Cyclone Gabrielle Baseline Sampling 2023

An overview of data collected following Cyclone Gabrielle
September 2023

Report prepared by Alex Dickson and Dan Bloomer (LandWISE Inc.), Alec Mackay (AgResearch), Alan Palmer (Massey University), Sally Anderson (Market Access Solutionz).

With additional contribution from Jo Cavanagh (Manaaki Whenua-Landcare Research), Nicole Schon (AgResearch) and Megan Devane (ESR)

Executive Summary

- This report summarises a comprehensive survey of sites impacted by Cyclone Gabrielle in Hawke's Bay, Tairawhiti, Northland, documenting flooding, wetness, sediment deposits, sediment and soil physical and nutrient status, potential contamination, and grower responses.
- The focus was on cropping land, vineyards, and orchards, the land use types most significantly impacted.
- Results are presented from field and laboratory analyses of 155 sediment and soil samples from 116 sites located on the highly productive soils of Hawke's Bay, Tairawhiti and Northland.
- On 13 February 2023, Cyclone Gabrielle tore across the North Island, causing devastation in Hawke's Bay, Tairawhiti, Northland and Auckland, with significant impact felt in parts of the Manawatu, Central Plateau and Wairarapa. The cyclone decimated homes, productive land, crops, and livelihoods, with an estimated cost of rebuilding in the billions of dollars.
- While the biggest impact of the cyclone on Hawke's Bay and Tairawhiti has been sediment deposition, extended waterlogging preventing sowing and harvesting has been the main challenge in Northland. Extended wetness in all regions over the last 18-24 months was already an issue for growers, prior to Cyclone Gabrielle.
- Following the Cyclone, a group of organisations came together to provide immediate advice to affected growers. Activities broadened to capture data on the initial impact of the cyclone on farmers, growers, and their productive land, **to fill a major gap in knowledge of the behaviour of soils and sediments in the weeks and months immediately following a storm event**.
- Sediment deposition on the Hawke's Bay and Tairawhiti varied in depth (< 5 cm to > 100 cm), texture (sand to silty clay loam), volumetric moisture content (10 – 80%), bulk density (0.75 – 1.65 g cm^{-3}), nutrient fertility including pH (5.5 – 8.5), Olsen P (2 – 30 µg ml^{-1}), exchangeable potassium (2 – 16 MAF units), sulphate sulphur (2 – > 200 mg/kg) and in its biology (12 – 70 earthworms m^{-2}). The physical condition of the sediment as assessed using the Visual Soil Assessment methodology varied from poor to moderate.
- Initial concern regarding chemical or biological contaminants in the sediments was not supported by any of 14 samples taken from sites in Hawke's Bay.
- The study recorded actions growers took, or were intending to take, where significant amounts of sediment (5 – 20+ cm) were deposited on their highly productive land. Orchardists have removed up to 50 cm of sediment from within the tree-rows. Cropping farmers' management included leaving sediment bare until the spring, sowing a cover crop, and mixing 5 – 20 cm of sediment into the soil. Vegetable growers have removed 20+ cm of sediment from some fields.

- **There is little or no documented information on best management of sediment impacted sites with high value crops on elite soils. Previous studies have been almost exclusively of re-grassing pastureland.**
- The work done through this project has provided the first documented records of site impacts, sediments and grower actions immediately following a major storm event on high value crops on elite soils.
- Selected sites were revisited approximately six months after the cyclone to collect information about the soil and sediment following growers' site management. The ongoing monitoring is part of an initiative to develop information and decision support tools that cover all land uses for the next time a community is impacted an extreme weather event.
- This report discusses some possible effects of sediment deposition and its properties on future crop performance, particularly where the sediment is more than 5 – 20 cm in depth and a major component of the growing medium for plants and new soil surface.
- **This comprehensive study establishes sound baseline data upon which an ongoing longitudinal study can be built.** Monitoring management, soil and crop performance at these sites for a five year period will help determine which practices enabled growers to most effectively build their soils back better. Best management guidelines should be developed for growers to be best placed to respond effectively and efficiently following future events.
- This project was funded by the Ministry for Primary Industries, with administrative support from Vegetables NZ.

Table of Contents

List of Figures

List of Tables

Background

On the 13th of February Cyclone Gabrielle tore a path across Hawke's Bay, Tairawhiti and Northland, causing devastation across much of the regions (Figure 1). The cyclone decimated homes, productive land and crops, and livelihoods, with the estimated cost of rebuilding in the billions of dollars. This cyclone was the third in a series of serious storms to hit New Zealand in the previous two months. Across Hawke's Bay, Wairoa, Gisborne and Northland highly productive cropping land, orchards, vineyards, and pastoral land were inundated with water and buried under sediment and debris after rivers burst through stop banks and shifted their courses. Cyclone Gabrielle also impacted coastal Wairarapa, parts of the Central Plateau and the Pohangina Valley in the Manawatu.

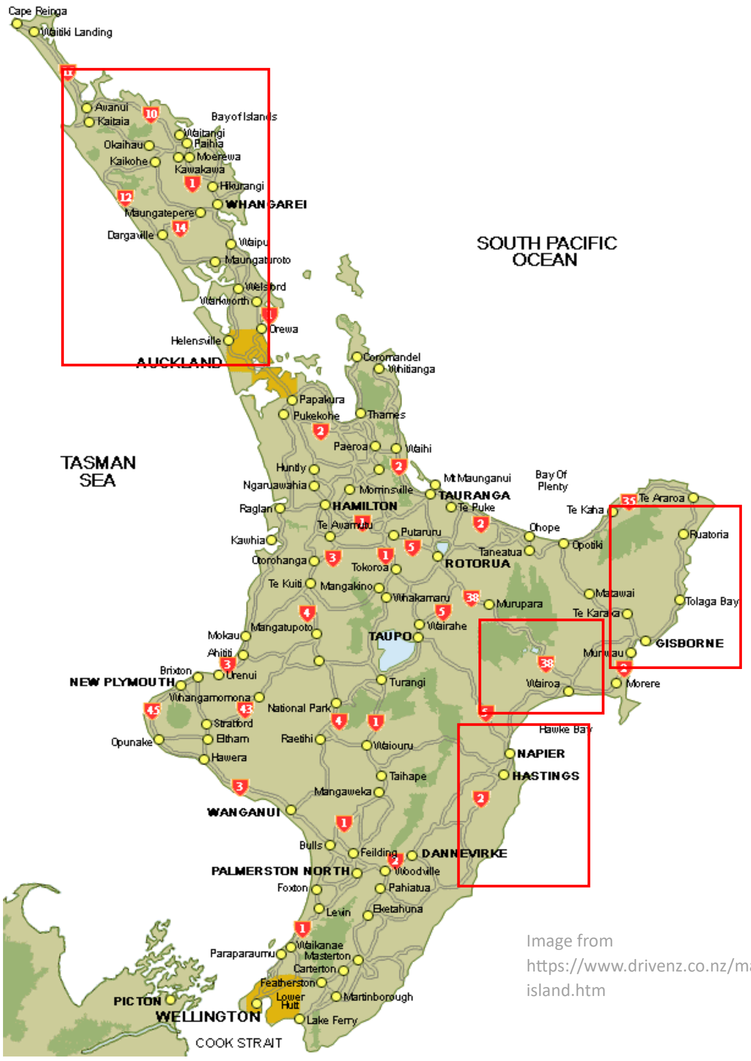

Image from https://www.drivenz.co.nz/map-north-island.htm

Figure 1 NZ map of areas impacted by Cyclone Gabrielle

Following Cyclone Gabrielle, our organisations came together to provide immediate advice to affected growers. Activities broadened to capture data on the initial impact of the cyclone on farmers, growers, and their productive land, and document the lessons that could be learnt in how to recover from a natural disaster such as this one. The group included LandWISE Inc., AgResearch, Massey University, Hawke's Bay Regional Council, Gisborne District Council, Plant and Food Research, Vegetable Research & Innovation Board, and Vegetables NZ, alongside the Ministry for Primary Industries and several of the national producer groups including NZ Apples and Pears, Summerfruit

NZ, Citrus NZ, Onions NZ, New Zealand Buttercup Squash Council and the Foundation for Arable Research.

After the 2004 Southern North Island Storm Event[1] impacted Manawatu, Rangitikei, Horowhenua, Wairarapa and Wanganui Regions, information from farmers on successes and failures of re-grassing sediment deposits (silt) was collated. Approximately 50 farmers were involved in that study. The data were collected a year after the event, predominantly from pastoral farmers, and does not provide information specific to cropping farmers, vegetable growers, orchardists or viticulturalists. The aim of collecting baseline information in the months after Cyclone Gabrielle is to build on that previous work, update information, and inform the creation of decision support tools that cover all land uses for the next time a community is impacted an extreme weather event.

The collection of baseline data was collected as soon as possible (before any significant remediation was carried out). The sampling was a priority, as the information will address gaps in the data sets collected in 2004 and inform and provide a baseline for a five year longitudinal study. The initial information was collected from the four most impacted areas; Hawke's Bay, Tairawhiti, Wairoa and Northland, in the first 1 – 3 months after the cyclone. Ministry for Primary Industries funding enabled commercial laboratory analyses for nutrients and contaminants, and labour and advisory costs. Funding was managed through Vegetables NZ. LandWISE, AgResearch, Massey University, Gisborne District Council and Plant and Food Research provided additional staffing supported by internal funds. The focus of the sampling was on cropping land, orchards and vineyards, which were the land use types most significantly impacted. A few sites sampled were impacted pastoral land.

The project budgeted on 200 samples across the four impacted regions. At the end of August 2023, 155 samples laboratory from 116 sites were completed as part of the initial baseline testing. A breakdown is given in Table 1. The remaining budget was used to revisit a selection of sites and capture information six months after the cyclone. This report focuses on the initial testing, a separate proposal document has been prepared to outline a proposed longitudinal study.

Table 1 Breakdown of number of samples and sites per region

Region	Number of samples	Number of sites
Hawke's Bay	82	60
Gisborne	55	39
Wairoa	6	5
Northland	12	12
Total	**155**	**116**

Sampling Method

Initial plans only considered sampling for nutrient analysis. However, with sampling activity happening so soon after the event, there was a unique opportunity to capture more characteristics of the sediment deposited and impacts of the cyclone. The aim of collecting a wider range of data was to better understand where sediment has come from, the variation in sediment types deposited across the landscape, to provide information to growers on what sediment characteristics they were working with, to understand implications for future land use and management, and add to the knowledge base on the impacts of flooding.

The extent of damage to a particular area varied enormously due to many factors. The sampling protocol was developed at a workshop held 9th March 2023, by representatives from a range of

[1] https://hwe.niwa.co.nz/event/February_2004_North_Island_Storm

organisations to create consistency in sampling across the three regions. Some flexibility was built into the protocol as some sites required a 'bespoke' approach to sampling.

The impact of the cyclone on highly productive land was divided into three main categories:

(i) soil eroded and stripped leaving subsoils exposed
(ii) soil impacted by sediment and
(iii) areas inundated with water for an extended period.

Eight key characteristics were captured across all sites, including sediment depth and texture, nutrient status, visual soil assessment, bulk density, earthworm abundance and diversity, eDNA, and contaminant levels (on selected sites). Details of how each characteristic has been measured are presented in Appendix 1.

Site Selection

Sites were selected to capture information in impacted catchments, with samples collected at different points along the river flow pathways. Different land uses were captured including orchards, vineyards, pasture, and cropland. Different sediment depth classes and textural types were included.

Site history and proposed recovery actions

Information on the land use and practices prior to the flood (soil fertility, crop type, etc.), along with any action the growers had taken or proposed to take was documented as part of the process at each site. It was critical to capture this information at this early stage as it builds a picture of management that will feed into the proposed longitudinal study.

Project challenges

Key challenges faced for baseline sampling were similar across all regions.

- Defining a sampling protocol to fit all land use types and scenarios to capture as much information as possible was an initial challenge.
- Given the magnitude of the cyclone and the land use types impacted there was significant variation across sites, which made gaining consistency across sites challenging. Where sampling needed to vary slightly from the sampling protocol, justification notes have been recorded.
- Access to blocks was impacted by extended wetness and sediment consistency i.e., very wet, deep sediment into which those collecting data sank.
- Prolonged wetness was a particular issue in Northland were consistent rain meant that sampling could not take place until June.
- Regional access was also a challenge as Gisborne and Wairoa were cut off from the south for many weeks, and it was not possible for sampling to be done from Hawke's Bay. Gisborne District council volunteered to complete the sampling in Wairoa.
- Time taken to complete the more comprehensive sampling deemed valuable was greater than originally budgeted.

Results and next steps

For each region details on site selection and an overview of the sampling are provided. Some of the results from the extended sampling programme are also presented. These include:

- Physical properties

- Sediment Texture
  - Bulk Density
  - Visual Soil Assessment
- Chemical properties
  - Nutrients (pH, Olsen P, Potassium, Sulphur profile)
  - Contaminants- Heavy Metals and Residues (Hawke's Bay only)
- Biological properties
  - Earthworms (Hawke's Bay only)
  - Contaminants (E. Coli Hawke's Bay only)

Further analyses would be extremely valuable and should be completed as part of the proposed longitudinal study.

Hawke’s Bay

Overview

Sampling in Hawke’s Bay was led by LandWISE, supported by AgResearch, Massey University and Plant and Food Research. Over a three month period, 82 samples were collected across 60 sites, engaging with over 30 growers from across the region. The cyclone hit just before most fruit and vegetable crops were harvested. Some crops could be salvaged, but in many cases flood water either damaged the crop, buried it in sediment, or the edible part of the plant was inundated with flood water making it unsuitable for harvest.

Figure 2 Examples of Hawke's Bay impacted areas: a sweetcorn paddock and an apple orchard.

Sites

There were nine key impacted areas in Hawke’s Bay:

- Dartmoor Valley
- Esk Valley
- Fernhill
- Meeanee
- Otane
- Pakowhai
- Puketapu
- Tangoio
- Twyford

Sites for sampling were identified through existing grower networks and product group referrals, and including some Hawke’s Bay Regional Council State of Environment monitoring sites.

The river catchments that were impacted and sampled in Hawke's Bay were:

- *Tutaekuri River*, leading from the Kaweka Ranges to the Pacific Ocean. Shares a river mouth with the Ngaruroro River and the Clive/Karamu River (LAWA, 2022).
- *Ngaruroro River*, headwaters in Kaweka and Ruahine Ranges (LAWA, 2022).
- *Tutaekuri/Ngaruroro Rivers*, where the two rivers became one in the flood through Pakowhai and Meeanee and sediment origin is difficult to determine.
- *Waipawa River*, largest tributary of the Tukituki River, draining from the Ruahine Ranges (LAWA, 2022).
- *Mangaone River*, which feeds into the Tutaekuri, upstream of Puketapu.
- *Wharerangi Stream*, historically flowed into the Tutaekuri, but was diverted into the Ahuriri Estuary for flood protection in the 1940's (LAWA, 2022).
- *Te Ngarue Stream*, flows through the Tangoio Valley, tributaries are Rauwhirikokomuka and Kareaara Streams (Maungaharuru-Tangitu Trust, 2013).
- *Esk River*, headwaters in the Maungaharuru Ranges (LAWA, 2022).

Samples were collected from many different land use types and have been grouped into three categories for displaying results (Table 2). The land use type 'Field Cropping' includes fresh vegetables, process vegetables and arable cropping land. The land use type 'Permanent Tree Crops' includes mostly apples, but also grapes, avocados, and cherries. 'Pasture' includes dairy and drystock sites.

Table 2 Land use types sampled in Hawke's Bay

Land Use Type	Number of sites	Number of samples
Field Crops	33	45
Apple Orchard	18	25
Dairy	1	2
Drystock	2	2
Vineyard	4	4
Avocado	1	2
Cherry	1	2
Total	**60**	**82**

Samples were collected in four management or depth zones. The number of samples collected from each zone is provided below in Table 3.

Table 3 Number of sites in each sediment management zone (Hawke's Bay)

Sediment Depth Zone	Number of sites in depth zone
0 cm (no sediment deposited, or topsoil removed)	5
< 5cm	13
5 – 20cm	16
➢ 20cm	26

The study documented actions growers had or were intending to take. Where there was a significant amount of sediment (5 – 20 cm or more), actions taken by cropping farmers include from leaving sediment bare until the spring, sowing a cover crop, through to mixing 5 – 20 cm of sediment into the soil. Some vegetable growers have mixed and or have removed 20+ cm of sediment from fields. Orchardists have removed up to 50 cm of sediment from within the tree-rows.

The spatial distribution of sampled sites and their land use type are presented in Figure 3. Several sites were not sampled in the 1 – 3 months following the cyclone, because the conditions

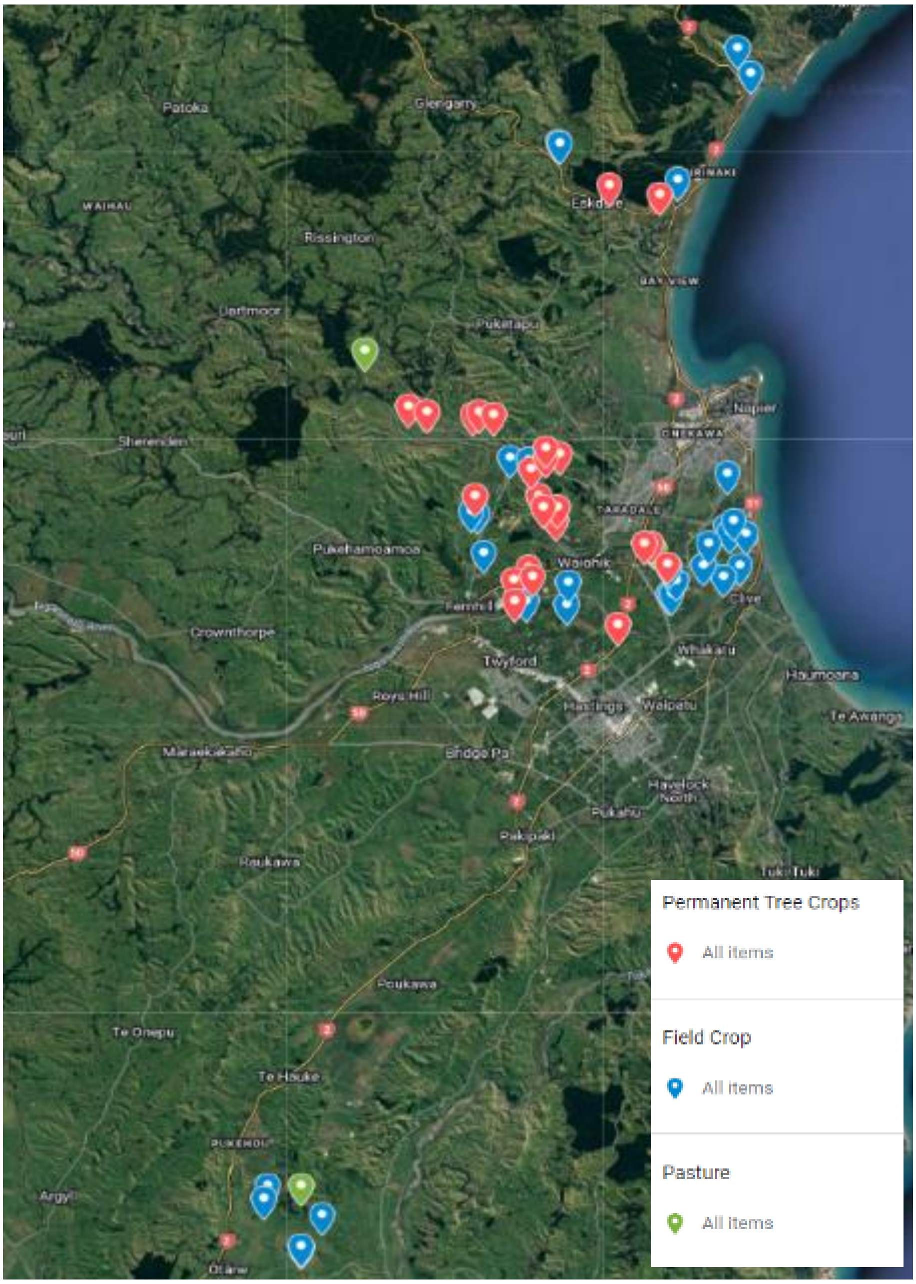

Figure 3 Map showing distribution of sites sampled (Hawke's Bay)

remained too wet and muddy (people sank into the sediment), access to the site was not safe, or were still awaiting grower approval to access. Collection of information from these sites was underway at the time of compiling this report.

Physical Properties

Sediment Texture

The texture of the sediment varied across the catchments in the Hawke's Bay. Textural classes were grouped for ease of interpretation (Figure 4). The map below shows locations of samples and the main texture class found. Description of textural classes can be found in Appendix 3.

