Wind Conditions, 10Year (ARI) Rainfall Event

FIGURE APPENDIX D: TSS -2



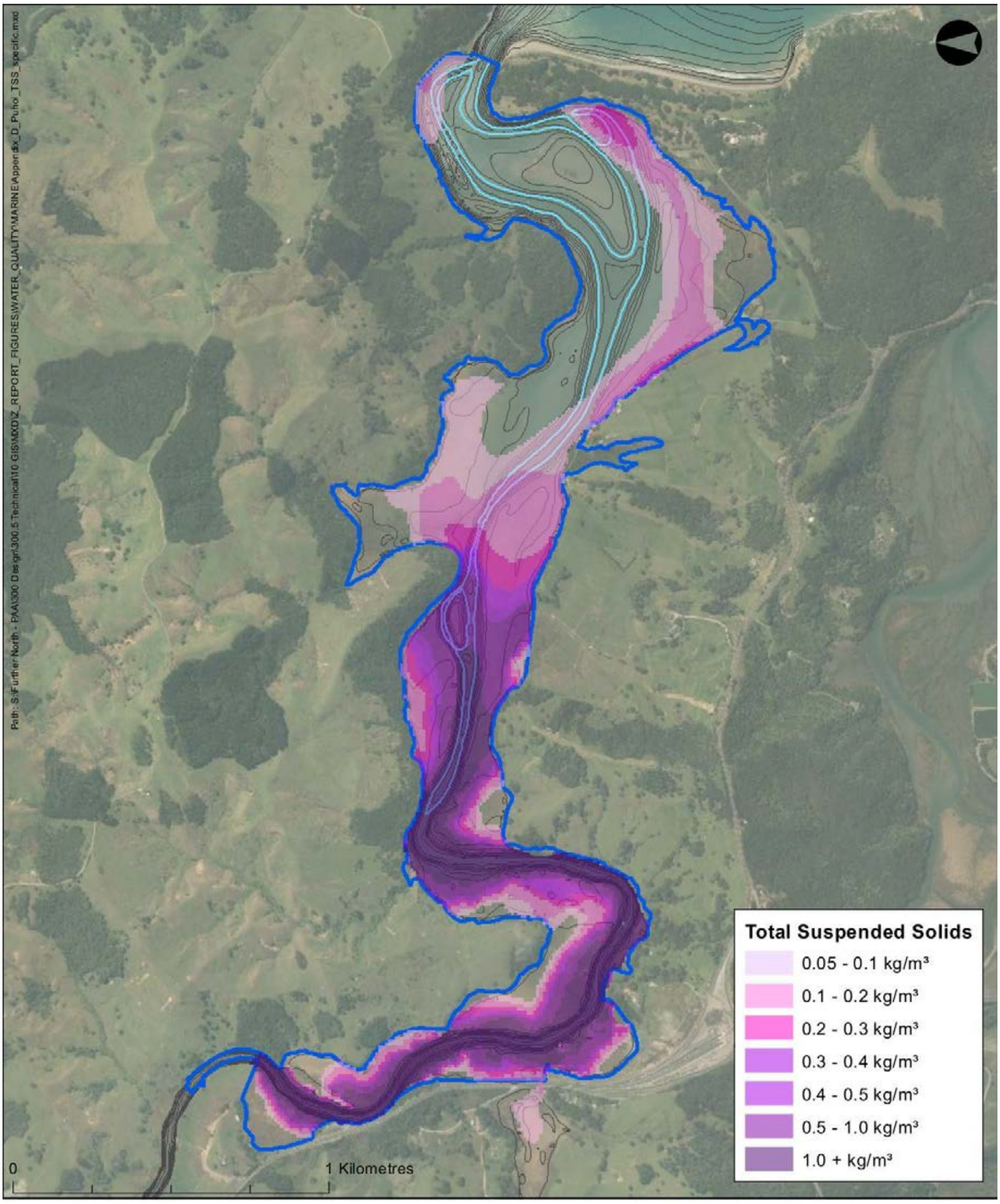
Puhoi Estuary Background Peak TSS
Calm Wind Conditions, 50Year (ARI) Rainfall Event

FIGURE APPENDIX D: TSS -3



Puhoi Estuary Background Peak TSS
ENE Wind Conditions, 50Year (ARI) Rainfall Event

FIGURE APPENDIX D: TSS -4



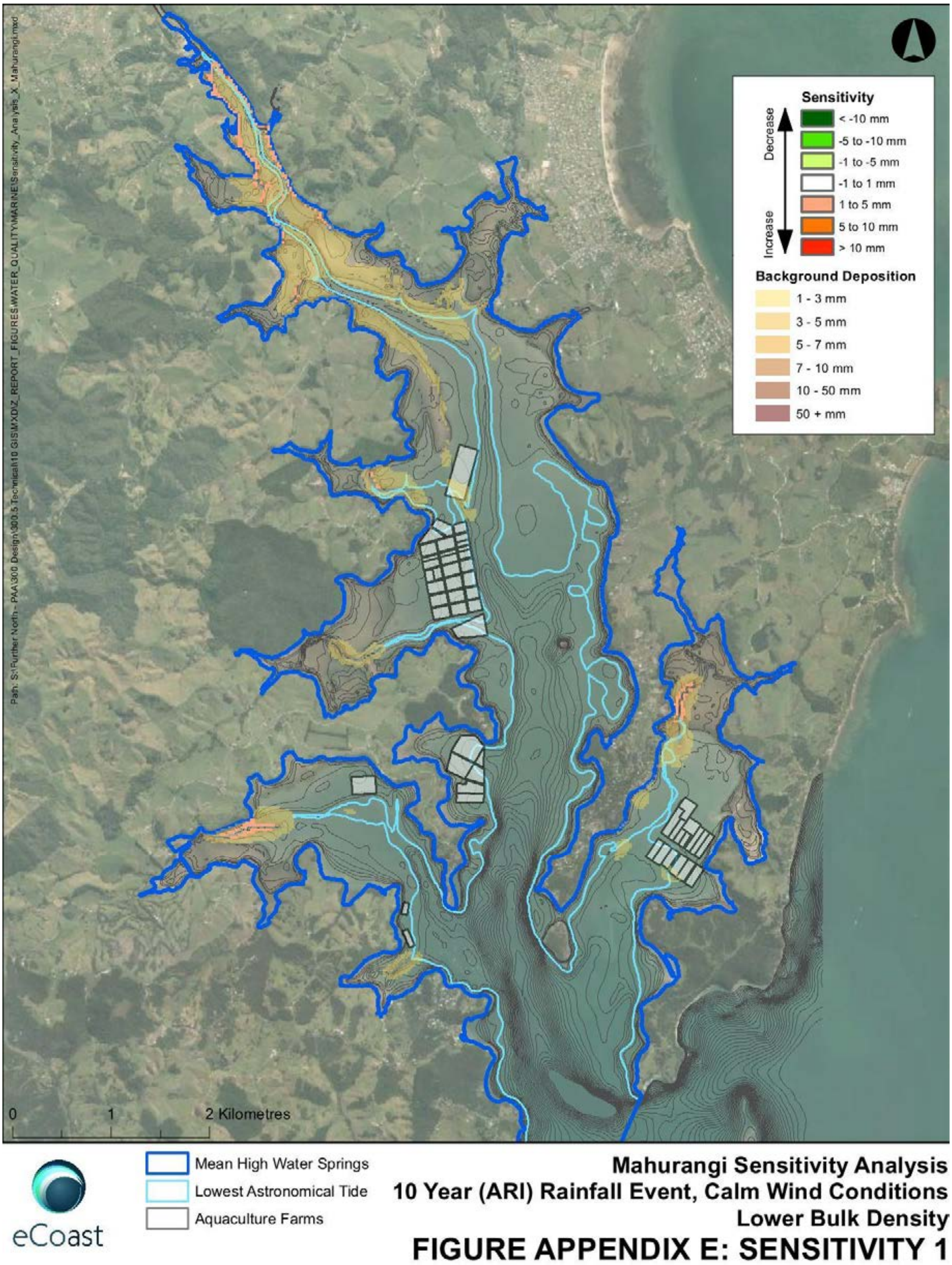
Mean High Water Springs
Lowest Astronomical Tide
Aquaculture Farms

eCoast

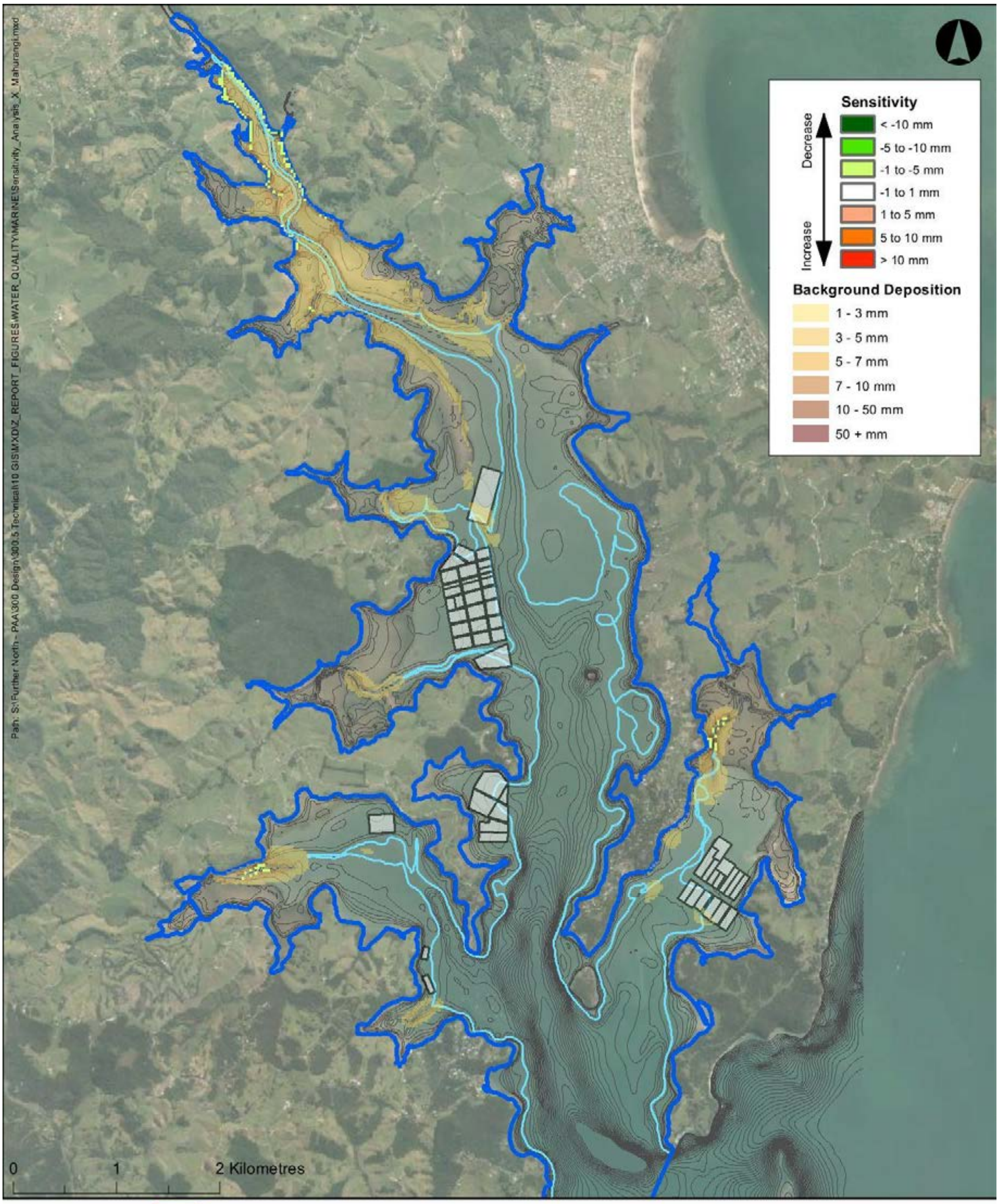
Puhoi Estuary Short Construction Period TSS
1 Days Following Peak of the Rainfall Event
ENE Wind Conditions, 50Year (ARI) Rainfall Event

