Manaaki Whenua
Landcare Research

Considerations for the beneficial use of sediments from stormwater ponds across Auckland

Prepared for: Auckland Council

December 2023

Considerations for the beneficial use of sediments from stormwater ponds across Auckland

Contract Report: LC4384

Jo Cavanagh, Robyn Simcock, Hadee Thompson-Morrison

Manaaki Whenua – Landcare Research

Reviewed by:	*Approved for release by:*
John Drewry Senior Researcher Manaaki Whenua – Landcare Research	John Triantafilis Portfolio Leader – Managing Land & Water Manaaki Whenua – Landcare Research

Disclaimer

This report has been prepared by Landcare Research New Zealand Ltd for Auckland Council. If used by other parties, no warranty or representation is given as to its accuracy and no liability is accepted for loss or damage arising directly or indirectly from reliance on the information in it.

Contents

Summary

Project and client

- Healthy Waters, Auckland Council, is responsible for maintaining over 650 stormwater ponds in the Auckland region. This includes periodic removal of sediments ('desilting'), which reduces pond capacity.
- Auckland Council contracted Manaaki Whenua – Landcare Research to provide advice on what factors to consider to enable the beneficial reuse of stormwater pond sediments.

Objectives

- Identify and assess the factors influencing the beneficial reuse of stormwater pond sediments.
- Develop a decision flow chart for determining management options for pond sediments.

Methods

- We carried out discussions with council staff and contractors, participated in a workshop hosted by Healthy Waters (March 2023), and reviewed the relevant literature to identify the available information on stormwater pond sediment and practices influencing its beneficial reuse.
- We sampled seven ponds across Auckland to provide an indication of the variation in metal contaminant concentrations, and selected attributes for assessing beneficial use (pH, nutrient levels).
- We undertook a beneficial reuse trial at Portland Road to assess the suitability of excavated sediments (dredged and digger-excavated) for native plant growth compared with site-won topsoil.
- Information from the above research was used to develop a decision flow chart to help inform the beneficial use of sediments by Auckland Council.

Results

- An analysis of sediments from a cross-section of pond types in the Auckland region showed that the excavated sediments generally contained soil properties beneficial for plant growth, and in most cases contained greater nutrients than *in situ* or imported topsoils.
- The Portland Road plant growth trial demonstrated the potential for excavated sediment to be beneficially used within a root zone as a substitute topsoil, with higher macro-nutrient status and higher plant water storage and supply than site-won soils. This trial also showed that flocculant use may lead to sustained low pH in sediments, which negatively affects plant growth, including native species.
- However, low pH of the digger-excavated sediment indicated that flocculant use is not the only reason for low pH at this site: the trial highlighted a marked reduction in zinc concentrations in the soil over the first year after placement, which is likely to be

due to the leaching of zinc from the soil given the low pH of both flocculated and digger-excavated sediments. This leaching appears to have stabilised after 12 months (and possibly earlier), as soil concentrations of zinc and copper at 18 months were similar to those at 12 months.

- The high sulphate content of sediments from Portland Road, combined with their low pH, may indicate that acid-sulphate soils were present in these sediments.

Conclusions

- What constitutes beneficial use needs to be clarified. For example, the burial of entire geobags containing excavated sediment within a landscaping bund is effectively disposal at a different location, because the sediment cannot be readily accessed by plant roots, and natural water-flow pathways may be disrupted. (This can be remedied by removing or slitting the geobag.)
- This project, including the development of the decision-making flow chart, focused on inorganic metal and metalloid contaminants (in particular zinc) rather than organic contaminants such as hydrocarbons, for three main reasons.
    - Metal contaminants, unlike organic contaminants such as hydrocarbons, cannot be degraded through biological or abiotic processes.
    - The ability of microbial communities to degrade organic contaminants is limited by high concentrations of metals, so it is important to ensure that metal concentrations are at levels that enable the ongoing degradation of organic contaminants. Information (e.g. concentration data) on organic contaminants will probably be required to meet regulatory requirements.
    - Zinc is widely recognised as the primary contaminant in urban sediments, frequently co-occurring with hydrocarbons (i.e. sediments that contain high concentrations of zinc are also likely to contain high concentrations of hydrocarbons). Therefore, managing sediments based on zinc concentrations will also manage organic contaminants in most cases.
- Considerations for the beneficial use of sediments removed from stormwater ponds and the beneficial use of ‘surplus’ soils[1] have substantial overlaps. These overlaps include the nature of beneficial use, contaminant concentrations identified as acceptable for reuse, and appropriate characterisation of the sediments or soils to match an identified beneficial use.
- The beneficial use of stormwater pond sediments is more complicated than for surplus soils due to the additional requirement for dewatering (and potentially also ‘ripening’/aeration) of the sediments to enable beneficial use. Nonetheless, in both cases a key challenge is linking the source site with an appropriate recipient site. The use of intermediary sites to stockpile and, where appropriate, process (e.g. dewater, ripen, amend sediments) is seen as a potential solution.
- Economic evaluation is required, probably on a case-by-case and sub-regional basis, to identify where cost savings can be made through the beneficial use of the removed

---

[1] Soils disturbed through land development processes that are unable to be beneficially used on-site

sediments. Key factors influencing cost are transportation distances and landfill disposal costs.

- Transport emissions and landfill space in addition to the value of beneficial use value – which can include enhanced amenity value of green space, reducing flood-prone areas, increasing the resilience of soils at receiving sites to drought, and nutrient loss (from suitable sediments) – are additional factors to consider when identifying the 'best' option.

Recommendations

- Further information is required to ensure environmental risks are appropriately managed. Specifically, evaluation is required to assess:
    - the potential leaching of metals during sediment 'ripening' processes (including dewatered, flocculated geobag sediments) to ensure that any associated risk to ground- or surface water is appropriately managed
    - the potential for ponds to contain acid-sulphate soils
    - whether the flocculants used are compatible with the proposed beneficial use (in the first instance this would simply involve a stock-take and literature review of flocculants commonly used in desilting operations).
- The pH of removed sediments should be routinely measured. This is a critical measure to assess the suitability of the sediment for use, particularly to identify when lime addition may be required to facilitate beneficial plant growth and reduce the potential for leaching of metals.
- Geotechnical suitability and compaction rates post-placement may need to be assessed to inform some beneficial uses; for example, the use of sediments in a landscaping bund, and for both geobag-contained and uncontained (ie digger-excavated, or removed or slit geobag) sediments.
- Sediments should be sampled *in situ*, prior to desilting operations, to provide a greater lead-time to assess potential beneficial use options. This information should be systematically captured to build a greater understanding of the beneficial (texture, total carbon, nitrogen, phosphorus, Olsen phosphorus) and constraining (pH, trace elements) characteristics of sediments in stormwater ponds across Auckland.
- The Canadian *Inspection and Maintenance Guide for Stormwater Management Ponds and Constructed Wetlands* (TRCA 2018) provides wider information on practices for the management and maintenance of stormwater treatment facilities that may be useful for Healthy Waters to consider, alongside an evaluation of existing design, maintenance, and desilting operations. Similarly, Australian guidance on the dredging of acid-sulphate soil sediments and associated dredge spoil management (Simpson et al. 2018) may be useful to consider if the potential occurrence of acid-sulphate soils in stormwater ponds is identified.
- It would be helpful to systematically capture costs and volumes of sediment removed from different ponds to build a better picture of what items create the greatest cost, and to consider that alongside costs and benefits of beneficial use.
- Efforts to facilitate the beneficial reuse of stormwater pond sediments should be coordinated with emerging efforts to facilitate the beneficial reuse of surplus soils.

1 Introduction

Healthy Waters, Auckland Council, is responsible for maintaining over 650 stormwater ponds in the Auckland region, which includes desilting the ponds. Auckland Council is keen to explore options to enable beneficial reuse of the resulting sediments and, in the process, avoid unnecessary carbon emissions and costs associated with transport to, and disposal at, landfills, and taking up valuable landfill space.