In the higher reaches of the Tutaekuri, in the Dartmoor valley coarser textures (fine to medium sands) were found. As the water flowed towards the coast the texture typically became finer (silty clay). The sediment textures from the flow path of the Ngaruroro are finer. Around Otane and Drumpeel Road, where a temporary lake formed from the Waipawa River moving into its historic flow path, water remained for several weeks, and a finer (silty clay) sediment was deposited. North

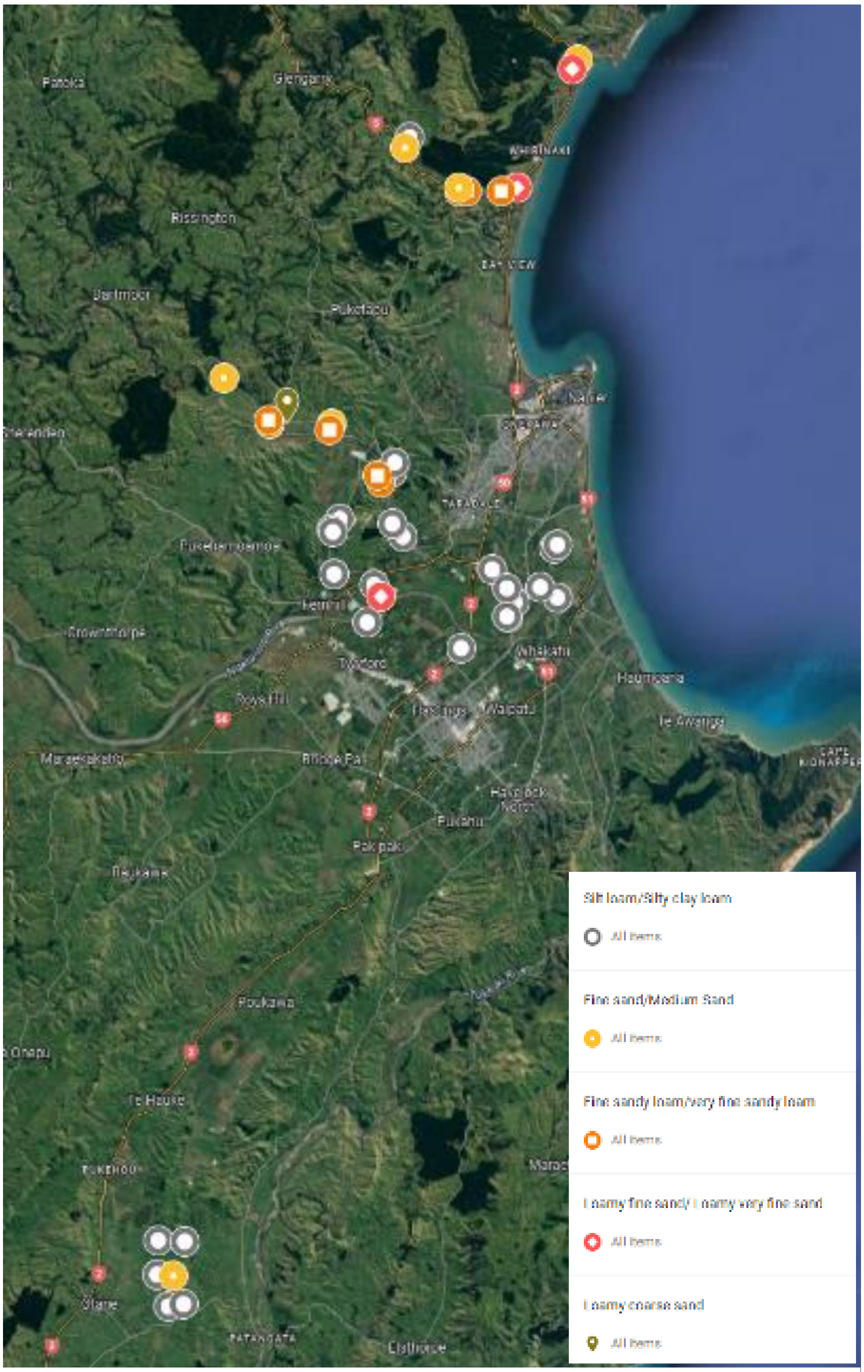

Figure 4 Map showing distribution of sediment texture- Hawke's Bay

of Napier, coarse textures (fine to medium sands) were found along the entire length of the Esk Valley, except for a small area where water sat for several weeks. The Tangoio area also had coarse sediment (sand) deposited along the Te Ngarue flow path.

Bulk Density

The bulk density of the sediment sampled in the Hawke's Bay ranged from 0.70 to 1.49 g cm^{-3} Sediments sampled in the Mangaone, Te Ngarue stream and Esk catchments all had a bulk density value > 1.2 g cm^{-3} (Figure 5). This was associated with textures ranging from a fine sand, loamy fine sand, sandy loam, to fine sandy loam. This was also the case in the upper reaches of the Tutaekuri catchment. In the middle and lower reaches of the Tutaekuri and other four catchments, bulk density values ranged from 0.81 to 1.03 g cm^{-3} and textures of the sediment varied from a silt loam to a silty clay loam. As a guide, soil bulk density higher than 1.6 g cm^{-3} tends to restrict root growth. Sandy soils are more prone to high bulk density. (See Appendix 5: Notes on Bulk Density and Total Porosity)

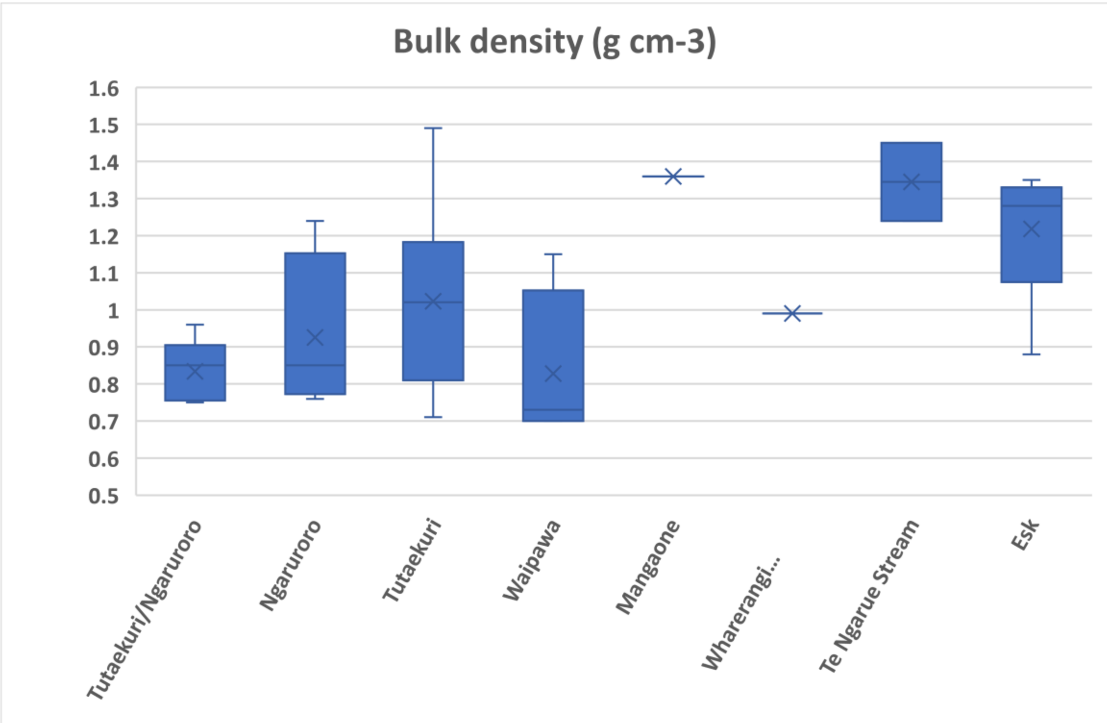

Figure 5 Bulk density of sediment samples (Hawke's Bay)

At the time of collection (33 – 80 days after the cyclone) the volumetric moisture content of the sediments sampled across the seven catchments within Hawke's Bay varied from 11 – 80%. The volumetric moisture content of the sediment at the time of sampling was highly correlated with the texture of the sediment (Figure 6 Relationship between volumetric water content and bulk density sediment samples (Hawke's Bay)). For example, the volumetric moisture content of the sediment collected from the Mangaone, Te Ngarue stream, Esk and upper reaches of the Tutaekuri catchments ranged from 12 – 33%, while the volumetric moisture content from samples from the middle and lower reaches of the Tutaekuri and other four catchments ranged from 43 – 61%. As sediment drains, particles slowly collapse, filling voids, and increasing the mass of material collected within a given volume.

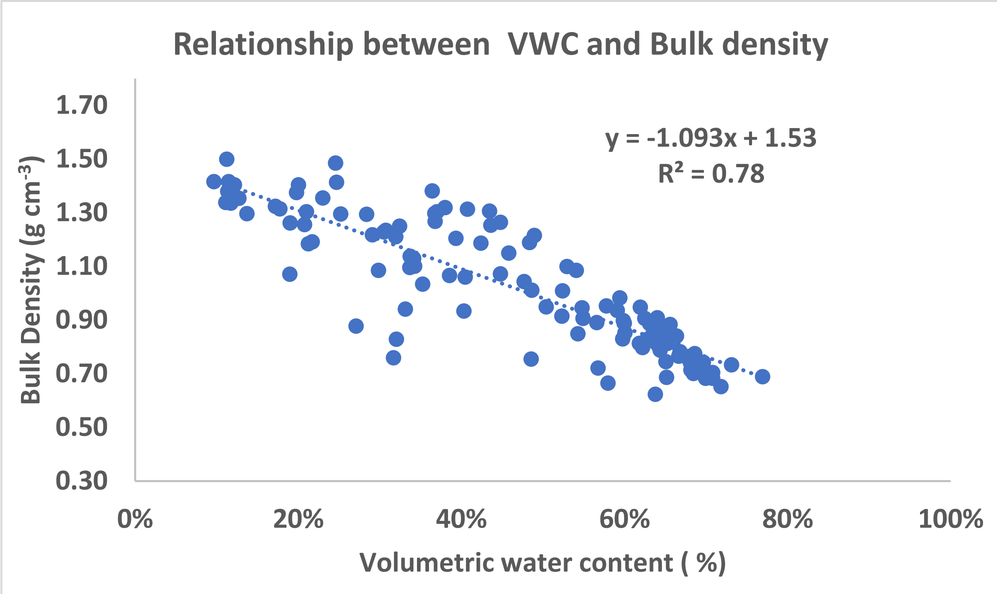

Figure 6 Relationship between volumetric water content and bulk density sediment samples (Hawke's Bay)

Scatter in the data may be due to the origin of the parent material containing different amounts of volcanic glass and organic matter, both of which will lower bulk density. In considering the effect of the physical properties of the sediment on plant growth, water infiltration, etc., bulk density, particle density and the porosity of the sediment have influence. The particle density of the coarse textured sediments (fine sand through to a loamy fine sand) which averaged 2.65 gm cm^{-3} was higher than the finer textured sediments (silt loam, silty clay loams) which averaged 2.48 gm cm^{-3} fine sandy loam. Most quartzo-feldspathic rocks such as greywacke, sandstone and mudstone are dominated by quartz and feldspar with specific gravities of 2.65 and 2.55-2.63 g cm^{-3}, respectively. Sediments and soils with appreciable organic matter can have lower particle density because organic matter is generally in the range 0.8 – 1.1 g cm^{-3}.

Soil porosity is the ratio of nonsolid volume to the total volume of soil. The porosities of the sediments across these two textural ranges were similar at 56 and 59%, respectively. In crop production, soil porosity is important in the conduct of water, air and nutrients. Further information and interpretation of bulk density and total porosity can be found in Appendix 5.

Visual Soil Assessment

Of the 60 sites visited in Hawke's Bay, 55 had conditions that allowed for VSA to be completed (Table 4). The method of scoring Visual Soil Assessment is included in Appendix 1. Sites generally achieved a moderate score where the sediment depth was less than about 15 cm and the pre-existing topsoil accounted for a significant proportion of the sample. Sites where soil structure was poor were generally deeper sediment deposits, where the topsoil below was not captured. The areas where the sites ranked as good had only a small amount of sediment deposited (< 5cm).

Table 4 Average VSA total ranking scores per site

Soil Quality Assessment	Number of Sites	Average Ranking Score
Poor	9	2.1
Moderate	44	12.1
Good	2	20.75

Chemical Properties

Contaminants (Heavy Metals and Residues)

Fourteen Hawke's Bay samples were submitted for contaminant testing. Results for heavy metals are presented in Table 5. The laboratory results were reviewed by Dr Jo Cavanagh at Landcare Research - Manaaki Whenua. Her full report is presented as Appendix 4. The conclusion of this assessment was:

"There is no evidence for chemical contamination present in the deposited sediments. Trace element concentrations were largely within background concentrations across the region. Remarkably high copper concentrations were detected at one sampling site and warrants further investigation including assessment of current state of the biological health of the soil. Opportunities to minimise any ongoing copper should be considered. Pesticide residues were detected at two sampling site locations, although the source for these residues is unclear."

Table 5 Contaminant sample results from randomised sites (heavy metals).

	Site Number													
Test	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Sediment texture	Silty clay loam	Silty clay loam	TBD	Silty clay loam	Silty clay loam	Silty clay loam	Silty clay loam	Silt	TBD	TBD	Mixed sample	Silty clay loam	Loamy very fine sand	Silt loam
Total Recoverable Arsenic (mg/kg dry wt)	8	9	8	9	9	8	9	4	9	-	13	4	2	9
Total Recoverable Cadmium (mg/kg dry wt)	<0.10	<0.10	0.12	0.11	0.19	0.1	0.11	<0.10	0.11	-	0.17	< 0.10	< 0.10	0.14
Total Recoverable Chromium (mg/kg dry wt)	23	25	23	27	29	24	29	14	25	-	18	14	12	19
Total Recoverable Copper (mg/kg dry wt)	15	11	10	17	12	12	12	5	12	-	151	5	3	21
Total Recoverable Lead (mg/kg dry wt)	17.1	17.6	16	23	18.7	16.5	18.7	7.6	18	-	19.6	7.7	4.6	26
Total Recoverable Nickel (mg/kg dry wt)	17	18	16	21	20	18	20	10	18	-	13	10	8	16
Total Recoverable Zinc (mg/kg dry wt)	71	71	62	88	78	69	75	40	74	-	84	39	31	84

Nutrients

Results for key nutrients are presented below. In the figures presented, indicative optimum bands for general crop performance are shown as green bands. Brief notes for each nutrient are provided.

pH

The pH of most sediment samples is elevated above the optimum range (Figure 7). This has been raised as an area of concern for nutrient availability in some crops. Outside of the optimum range, pH can lead to reduced availability of some macro and trace elements. The Waipawa samples had lower pH's, possibly due to a higher level of topsoil from upstream sites being included in the sediment samples. The source parent material (Whangai shale or Waipawa siltstone) also tends to be more acidic.

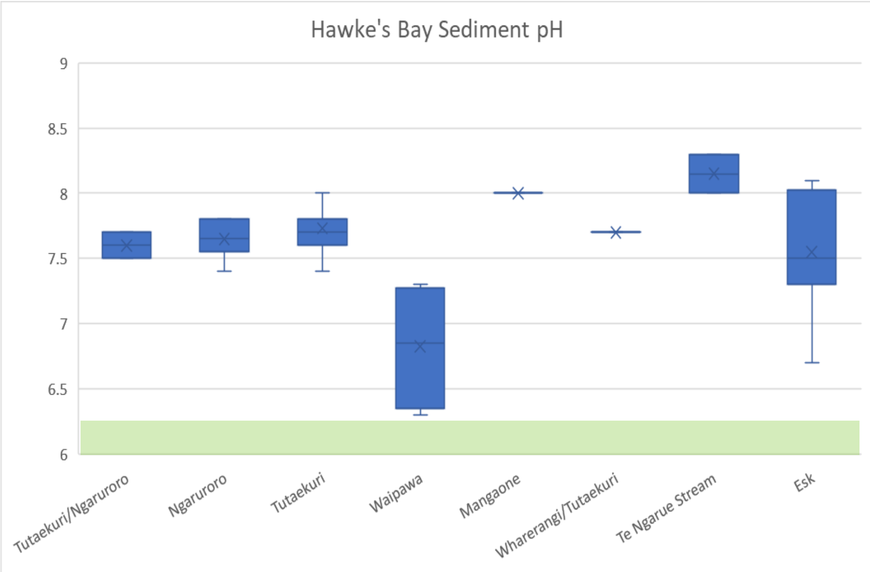

Figure 7 Hawke's Bay sediment pH results by catchment

Olsen P

With the exception of some samples collected in the Waipawa catchment, Olsen P was below optimum for most crop types (Figure 8). This can reduce crop yields and may need to be addressed through capital fertiliser programmes. Where sediment depth is within a cultivatable range (less than

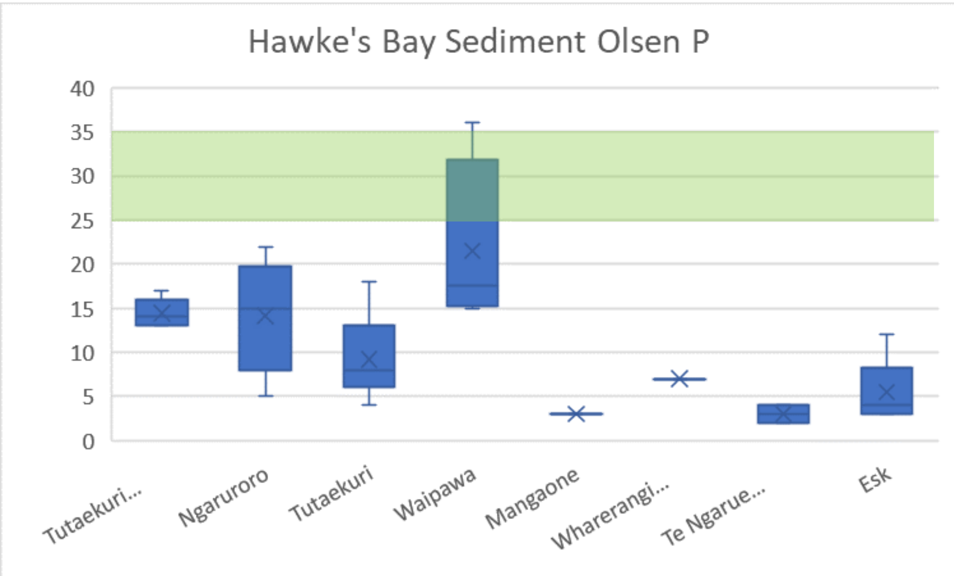

Figure 8 Hawke's Bay sediment Olsen P results by catchment

about 20 cm) the lower fertility sediment may be incorporated with existing topsoil, ‘diluting’ the sediment and raising phosphorous levels.

Quick Test (MAF K)

Quick Test Potassium (QTK) varied across catchments, and across the region (Figure 9). Potassium is an important driver of yield for many crops (e.g. onions and tomatoes) so low potassium levels are likely to limit production. Higher K levels are not likely to cause concern. Low K levels are typically associated with sandier textured soils/sediments. These soil types can have high Total K levels (high proportions of orthoclase and mica) yet have low plant available K. Total K was not measured as part of the baseline sampling project.

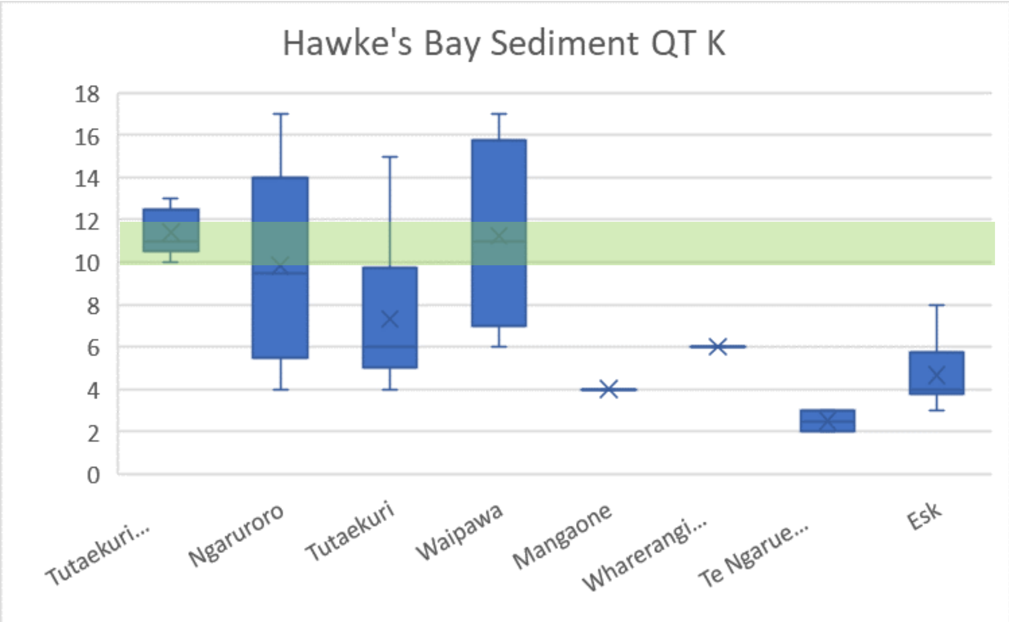

Figure 9 Hawke's Bay Sediment Quick Test (MAF) Potassium Results by catchment

Sulphate Sulphur

Sulphate sulphur (plant available sulphur) levels across Hawke’s Bay are typically low, generally less than 10 mg kg-1 pre-cyclone. Laboratory analysis of sediment samples following Cyclone Gabrielle showed that across most catchments sulphate sulphur is elevated and very high at some sites (Figure

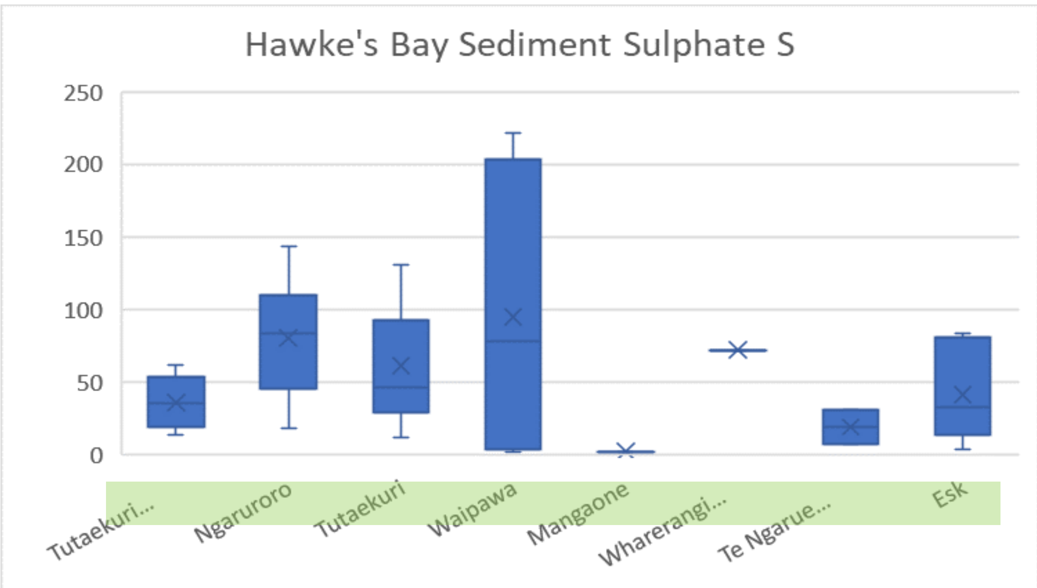

Figure 10 Hawke's Bay sediment sulphate sulphur results by catchment

10). Inconclusive discussion as to possible causes and impacts of the high sulphate sulphur levels indicates this should be further investigated.