FIGURE APPENDIX D: TSS -5

Appendix E Sensitivity analysis plans



Mahurangi Sensitivity Analysis
10 Year (ARI) Rainfall Event, Calm Wind Conditions
Lower Bulk Density
FIGURE APPENDIX E: SENSITIVITY 1

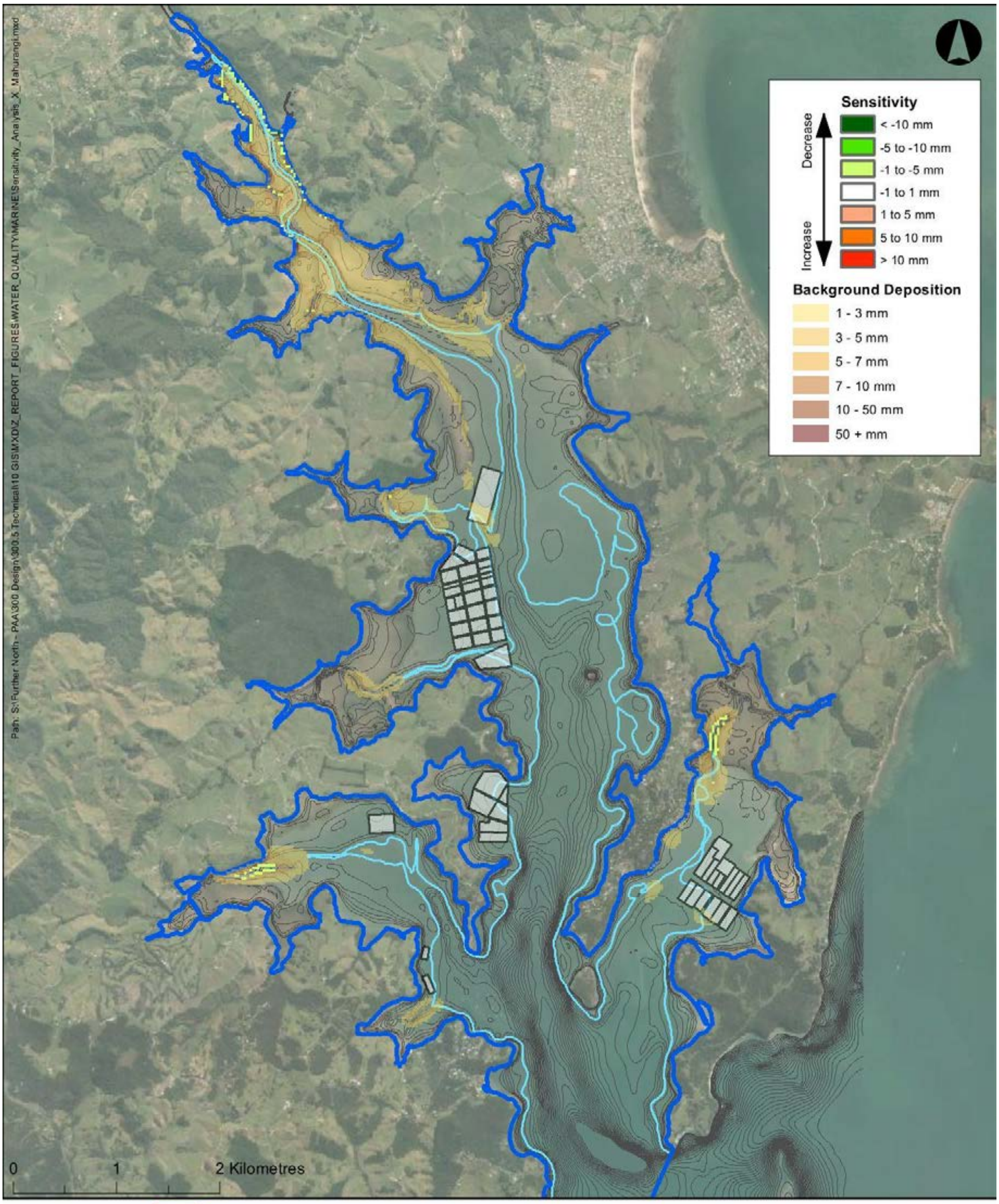


Mean High Water Springs
Lowest Astronomical Tide
Aquaculture Farms

eCoast

Mahurangi Sensitivity Analysis
10 Year (ARI) Rainfall Event, Calm Wind Conditions
Higher Bulk Density