Healthy Waters has a discharge consent target of 10,000 tonnes per annum of sediment from about 30 ponds and wetlands, with recent annual rates ranging between 1,900 and 4,000 tonnes. Some alternative uses have been considerably cheaper than existing limited treatment and disposal in landfills. Auckland Council could also offset management activities if alternative uses increased soil carbon and plant sequestration.

Currently identified alternatives include the use of sediments as a soil amendment or material for creating elevated topographic features (e.g. bunds) in council reserves, roadsides or farm parks, and additional capping material on old landfills. Ponds may also be converted to wetlands.

Auckland Council contracted Manaaki Whenua – Landcare Research (MWLR) to provide advice on the factors to consider in enabling the beneficial reuse of pond sediments.

2 Objectives

- Identify and assess the factors influencing the beneficial reuse of stormwater pond sediment.
- Develop a decision flow chart to determine management options for pond sediment.

3 Methods

3.1 Workshops and literature review

Various discussions were held with Auckland Council staff to identify what information is available on stormwater ponds and their chemical composition, and to gain an understanding of the regulatory processes that influence decision-making on the beneficial use of stormwater pond sediments. A workshop was organised by Healthy Waters in March 2023 to bring together the various parties involved in the management of stormwater ponds in Auckland. The aim was to explore opportunities for the sustainable management of stormwater ponds, and, in particular, for reducing the amount of stormwater pond sediment being disposed to landfill. Attendees included stormwater pond designers (WSP, Aurecon), physical works contractors (Glasgow Contractors), consultants involved in the management of stormwater devices for Auckland motorways (WSP), MWLR, and various Healthy Waters staff members.

3.2 Pond sampling

To gain an understanding of the variation in attributes that might influence the beneficial use of sediments, sediment from a cross-section of ponds of various ages (broadly categorised as old and young) was collected, along with information on surrounding land use and removal method (Table 1).

Two removal methods are used: digger excavation and sediment dredging (Figure 1). Dewatered, 'digger-excavated' sediment comprises sediment and attached plant roots excavated by a digger, then put into the back of a truck and stockpiled or transported to landfill. No flocculant is added. Digger-excavated sediment can contain larger chunks of roots or other vegetative material and may have sawdust or wood waste added to increase the density of the sediment.

Dredged sediment is removed by a dredge, with any roots mulched by a rotating cutting blade. The sediment/roots mixture is pumped through a tank, where flocculant is added before dewatering in geobags. Different flocculants may be used depending on the nature of the sediment. The product is relatively uniform as the roots are cut into <1 cm pieces, whereas digger-excavated sediment will contain larger, heterogeneous chunks of organic material.

Figure 1. Upper row: digger excavating sediment from Sunnyvale stormwater pond. Lower image: dredge removing sediment from Van Dammes Lagoon.

Ponds sampled were in the process of being de-silted, and samples of dewatered silt were obtained either from the geobags or from digger-excavated sediment stockpiles. Sawdust/wood waste used to mix with sediment was sampled separately from the sediment, and samples of the combined wood waste/sediment were also collected.

Sediment samples were sent to Hill Laboratories for analysis of metals (arsenic, cadmium, chromium, copper, lead, nickel, zinc), pH, total carbon and nitrogen, and Olsen and total phosphorus. An extended suite of analyses was undertaken on the Sunnyvale and Portland Road samples to provide an assessment of the value of additional parameters. Analyses of organic contaminants (polycyclic aromatic hydrocarbons, organochlorine pesticides) were not undertaken because these analyses were typically completed by the contractor desilting the pond.

Table 1. Description of ponds sampled – including dominant surrounding catchment land use, samples collected, and sampling dates

Pond name	Age, location	Catchment land use[a]	Sediment type	Sample date
Sunnyvale	Young; off-line[c]	Residential	Digger-excavated, +/- sawdust	April 2022
Onepoto	Old; off-line	Residential	Dredged and flocculated	Jan 2023
Portland Road[a]	Old; on-line	Residential	Digger-excavated, flocculated	May 2022, and May & Sept 2023
Parlane	Young; off-line	Residential	Digger-excavated	May 2023
Te Koiwi Park[b]	Old; off-line	Industrial/residential	Digger-excavated	May 2022
Van Dammes	Old, on-line	Industrial	Flocculated	Sept 2022
Aranui	Old, off-line	Motorway	Digger-excavated +/- sawdust	May 2023

[a] Based on aerial photography and land use in proximity to a specific stormwater pond (see Figures 3–9).

[b] Samples of imported garden-bed soil and adjacent earthworked soil in a bund were also collected for comparison with pond sediment. Pond sediment was collected from within 1 to 2 m of the edge using a digger and left to drain at the edge without mixing with wood chip or sawdust.

[c] Off-line ponds are away from the watercourse to which they discharge; on-line ponds are located within the watercourse, so are more vulnerable to water-flows that may move sediment out of the device, downstream.

The location of all ponds sampled is shown in Figure 2, with Figures 3–9 showing the land use and stormwater catchments, as identified through Auckland Council GIS layers (see Appendix 3 for details of the layers used) for individual ponds.

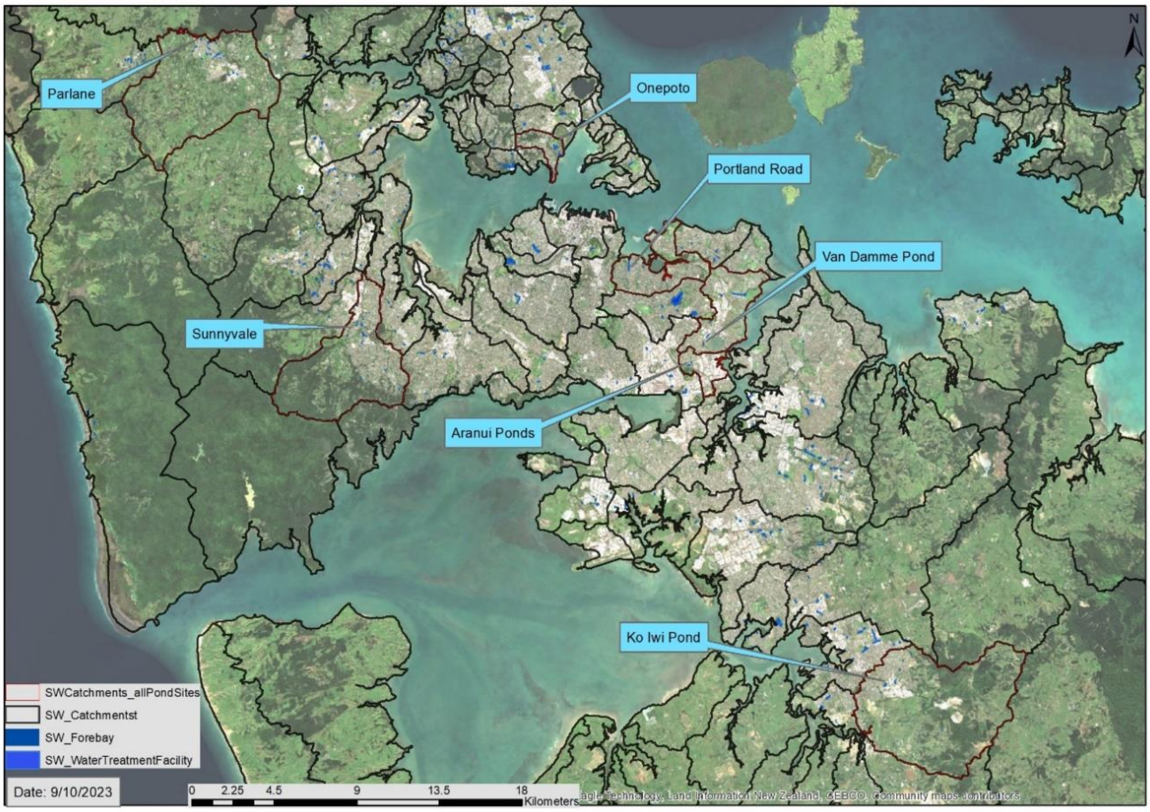


Figure 2. Location of stormwater treatment facilities sampled for this project, and stormwater catchment boundaries (black lines) across the Auckland region.