Organic Sulphur

While sulphate sulphur appears to be high, Extractable Organic Sulphur (slowly available) appears to be low (Figure 11). Where laboratory analyses found < 2 mg kg-1, the limit of detection, the data have been input with a value of 1.

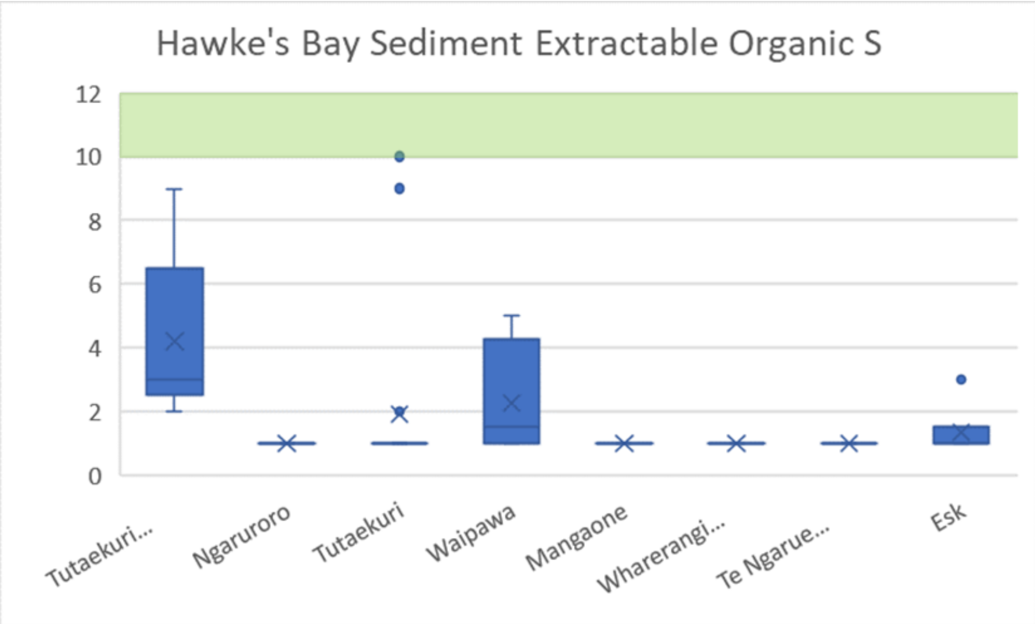

Figure 11 Hawke's Bay sediment organic sulphur results by catchment

Potentially Available Nitrogen (PAN)

PAN is a nitrogen test commonly used by vegetable and arable growers and provides an indication of how much nitrogen could be mineralised under ideal soil conditions. Results show a range of PAN values, most catchments had very low- low PAN, with the exception of Otane which had medium to

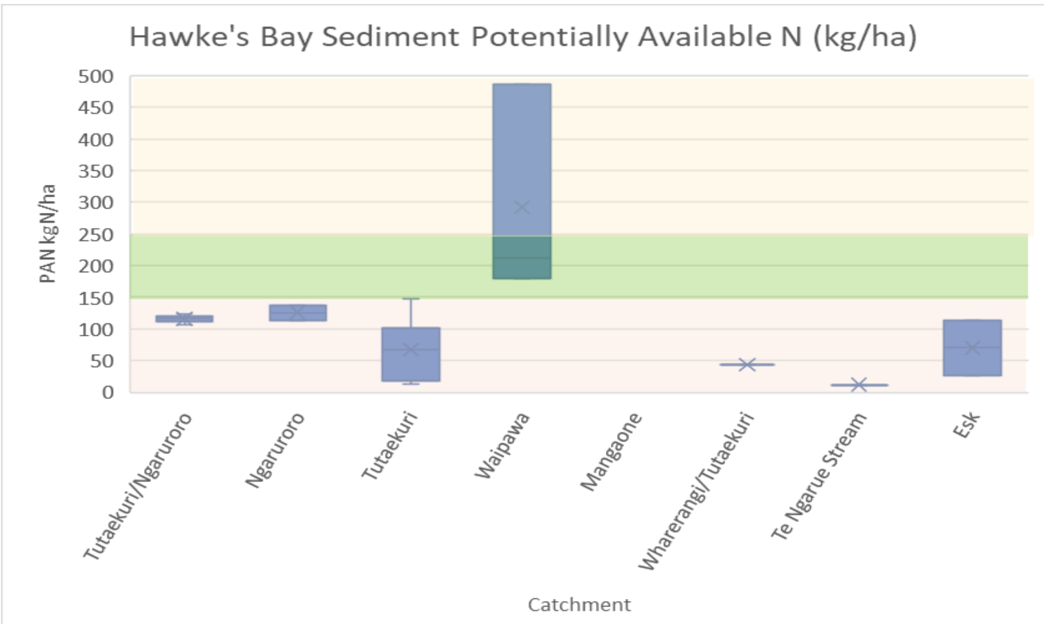

Figure 12 Hawke's Bay sediment potentially available N by catchment

very high PAN results (Hill Labs, 2023). 5 sites are excluded from this data as PAN was less than the minimum detection limit of 10kgN/ha.

Organic Matter Percentage

Organic matter plays a role in soil physical and chemical characteristics like nutrient availability, Cation Exchange Capacity (CEC), structure, moisture infiltration and retention. Hill Laboratories state that organic matter levels of 3 –7% are considered low, and < 3% is considered very low. On this basis, all sediment organic matter levels from Hawke's Bay are low or very low.

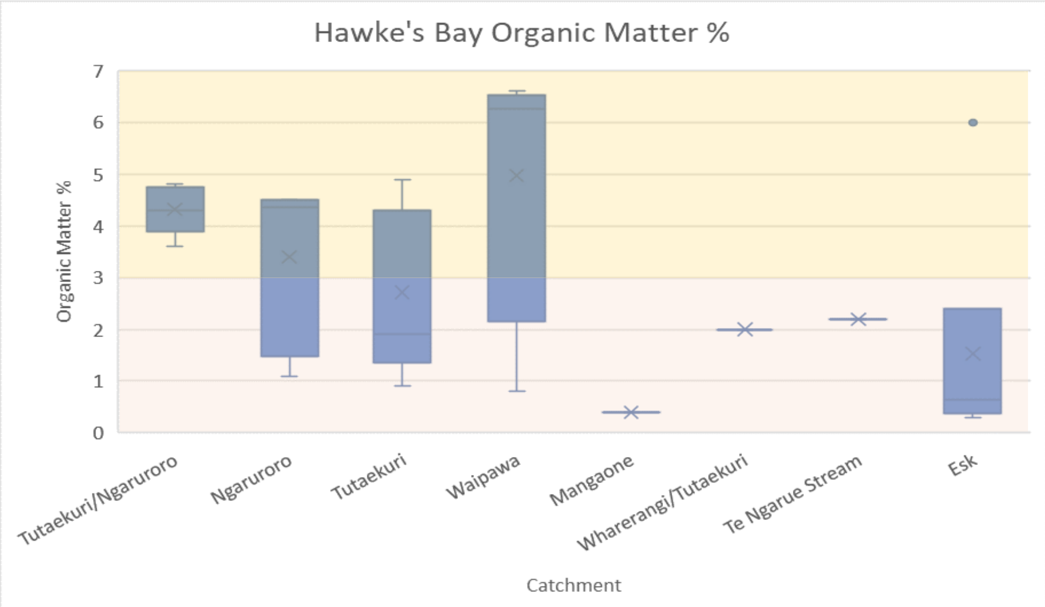

Figure 13 Hawke's Bay sediment organic matter percentages by catchment

Organic Matter vs Cation Exchange Capacity

As part of the interpretation of data, concerns have been raised over the low organic matter percentage and low CEC of some sediment deposits. Organic matter and CEC are two contributing soil characteristics that influence the soils ability to buffer herbicides. The below graph shows CEC vs organic matter percentage. All of the organic matter levels are low or very low. However there is a range of CEC's from low to high.

Sites that are of concern are shaded blue in Figure 14 where organic matter levels are very low, and CEC is also low. We are concerned, but do not know, what this means for herbicide mobility, harm to crop, and loss to ground water.

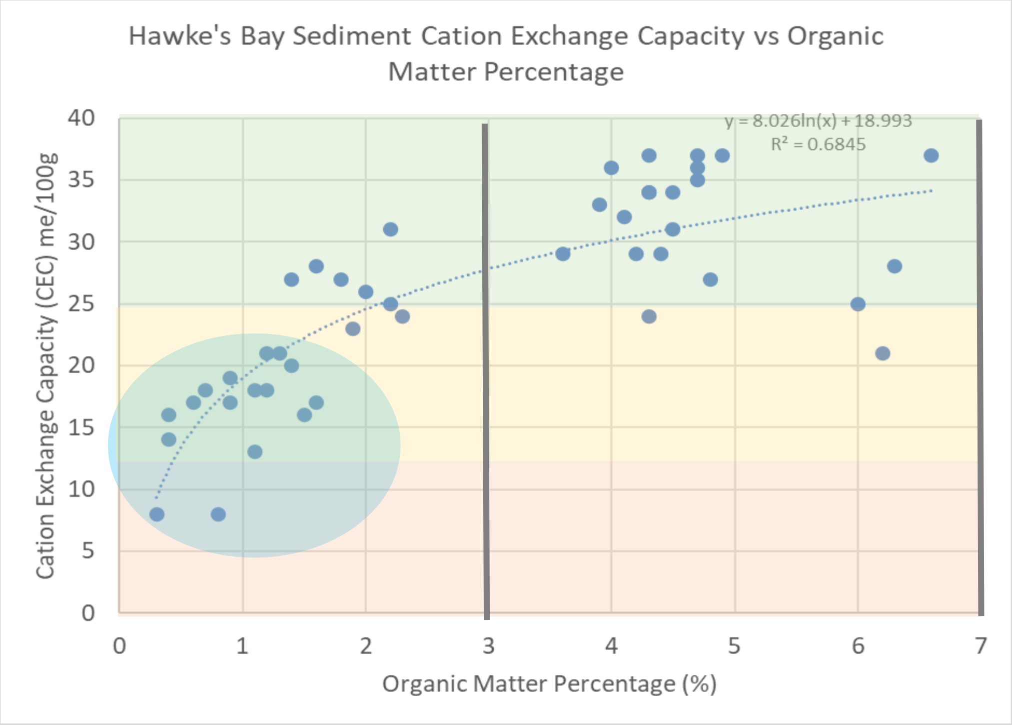

Figure 14 Scatter plot of Hawke's Bay sediment cation exchange capacity versus organic matter percentage, showing many sites have very low levels which are of concern for herbicide use.

Total N Percentage

Total N content represents both chemically stable humus and partially decomposed organic matter fractions. This provides an indication of the amount of N the soil can provide. Most of the sites show low-medium Total N. One site in Otane had a very high Total N percentage. It is the same site that has higher PAN and OM% than other sites. Seven sites are excluded from this data as PAN was less than the minimum detection limit of 0.04%.

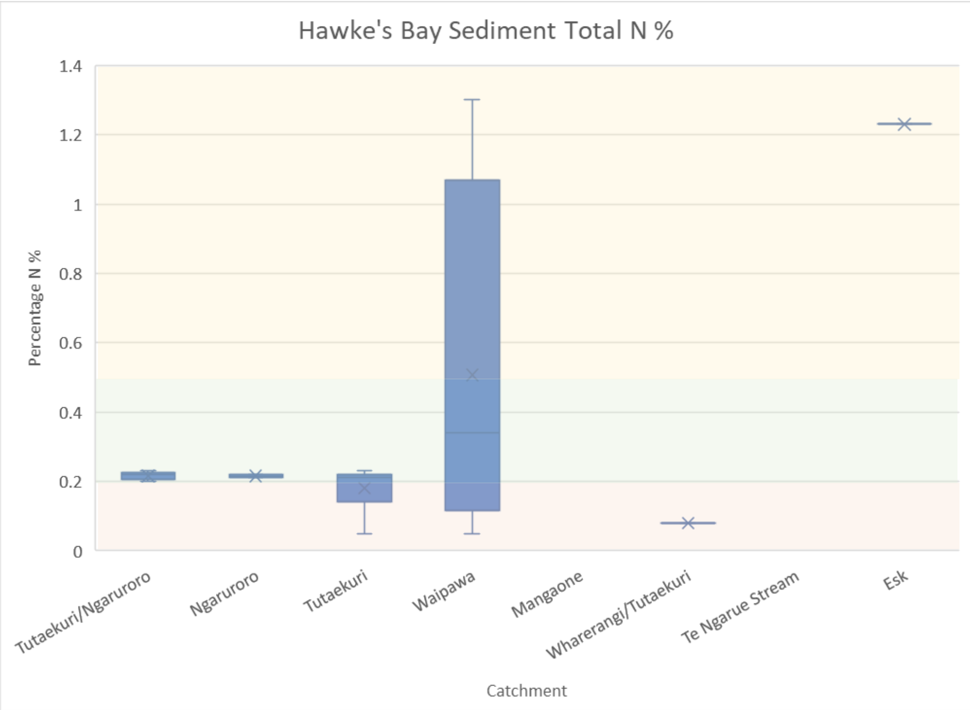

Figure 15 Hawke's Bay Total N % by catchment

Biological Properties

Earthworm abundance and diversity

Results from earthworm collection have been received for Hawke's Bay samples. A short summary is provided from Dr Nicole Schon who completed the analysis, and data summarised in Table 6, Table 7 and Table 8.

Note: No statistical analysis has been completed, commentary is based on observations only and care should be taken when using this information.

"The most common earthworm detected was endogenic Aporrectodea caliginosa, this species is the most common species found in agricultural soils in New Zealand. Endogenic species burrow extensively throughout the topsoil and form semi-permanent burrows. Other endogenic species found include Aporrectodea rosea and Aporrectodea trapezoides. Lumbricus rubellus was also found, this is an epigenic earthworm which decomposes organic matter on the soil surface, with another epigenic species, Eisenia andrei also found. Deeper burrowing anecic earthworms consisted of Aporrectodea longa. Native earthworms were also observed at two sites (#63 and 76).

Earthworm samples are normally collected in winter/spring to get the highest earthworm populations (aiming for 400 m^{-2}). Samples were collected in March to June (1-3 months) after flooding caused by Cyclone Gabrielle.

The effect of sediment depth, time since cyclone and the underlying land use had on earthworm abundance and diversity is summarized below. Given the samples are not balanced across sediment depth, time since the cyclone and underlying land use, treat any trends with caution.

Average earthworm abundance was low across all sites. Abundance tended to be lower at sites with > 20cm of sediment, these also had the smallest precent of samples with earthworms. The highest abundance of earthworms tended to be found on < 5cm of sediment, with the highest percent of samples with earthworms present in samples with no sediment."

Table 6 Earthworm type and abundance (m-2) by land use category

	Orchard	Cropping	Pastoral	Vineyard
Total earthworms	55	27	0	13
Epigeic	8	6	0	0
Endogeic	38	20	0	2
Anecic	8	1	0	10
Native	1	0	0	0

Table 7 Earthworm type and abundance (m-2) found in different depths of sediment.

	0	<5	5-20	>20
Total earthworms	18	70	41	12
Samples with earthworms (%)	40	31	32	24
Epigeic	3	13	9	1
Endogeic	13	54	26	9
Anecic	3	4	5	2
Native	0	0	2	0
Mature	7	21	10	2
Immature	12	49	31	10
Juvenile	9	14	7	0

Table 8 Earthworm type and abundance (m^{-2}) found in sediment sampled less than 40, between 40 and 80, and more than 80 days after flooding.

	<40	41-80	>81
Total earthworms	28	14	77
Epigeic	2	4	14
Endogeic	23	10	49
Anecic	2	0	12
Native	0	0	2

Figure 16 Earthworms found in Hawke's Bay samples

Contaminants

E. coli

Interpretation of *E. coli* concentration results was sought from industry experts. ESR Senior Scientist Dr Megan Devane provided an overview for the purpose of this report.

"There are some high concentrations of E. coli in sediment samples, which could be associated with faecal contamination. According to the current Biosolids Guidelines 2003 page 130 (and the draft revised guidelines, 2017) concentrations of E. coli > 100 MPN per gram of silt/sediment, indicate that there is a risk of exposure to disease-causing organisms from the sand/sediment.

Spatial variability of E. coli concentrations is expected as sediment/silt is a heterogenous environment, which is very different to the homogenous mixing that occurs in water samples.

E. coli will persist in sediment, especially the silty clay loams and less so for material with higher sand content. The concentrations are high for more than one month after the event. It is important to note that some pathogens associated with faecal contamination such as protozoa (Cryptosporidium and Giardia) and viruses will also persist long-term in environments such as sediments.

In future analyses, it would be appropriate to investigate those E. coli concentrations >100 E. coli /gram sediment by looking for faecal source tracking markers that identify human, ruminant (e.g. cows and sheep) and bird sources of faecal contamination. This could provide useful information and confirm the source of the E. coli particularly where you have indicated sites with proximity to sewage treatment plants etc."

From the data presented, 12 out of the 14 samples submitted for *E. coli* testing exceeded 100 MPN/g, however the origin of this cannot be determined at this level of testing. Further evaluation by faecal source tracking could be warranted.

Table 11 E. coli sampling results from fourteen Hawke's Bay sites

	Site Number													
Test	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
E. coli MPN/g	350	1,600	350	>1,600	920	240	540	70	1,600	350	<180	1,700	22	110
Sediment texture	Silty clay loam	Silty clay loam	TBD	Silty clay loam	Silty clay loam	Silty clay loam	Silty clay loam	Silt	TBD	TBD	Mixed sample	Silty clay loam	Loamy very fine sand	Silt loam

Gisborne

Overview

Sampling in Gisborne was undertaken by the Gisborne District Council Land Management team. Over

Figure 17 Gisborne impacted areas: a maize paddock and a citrus orchard

three months, 55 samples were collected across 30 sites, engaging with over 22 growers from across the region. There was considerable impact to many crops including maize, squash, citrus, apples, and kiwifruit, as well as in the hill country. Cyclone Gabrielle came after two years of wet conditions, and the northern East Coast had already suffered several major weather events. There was already pressure on the region's people, crops and soils.

Sites

There were eight key impacted districts/catchments in the region:

- Hikuwai/Uawa
- Mangaheia
- Mata
- Pakarae
- Te Arai
- Waiapu
- Waihuka
- Waipaoa

The key impacted rivers are:

- *Hikuwai River,* the middle section of the Uawa River, north of Tolaga Bay (LAWA, 2022).
- *Uawa River,* headwaters near Tauwharepare, gullies prone to slipping and erosion (LAWA, 2022).
- *Mata River,* headwaters from the Raukumara Ranges, joins the Waiapu River (Gisborne District Council, 2022).
- *Pakarae River,* winds through hill country North of Gisborne. Highly erodible mudstones and sandstones (LAWA, 2022).
- *Te Arai River,* tributary of the Waipaoa River, lower reaches have tidal effects (Gisborne District Council, 2022).

- *Waiapu River,* formed by the joining of the Mata River from the Raukumara Ranges. Catchment prone to erosion (Gisborne District Council, 2022).
- *Waipaoa River* has a large catchment which formed the Poverty Bay Flats (highly productive soils). Typically, high sediment loading (Gisborne District Council, 2022).

Table 12 Land use types sampled in Gisborne.

Land Use Type	**Number of sites**	**Number of samples**
Cropping	11	16
Apple Orchard	9	14
Citrus	4	6
Kiwifruit	3	4
Vineyard	2	3
Pasture	10	12
Total	**39**	**55**

Samples were collected in four management or depth zone categories. The number of samples collected from each category is presented in Table 13.

Table 13 Number of sites in each sediment management zone (Gisborne)

Sediment Depth Zone	**Number of sites in depth zone**
0cm (no sediment deposited, or topsoil removed)	0
<5cm	7
5-20cm	23
>20cm	9

The spatial distribution of sites that have been sampled to date and their land use type are described in Figure 18 Map showing distribution of sites sampled (Gisborne)

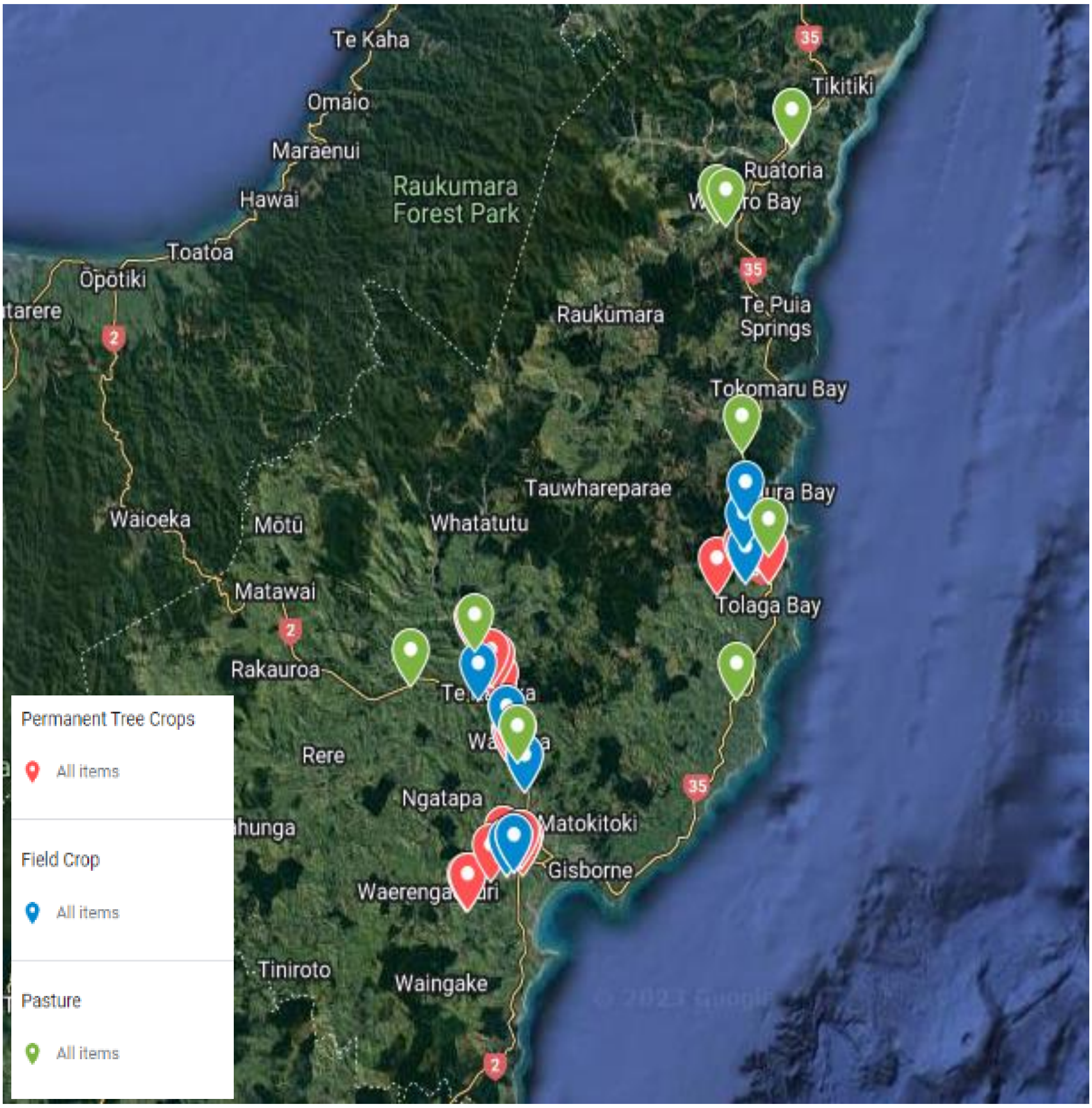

Figure 18 Map showing distribution of sites sampled (Gisborne)

Physical Properties

Sediment Texture

There are a range of sediment textures deposited around the Gisborne and Northern- East Coast areas. In the northern end, deposits from the Mata River are medium sands-medium sandy loams. Where the Mata enters the Waiapu River which makes its way to the coast, deposits are coarse silts/coarse silt loams.