FIGURE APPENDIX E: SENSITIVITY 2

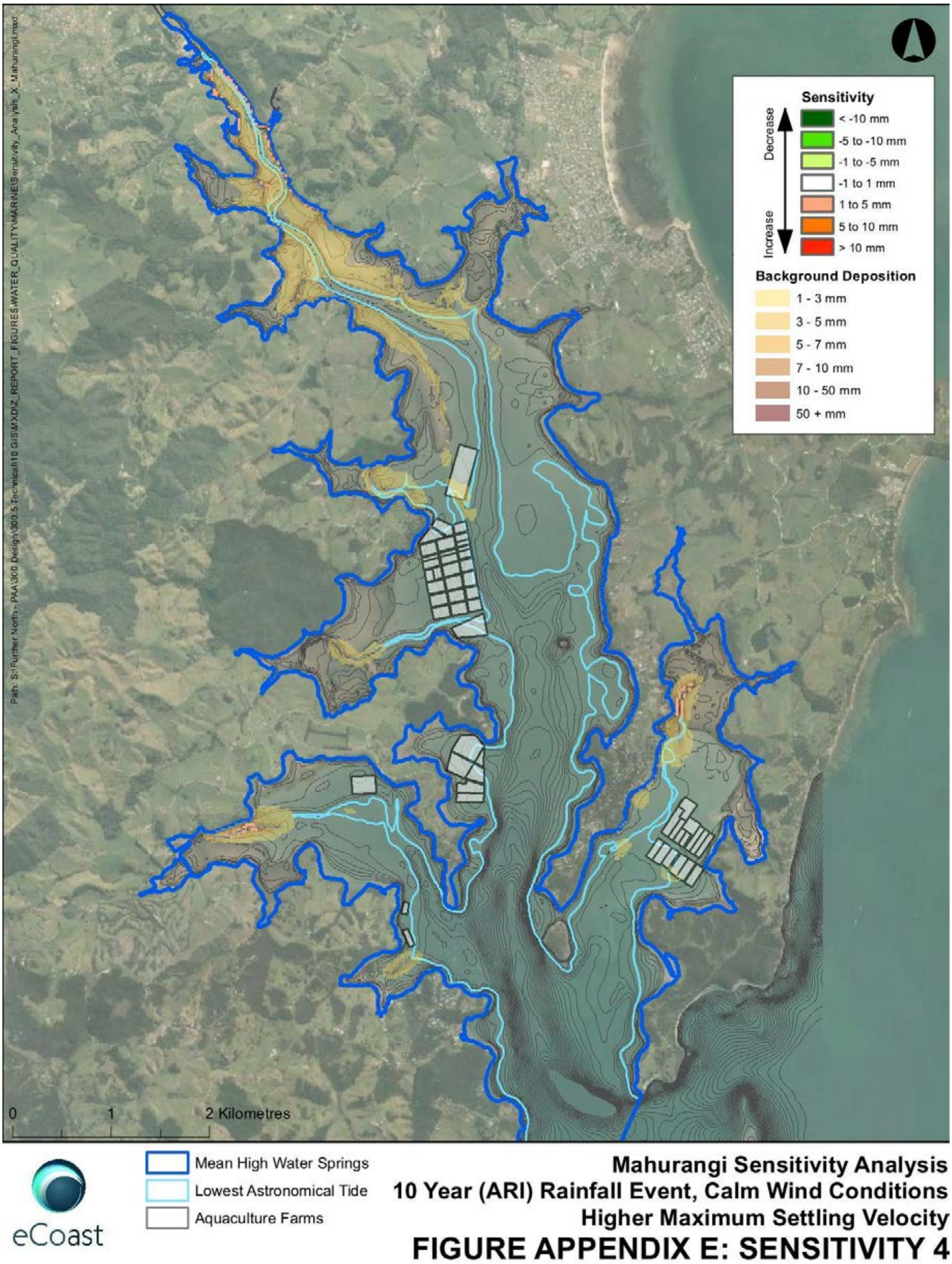


Mean High Water Springs
Lowest Astronomical Tide
Aquaculture Farms

eCoast

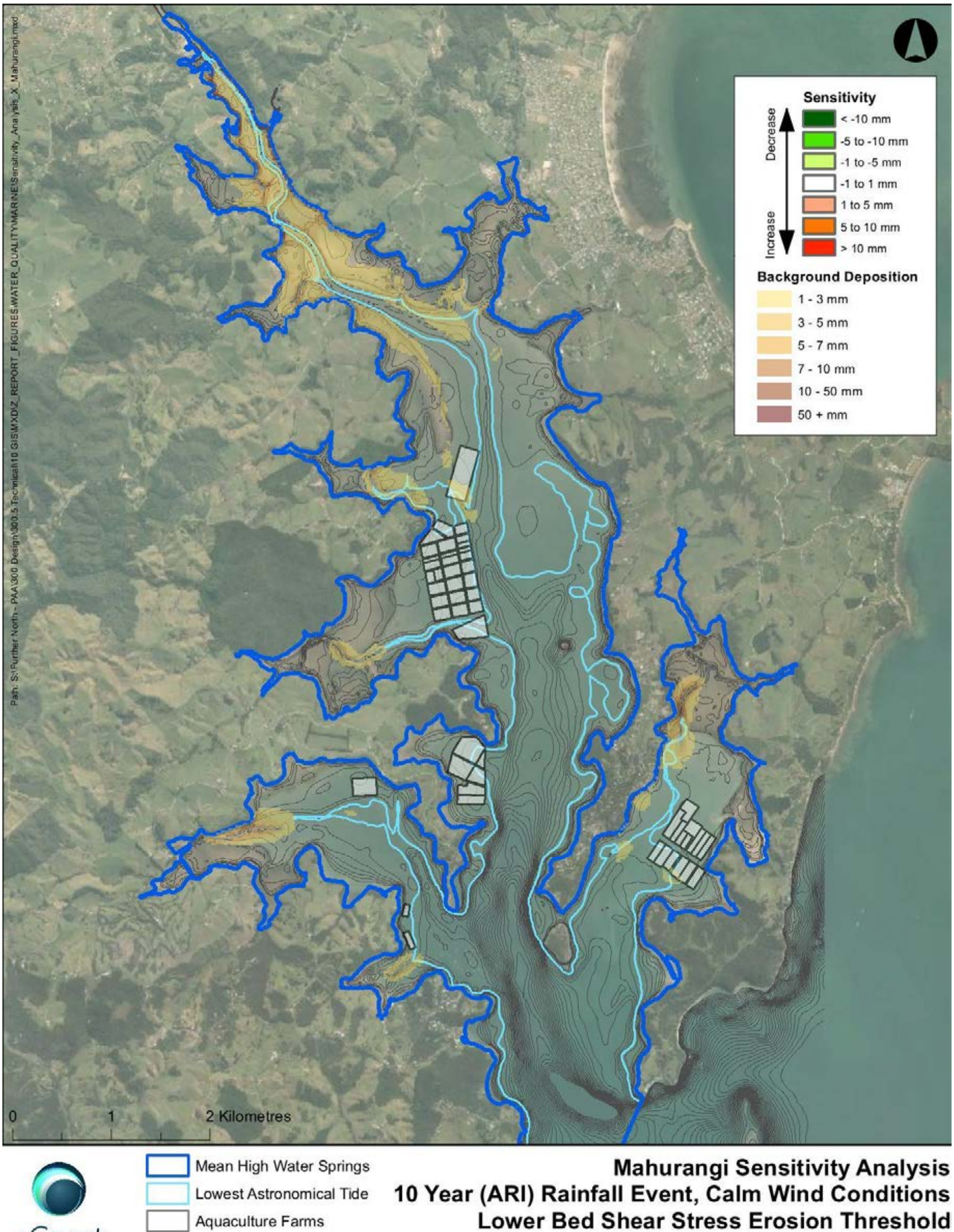
Mahurangi Sensitivity Analysis
10 Year (ARI) Rainfall Event, Calm Wind Conditions
Lower Maximum Settling Velocity

FIGURE APPENDIX E: SENSITIVITY 3



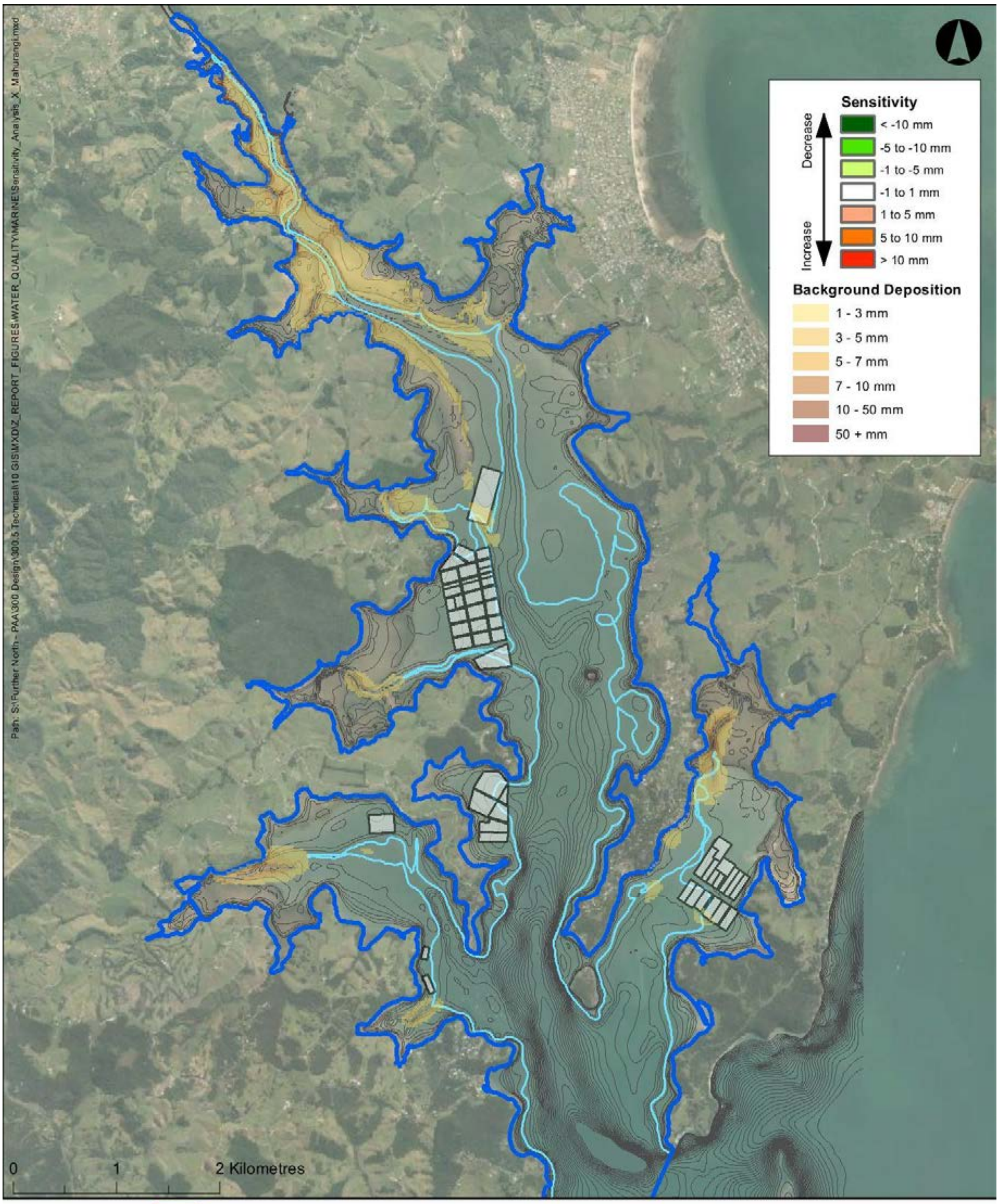
Mahurangi Sensitivity Analysis
10 Year (ARI) Rainfall Event, Calm Wind Conditions
Higher Maximum Settling Velocity

FIGURE APPENDIX E: SENSITIVITY 4



Mahurangi Sensitivity Analysis
10 Year (ARI) Rainfall Event, Calm Wind Conditions
Lower Bed Shear Stress Erosion Threshold

FIGURE APPENDIX E: SENSITIVITY 5

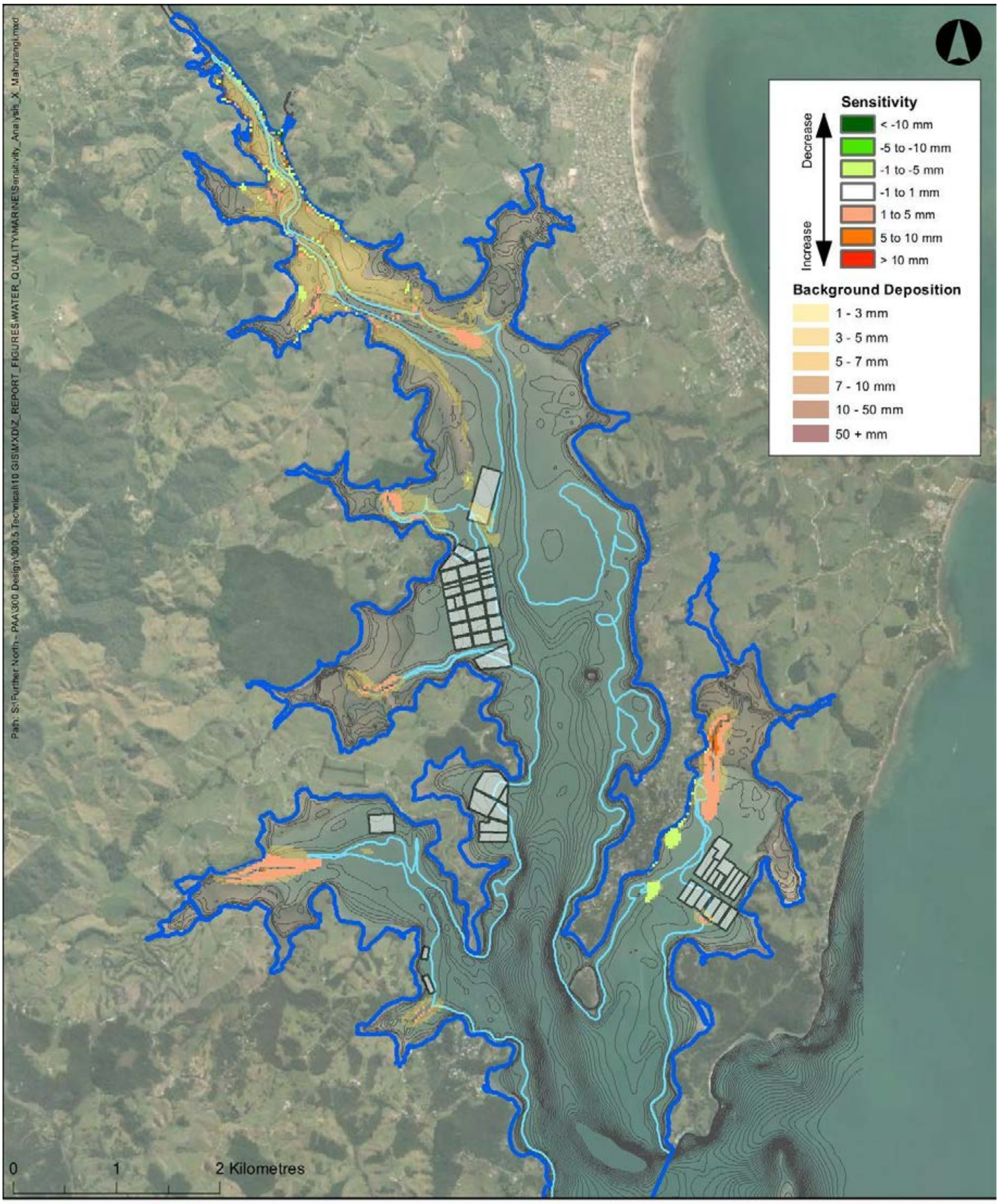


Mean High Water Springs
Lowest Astronomical Tide
Aquaculture Farms

eCoast

Mahurangi Sensitivity Analysis
10 Year (ARI) Rainfall Event, Calm Wind Conditions
Higher Bed Shear Stress Erosion Threshold