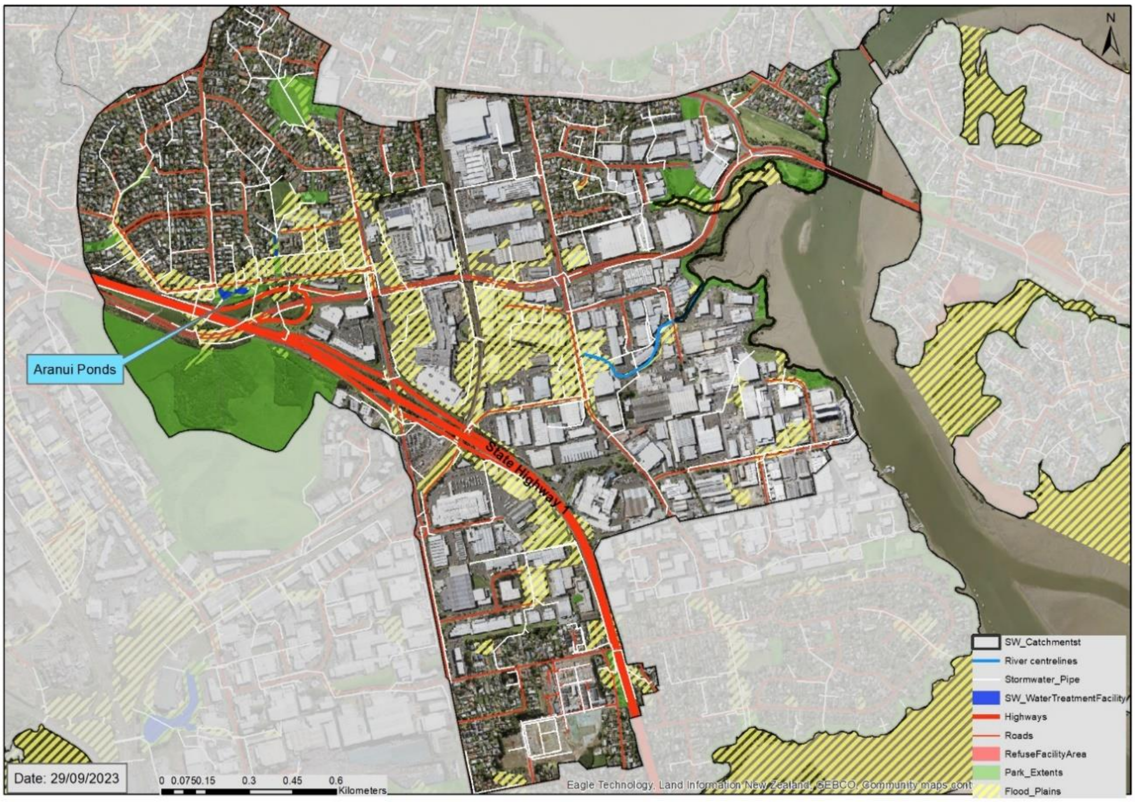


Figure 3. Zoomed-in view of Aranui stormwater treatment facility, showing the proximity of major roadways, nearby greenspace, the stormwater pipe network, flood plains, and the stormwater catchment boundary.

Figure 4. Zoomed-in view of Portland Road 'run of the river' stormwater treatment facility, showing the surrounding residential land and greenspace, the stormwater pipe network, the closed landfill location, and flood plains within the stormwater catchment boundary.

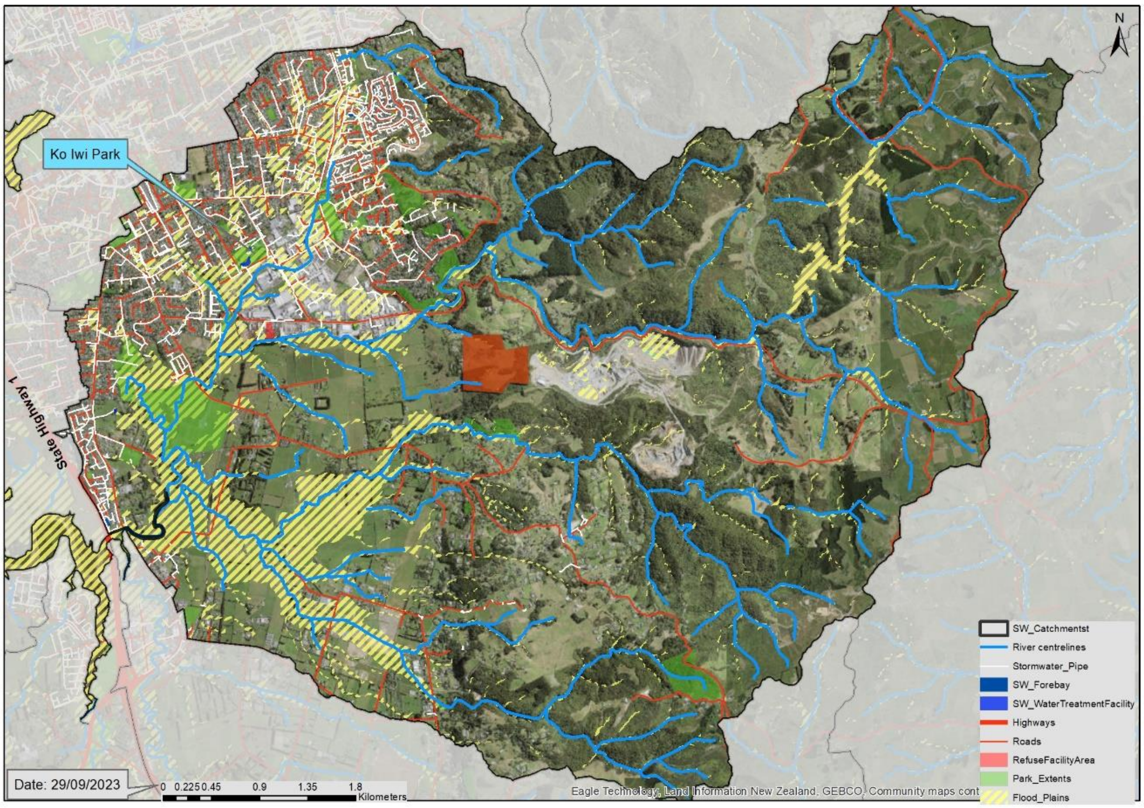


Figure 5. Zoomed-in view of Te Koiwi stormwater treatment facility, showing surrounding residential and industrial land use, greenspace, closed landfill location, and flood plains within the stormwater catchment boundary