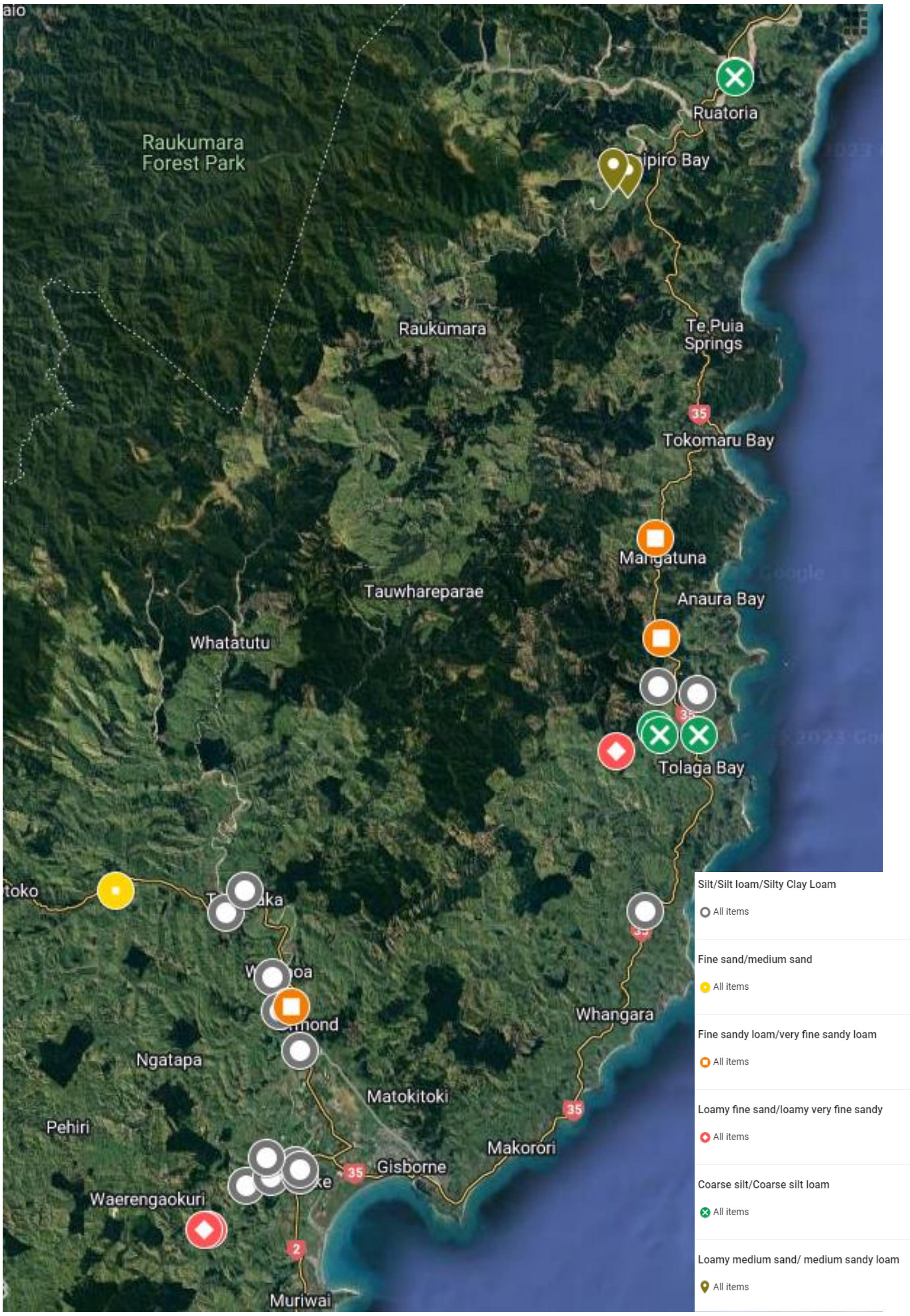

Figure 19 Map showing distribution of sediment textures (Gisborne)

In the northern reaches of the Hikuwai River, north of Tolaga Bay, sediment deposits are fine sandy loams/very fine sandy loams. As the Hikuwai becomes the Uawa river closer to Tolaga Bay, deposits are silt loams/silty clay loams, and are coarse silts/coarse silt loams at the bottom of the catchment.

Closer to Gisborne, along the Waihuka river, deposits are fine sands. Along the Waipaoa River, where the majority of samples were collected, deposits are silt loam/silty clay loams. Samples collected along the Te Arai are loamy fine sands/loamy very fine sands.

Further details on textural classes can be found in Appendix 3.

Bulk Density

The bulk densities of sediments sampled in the Gisborne District ranged from 0.91 to 1.55 g cm^{-3}, higher than those in Hawke's Bay. Within each catchment there was a greater range in the textural classes of sediment than documented in the Hawke's Bay, which in part explains the wide range in the bulk density values reported. For example, in the Te Arai catchment the textures of the sediment varied from loamy fine sands through to silt and silt clay loams, and in the Waipaoa catchment the texture classes ranged from a very fine sandy loam through to silt loam to silty clay loam to a clay loam. The sediment in the Waihuka, Mata, and Waiapu catchments were less variable and tended to be at the coarse end of the textural range.

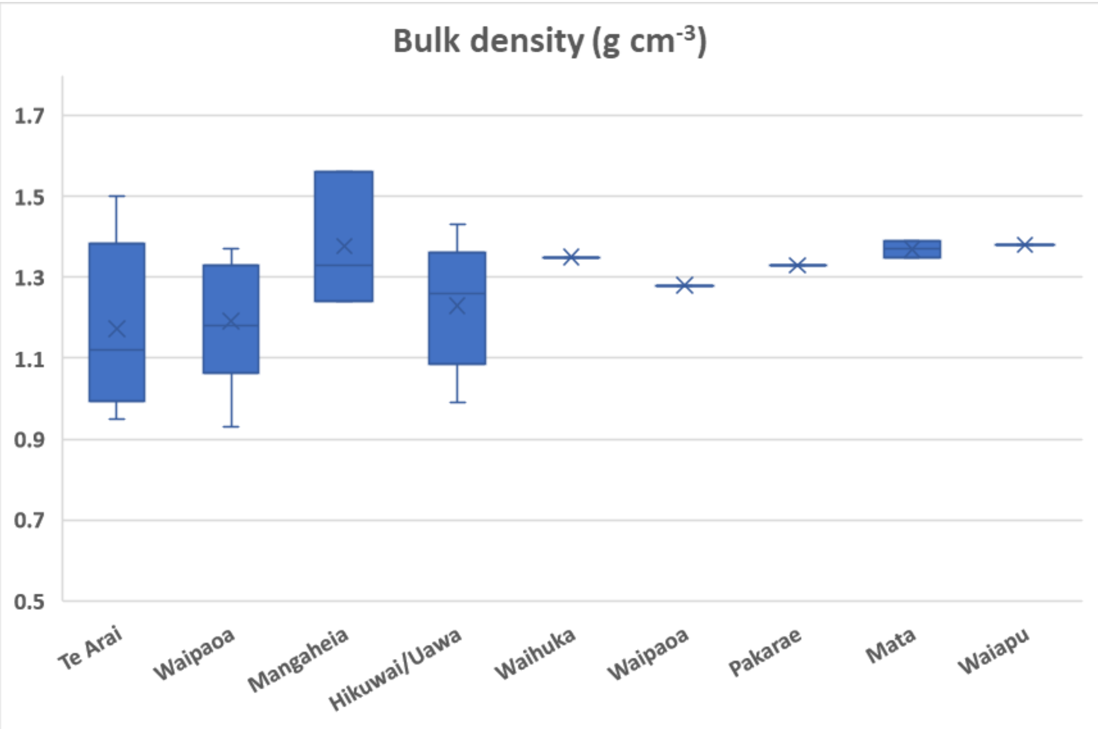

Figure 20 Bulk density of sediment samples (Gisborne)

Visual Soil Assessment

Visual Soil Assessment for all 49 Gisborne sites was completed on sediment samples and on mixed samples (more than one VSA completed on some sites). If a site had a layer of sediment less than a spade depth, a VSA was completed on the whole top 20cm profile, and an additional VSA was completed for the sediment layer alone. Results below are split into two tables, one for sediment alone and one for mixed sites (Table 14).

Table 14 Visual Soil Assessment Results Gisborne

Soil Quality Assessment	Number of Sites (mixed soil + sediment)	Average Ranking Score
Poor	9	2.2
Moderate	14	11.6
Good	0	N/A
Soil Quality Assessment	**Number of Sites (sediment only)**	**Average Ranking Score**
Poor	11	2.7
Moderate	17	11.1
Good	3	20

Chemical Properties

Nutrients

Soil pH

The pH levels of all Gisborne sediment samples were significantly higher than the optimum range for most crop types (Figure 21). This is similar to Hawke's Bay's results and could impact macro nutrient and trace element availability of future crops and animal health.

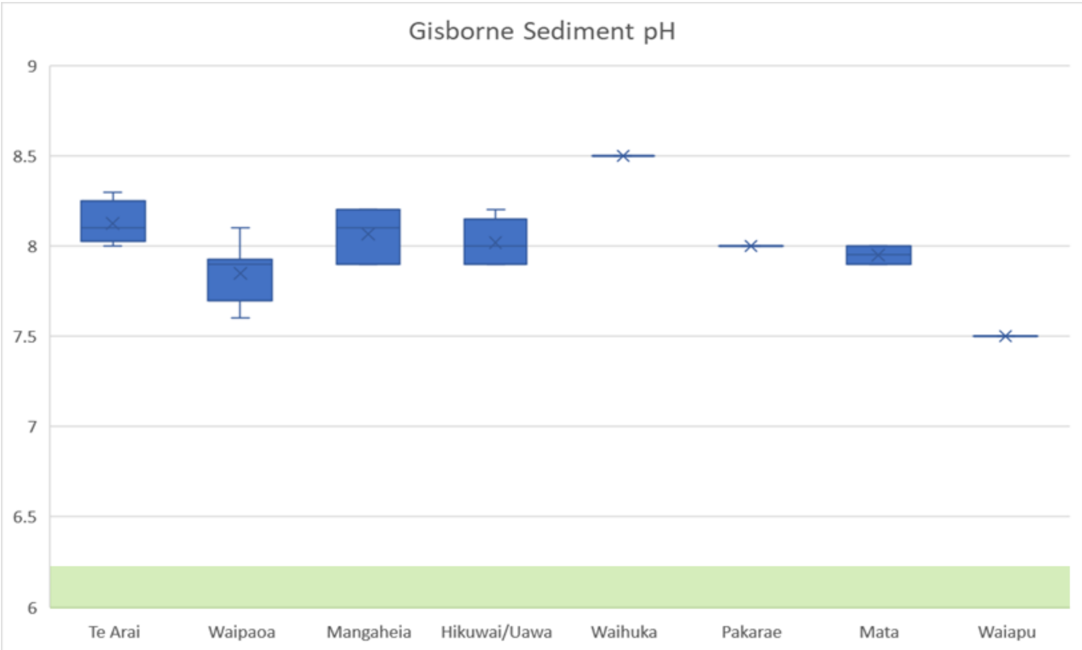

Figure 21 Gisborne sediment pH levels by catchment

Olsen P

For the majority of samples, Olsen P is below optimum for most crop types (Figure 22). This may reduce potential crop yield, although there may be opportunity to mix sediment with the pre-existing topsoil below. Questions have arisen as to whether maize planted directly into deeper sediment would be able to grow roots to access nutrients in the buried underlying soil.

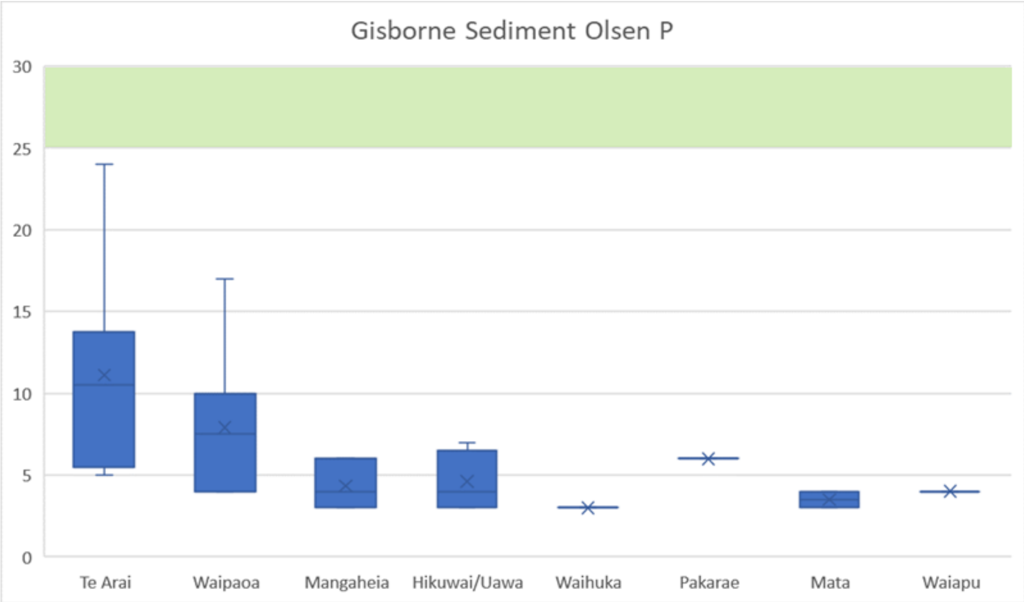

Figure 22 Gisborne sediment Olsen P levels by catchment

Quick Test K

Quick Test Potassium (QTK) varies across catchments, and across the region (Figure 23). Potassium is an important driver of yield for many crops, and low levels of K may limit yield. Growing depletive crops such as tomatoes that remove significant amounts of potassium from the soil may exacerbate already low soil K levels,

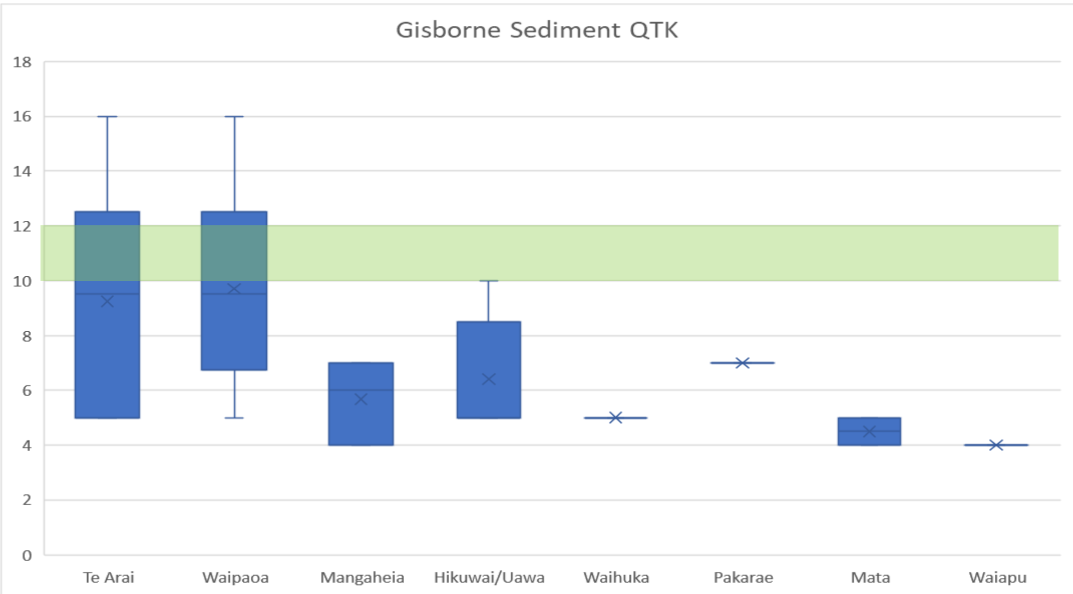

Figure 23 Gisborne Sediment QTK Results by catchment

Sulphate sulphur

Laboratory analyses found sulphate sulphur levels were very high across most catchments (). Inconclusive discussion of possible causes and impacts indicates this should be further investigated. Other questions raised include the interaction between sulphur, molybdenum (as influenced by pH) and copper availability to livestock, if these areas are sown to pasture as part of the restoration process.

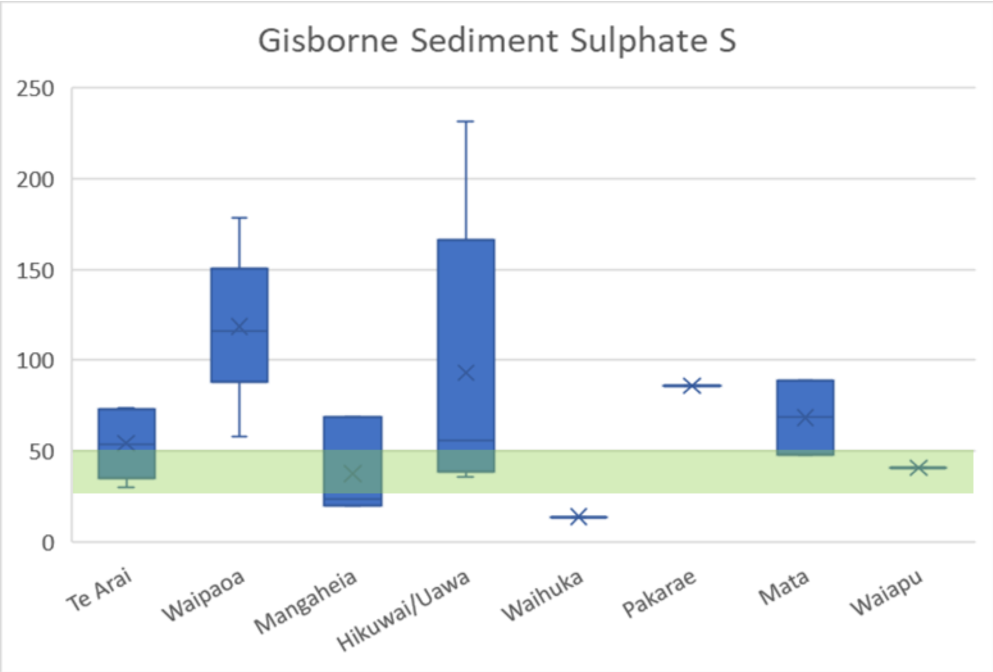

Figure 24 Gisborne sediment sulphate sulphur by catchment

Organic Sulphur

While sulphate sulphur appears to be high, Extractable Organic Sulphur (slowly plant available) is low. In Figure 21, laboratory results below the minimum test level of 2mg/kg have been input as 1, showing very low levels of organic sulphur.

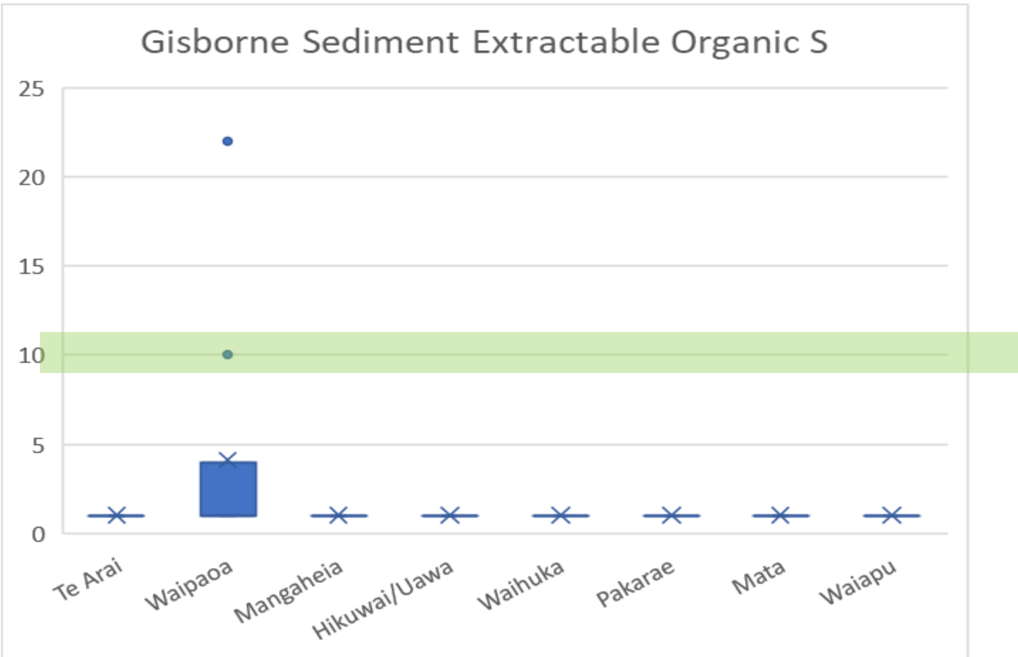

Figure 25 Gisborne sediment Extractable Organic Sulphur (mg/kg) by catchment

Potentially Available Nitrogen

In Gisborne PAN of sediment is very low (<50kg/ha) to low (50-150kg/ha). This shows that the ability for the sediment to provide N to growing plants is low (Hill Labs, 2023). Seven sites are excluded from this data as PAN was less than the minimum detection limit of 10kg/ha.