FIGURE APPENDIX E: SENSITIVITY 6

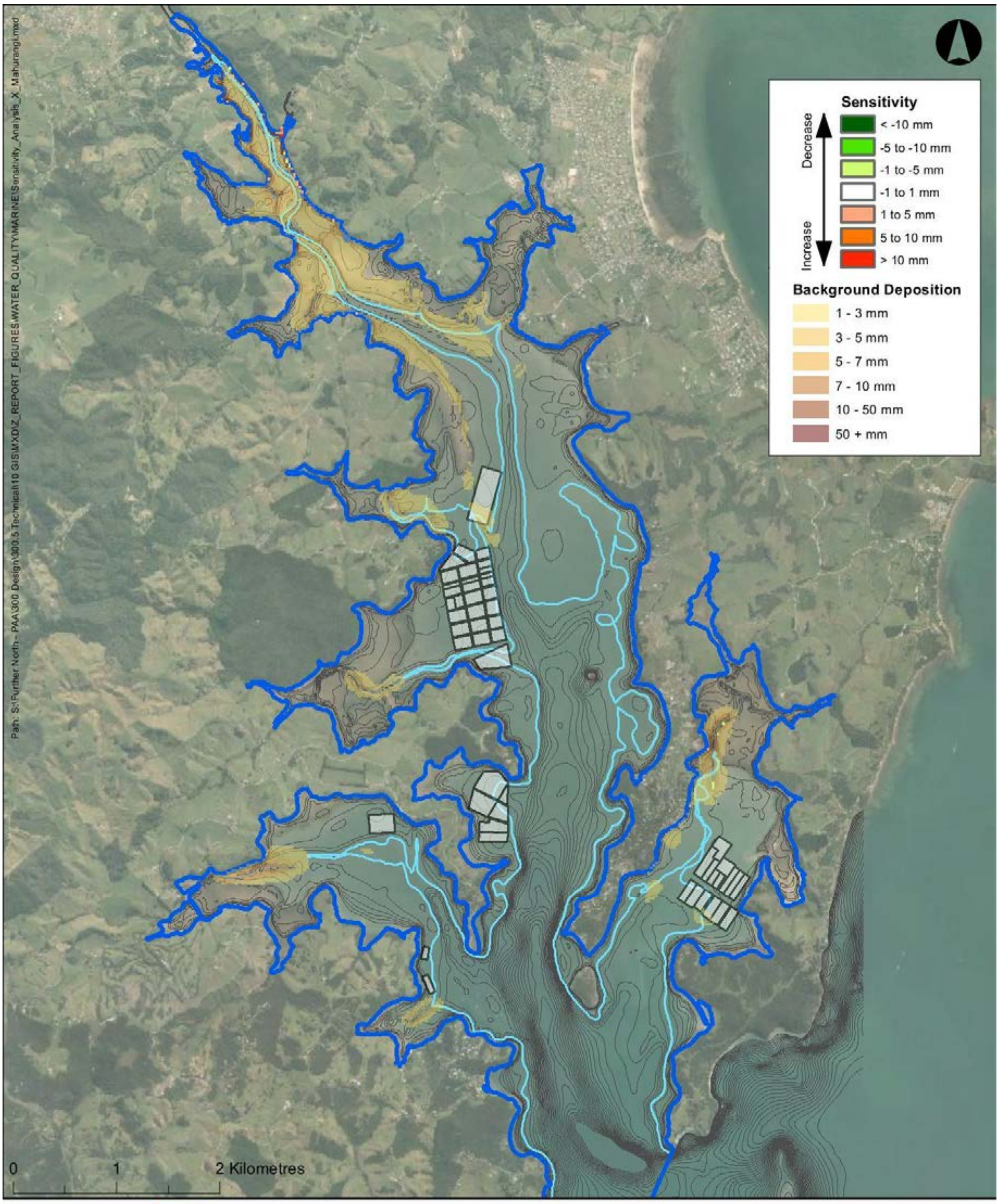


Mean High Water Springs
Lowest Astronomical Tide
Aquaculture Farms

eCoast

Mahurangi Sensitivity Analysis
10 Year (ARI) Rainfall Event, Calm Wind Conditions
Peak Inputs at Neap Tide

FIGURE APPENDIX E: SENSITIVITY 7

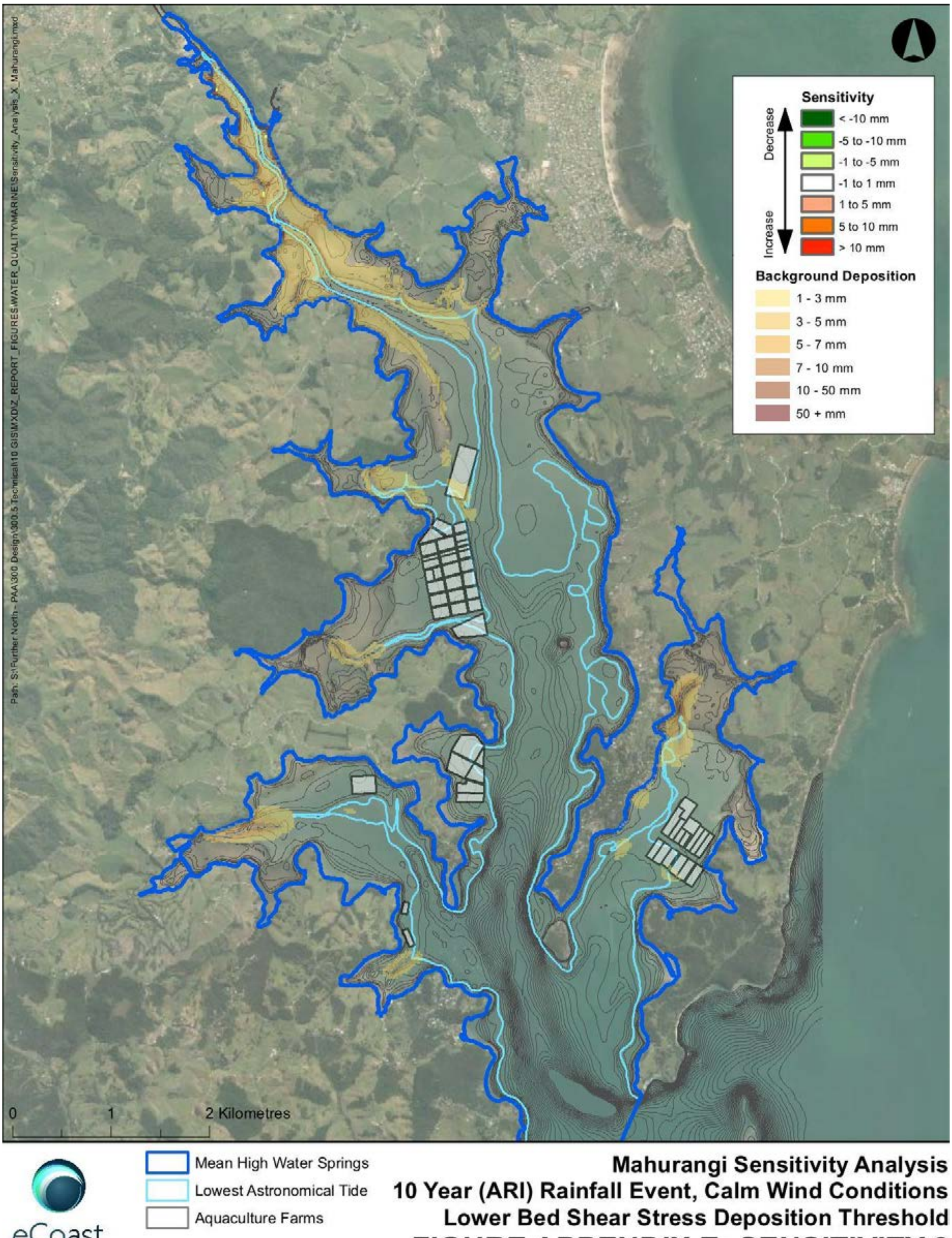


Mean High Water Springs
Lowest Astronomical Tide
Aquaculture Farms

eCoast

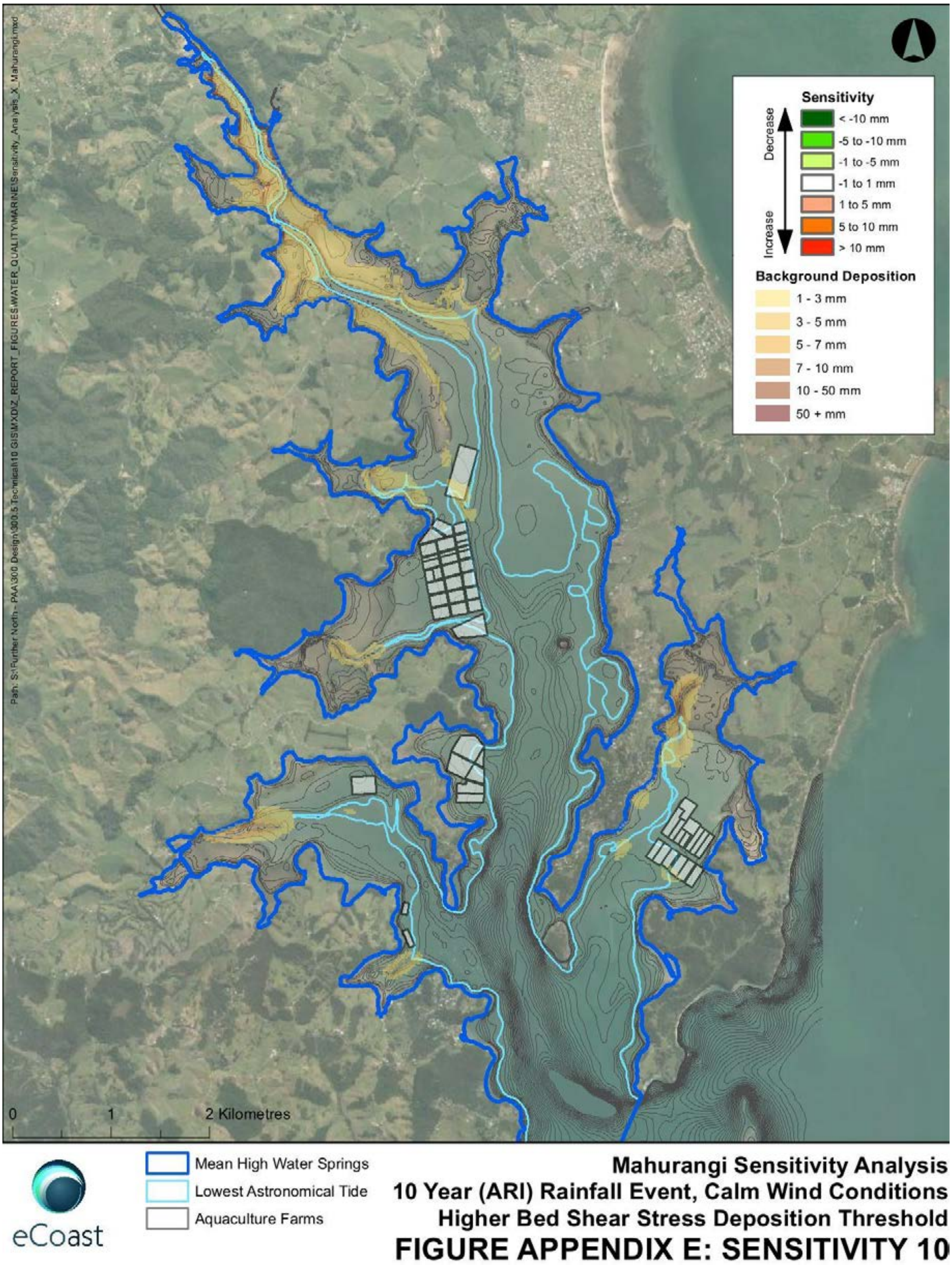
Mahurangi Sensitivity Analysis
10 Year (ARI) Rainfall Event, Calm Wind Conditions
Peak Inputs at Spring Tide