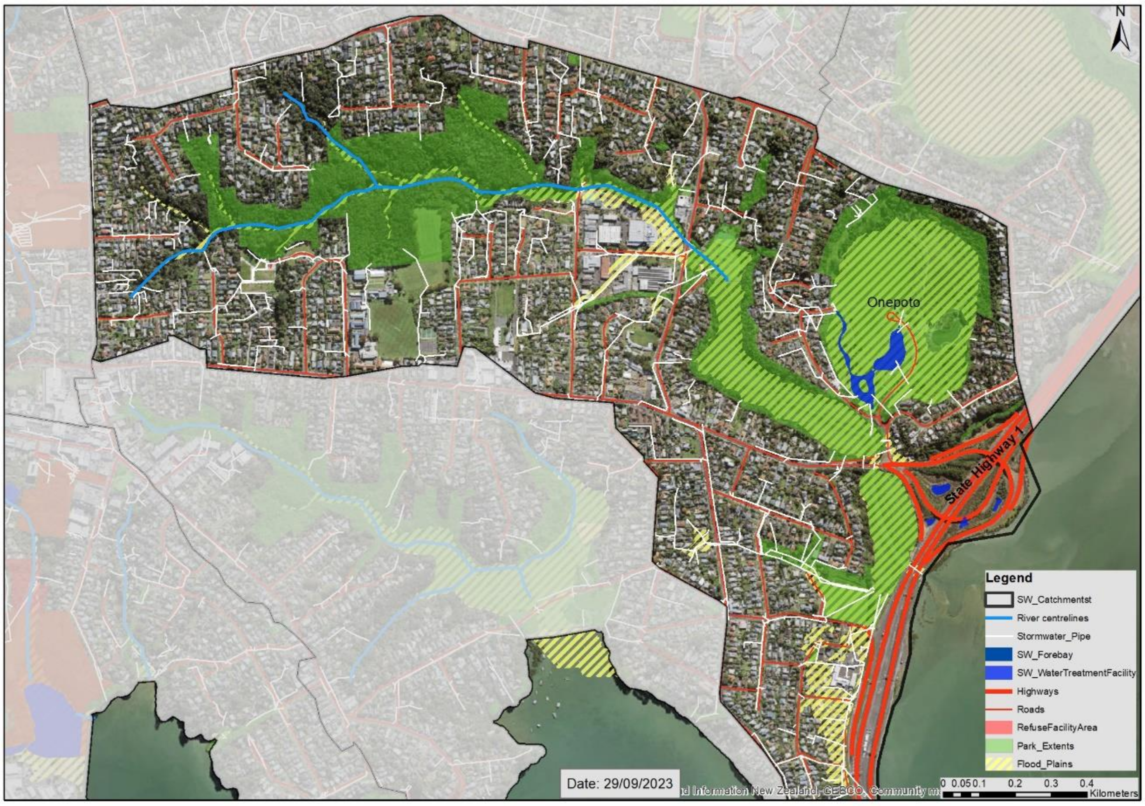


Figure 6. Zoomed-in view of Onepoto stormwater treatment facility, showing the proximity of roadways, nearby greenspace, flood plains, and the stormwater pipe network within the stormwater catchment boundary.

Figure 7. Zoomed-in view of Parlane stormwater treatment facility, showing the surrounding residential land use and nearby green space, flood plains, and the stormwater pipe network within the stormwater catchment boundary.

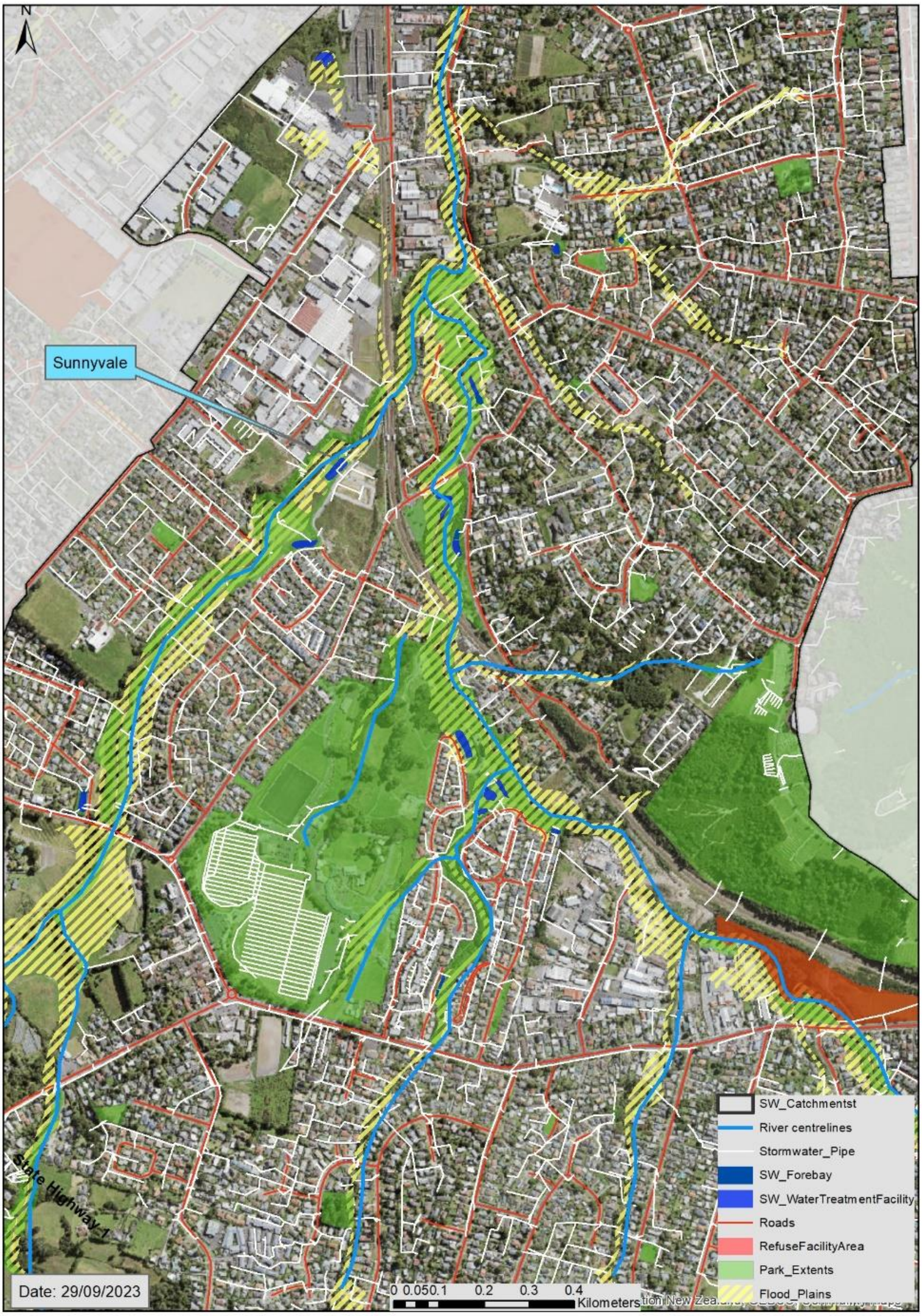


Figure 8. Zoomed-in view of Sunnyvale stormwater treatment facility, showing the surrounding industrial and residential land use and green space, flood plains, and the stormwater pipe network within the stormwater catchment boundary.