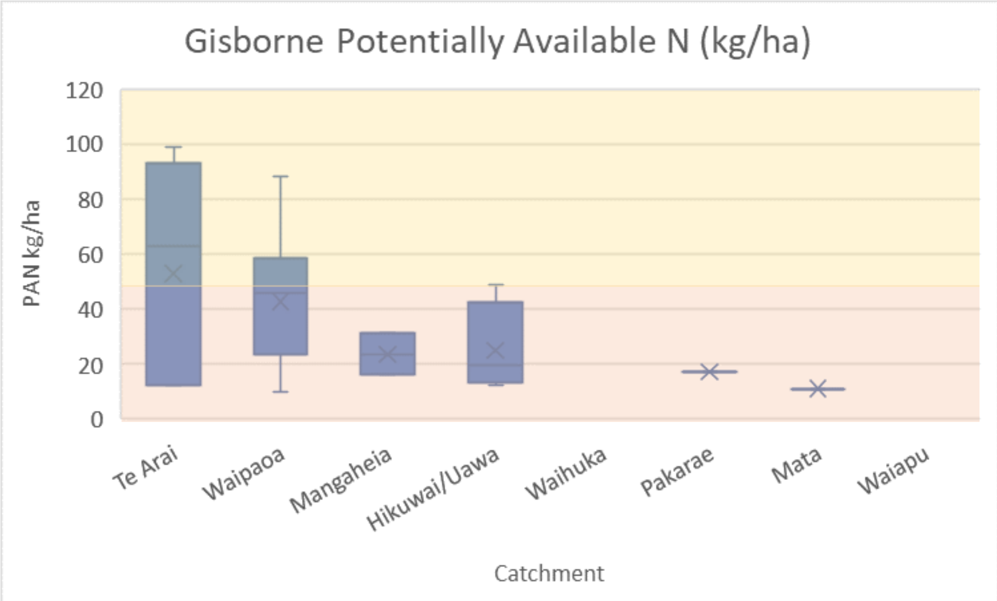

Figure 26 Gisborne Sediment Potentially Available N

Organic Matter Percentage

In Gisborne the organic matter content of sediments is low (3-7%) to very low (<3%). These low organic matter levels may adversely affect soil structure, nutrient availability and water retention.

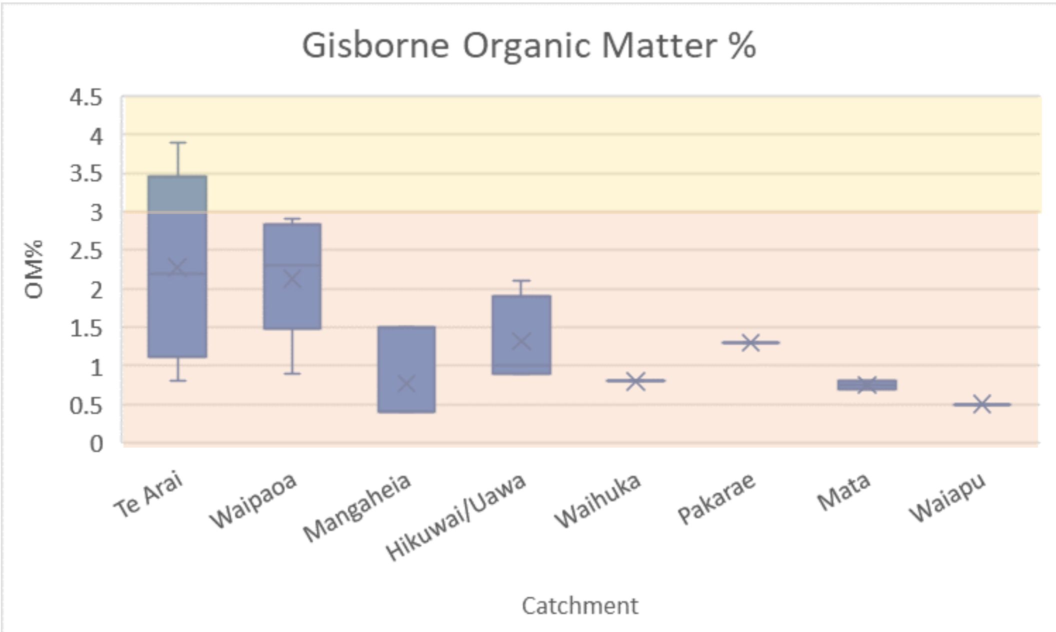

Figure 27 Gisborne Sediment Organic Matter %

Total N

Due to submission error Total N was not tested for on the Gisborne samples.

Wairoa/Nuhaka (Northern Hawke's Bay)

Overview

Sampling in Wairoa was undertaken by the Gisborne District Council Land Management team. Wairoa was the last region on the East Coast to be sampled, due to access challenges. Six samples were collected across five sites, engaging with four impacted growers in the region. Nine farmers and growers were impacted by sediment deposition in the lower Wairoa catchment. Most of the impact was on lowland areas growing maize, squash and grass, as well as an apple orchard. Some of the impacted areas are part of dairy or drystock farms that have productive flats planted for maize over the summer.

Cyclone Gabrielle followed two previous very wet years, with Wairoa having been hit with several major weather events. The impacted flats are an important part of many farm systems in the area, providing feed for winter grazed stock.

Figure 28 Wairoa impacted areas: maize paddocks.

Sites

There were two key impacted areas in the region:

- Nuhaka
- Wairoa

The key impacted rivers are:

- *Wairoa River*, Hawke's Bay's largest river. River mouth can close due to sea currents. Upper boundaries in the Te Urewera National Park. Catchment dominated by soft sedimentary rock, prone to erosion (LAWA, 2022).
- *Nuhaka River,* origin in the Whareata Ranges.

Table 15 land Use Types Sampled in Wairoa

Land Use Type	Number of sites	Number of samples
Cropping (sample no. 1-4)	4	5
Orchard (sample no. 5)	1	1

Samples were collected in four management or depth categories. The number of samples collected from each category is shown in Table 16. With the depth of the sediment at four of the sites well in excess of 20 cm, the sediment and its properties represent the new soil surface.

Table 16 Number of sites in each sediment depth category (Wairoa)

Sediment Depth Category	Number of sites in depth zone
0cm (no sediment deposited, or topsoil removed)	0
< 5 cm	0
5 – 20 cm	1
> 20 cm	4

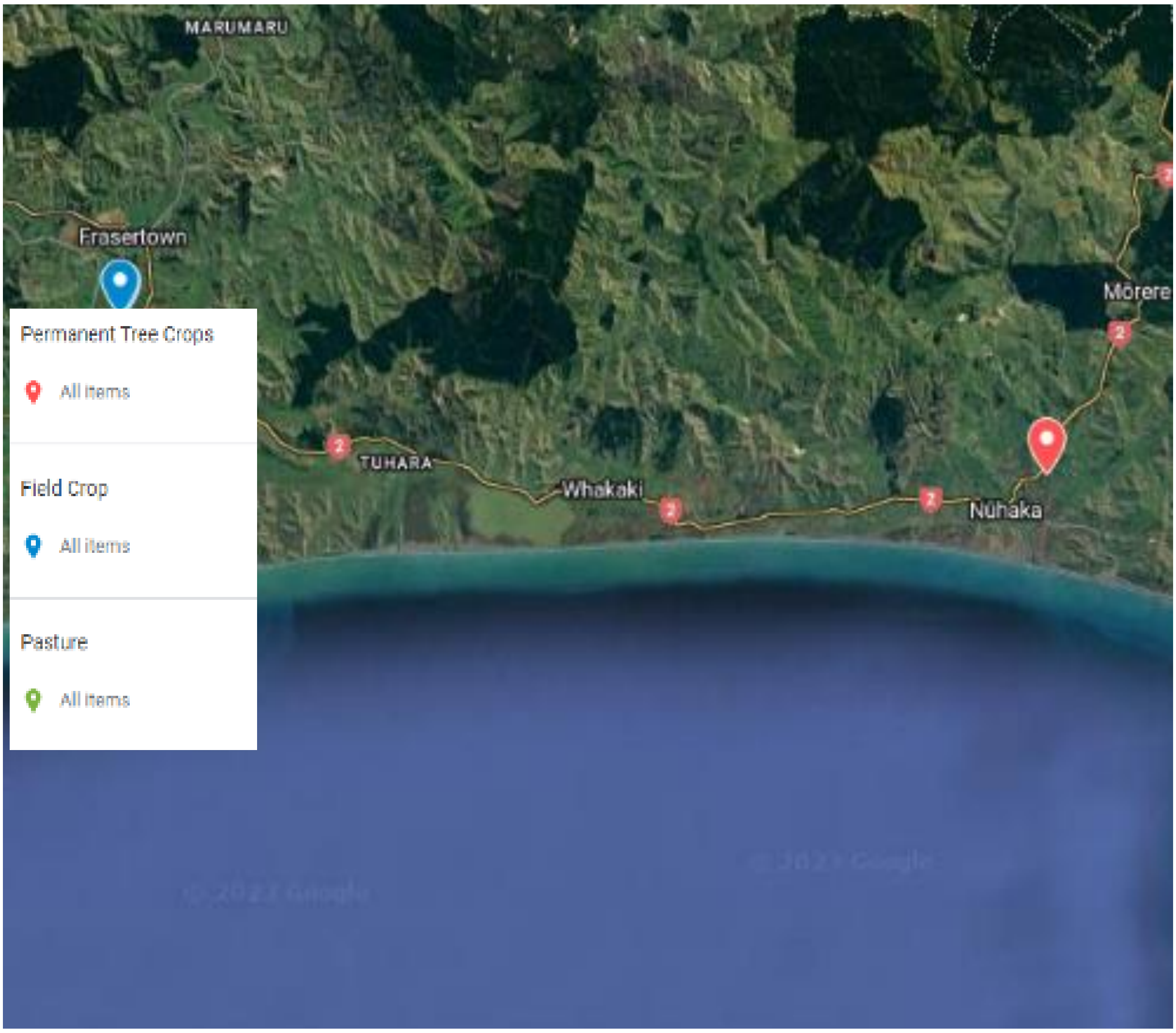

Figure 29 Map showing distribution of sites sampled (Wairoa)

Physical Properties

Sediment Texture

Sediment textures along the Wairoa River are either silt loam, silty clay loam or loamy medium sand. The sediment texture from the sample taken from Nuhaka (Nuhaka River) was a fine sandy loam.

Bulk Density

The bulk density of sediment sampled in Wairoa averaged 1.09 g cm^{-3} with a volumetric moisture content of 53% (Figure 30). These values are similar to those reported in Hawke's Bay. The textures of Wairoa samples varied from a fine sandy loam (site 44 W), loamy medium sand (site 41 W) through to a silt loam (site 43 W) and silty clay loam (site 42 W). The low bulk density of the sediment samples at site 42 W was associated with a very high volumetric moisture content (70%) compared with the volumetric moisture content (40 – 43%) at the two sites where the sediment had a sandy texture.

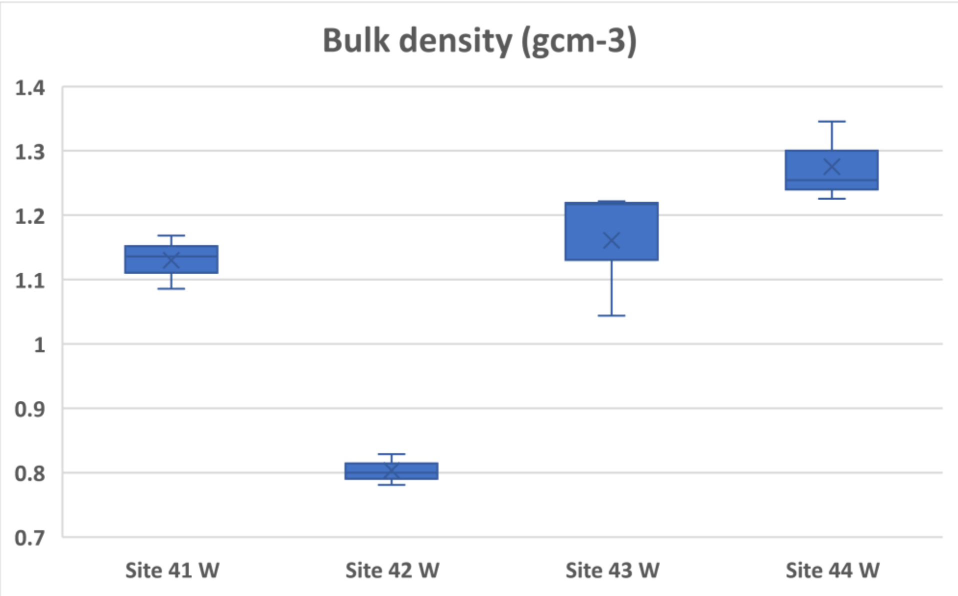

Figure 30 Bulk density of sediment samples collected in Wairoa.

Visual Soil Assessment

VSA was completed at all five sites visited in Wairoa and Nuhaka (Table 17). Four of the five sites had a 'poor' VSA score, and the moderate score was at the very low end of the moderate range. With the depth of sediments greater than 20 cm, these values represent the new growing surface.

Table 17 Visual Soil Assessment Results Wairoa

Soil Quality Assessment	Number of Sites (sediment only)	Average Ranking Score
Poor	4	2.75
Moderate	1	7
Good	0	N/A

Chemical Properties

Nutrients

pH

All sediment samples analysed for Wairoa/Nuhaka have pH values in excess of the optimum range for most crop types (Figure 31). This is similar to Gisborne and Hawke's Bay and could impact macro and trace element availability for future crops and may impact animal health.

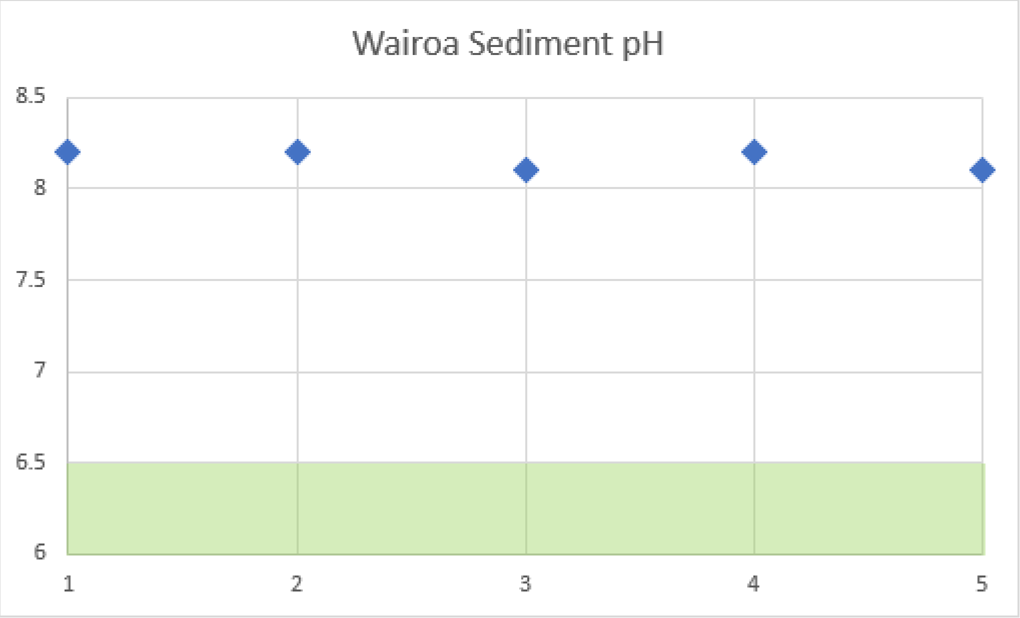

Figure 31 Wairoa Sediment pH Results by catchment

Olsen P

Sediment samples from Wairoa/Nuhaka have very low Olsen P values (Figure 32). Phosphorus availability is a key driver of yield in crops and pastures and a low Olsen P level will likely impact future crop performance. With the sediment at four sites in excess of 20 cm, limiting the ability of

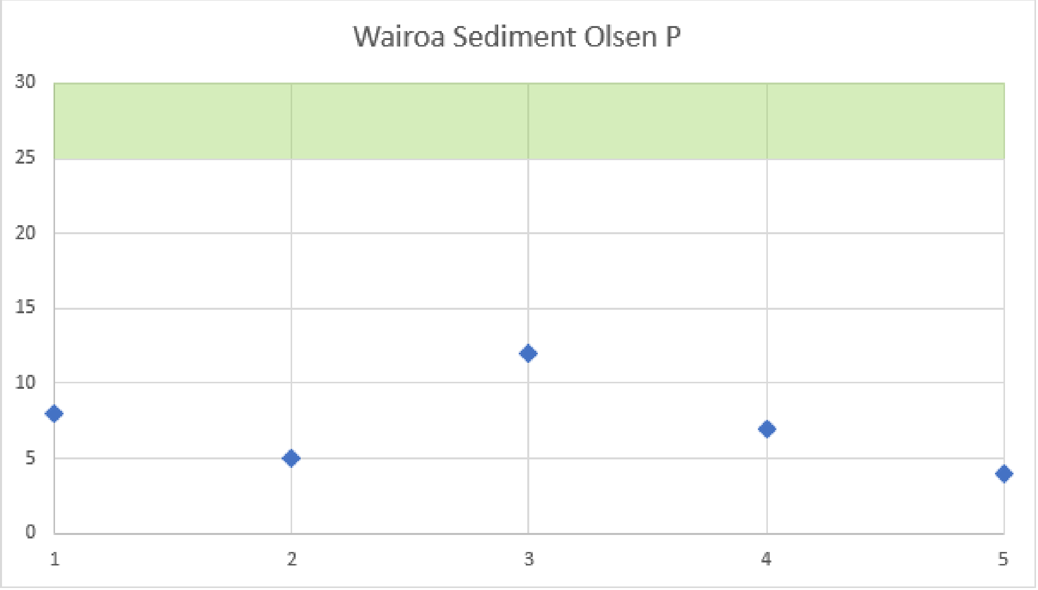

Figure 32 Wairoa Sediment Olsen P Results by catchment

plants to access nutrients in the underlying soil, these low P levels will have a major impact on the performance of crops like maize which are typically grown in these areas.

Quick Test K

Quick Test Potassium (QTK) varies across catchments, and across the region (Figure 33). Potassium is an important driver of yield for many crops, so low levels of K may limit yield. This will be an important consideration where maize is grown, or if grass is planted and feed is cut and carried, removing large amounts of K from the soil. The further reduction of already low K levels may reduce yield potential and increase the cost of production if high rates of potassium fertilisers are required.

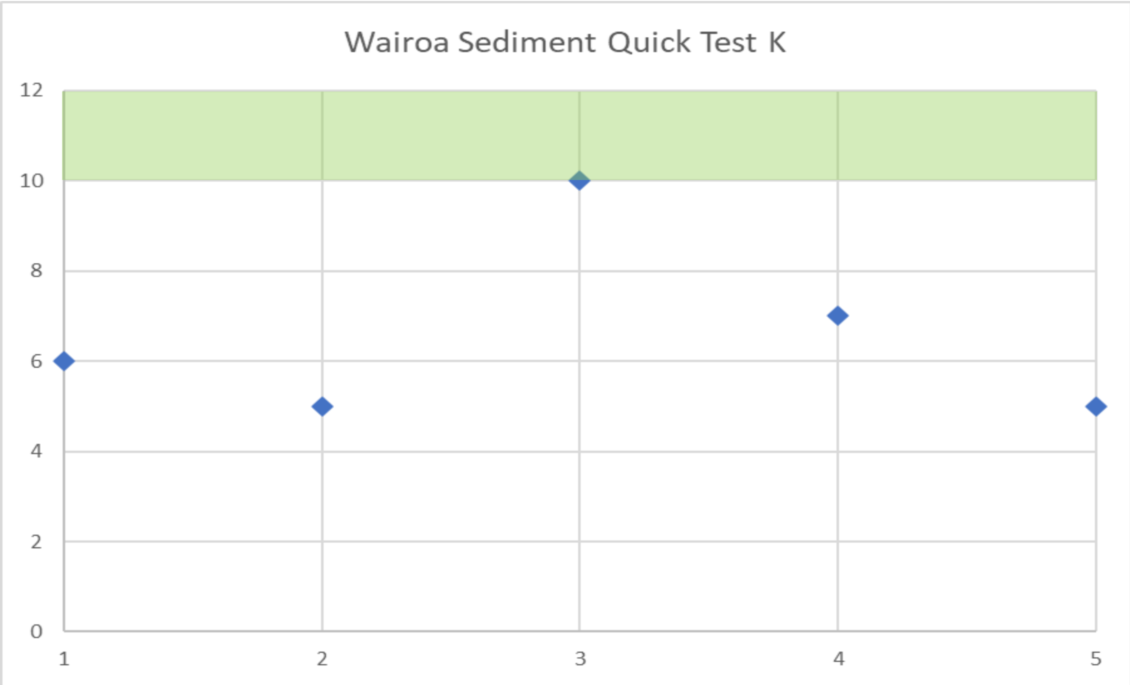

Figure 33 Wairoa sediment Quick Test (MAF) Potassium levels

Sulphate Sulphur

Sulphate S is elevated at two sites in the Wairoa/Nuhaka catchment, within the expected range at two sites and slightly low at one site (Figure 34). This is different to results from Hawke's Bay and Gisborne.