FIGURE APPENDIX E: SENSITIVITY 8

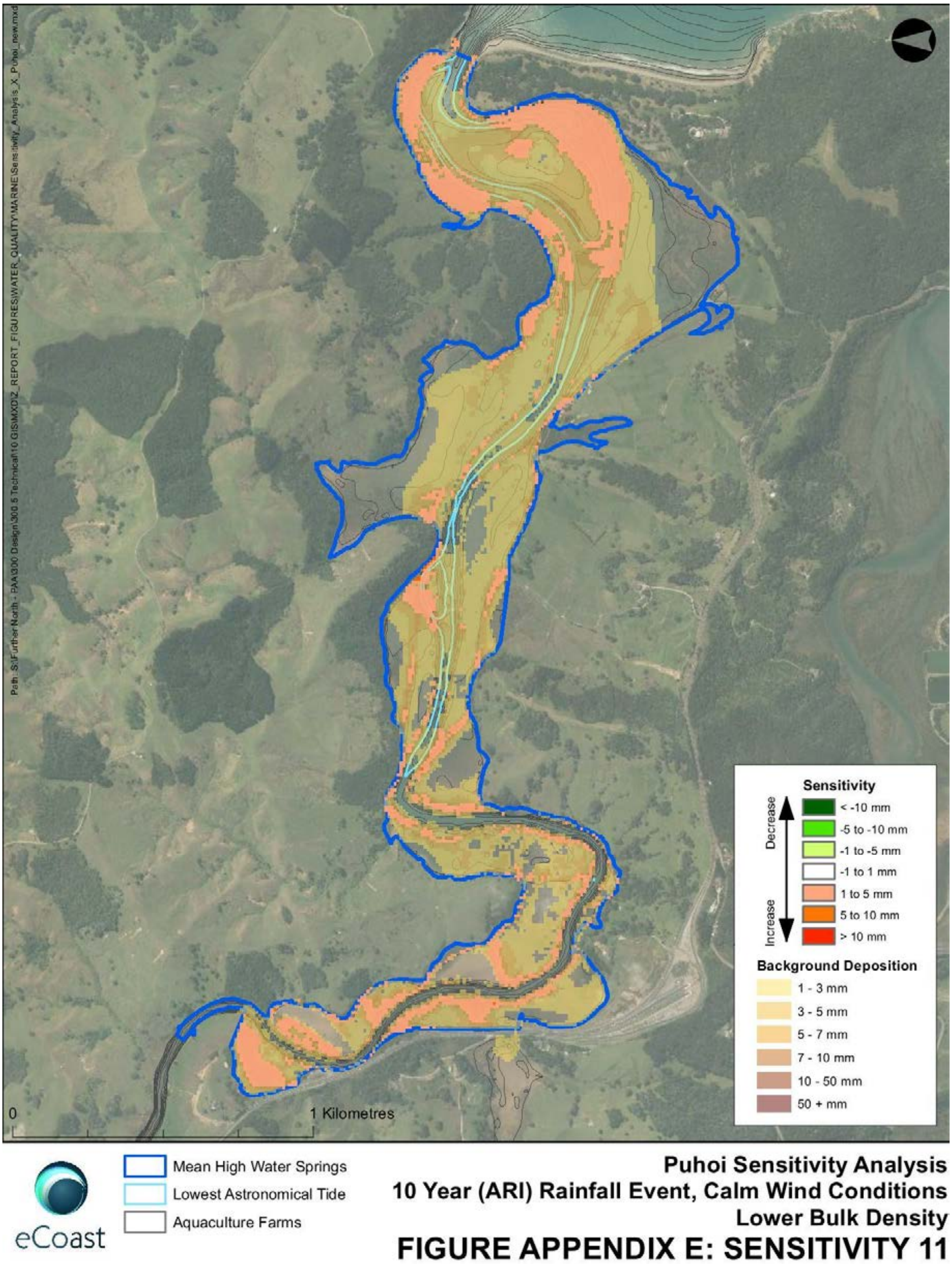


Mahurangi Sensitivity Analysis
10 Year (ARI) Rainfall Event, Calm Wind Conditions
Lower Bed Shear Stress Deposition Threshold

FIGURE APPENDIX E: SENSITIVITY 9

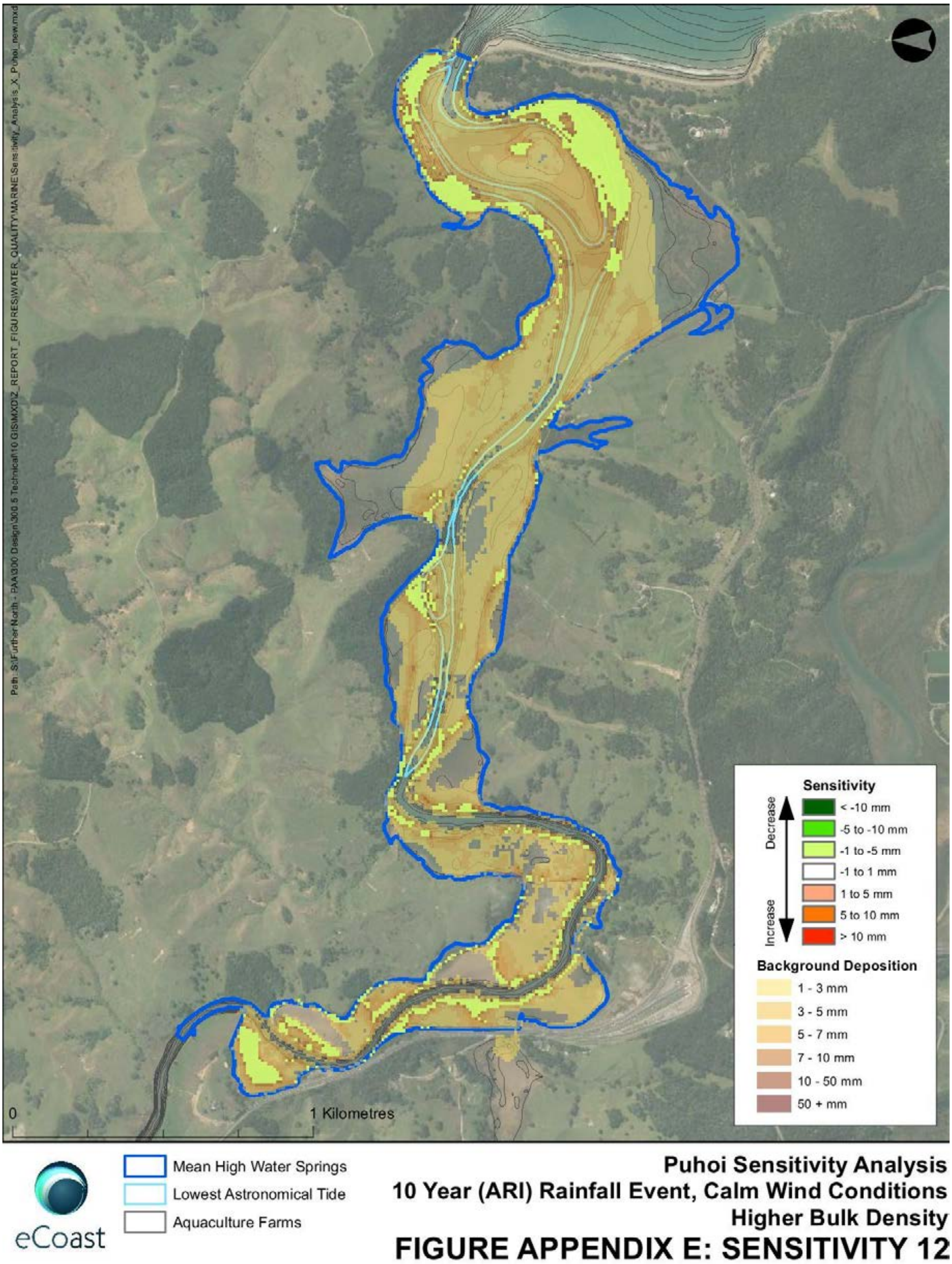


Mahurangi Sensitivity Analysis
10 Year (ARI) Rainfall Event, Calm Wind Conditions
Higher Bed Shear Stress Deposition Threshold
FIGURE APPENDIX E: SENSITIVITY 10