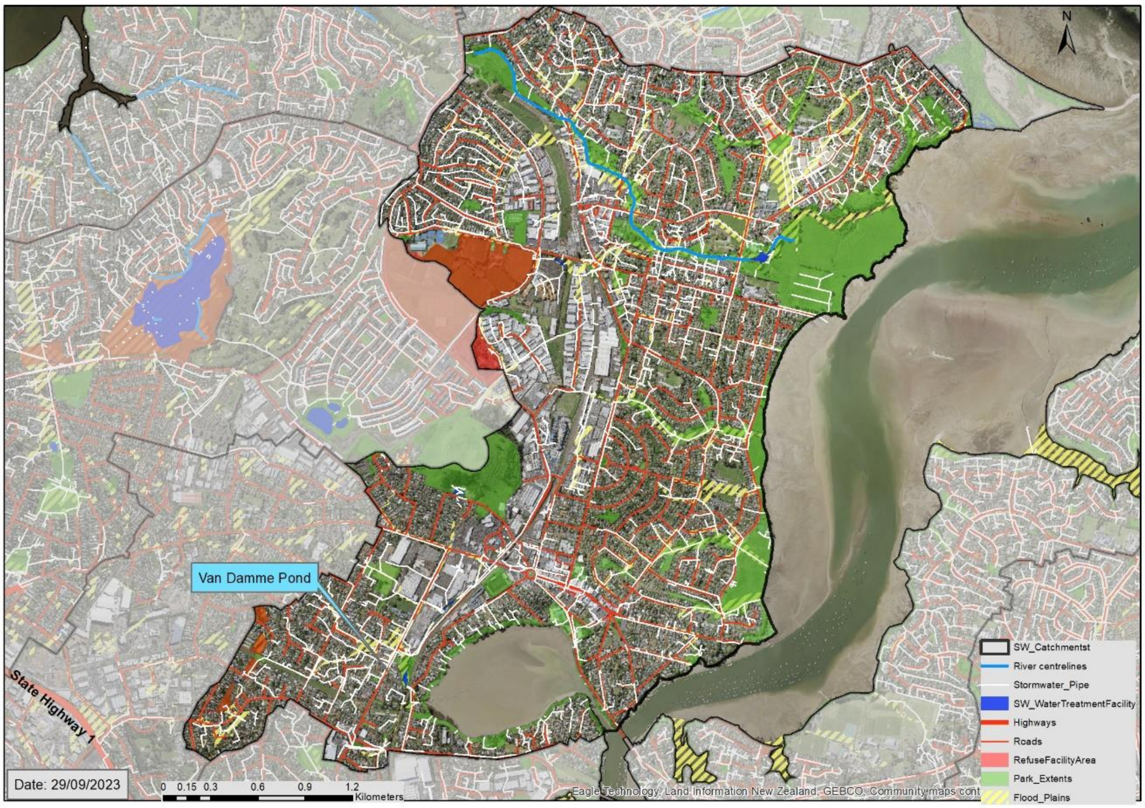


Figure 9. Zoomed-in view of Van Dammes Lagoon showing the surrounding industrial and residential land use and green space, flood plains, and the stormwater pipe network within the stormwater catchment boundary.

3.3 Portland Road beneficial use trial

A trial of the use of pond sediments as a growth medium for native riparian plants was installed in May 2022 at the Portland Road desilting and stream remediation project site (Figures 10 and 11). The trial compared three growth media.

1 Dredged sediment containing roots and some aquatic plant stems were mulched with a rotating cutting blade. The sediment/plant mixture was pumped through a c. 1 m^3 tank, where flocculants were added before being pumped into geobags, where dewatering occurred. The product was relatively uniform as the roots were cut into <1 cm pieces, although some layering occurred down the geobag between days and areas/depths of sediment, as shown in Figure 10. This medium is hereafter referred to as 'flocculated sediment'.

2 Site-won silty-clay topsoil had been stripped from the grassed area and used to create a bund (Figure 10 and 11). Given unrelenting wet weather, this topsoil had to be reworked under wet conditions to construct the trial plot. The site-won topsoil contained small clods of subsoils and had originally been imported to the site decades before to cover a cleanfill within an estuary (Figure 10). Soils were probably largely Ultic Soils from nearby subdivisions, now classified as Anthropic Soils (Hewitt

1998[2]). They were fine-textured, with just 5–6% coarse sand (0.6 to 2 mm) and 27:35:38 %w/w sand:silt:clay.

3 Dewatered, 'digger-excavated' sediment comprised sediment and attached plant roots excavated by a digger. This was allowed to drain at the edge of the excavated area for minutes to hours before being stockpiled[3]. No flocculant was added. Gross litter (mainly plastics) were included (Figure 10).

Figure 10. Portland Road, May 2022. Left: digger-excavated sediment shortly after deposition and before 'ageing', with gross contaminants visible and the stripped topsoil in the background. Right: flocculated geobag sediments showing the banding/layering that can occur over different excavation days: the surface layer is more fibrous than the underlying layer.

Figure 11. Portland Road, May 2022. establishing the trial plots. The plot with site-won topsoil is the middle of the three plots, with the darker plots on each side containing sediment.

---

[2] This summary has photographs of each of New Zealand's Soil Orders and is an addendum to 'The Living Mantle, Soils in the New Zealand Landscape'. [The New Zealand soil classification (landcareresearch.co.nz)](landcareresearch.co.nz)

[3] The time varies with the substrate and whether eels are present, as the dewatering period also gives time for eels present to escape back to the pond.

In May 2022 each plot was planted with 16 *Carex testacea* (eight 'green form' and eight 'brown form') in c. 1 litre pots and three *Coprosma repens* in root trainers. The potting mix was shaken from plant roots before planting to maximise root contact with the different media and minimise potential buffering from the potting mix. Weeds were removed from the plots in February, May, and July 2023, but self-established native species were retained.

3.3.1 Sample collection and analysis

Slurry and leachate – geobags

Sediment removed by dredging is initially discharged to a flocculant-mixing chamber, where flocculant is added to the slurry, which is then pumped into a geobag. Duplicate samples were taken from the flocculant-mixing chamber (labelled 'inlet'), and the leachate immediately downstream of the geobags (Figure 12) before discharge (labelled 'outlet'). The samples were chilled and sent to Hill Laboratories for analysis of total and dissolved metals.

Figure 12. Left: Clear leachate seeping (outlet) from geobags after flocculation. Right: dredging in action (top left) with excavated material containing shells in the foreground.

Soil

All media were sampled at trial construction (May 2022) and in May and September 2023. Samples from 0–100 mm depth were taken using a 25 mm diameter stainless steel corer. Within each plot 6 to 10 cores were combined to form a bulk sample, with care taken to avoid the root ball of seedlings. Samples from May 2022 were stored chilled until analysis in August 2022 by Hill Laboratories for use in their 'soil health suite', which includes pH, Olsen P, exchangeable cations (calcium, magnesium, potassium, sodium), cation exchange capacity, % base saturation, volume weight, sulphate-sulphur, extractable organic sulphur, anion storage capacity, organic matter (from total carbon), total nitrogen, potentially available nitrogen (AMN), carbon:nitrogen ratio, and hot-water-extractable carbon, plus estimated microbial biomass carbon.

Intact 100 mm diameter and 75 mm deep cores were taken within the surface 0–100 mm depth of each plot to establish key physical properties that control plant growth by influencing air and water supply to plant roots. These analyses were done by the MWLR Soil Physics Laboratory in Palmerston North and included total porosity (calculated from particle density and dry bulk density) and moisture release at 5, 10, 100, and 1,500 kPa tension. From these, air-filled porosity and available water-holding capacity were calculated.

Two additional topsoil cores were taken from the adjacent topsoil bund (i.e. not in the trial plot), because this was uncompacted compared to the soil in the plots (Figure 13). In addition, bulk samples of flocculated sediment and onsite topsoil were used to compare vulnerability to compaction over a range of moisture content, as indicated by dry bulk density and penetration resistance. Analyses were done by the MWLR Palmerston North Soil Physics Laboratory.

Figure 13. Left: a filled geobag in front of a bund made with natural soil (lighter brown on right) and excavated sediment (darker brown on left). Behind the bund, a black plastic liner is ready for placement of large geobags to be filled with sediment, allowing for the discharge of leachate back to the stream. Right: the soil on the bund is well aerated and has a favourable crumb texture that together allow grass roots to extend to 30 cm depth (the height of the orange ruler).

Plants

About 2 weeks after weeding in February 2023, leaves from the green form of *Carex* were sampled[4] and analysed for major nutrients and metals. The height, spread, and health of each plant were measured. Overall plot cover was assessed (i.e. bare ground, planted species, self-established species) and the plant species present noted. These measurements were repeated in July 2023.

---

[4] The green form was the only species to have a full complement of actively growing plants.