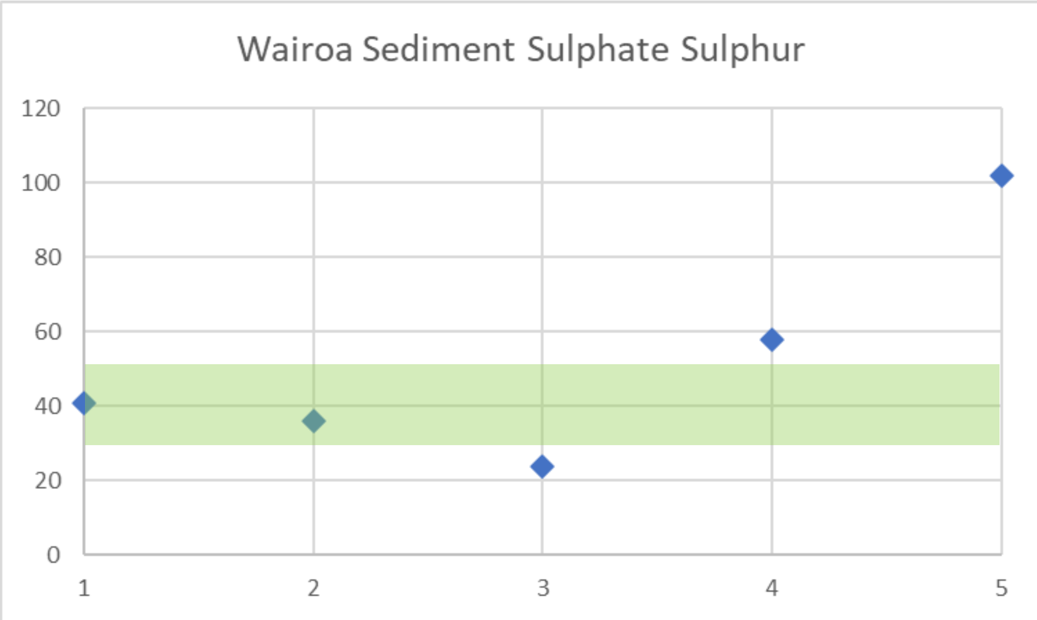

Figure 34 Wairoa sediment Sulphate Sulphur results

Organic Sulphur

While sulphate sulphur appears to be high, Extractable Organic Sulphur (slowly plant available) appears to be low for most sites (Figure 35). This also aligns with results from Hawke's Bay and Gisborne.

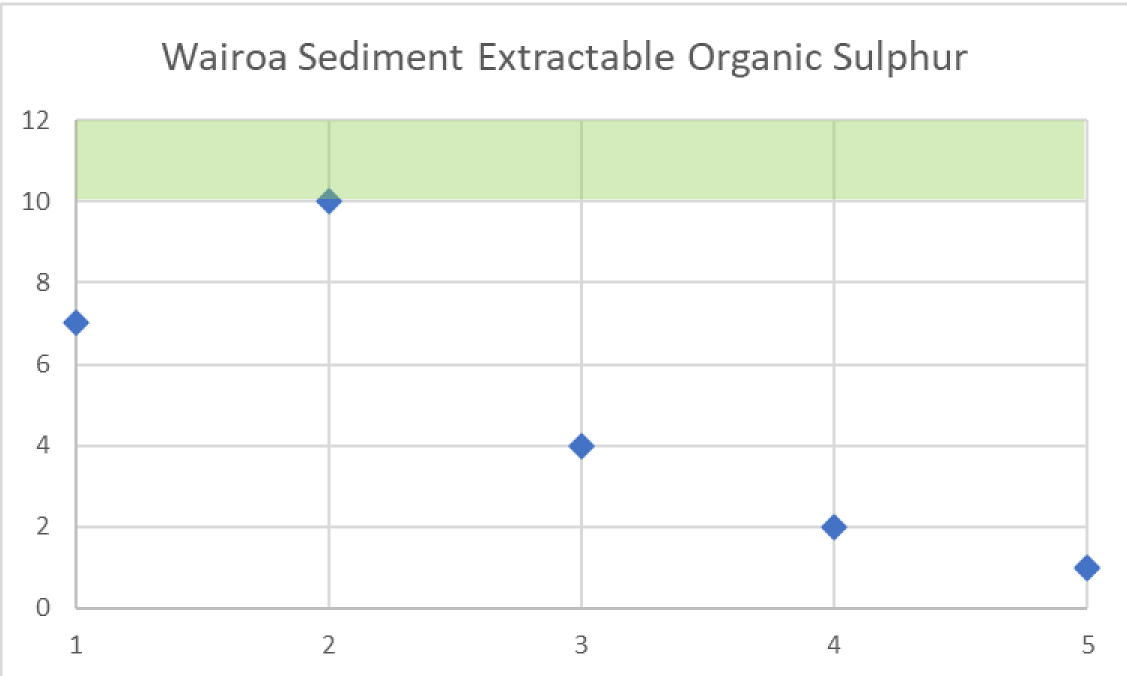

Figure 35 Wairoa sediment Extractable Organic Sulphur levels

Potentially Available Nitrogen

Potentially Available Nitrogen from the Wairoa/Nuhaka catchment is either very low (<50kg/ha) or low (50-150kg/ha) (Figure 36). This is important to consider in the use of these areas for the production of maize which has a high N demand.

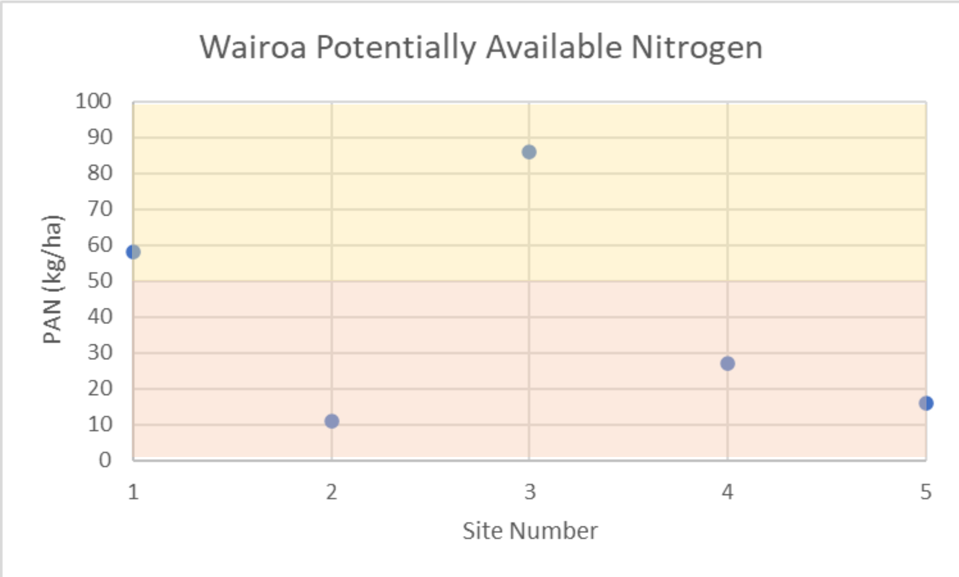

Figure 36 Wairoa sediment Potentially Available Nitrogen

Organic Matter

In Wairoa/Nuhaka the organic matter content of sediments is similar to Gisborne and is low (3-7%) to very low (<3%) (Figure 37). Low organic matter levels can relate to poor structure, nutrient availability and water retention.

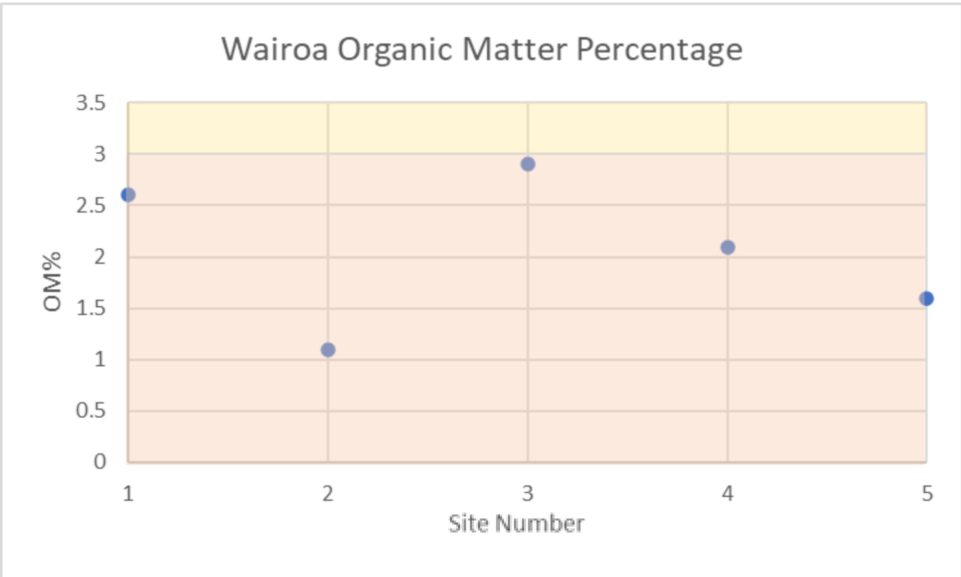

Figure 37 Organic matter content as a percentage in Wairoa sediment samples by catchment

Total N

Due to submission error Total N was not tested for on the Wairoa samples.

Northland

Overview

Sampling was carried out by Luke Posthuma, a kumara grower based in Dargaville. Sampling in Northland was delayed due to continued heavy rain and extended wetness.

In Northland, sediment deposition was minimal if any, and the main challenge was that soils remained waterlogged until June 2023. Waterlogging can affect soil properties and functions and impact production. Most plants thrive in soil with a moisture level between 20 and 60%. Above 60% plants struggle to function, as plant roots need oxygen. Maintaining adequate oxygen in the crop root zone is critical for healthy crop growth and yield. When soil is wet or waterlogged for prolonged periods, the oxygen content is reduced, and minimal oxygen is absorbed by the plant roots. The biology of the soil is also compromised when soils are wet for long periods.

Sites

The area focused on for the purpose of the sampling programme was on the Dargaville area, where sites were inundated by water from the Wairoa River. All sites belonged to growers that grow kumara and maize. Most of the impacted areas, and the sampling in this study, were kumara paddocks.

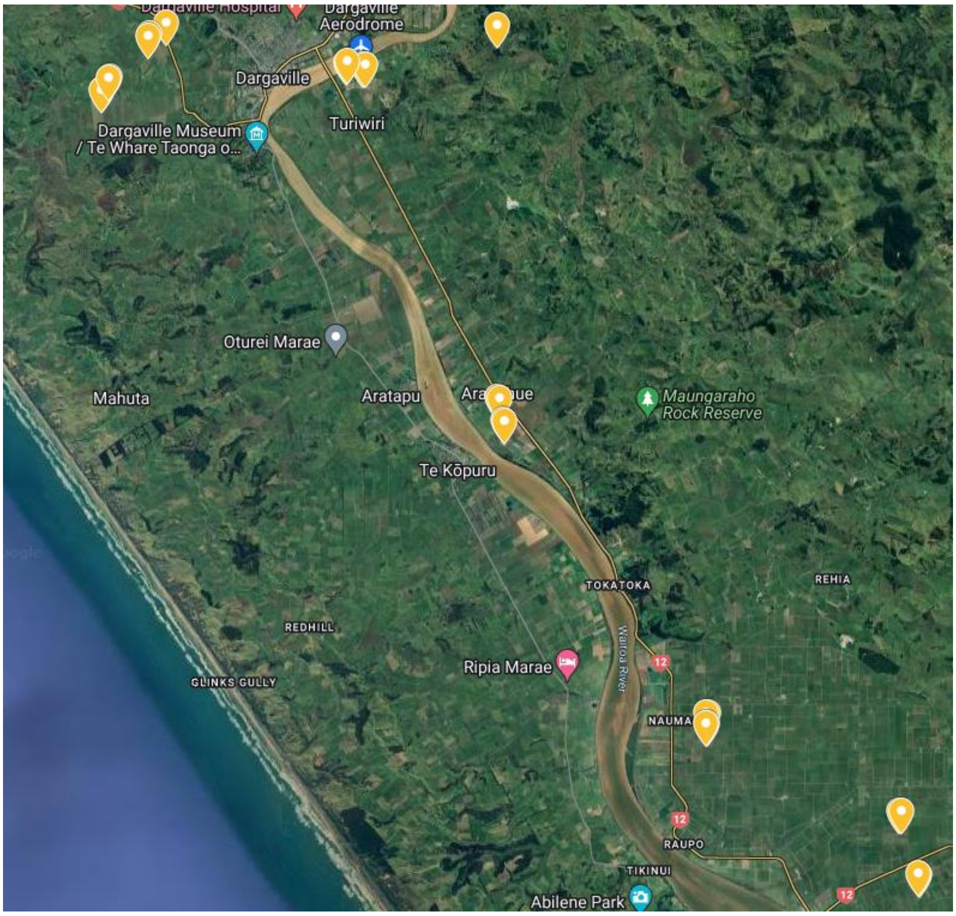

Figure 38 Map showing distribution of sites sampled (Northland)

The Wairua and Mangakahia Rivers meet north of Tangiteroria to form the Wairoa River. The river is 91 km long and drains a significant catchment area (LAWA, 2022).

Table 18 Land use types sampled (Northland)

Land Use Type	Number of sites	Number of samples
Cropping	12	12

Physical Properties

Visual Soil Assessment

VSA was completed on all 12 sites in the Northland region. Two sites had "poor" VSA scores, eight had "moderate" scores and two had "good" scores (Table 19). Given that sediment was not an issue on these sites, VSA results may be more greatly impacted by past and current management practices. The extended wet period experienced in the North, prevents the soil from drying, shrinking and cracking, all important processes that assist in sustaining and restoring physical structure. Extended wetness would also impact negatively on the biology of the soil, again limiting another important factor important in sustaining the physical health of soil.

Table 19 Visual Soil Assessment results (Northland)

Soil Quality Assessment	Number of Sites	Average Ranking Score
Poor	2	4
Moderate	8	11.25
Good	2	20

Chemical Properties

Nutrients

Nutrient tests for base soil fertility were completed for Northland sites. In contrast to the other regions, the tests were made up of existing soil only, as sediment was not deposited. Soil fertility is driven by grower management practices and natural soil characteristics. Key nutrient information is displayed, for each test there is a range of results from along the catchment.

Soil pH was generally very good with only one site below optimum (Figure 39). Olsen P ranged from below to above optimum levels (Figure 40). Sites with above the optimum range may in part reflect lower previous yields caused by wetness, which would reduce P uptake by the crop.

The low exchangeable K (Figure 41) and sulphate-S (Figure 42) levels are consistent with the extended wet periods. These low values should be factored into nutrient recommendations for the coming season.

Although not measured, one of the consequences of extended wetness is the risk of increased loss of nitrate-N through leaching and denitrification. N supply should be addressed in nutrient budgets for the coming season.

pH

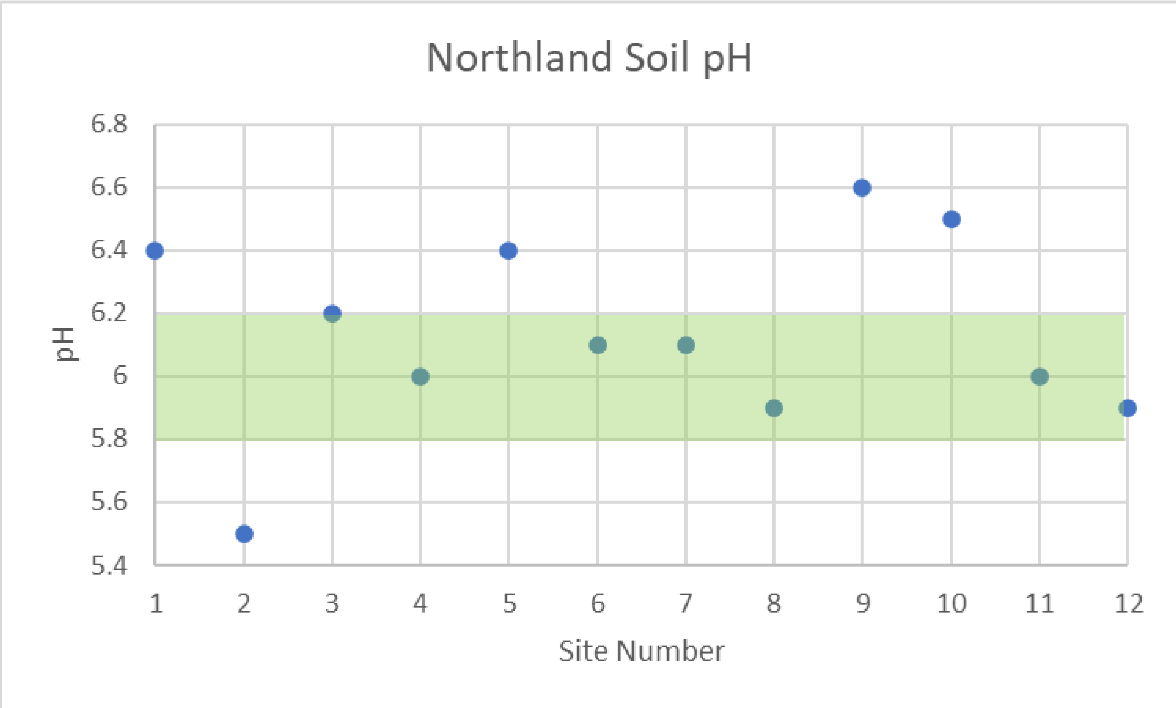

Figure 39 Northland soil pH results

Olsen P

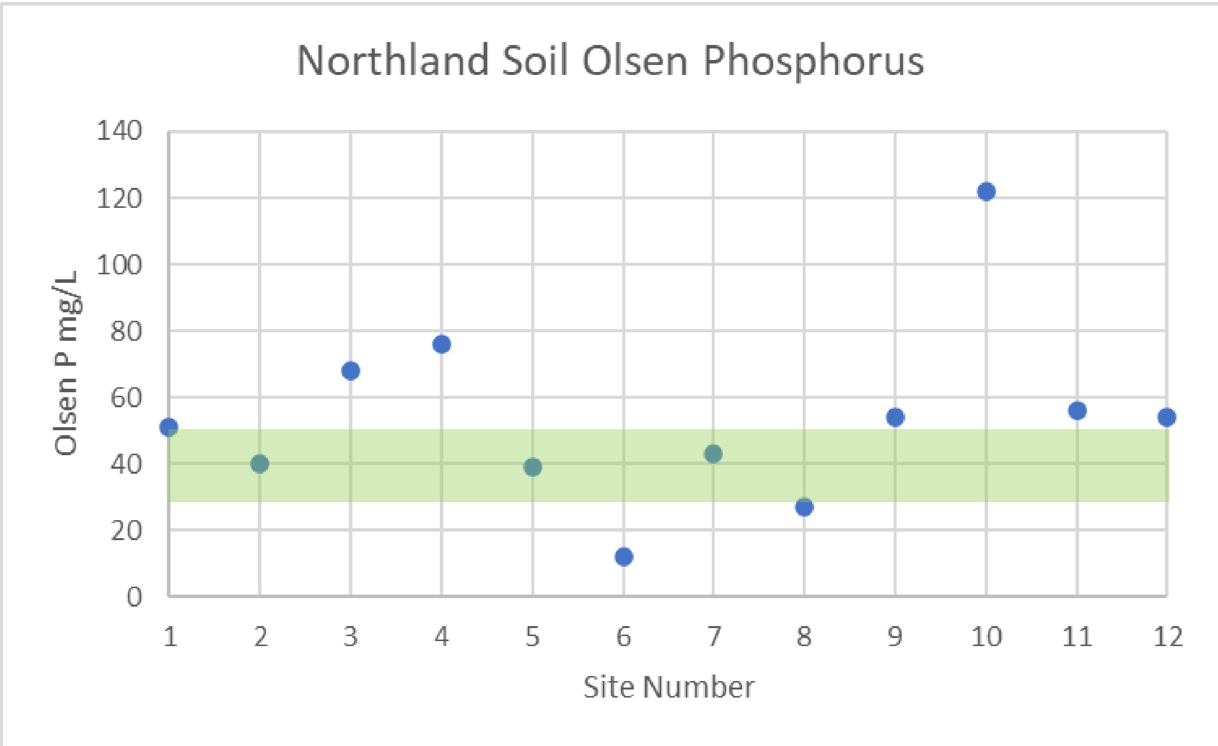

Figure 40 Northland Soil Olsen P results

Quick Test K

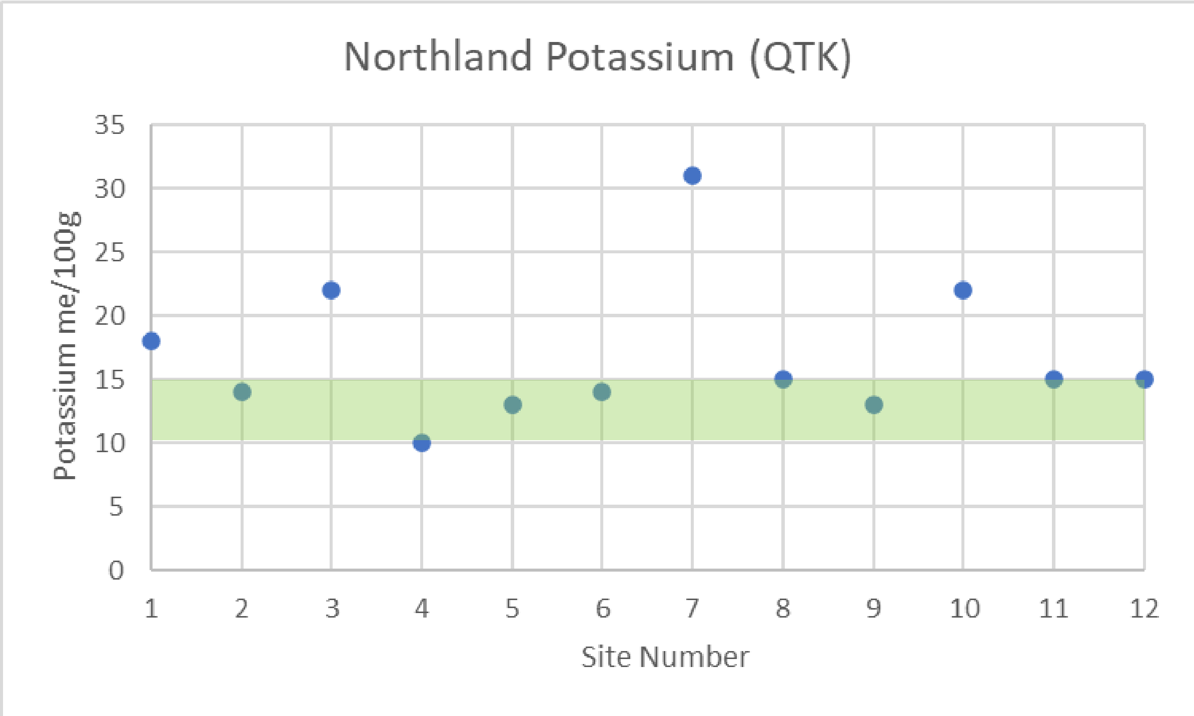

Figure 41 Northland Quick Test K results (soil only)