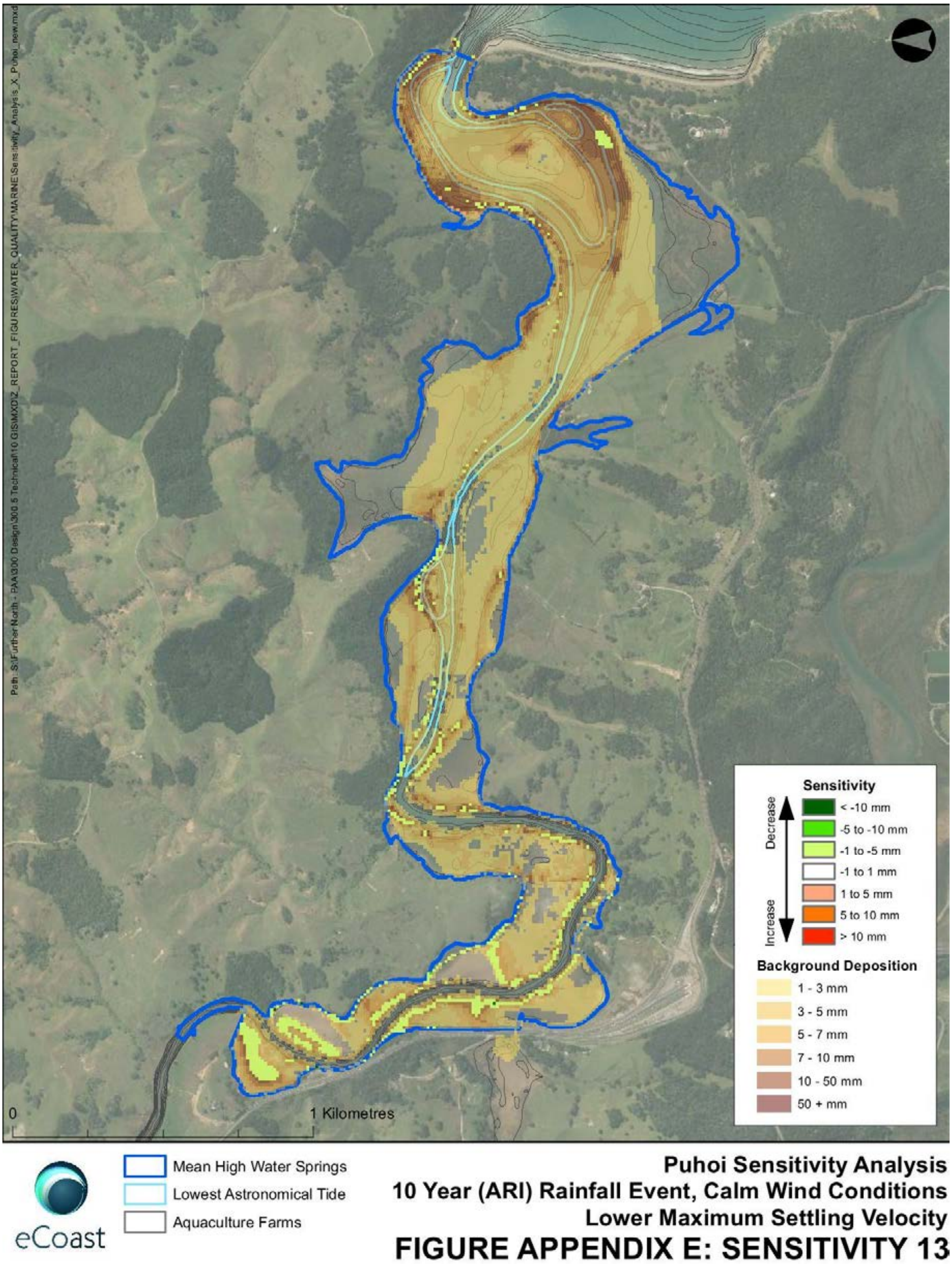
Puhoi Sensitivity Analysis
10 Year (ARI) Rainfall Event, Calm Wind Conditions
Lower Bulk Density

FIGURE APPENDIX E: SENSITIVITY 11



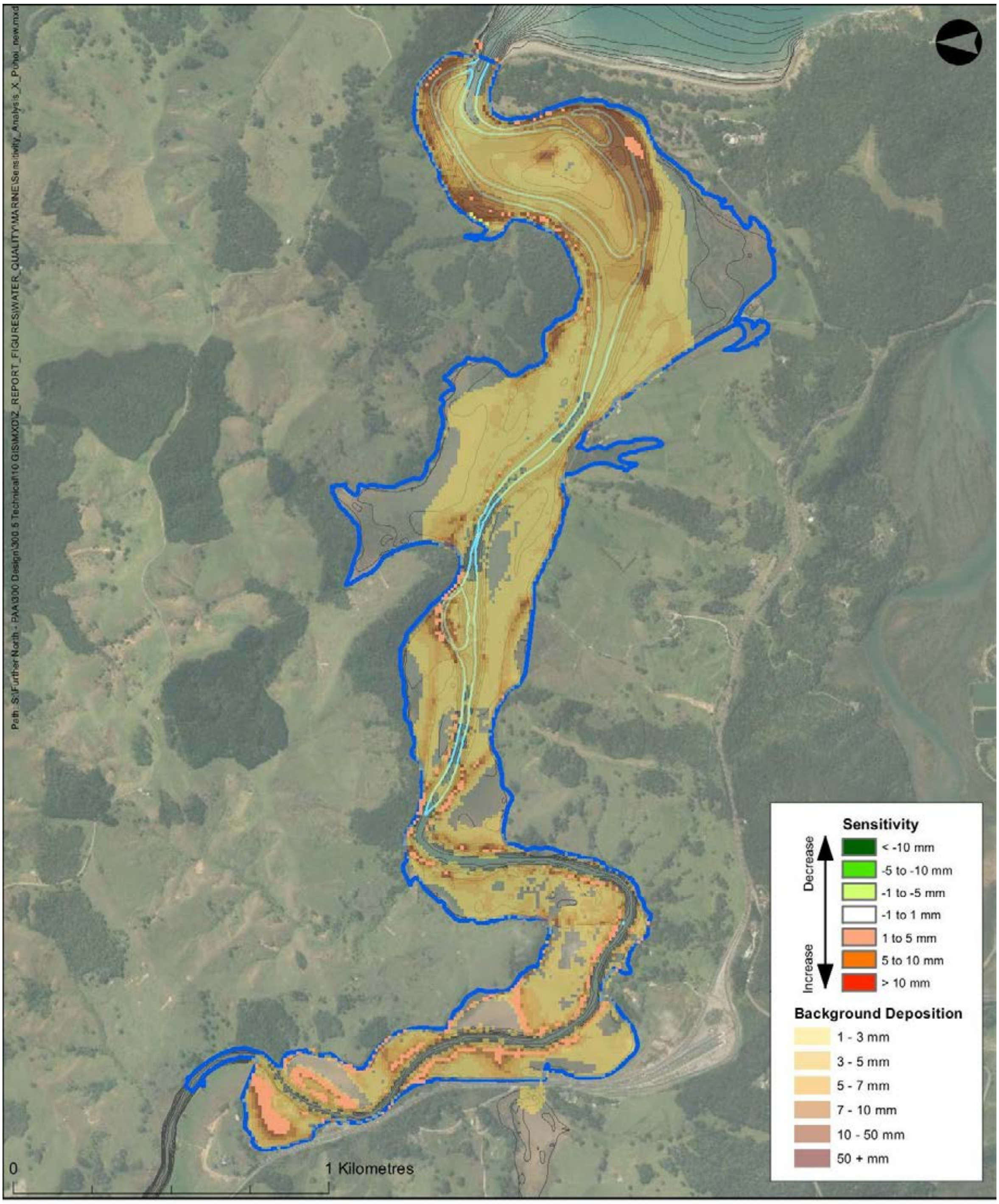
Puhoi Sensitivity Analysis
10 Year (ARI) Rainfall Event, Calm Wind Conditions
Higher Bulk Density

FIGURE APPENDIX E: SENSITIVITY 12



Puhoi Sensitivity Analysis
10 Year (ARI) Rainfall Event, Calm Wind Conditions
Lower Maximum Settling Velocity

FIGURE APPENDIX E: SENSITIVITY 13

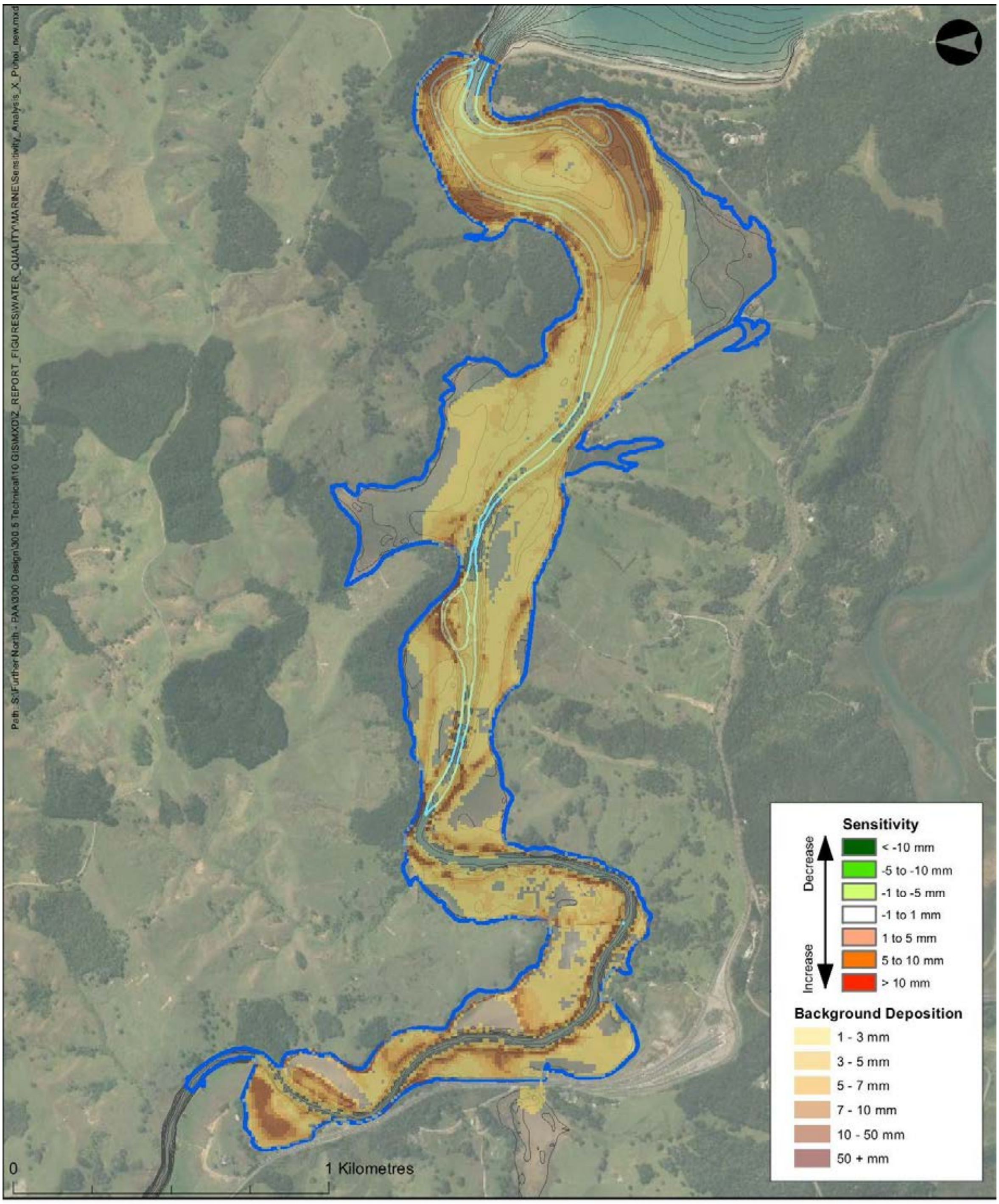


eCoast

Mean High Water Springs
Lowest Astronomical Tide
Aquaculture Farms

Puhoi Sensitivity Analysis
10 Year (ARI) Rainfall Event, Calm Wind Conditions
Higher Maximum Settling Velocity