4 Results

4.1 Literature review and workshops.

4.1.1 Literature review – New Zealand studies

There are limited published New Zealand studies on the sediment quality of stormwater ponds. Of these, most have focused on road-derived sediments (e.g. Zanders 2005; Mayson et al. 2010; Moores, Hunt et al. 2009; Moores, Pattinson et al. 2009, 2010; Depree et al. 2010; Depree 2011). Stormwater runoff to sediment ponds is generated by impervious surfaces – in most cases, carparks or roads. Trowsdale and Simcock (2011) reported contaminant loads carried by 12 storms from a 1.5 ha catchment containing a light industrial road in Auckland that received c. 15,000 vehicles per weekday, with about one-third of these being trucks.

The key contaminants generated were sediment (mean inflow 30 mg/L, max inflow 375 mg/L) and zinc (median inflow 659 ug/L) (Figure 14). These data supported the classification of 'high contaminant generating surfaces', including carparks and roads, and was consistent with several other New Zealand studies indicating that carparks and roads are the main sources of stormwater sediment (Charters et al. 2014, 2016, 2021, 2022). In fact, our literature review found no New Zealand studies on stormwater ponds that did not have a significant road or carpark input.

The above-mentioned studies show variable concentrations of metals in stormwater that depend largely on the volume and type of vehicles using the roads in the surrounding area. Other studies have shown runoff from areas with high tyre wear (e.g. acceleration/deceleration zones), which also had higher trace element concentrations.

The greatest focus has been placed on assessing and managing road-derived sediments. Mayson et al. (2010) evaluated the potential beneficial use of road-derived sediments through composting trials, but no reports containing details of the trials were found. Multiple papers have also addressed the efficacy of bioretention devices such as swales and raingardens for treating road-derived sediment (e.g. Figure 15) (Fassman et al. 2009; Fassman 2012; Moores et al. 2009a, b).

These studies have also generally reported sediment inflow rates and sediment chemistry, with most including measures of total suspended sediments (TSS). Prior to the Auckland Unitary Plan, and under TP90 (ARC 1999) and TP10 (ARC 1992 & 2003), removal of 75% TSS was the key performance criterion for sediment ponds (e.g. Moores & Pattinson 2008;; Semadeni-Davies 2013). For this reason there is an abundance of studies on water quality, both entering and leaving sediment ponds, focusing on TSS.

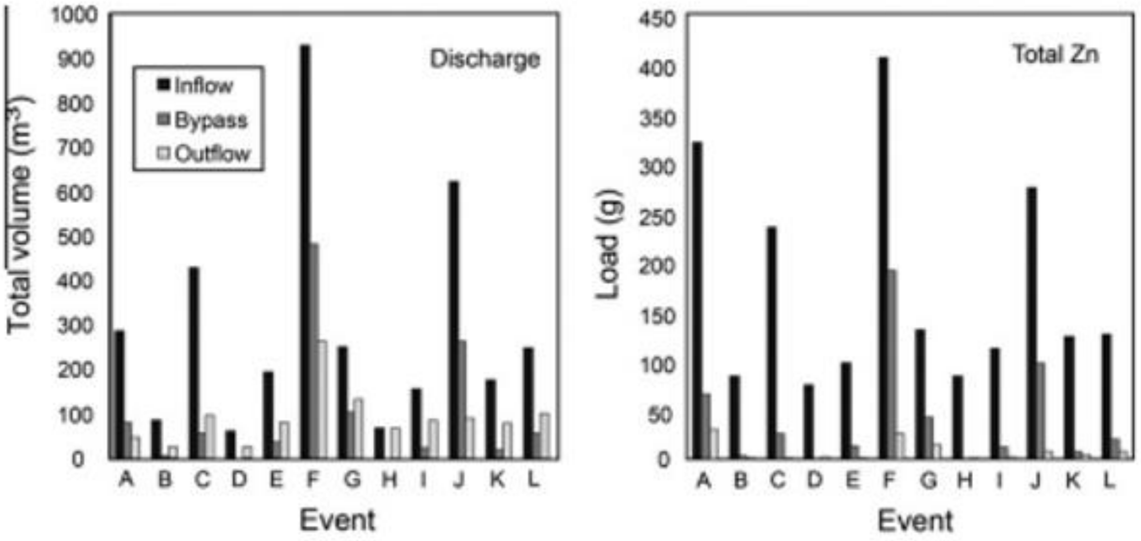
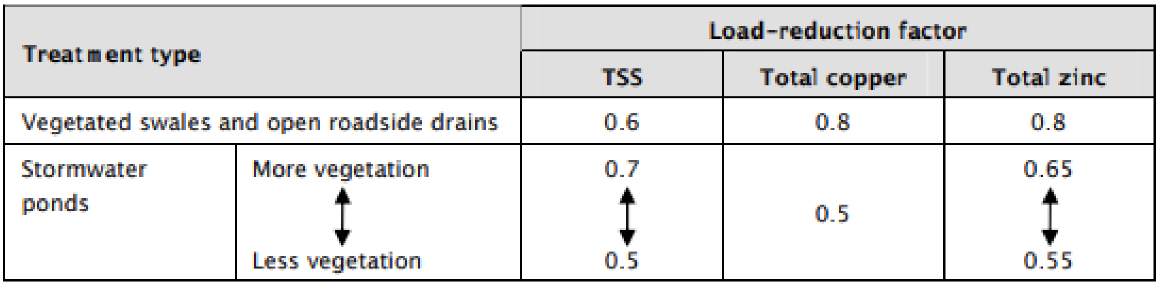


Figure 14. Total stormwater volume and zinc loads from 12 storms (events), measured entering and leaving an Auckland raingarden that serves a 1.5 ha light-industrial catchment. Source: Trowsdale & Simcock 2011



Treatment type		Load-reduction factor		
		TSS	Total copper	Total zinc
Vegetated swales and open roadside drains		0.6	0.8	0.8
Stormwater ponds	More vegetation ↕ Less vegetation	0.7 ↕ 0.5	0.5	0.65 ↕ 0.55

Figure 15. Load reduction factors as a basis for estimating loads of copper and zinc discharges. Source: Moores et al. 2009b.

4.1.2 Literature review – international studies

Internationally there are various initiatives to reuse dredged sediments, particularly in the US, Canada, and the EU. Many of the US (USACE 2015; US EPA 2020) and European examples (e.g. CEDA 2019) are at much larger scales (e.g. dredging sediments to facilitate navigable rivers or lakes) than is relevant here. Nonetheless, some of the processes used to determine beneficial use, or the nature of the beneficial use, are relevant.

A range of beneficial reuses of sediments from large-scale dredging operations are available here: https://dredging.org/resources/ceda-publications-online/beneficial-use-of-sediments-case-studies. Examples include:

- the construction of dikes using dredged sediments, following testing of the effects of over 250 combinations of specific additives on the geotechnical characteristics of the dredged material, and field testing to determine the strength and permeability of the engineered sediments in the dike body

- the use of nutrient-rich dredged sediments to raise the elevation of near-shore agricultural fields adjacent to Lake Erie, USA, with sediment placed in 'cells' and 'return water' managed through passive water control structures such as weirs and underdrains (field tiles)
- the production of raw materials (silt) through the use of large-scale dewatering fields, often for use in the construction sector (e.g. Henry et al. 2023).

The US Core of Engineers' *Engineer Manual: Dredging and Dredged Material Management* (USACE 2015) is the most recent version of the manual, first published in 1983, that informs dredging operations, including beneficial reuse of the dredged sediments. Basic data on physical and chemical characteristics of the sediments to be dredged are recognised as providing an initial screen of possible beneficial use options. For example, pure sand dredged material would not generally be suitable for agricultural land applications, but as fill material and for some dike construction it may be excellent. Predominantly uncontaminated silt can be a useful amendment for agriculture and forestry, as well as for some habitat development sites.