Sulphate Sulphur

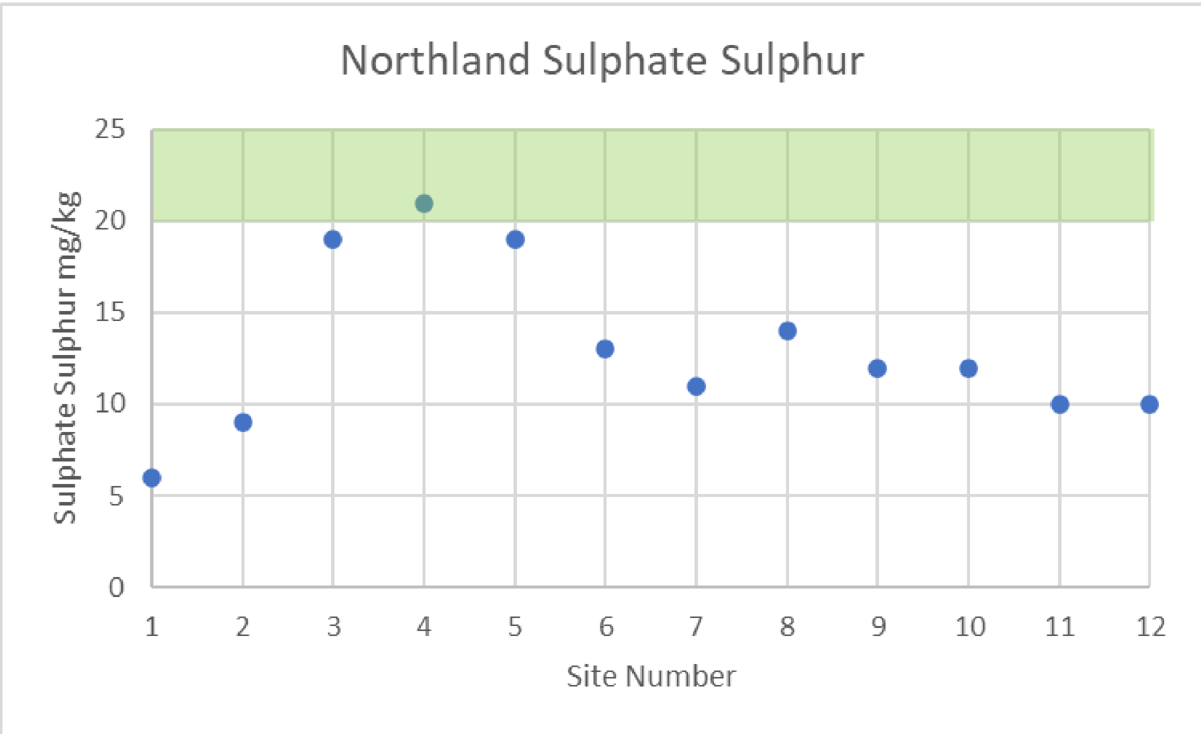

Figure 42 Northland Sulphate Sulphur results (soil only)

Organic Sulphur

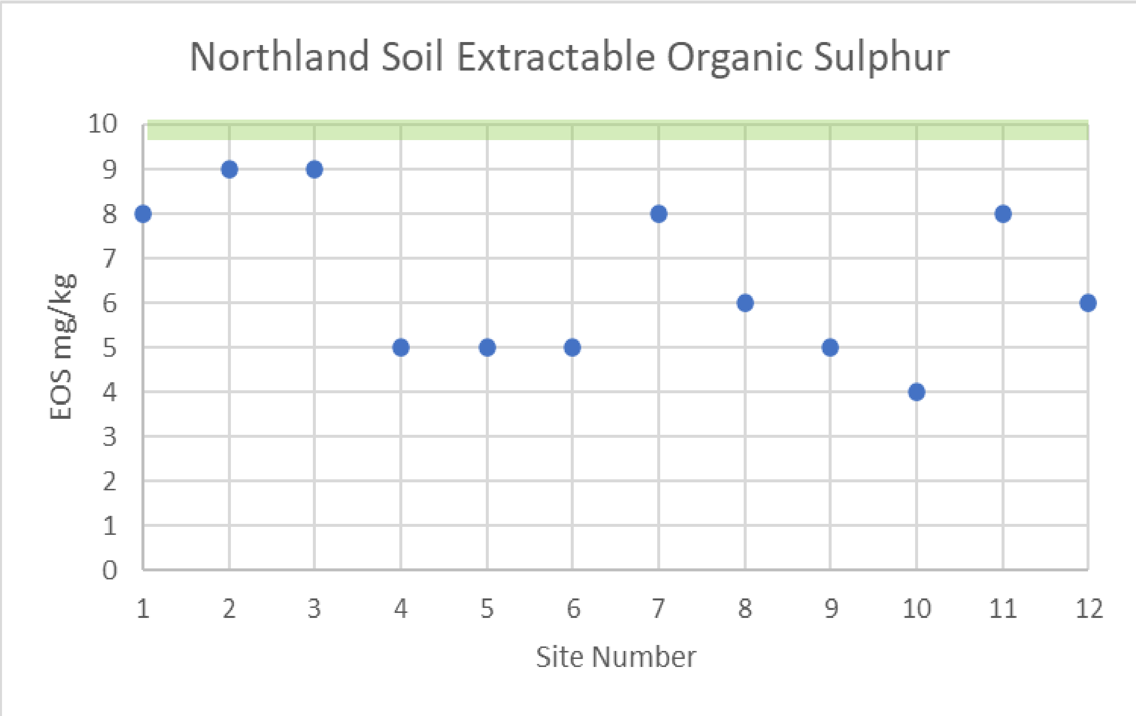

Figure 43 Northland soil extractable organic sulphur results (soil only)

Potentially Available Nitrogen

There was a range of PAN levels found in Northland (Figure 44). Sites 2, 3 and 4 have low levels (50-150kg/ha), site 7 has high levels (250-350kg/ha), and the rest of sites have medium levels (150-250kg/ha). As results are for soil only, regional soil type, previous land use and management will influence these results.

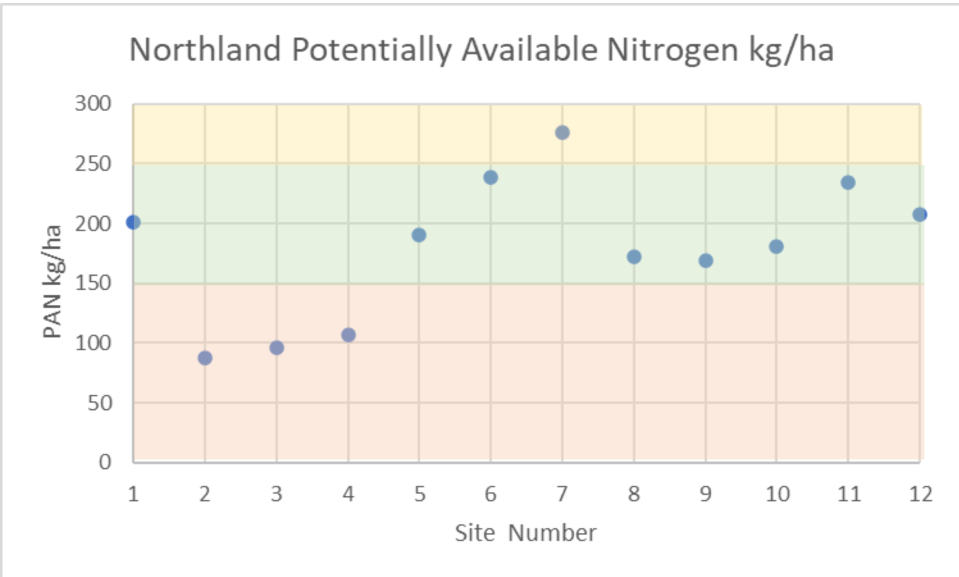

Figure 44 Northland Potentially Available N kg/ha

Organic Matter Percentage

Organic Matter percentage is low at 4 of the Northland sites at 3-7%, 6 of the sites levels are medium, and 2 of the sites levels are high (Figure 45).

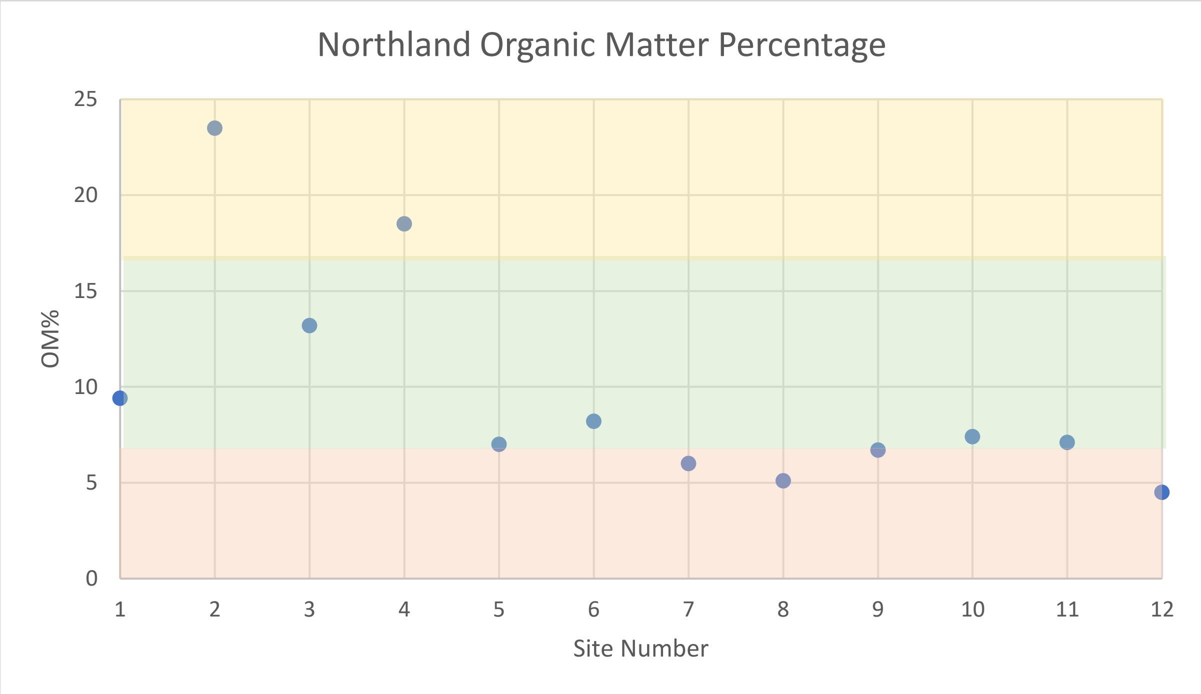

Figure 45 Soil organic matter context as a percentage found at sampled sites in Northland

Outreach

LandWISE Website

Immediately following Cyclone Gabrielle, the LandWISE website was updated to include useful resources for growers and wider industry bodies. Information included previous studies and decision support tools. The information was further shared with growers by Hawke's Bay Regional Council, Horticulture New Zealand and others. See https://www.landwise.org.nz/projects/soil-repair-after-cyclone-gabrielle/.

Grower meetings and other extension activities

Hawke's Bay Vegetable Growers' Meeting 1st March

A meeting was held for vegetable growers in Hawke's Bay to provide critical information and support to growers. Presenters included Rural Support, Hawke's Bay Regional Council, Ministry of Primary Industries, consultants etc. Dan Bloomer, LandWISE presented resources for growers and discussed key considerations for sediment management and recovery. This event was well attended by growers, advisors and other industry people.

Hawke's Bay Vegetable Growers' Meeting 20th April

A second grower meeting was held in April with a similar turn out to the first event. Mayor Sandra Hazlehurst provided council updates, alongside council staff who discussed sediment collection and waste management. Short presentations were given by those working with growers to provide updates, decision making and avenues for support. Dan Bloomer presented an update on the baseline testing project to date, as well as further useful information on sediment revegetation.

LandWISE Conference 24th - 25th May 2023

The annual LandWISE conference was held in Havelock North in late May. The event was attended by 90 delegates from across the country, and included growers, technical advisors, researchers, and council staff. The conference session 'Starting Afresh' focused on cyclone recovery, with five speakers from across the primary sector. Dereck Ferguson (Ferguson Agronomy) and Brittany McCloy (Apatu Farms) presented impacts, industry response, crop recovery and actions taken so far for the vegetable sector. From the fruit sector Sarah de Bruin (AgFirst) and Richard Pentreath (Ngai Tukairangi Trust) discussed impact to apple and kiwifruit orchards, responses, decision making and logistics and cost of orchard restoration. Alex Dickson (LandWISE) presented progress to date on the baseline sampling project and presented some preliminary findings.

Wairoa Growers' Meeting 19th June 2023

Hawke's Bay Regional Council have been coordinating recovery action in Wairoa, working closely with the nine impacted growers along the Wairoa River. Alice Wilson (HBRC Catchment Advisor) has been tasked with coordinating a catchment collective to provide resources to farmers and growers to support their response efforts. LandWISE met with HBRC and three of the impacted growers to discuss baseline sampling, lessons from Cyclone Bola, and recovery. This was followed by field trips onto four farms to look at damage and discuss pathways moving forward.

Gisborne Growers' Workshop 20th June 2023

In response to several requests for LandWISE from Gisborne growers, a workshop was organised and invitation extended to anyone interested. The event was attended by more than 40 growers with arable, apple, grape and citrus growers present, as well as technical field reps. The workshop was supported by Gisborne District Council, who presented their initial findings from the baseline sampling. LandWISE presented sampling details, observations and offered some possible pathways to recovery.

Vegetables NZ Conference Presentation 2ndt August 2023

As part of the conference presentations at the Vegetables NZ Conference held in Christchurch, Alex Dickson (LandWISE) was asked to present alongside Scott Lawson (Hawke's Bay Vegetable Growers' Association/Grower) on Cyclone Gabrielle. Scott provided an overview of initial response, and details of industry coordination. Alex discussed baseline sampling project and looked ahead to a potential longitudinal study.

NZPPS Conference Presentation 9th August 2023

The annual New Zealand Plant Protection Society Conference was held in Rotorua 8-10 August. There was a short session on Cyclone Gabrielle's impacts including a session from Plant and Food Research on work completed in apple orchards. Alex Dickson (LandWISE) presented on baseline sampling project, as well as adding a plant protection flavour, highlighting observations made during sampling including a changing weed spectrum, weeds providing ecosystem services in the short term, and potential issues associated with herbicide use on low Cation Exchange Capacity sediment deposits and low organic matter soils.

Wairoa Tour to Heretaunga Plains sites – 11th August 2023

"Wairoa coming to Central". At the request of Hawke's Bay Regional Council we arranged and co-hosted a site visit to a severely affected farm in Swamp Road, Omahu. The visit provided an opportunity to see what the grower had done and the subsequent effects of remediation management, and an opportunity to discuss possible strategies for Wairoa sites.

Wairoa Grower Meeting 29th August 2023

"Central region comes to Wairoa". At the request of Hawke's Bay Regional Council we joined a visit to farm sites in Wairoa, rounding out discussions about where to next, and what has worked (and hasn't), to build deposition affected flats back to production. This was a follow up to the previous visit, "Wairoa coming to Central".

Co-ordination of sampling

Regular "Teams" meetings have been held since the outset of the sampling. Meetings included all those involved in the sampling, reps from a wide range of sectors, councils, and ministries, and provided regular updates on progress, review of sampling protocols and sites to sample, and planning next steps.

Stakeholders

Stakeholders including the Ministry for Primary Industries and Vegetables New Zealand were provided with an interim summary report in August. Additionally, meetings have been held with other agencies to update them on progress, and to explore the interest and support for developing a longitudinal study.

References

Gisborne District Council. (2022). *Our Rivers*. Retrieved from Gisborne District Council: https://www.gdc.govt.nz/environment/our-rivers/rivers

Hill Labs. (2023). *Soil tests & interpretation.* Retrieved from Technical notes : https://www.hill-labs.co.nz/media/djdbzzhl/3196v6_technical-note-soil-tests-and-interpretation.pdf

LAWA. (2022). *Esk River* . Retrieved from Land Air Water Aotearoa: https://www.lawa.org.nz/explore-data/hawkes-bay-region/river-quality/esk-river/

LAWA. (2022). *Hikuwai River at Willowflat*. Retrieved from Land Air Water Aotearoa: https://www.lawa.org.nz/explore-data/gisborne-region/water-quantity/surface-water-zones/gisborne-east-coast-surface-water/hikuwai-river-at-willowflat

LAWA. (2022). *Ngaruroro River*. Retrieved from Land Air Water Aotearoa: https://www.lawa.org.nz/explore-data/hawkes-bay-region/river-quality/ngaruroro-river/

LAWA. (2022). *Northern Wairoa River*. Retrieved from Land Air Water Aotearoa: https://www.lawa.org.nz/explore-data/northland-region/river-quality/northern-wairoa-river/

LAWA. (2022). *Pakarae River at Pakarae Station Bridge*. Retrieved from Land Air Water Aotearoa: https://www.lawa.org.nz/explore-data/gisborne-region/river-quality/pakarae-river/pakarae-river-at-pakarae-station-bridge/

LAWA. (2022). *Tukituki River*. Retrieved from Land Air Water Aoteroa: https://www.lawa.org.nz/explore-data/hawkes-bay-region/river-quality/tukituki-river/

LAWA. (2022). *Tūtaekurī River*. Retrieved from Land Air Water Aotearoa: https://www.lawa.org.nz/explore-data/hawkes-bay-region/river-quality/t%C5%ABtaekur%C4%AB-river/

LAWA. (2022). *Uawa River.* Retrieved from Land Air Water Aotearoa: https://www.lawa.org.nz/explore-data/gisborne-region/river-quality/uawa-river/

LAWA. (2022). *Wairoa River*. Retrieved from Land Air Water Aotearoa: https://www.lawa.org.nz/explore-data/hawkes-bay-region/river-quality/wairoa-river/

LAWA. (2022). *Wharerangi Stream U/S Ahuriri Estuary*. Retrieved from Land Air Water Aoteroa: https://www.lawa.org.nz/explore-data/hawkes-bay-region/river-quality/ahuriri-catchment/wharerangi-stream-us-ahuriri-estuary/

Maungaharuru-Tangitu Trust. (2013). *Deed of settlement of historical claims.* Maungaharuru-Tangitu Trust.

Appendix 1 Sampling Method

Sampling Transects and Sediment Depth

Sampling was conducted along a 50m transect at each site, with samples collected at 0m, 25m and 50m (three points along the transect). The GPS co-ordinates for each point are recorded. The transect was measured out after the site was assessed, with the transect capturing one of the three categories. Sites impacted by sediment deposition were divided into four further categories. Previous studies of sediment deposits developed a decision support tool which discussed three different management pathways based on depth of sediment (Appendix 2).

Across the impacted regions where sediment was the issue, the depth of sediment varied widely. As sediment depth, alongside texture, were determined to be the two biggest factors when considering management options, transect location was determined based on four sediment depth classes:

- 0 cm
- < 5cm
- 5 – 20cm
- > 20cm

This is important to note as some areas had varying depths of sediment, so instead of capturing an average depth, i.e., from 5 cm to 50 cm, transects captured just one depth class, for example it would be 5 – 15cm or > 20 cm, as the management for each of these areas is quite distinct. Some sites had more than one transect and therefore more than one sample in order to capture these differences.

Depth was important to consider when taking a sample for nutrient analysis. The standard sampling depth for horticultural and cropping soils is 15 cm. In areas where sediment depth was less than 15 cm, two samples were collected for nutrient analysis.

- The first sample is of *sediment only*, the information from this sample can be used to classify sediment type etc.
- The second sample is a *mixed sample*, e.g., could be 10 cm sediment and 5 cm of original topsoil. This information is more useful to growers as this provides an indication of the nutrient levels in their new growing surface, should the sediment be incorporated.

See also “Bulk Density” which changes as sediments settle and are mixed with underlying soil layers.

Nutrient fertility

Analysis of nutrient fertility was conducted by Hill Laboratories. Samples were sent chilled so that Mineral N tests could be completed. Hill’s technical team recommended the suite of tests to be completed and included:

- Basic Soil nutrient fertility
- Extractable Sulphur
- Mineral N
- Anion Storage Capacity
- Hot Water Extractable Organic N
- Potentially Mineralisable N
- Organic Matter
- Soluble Salts
- Total P

Some sites had more than one laboratory sample completed if the sediment depth was less than 15 cm. Three categories of samples were sent for nutrient analysis; 1) no sediment 2) sediment only 3) mixed (soil and sediment). For this report, only results from the sediment samples are presented.

Nutrient information can be grouped, interpreted, and presented in several ways. For this report, nutrient information on the sediment is presented by catchment.

Contaminant Analysis

Following the cyclone there was considerable concern that the sediments may be contaminated. Contaminant tests were completed on a small number of strategically selected sites in Hawke's Bay as 'spot checks' to see if there was reason for concern. Contaminant samples were collected from sediment only, to avoid the previous soil surface influencing the results.

Collected with grower and industry approval, samples were sent to the laboratory anonymously. Testing was completed by Hill Laboratories and included:

- Multiresidues Pesticides
- Acid Herbicides
- Faecal Coliforms and *E. coli* Profile
- Heavy Metals

Visual Soil Assessment (VSA)

Visual soil assessment is a tool developed for farmers and growers (as well as wider industry) to assess the physical properties of soils, a key element of soil quality. This method of determining soil quality is relatively quick and can be completed in the field on a paddock scale across a farm. A 20cm cube of soil is dug, dropped several times on to a hard surface from 1m height, and then graded based on size of the resulting clods of soil. Reference images are then used to score structure, porosity, colour, and mottling, and earthworm numbers are counted.