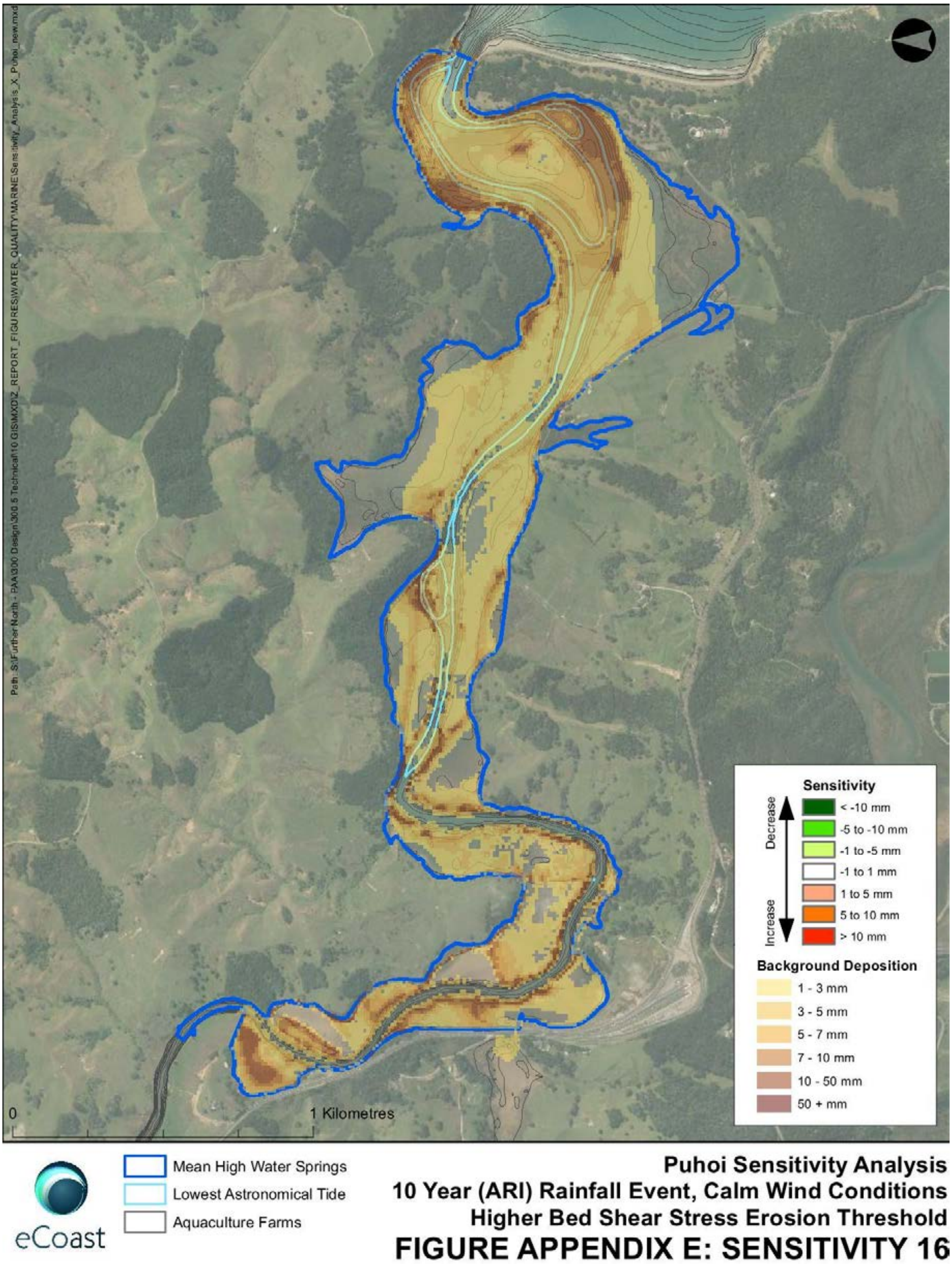
FIGURE APPENDIX E: SENSITIVITY 14



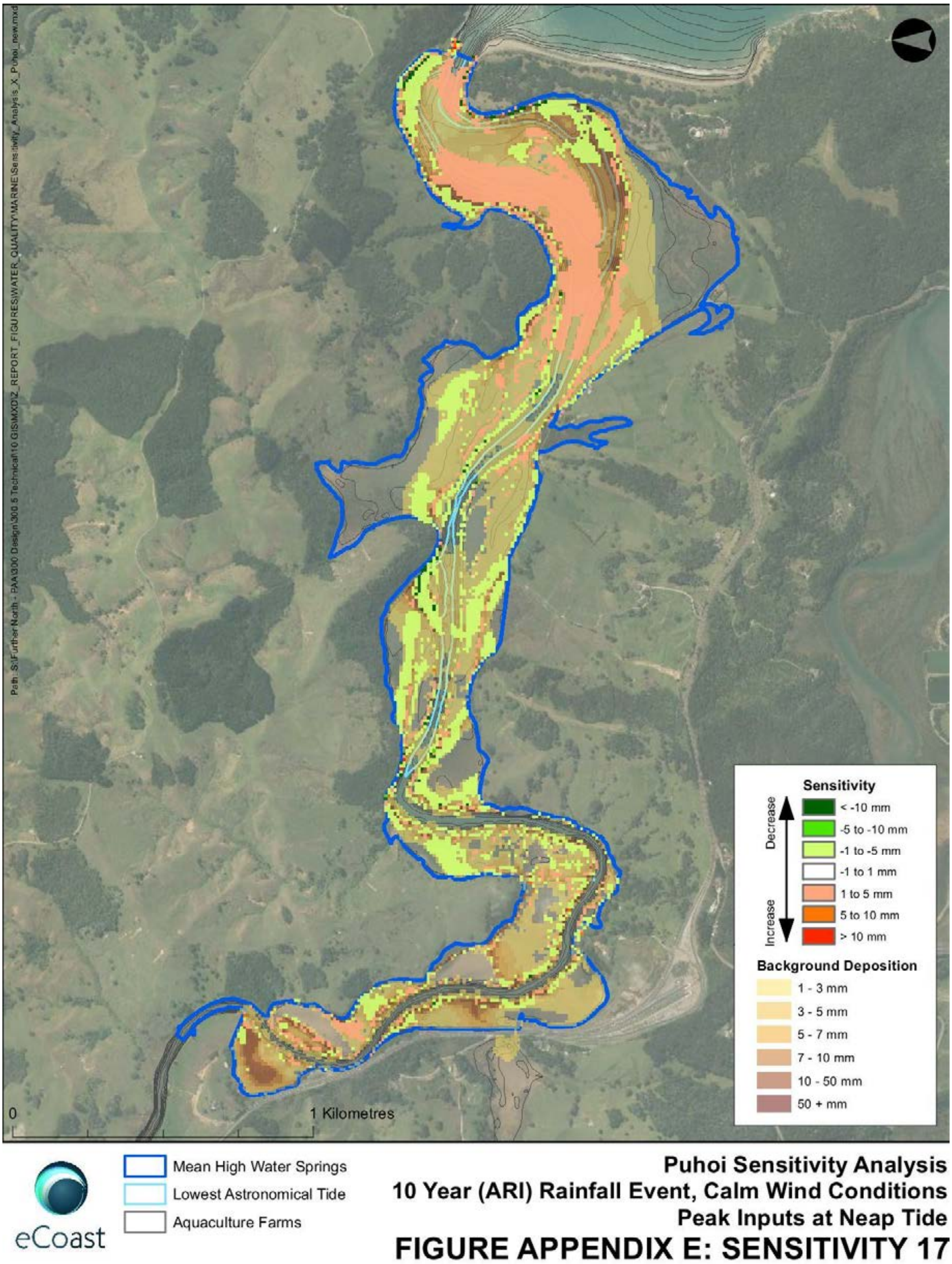
Mean High Water Springs
Lowest Astronomical Tide
Aquaculture Farms

eCoast

Puhoi Sensitivity Analysis
10 Year (ARI) Rainfall Event, Calm Wind Conditions
Lower Bed Shear Stress Erosion Threshold
FIGURE APPENDIX E: SENSITIVITY 15