Physical and engineering characteristics that were broadly considered relevant to different potential use options include particle size, bulk density, plasticity, specific gravity, water retention and permeability characteristics, and volatile solids. Important chemical characteristics included:

- cation exchange capacity
- total nitrogen (recognising that the predominant form of nitrogen in inorganic sediments would be ammonium nitrogen, which could undergo rapid nitrification to plant-available nitrate)
- sulphur, particularly in tidally influenced systems, where oxidation of sulphides can result in significant pH drops
- metals, to assess the level of contamination to determine its suitability for beneficial uses, with the key consideration being whether the level and type of contamination are consistent with the intended use.

Beneficial uses for which more detailed guidance is provided include:

- habitat development for a range of habitats, with specific guidance provided for wetland habitats, wooded wetland, 'upland' habitats (which effectively covers all other terrestrial habitats that are not specifically mentioned), as well as aquatic habitats (e.g. seagrass beds and beach 'nourishment')
- recreational uses of dredged material placement sites, which were considered to be 'practically unlimited' and 'one of the more promising and implementable beneficial uses of dredged material', noting that it is heavily dependent on financial backing at a local level
- agriculture, horticulture, forestry, and aquaculture
- strip mine reclamation, solid waste landfill, and alternative uses
- construction and industrial/commercial uses, such as airports, ports, and harbours.

The guidance provided is focused on the uses of large volumes of dredged, and typically dewatered, sediments. The primary approach for dewatering appears to be through hydraulic placement of sediment slurries in confined areas, with the removal of water occurring through overflow weirs and evaporation. When the sediment has dried sufficiently to be able to be handled by heavy machinery, drainage trenches may be constructed in the placement area to promote further drying. The sediment may then be moved from this site to the beneficial use site. Transport costs were considered to account for 90% or more of total land improvement and beneficial use budget costs, thus requiring careful consideration of the location of the dewatering and beneficial use locations.

The guidance recognises that soil 'treatment' through a variety of activities (such as burying problem materials, mixing materials to obtain improved soil characteristics, leaching, fertilisation, and liming) may be required to achieve successful beneficial use. For habitat development, consideration of the soil properties and the desired plant communities go hand in hand, with both the soil treatment required, plants selected, and landscaping to develop site conditions (soil, elevation, diversity) similar to those for desirable plant communities.

Figure 16 shows the key factors to be considered for agricultural purposes, although they are fundamentally applicable to most non-engineering beneficial uses of dredged sediment. Managing weed infestations associated with dredged sediment and the use of dredged materials to improve marginal land (e.g. through increasing available water capacity and nutrient supply when fine-grained dredged material is mixed with coarse-grained marginal soils, or improving drainage when coarse-grained dredged material is mixed with fine-grained marginal soils) are highlighted for beneficial use for agricultural purposes.

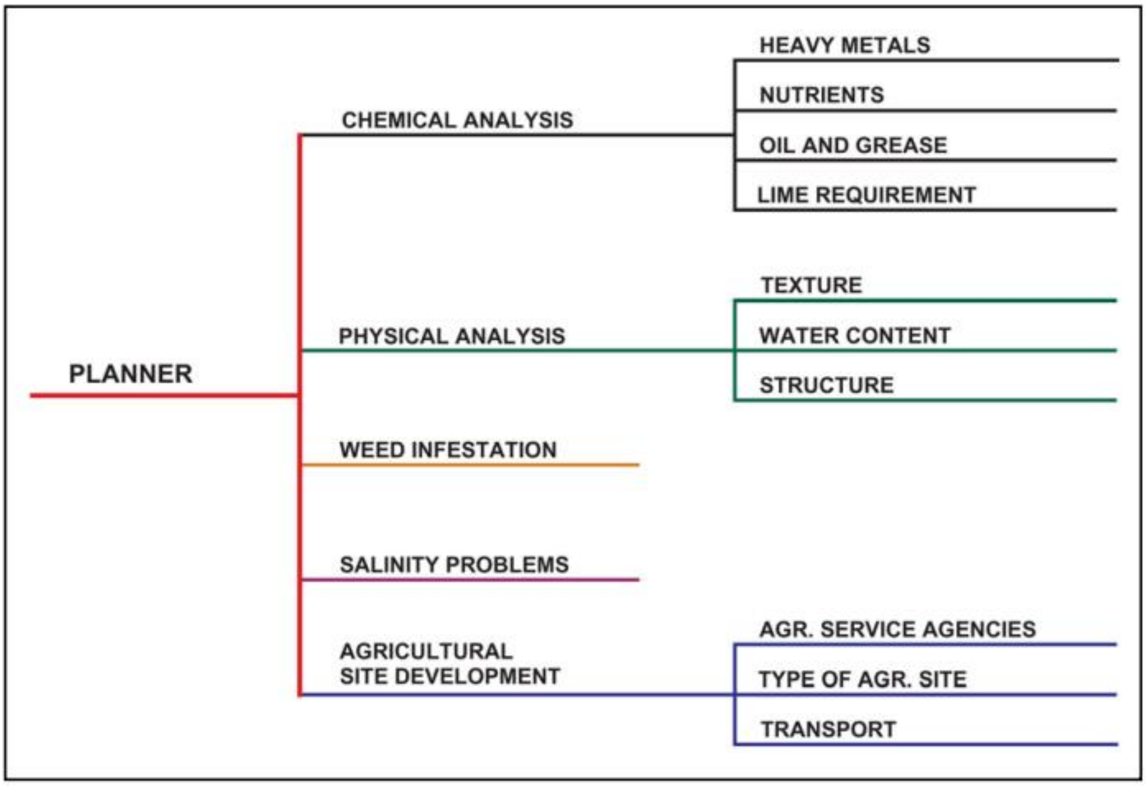


Figure 16. Factors to be considered before the application of dredged material for agricultural purposes. Source: USACE 2015

The USACE (2015) also emphasise the importance of ongoing monitoring of existing dredged material sites to ensure compatibility between or among the proposed uses and the dredged material placement activities, as well as providing evidence that dredged material has been used as planned.

The US Environmental Protection Agency (EPA) has developed a dredged material decision tool (DMDT, Williams et al. 2020). This was stimulated by traditional disposal methods such as open-water disposal and placement in confined disposal facilities (CDFs) becoming less feasible or prohibited, resulting in the need for alternative disposal options or sustainable uses of the material. The DMDT calculates the benefits and costs of beneficially using dredge materials to help communities make decisions based on multiple criteria (i.e. biophysical, social, and economic).

The Canadian *Inspection and Maintenance Guide for Stormwater Management Ponds and Constructed Wetlands* (TRCA 2018) provides information more directly relevant to the current project. It also provides information on wider practices for the management and maintenance of stormwater treatment facilities that may be relevant for Healthy Waters to consider, alongside an evaluation of their existing maintenance and desilting operations.

TRCA 2018 includes guidance on sampling protocols for stormwater ponds. Specifically, stormwater ponds are separated into different zones related to water flow – most commonly inlet, centre, and outlet zones – with composite samples collected from each zone. Where additional inlets or outlets are present, additional zones may be identified and an additional composite sample collected (Figure 17). The number of sub-samples depends on the size of the sampling zone: the larger the zone, the more samples that should be collected for the composite sample.

As illustrated in Figure 18, there is a variation in texture throughout the stormwater pond: where a forebay is present (as required in current Auckland design guidance for sediment ponds), most of the coarse sediment settles out in the forebay, which provides for more frequent sediment removal from a smaller, highly accessible area. Sampling is undertaken in line with routine maintenance, typically *prior* to desilting operations (i.e. sampling is undertaken on sediments *in situ*, which perhaps contrasts with current sampling in Auckland, where grab samples tend to be collected during desilting operations).

Sampling of the sediment stockpile after bulking and/or dewatering, just prior to hauling, is recommended to provide certainty about the quality of the sediment and to help inform the final decision on the fate of the sediment. The collection of 15 discrete samples throughout the sediment stockpile is recommended, and then compositing of every five samples to create three homogenised samples, which are submitted for laboratory analysis.