Three VSAs were completed along each transect as an assessment of the sediments' "soil quality". Where sediment depth was less than 20cm, the test included some underlying soil. The soil conditions in which these VSAs were completed was not ideal, as the samples were very wet, however useful information was captured from the process and baseline photos taken. See Figure 46 for two examples of VSAs from different sites.

Figure 46 Examples of Visual Soil Assessment Results

An adapted VSA scorecard based on VSA Volume 1was used for baseline sampling (Table 20). Each indicator is given a weighting which contributes towards a total score.

Table 20 An example of an Adapted VSA scorecard completed for a site as part of sampling.

Visual Indicator	VS Score 0= Poor 1= Moderate 2= Good Condition	Weighting	Maximum Score
Porosity		X 3	6
Colour		X 2	4
Mottles		X 2	4
Structure		X 3	6
Earthworm abundance	>35= 2 29-35= 1.5 22-28= 1 15-21=0.5 <15= 0	X 2	4
		Maximum score	24

Soil Quality Assessment	Ranking Score (Baseline Sampling
Poor	<7 (<30% of total score)
Moderate	7-18 (30-74% of total score)
Good	>18 (>74% of total score)

Bulk Density

Soil bulk density is the weight of soil in a specified volume. Bulk density rings are used to take a sample core of soil of a known volume. The soil is dried and weighed to determine 'dry bulk density'. Bulk density is typically used as a measure of soil compaction and soil physical quality. For baseline sampling, bulk density is also used to understand more about the sediment type. Typically the larger the soil particle size, the higher the bulk density, so sands will have a higher bulk density (e.g., 1.6g/cm3) compared to clays (e.g., 1.1g/cm3), with silts being somewhere in the middle (e.g., 1.3g/cm3).

Three 10cm bulk density cores were taken per transect, and processing was completed by AgResearch in Palmerston North.

Earthworm abundance and biology

While soil biology is difficult to measure, how soil biology responds after an event like Cyclone Gabrielle is a key area of interest. Earthworm numbers can be used as a 'proxy' for soil biology i.e., if soil quality is good more earthworms will be present, acting to an extent as a surrogate for other microscopic soil biology.

Earthworms were counted as part of the VSA sampling, and the estimated total population over a given area was calculated. Earthworms collected along each transect were sent to Dr Nicole Schon at AgResearch for identification to species and functional group. The purpose was to determine what surviving populations might be present in different scenarios and follow changes over time.

Figure 49 Examples of earthworms found in sediment deposits.

Texture

The texture of sediment deposited is related to water velocity. It varies across and along river flow paths and catchments and is influenced by factors such as sediment source, distance from a stop bank breach or water movement slowing through an orchard. Typically, sandy material is deposited

Figure 50 Example of two sediment deposits on one site

at the higher reaches of a river where water velocity is fastest and as water movement slows, more of the silt, then clay, fractions will be deposited. Sediment texture is an important factor for growers to consider in recovery efforts, as it is likely to influence nutrient content, moisture content and revegetation options. Textural samples were taken from each site and sent to Dr Alan Palmer at Massey University for analysis. In some situations there were two distinct layers of sediment deposited, in which case two samples were sent to be analysed.

Soil texture has been categorised as per the USDA texture nomenclature. Textural class information is attached as Appendix 3.

Environmental DNA (eDNA)

Environmental DNA is a way to determine and classify microbial populations present in soil and water, providing information about soil biology and microbial communities. Samples were collected and frozen as part of baseline testing. Should future funding provide opportunity for analysis, these samples collected soon after the event can be used with additional sampling over time to describe changes to population.

Appendix 2 Regrassing Decision Tree 2004

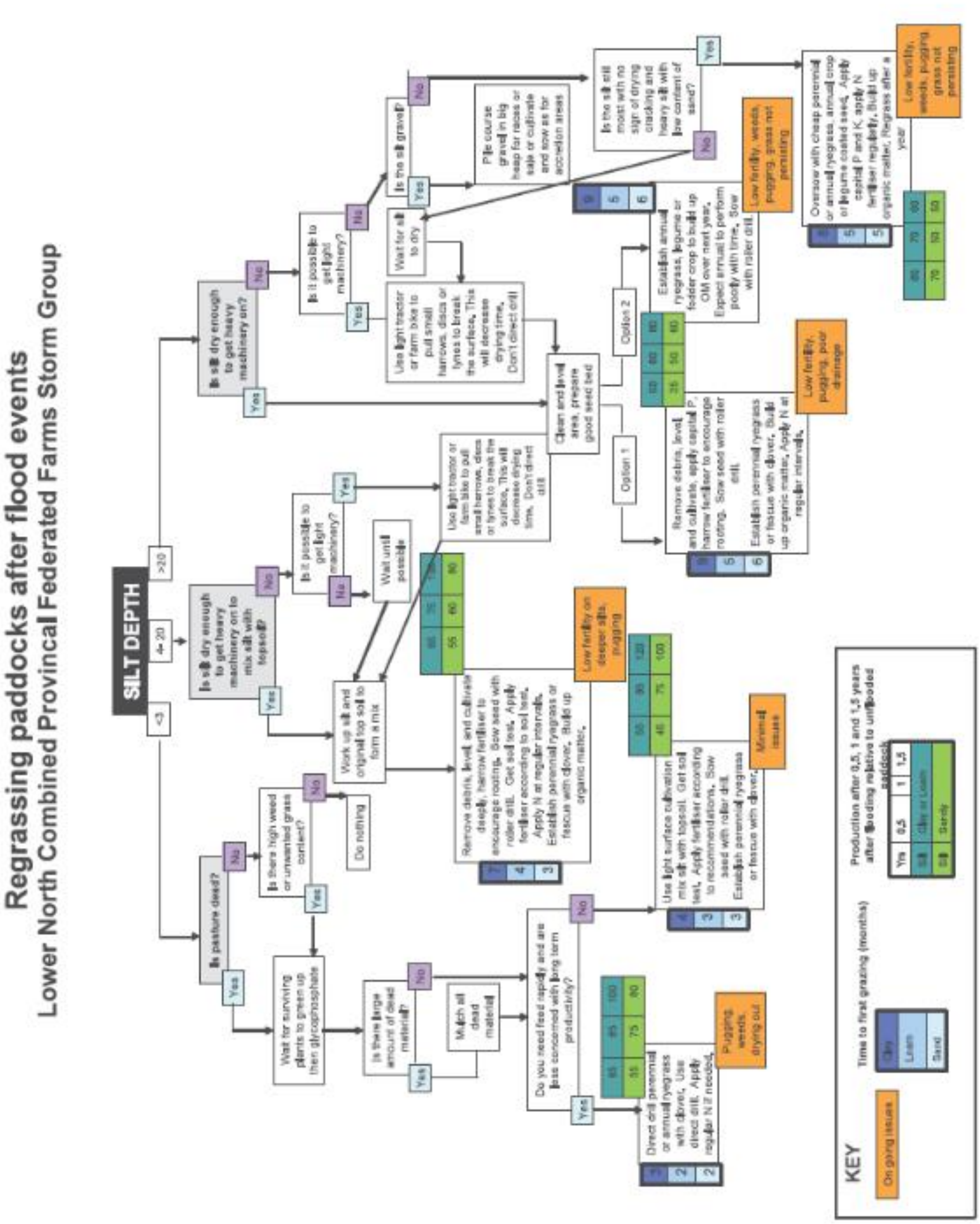

Figure 51 Decision tree for regrassing paddocks after flood events (Lower North Island Combined Provincial Federated Farms Storm Group)

Appendix 3 USDA Textural Triangle

Retrieved from https://www.researchgate.net/figure/USDA-Soil-Texture-Triangle_fig2_279631053

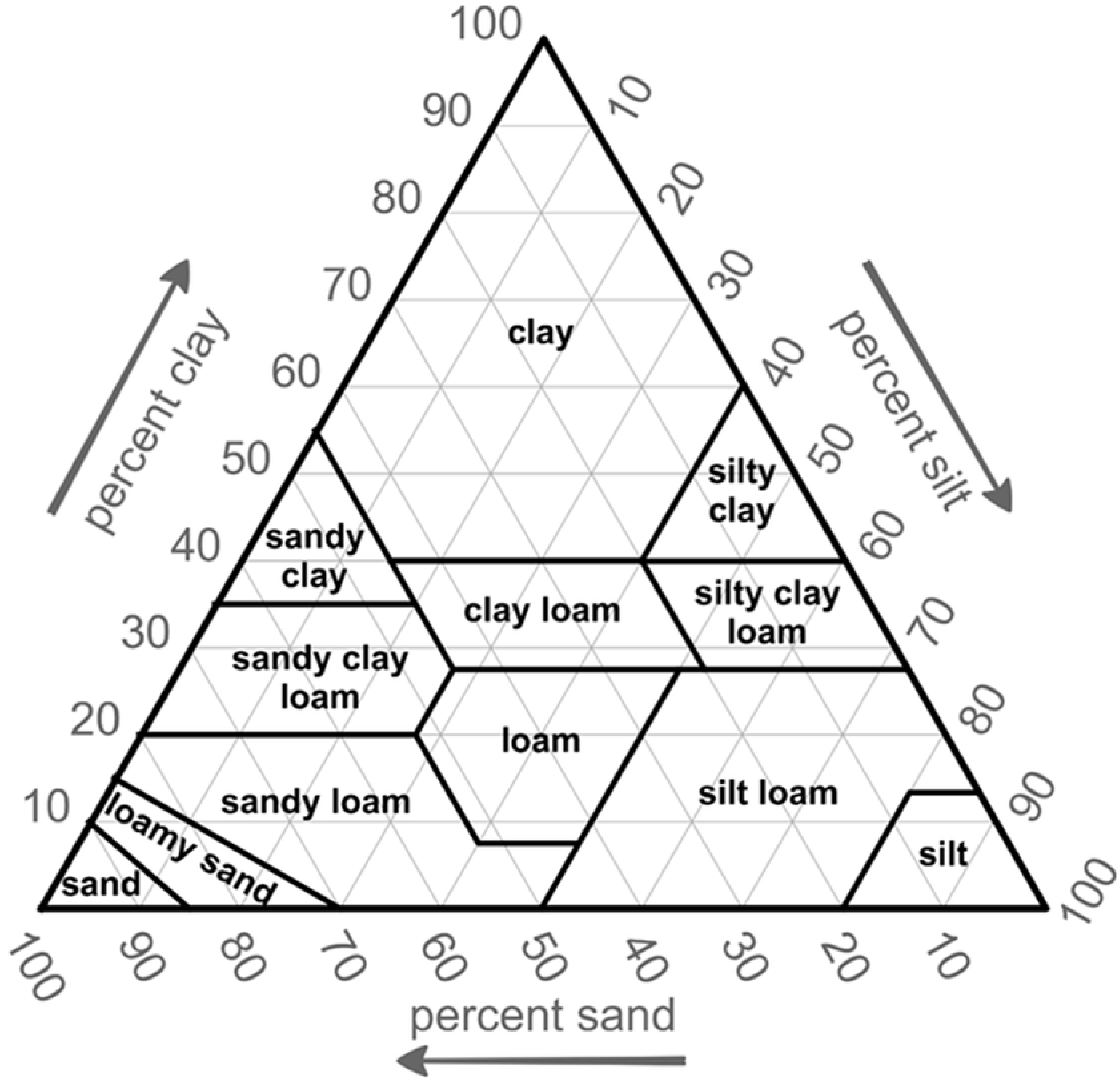

Figure 52 Soil texture triangle (USDA)

Appendix 4 Contaminant Results Summary Report

Assessment of potential contaminants present in sediment samples post-cyclone Gabrielle

Jo Cavanagh
Manaaki Whenua Landcare Research
Prepared for LandWISE, Hawke's Bay
September 2023

Introduction

LandWISE undertook sampling of sediment deposited at 14, predominantly vegetable cropping, sites in the Hawke's Bay area post-cyclone Gabrielle to assess potential biological and chemical contamination. Samples were collected using a 15cm corer with approximately 15 to 18 cores collected along a 50m transect and composited as one sample. The results biological and contaminant analysis (pesticides, metals) along with other parameters including, pH, texture and CEC, and some site information, were provided to Manaaki Whenua for interpretation. This note provides assessment of the results of pesticide and trace element contaminant analyses.

Summary of results

For all sites except one, samples of the deposited sediment were collected, and sediment depth noted. At site 11, deposited sediment had been cultivated into the underlying soil, hence a mixed soil and sediment sample was collected for analysis. A summary of the chemical analysis results is provided in Table 1.

The pH of the sediment samples (6.9-8.1) appears to be generally higher than is typically observed at state of the environment soil quality monitoring sites (typical range 6-7). A higher pH can reduce the bioavailability of metals – including essential elements such as copper and zinc.

With the exception of copper concentrations at site 11, trace element concentrations are largely within naturally occurring concentrations for the region (Cavanagh et al 2023). Copper concentrations at site 11 are remarkably high and fall between ecological soil guideline value protecting 80% and 95% of soil species (110 mg/kg - 95% protection; 245 mg/kg – 80% protection for a typical soil (pH> 5,4, CEC c.20 cmol/kg), Cavanagh and Harmsworth 2023). This site is the only location where a mixed soil and sediment sample was collected and suggests that the elevated copper is present in the soil. It would be useful to consider reducing any ongoing inputs of copper at this site, and to assess the biological health of soil at this site to ensure that functioning of the soil is not impaired (including crop productivity). Sediment from sites 8, 12 and 13 have very similar profiles in trace element concentrations, which are different to the other sites, suggesting a similar source of the deposited sediment.

Table 21 Summary of sampling sites and results of chemical analysis.

Sample Name	Location	Land Use Type	Sediment depth	pH	CEC	Trace element concentrations (mg/kg)							# Pesticides detected[1]
						As	Cd	Cr	Cu	Pb	Ni	Zn	
Site 1	Fernhill	Vegetable Cropping	<5cm	7.3	26	8	< 0.10	23	15	17.1	17	71	-
Site 2	Fernhill	Vegetable Cropping	5-20cm	7.8	35	9	< 0.10	25	11	17.6	18	71	-
Site 3	Meeanee	Vegetable Cropping	>20cm	7.9	33	8	0.12	23	10	16	16	62	-
Site 4	Pakowhai	Vegetable Cropping	>20cm	7.6	29	9	0.11	27	17	23	21	88	-
Site 5	Meeanee	Vegetable Cropping	>20cm	7.9	37	9	0.19	29	12	18.7	20	78	4[2]
Site 6	Meeanee	Vegetable Cropping	5-20cm	7.6	34	8	0.1	24	12	16.5	18	69	-
Site 7	Meeanee	Vegetable Cropping	5-20cm	7.6	37	9	0.11	29	12	18.7	20	75	-
Site 8	Puketapu	Orchard	5-20cm	7.6	27	4	< 0.10	14	5	7.6	10	40	-
Site 9	Pakowhai	Pasture	>20cm	7.7	36	9	0.11	25	12	18	18	74	-
Site 10	Pakowhai	Cropping	5-20cm	7.5	34	-	-	-	-	-	-	-	1[3]
Site 11	Twyford	Cropping	<5cm	6.9	25	13	0.17	18	151	19.6	13	84	-
Site 12	Puketapu	Vineyard	>20cm	7.7	26	4	< 0.10	14	5	7.7	10	39	-
Site 13	Esk	Vegetable Cropping	>20cm	8.1	16	2	< 0.10	12	3	4.6	8	31	-
Site 14	Otane	Vegetable Cropping	>20cm	7.2	21	9	0.14	19	21	26	16	84	-

[1]A total of 192 pesticides tested for as pesticide suite, organochlorine pesticide suite
[2]Alachlor – 0.082 mg/kg; Cyhalothrin – 0.027 mg/kg; Metribuzin – 0.049 mg/kg; Procymidone – 0.196 mg/kg
[3]Pendimethalin – 0.024 mg/kg

Pesticide residues were detected in only two samples, with four residues detected at site 5 (herbicides – alachlor and metribuzin, insecticide – cyhalothrin, fungicide - procymidone) and one at site 10 – the herbicide pendimethalin. Procymidone was present in the highest concentrations at 0.196 mg/kg. Information on the toxicity (and other information) of all detected residues to soil organisms is available from the University of Hertfordshire Pesticide properties database (http://sitem.herts.ac.uk/aeru/ppdb/en/), largely sourced from existing dossiers for pesticide registration. A summary of the available data is provided in Table 22, and suggests that no negative effects on soil organisms would be expected at the observed concentrations. No information was available on concentrations that might elicit non-target plant effects for the two herbicides (alachlor, metribuzin), although observed concentrations are generally low. It is unclear why site 5 has the highest number of residues – it is in close proximity to site 7 in particular, and over time these sites often appear to have been managed as a single pastoral land management unit (assessed via google earth imagery). The most recent imagery (04/2023) suggests site 5 may be slightly lower lying than the surrounding area, hence may be a preferential deposition zone for fine sediment containing pesticide residues.

Table 22 Summary of terrestrial toxicity data and environmental half-life (days) for pesticide residues detected in sediment samples.*

Pesticide	**Terrestrial Toxicity data[1]**	**Environmental half-life (lab DT50, 20C) days**
Alachlor	Earthworms -acute 14 day LC50 – 368 mg/kg	35
Cyhalothrin	Earthworms -acute 14 day LC50 – >1000 mg/kg	57
Metribuzin	Earthworms -acute 14 day LC50 – >1000 mg/kg Earthworms reproduction NOEC - >52 mg/kg No significant effect on carbon or nitrogen mineralisation in 28 day study.	7
Procymidone	Earthworms -acute 14 day LC50 – >1000 mg/kg No significant effect on carbon or nitrogen mineralisation at 20 mg product/kg.	784
Pendimethalin	Earthworms -acute 14 day LC50 – >1000 mg/kg Earthworms reproduction NOEC – 33.45 mg/kg No significant effect on carbon or nitrogen mineralisation at 20 kg/ha Collembola (springtails) chronic NOEC – 193 mg/kg.	182

*Source: University of Hertfordshire Pesticide Properties Database. http://sitem.herts.ac.uk/aeru/ppdb/en/index.htm

[1] LC50 - lethal concentration at which 50% of the test population died; NOEC – no observable effect concentration

Conclusions

There is no evidence for chemical contamination present in the deposited sediments. Trace element concentrations were largely within background concentrations across the region. Remarkably high copper concentrations were detected at one sampling site and warrants further investigation including assessment of current state of the biological health of the soil. Opportunities to minimise any ongoing copper should be considered. Pesticide residues were detected at two sampling site locations, although the source for these residues is unclear.

References

Cavanagh JE, McNeil S, Thompson-Morrison H, Roudier P, Martin A, Turnbull R 2023. Determining background soil concentrations of trace elements across New Zealand. Manaaki Whenua – Landcare Research Contract Report LC4324. Envirolink Grant: 2321-HBRC267.

Cavanagh JE, Harmsworth G 2023. An implementation framework for ecological soil guideline values. Manaaki Whenua – Landcare Research contract report LC4311. Envirolink Tools Grant C09X2206

Appendix 5 Notes on Bulk Density and Total Porosity

Alan Palmer

Massey University

Soils with a bulk density higher than 1.6 g/cm3 tend to restrict root growth. Bulk density increases with compaction and tends to increase with depth. Sandy soils are more prone to high bulk density.

- Measures mass/unit volume, so includes pore spaces but not the mass of water within
- Most NZ soils in the range 0.6-1.8 Mg m^{-3}
- Organic, Pumice and Allophanic soils are lowest.
- Pallic and Podzol soils highest
- Topsoils are generally lower bulk density than subsoils because of the influence of organic matter and aeration by earthworms on soil structure.
- Sandy soils are generally higher density than clay rich soils, particularly if the sand particles are even sized and well packed.
- Clay rich soils usually have greater total pore space leading to lower density.
- The same applies to rocks. Closely packed sandstones have higher density than mudstone.
- When sediment is gently settled through water, as in a flood, the particles are loosely packed with water filled voids between.
- If the samples taken for dry bulk density are carefully taken from wet sediment in the field and dried in the laboratory, this open framework remains, and bulk densities recorded can be very low.
- As flood sediment dries in the field, cracks develop. This shows that the sediment is becoming denser as the water drains, evaporates or is transpired through vegetation cover. High densities can result.
- Therefore, bulk density results must be interpreted with the state of the sediment (wet, cracking, or dry) in mind.
- This will depend on landscape position and underlying soil, sediment texture, days since flooding, vegetation cover and weather conditions.

Notes on particle density

- Measures mass/unit volume of the solid portion of the soil or sediment, so excludes pore spaces.
- Most quartzo-feldspathic rocks such as greywacke, sandstone and mudstone are dominated by quartz and feldspar with specific gravities of 2.65 and 2.55-2.63 respectively.
- Sediments derived from quartzo-feldspathic rocks whether sand silt or clay, tend to have particle densities in the range 2.5-2.7 with sediment 0n the lower side of the range containing more clay, and sediments on the upper side of the range containing more sand with some heavier minerals such as titanomagnetite (4.5-5.5 Mg m^{-3}) or ferromagnesian minerals (3-4 Mg m^{-3}).
- Sediments and soils with appreciable organic matter can have lower particle density because organic matter is generally in the range 0.8-1.1 Mg m^{-3}.
- Sediment and soils with appreciable rhyolitic volcanic glass can have slightly lower particle densities because rhyolitic glass has a particle density of about 2.5 Mg m^{-3}.

Notes on total porosity

- Total porosity is calculated as 1- (pb/ps) where pb is dry bulk density and ps is particle density.
- Porosity is influenced by texture and the way that sand, silt, and clay particles are packed.
- Sediments deposited by moving currents, such as on the bed of a river, are usually more tightly packed with fewer pore spaces.
- Sediments gently settled through still water are loosely packed until either dried or compacted by the weight of more sediment on top.
- Total porosity of soils is influenced by texture, mineralogy (quartzo-feldspathic vs volcanic parent materials), formation of structure and earthworm activity.
- Wetting and drying of soils tends to lower total porosity as particles pack more tightly together.
- Compaction by traffic or animals lowers total porosity.
- Total porosity is a crude measure and far less important than the distribution of pore sizes and their connectivity.
- Connected macropores (> 63 microns) provide drainage and aeration.
- Mesopores (2-63 microns) provide plant available moisture storage in the soil.
- Fine pores may store water but generally this water is not available to plants and nor does it drain readily from the soil.