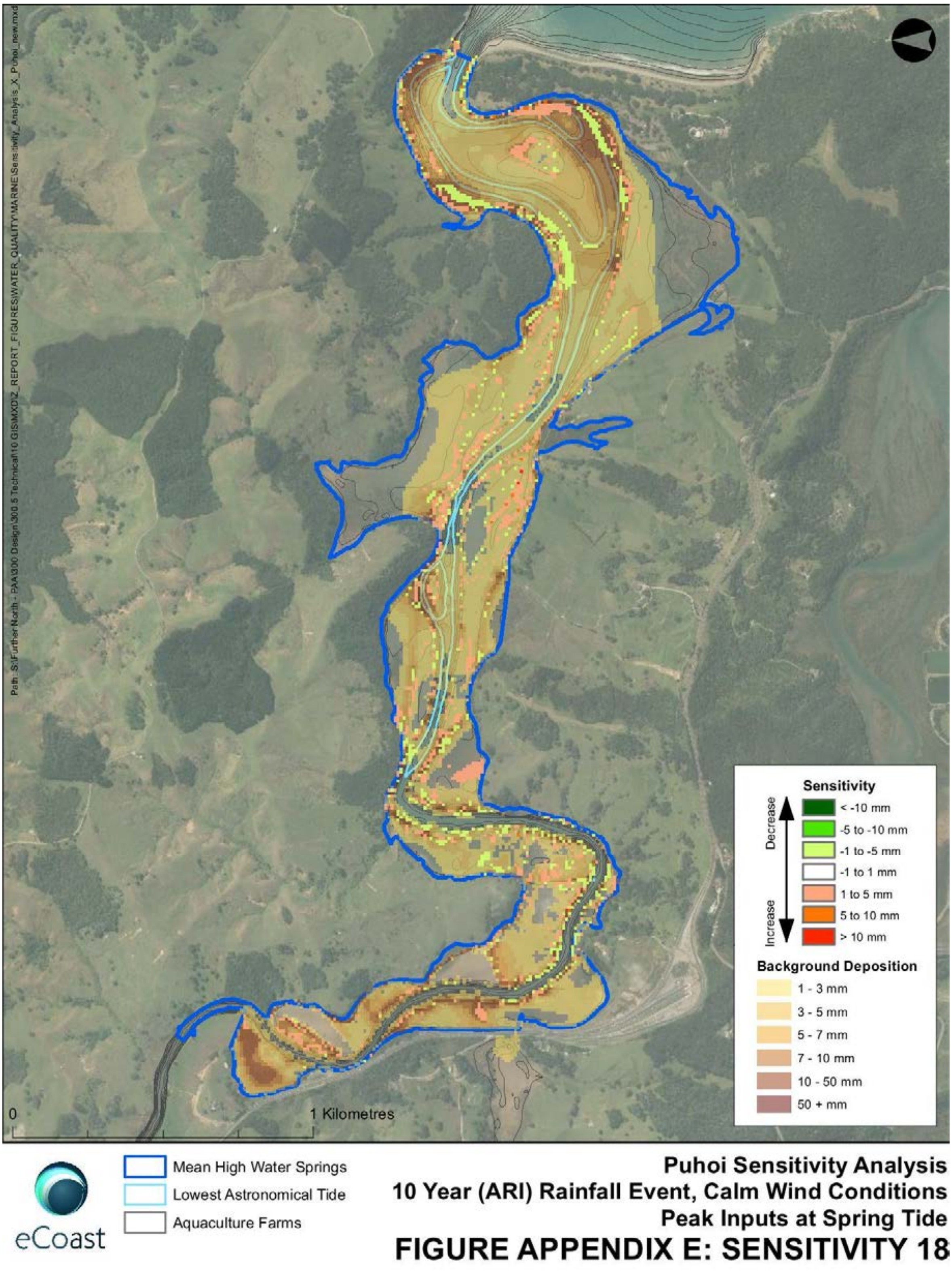


Puhoi Sensitivity Analysis
10 Year (ARI) Rainfall Event, Calm Wind Conditions
Higher Bed Shear Stress Erosion Threshold
FIGURE APPENDIX E: SENSITIVITY 16



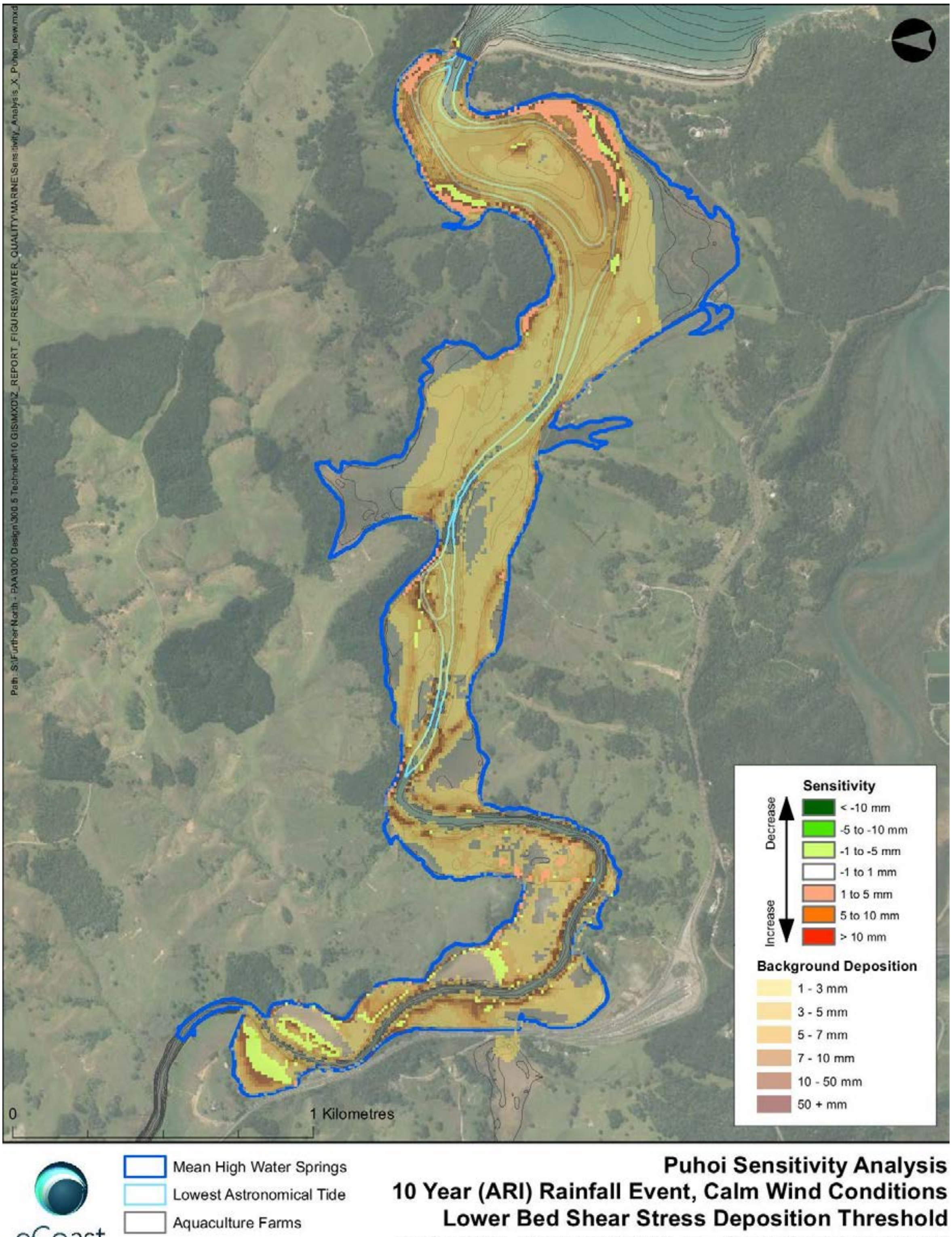
Puhoi Sensitivity Analysis
10 Year (ARI) Rainfall Event, Calm Wind Conditions
Peak Inputs at Neap Tide

FIGURE APPENDIX E: SENSITIVITY 17

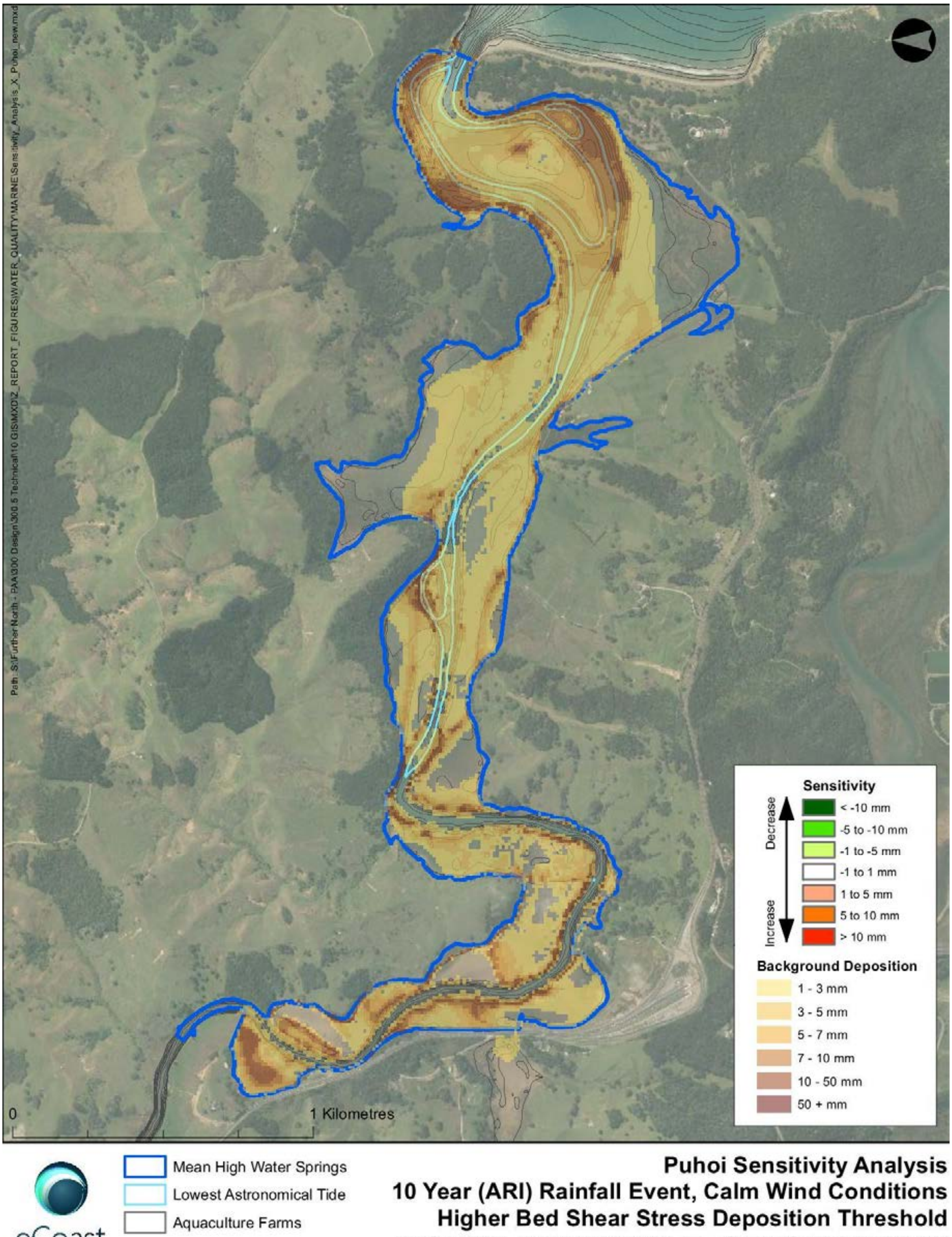


Puhoi Sensitivity Analysis
10 Year (ARI) Rainfall Event, Calm Wind Conditions
Peak Inputs at Spring Tide

FIGURE APPENDIX E: SENSITIVITY 18



Puhoi Sensitivity Analysis
10 Year (ARI) Rainfall Event, Calm Wind Conditions
Lower Bed Shear Stress Deposition Threshold
FIGURE APPENDIX E: SENSITIVITY 19



Puhoi Sensitivity Analysis
10 Year (ARI) Rainfall Event, Calm Wind Conditions
Higher Bed Shear Stress Deposition Threshold
FIGURE APPENDIX E: SENSITIVITY 20