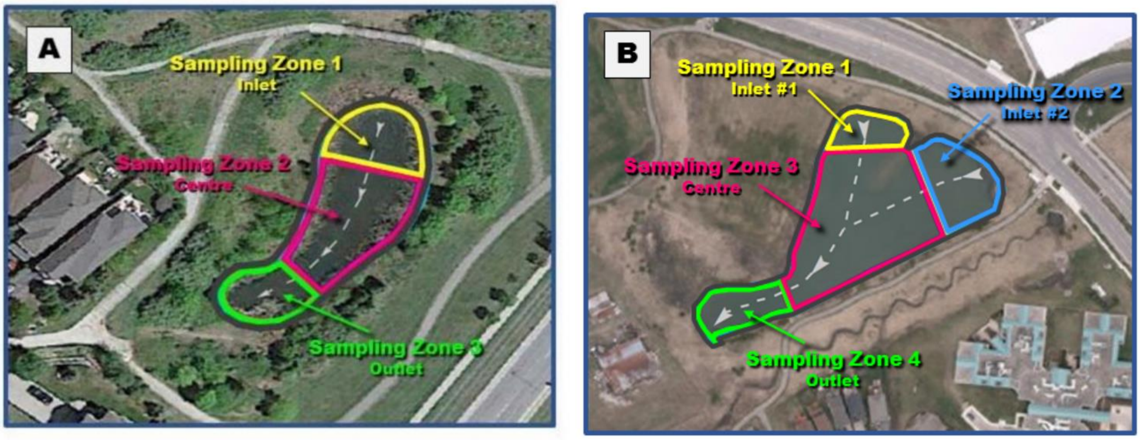


Figure 17. Example of sampling zones used for the assessment of Canadian sediment sample zones identified by inlet/outlet locations and flow patterns. A: three sample zones for a stormwater pond with one inlet, one outlet, and a linear flow path. B: four sample zones for a stormwater pond with two inlets, one outlet, and a forked flow path. Source: TRCA 2018. Notes: The grey dashed line indicates the flow path direction. Composite samples are collected from within each zone. The number of sub-samples depends on the size of the sampling zone: the larger the zone, the more samples that should be collected for the composite sample.

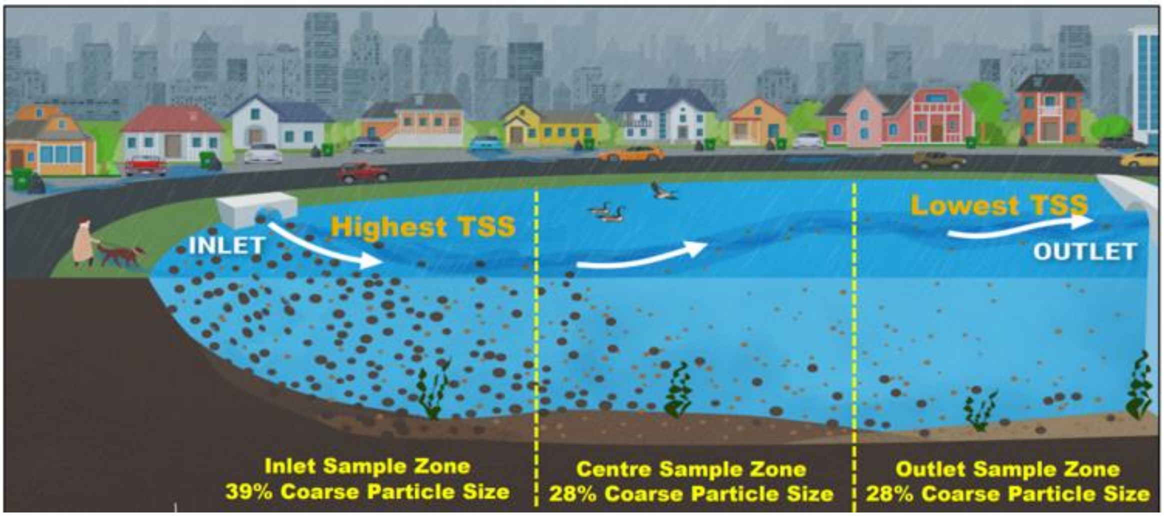


Figure 18. An illustration of the change in total suspended solids (TSS) and sediment particle size composition along the flow path of a stormwater pond. Source: TRCA 2018
Notes: Neither TCRA figure include forebays, which if present, would be a discrete sampling area.

The water content of the sediment is recognised as a key limiting factor for sediment transport and disposal, and it will typically need to be reduced before the sediment can be transported as a solid material. Specifically, the material must pass a 'slump test' to determine whether it is a liquid or a solid (Figure 19). During mechanical dredging, sediment removed from the stormwater pond is typically stockpiled in a designated sediment management area and left to dewater by gravity and air drying before it is hauled off-site. Fine-grained sediments (e.g. silt, clay) have a high water-holding capacity and lower permeability so are more difficult to dry than coarse-grained sediments (e.g. sand, gravel) and need to be spread more thinly over a larger land area to dry.

For this reason, and similar to New Zealand, the addition of bulking and water-absorbing materials such as sawdust, mulch, and/or straw is a common approach to expedite the sediment drying or consolidation process. Similarly, flocculants (primarily anionic polyacrylamide [PAM]) – may also be used for sediment dewatering. Guidance on the use of anionic PAM for sediment management applications is provided in the *Anionic Polyacrylamide Application Guide for Urban Construction in Ontario*, released by TRCA in 2013 (TRCA 2013, cited in TRCA 2018). Superabsorbent polymers, which absorb water from the slurry rather than binding sediment particles together, may also be used.

Figure 19. Examples of slump tests on sediment that has been consolidated. Source: TRCA 2018.

Section 9 of TRCA 2018 highlights the role of regulatory requirements for sediment quality – particularly contaminant concentrations – for informing how sediments can be beneficially used. This role is illustrated using information on contaminant concentrations in stormwater ponds across Canada. The information on contaminant concentrations presented in TRCA 2018 is updated by Kelly-Hooper et al. (2022), who present the results from 371 sediment samples collected between 2005 and 2022 from 121 municipal stormwater ponds, ranging from approximately 15 to 30 years of age and located in fully developed residential and commercial catchment areas in five Canadian provinces. Comparison with various regulatory standards, including 'excess' soils waste and biosolids legislation, highlighted that hydrocarbons (either specific total petroleum hydrocarbon fractions or specific polyaromatic hydrocarbons) most frequently exceeded regulatory criteria.

However, it is worth noting that the selected criteria – notably, the standards most frequently exceeded – were those related to soils above potable aquifers, assuming the full soil profile was at that concentration. It is further worth noting that the purpose and intent of Ontario's 'excess soils' legislation echoes similar current discussions in New Zealand on the beneficial use of excess or surplus soils (Cavanagh, Simcock et al. 2023). Additional regulatory requirements discussed included topsoil analysis to demonstrate that amending the receiving site soils with the sediment would provide a benefit to the soils. The list of analytes to be considered included trace metals, hot-water-extractable boron, sodium adsorption ratio, conductivity, pH, available nutrients, and particle size distribution.

TRCA 2018 highlights various features that should be incorporated into stormwater pond designs whenever possible, including a maintenance drawdown pipe for gravity dewatering of the permanent pool, a maintenance by-pass valve, sediment maintenance and drying areas, and easily accessible outlet structures.

Finally, TRCA 2018 illustrates the variability in costs associated with the removal of sediment from different individual ponds (Figure 20). The lowest cost per cubic metre (pond 1) was associated with the on-site use of the sediment in the creation of a berm, which reduced transport and disposal costs for the project. The lower graph shows the projected cost per cubic metre difference between on-site and off-site disposal. Details of the cost components of the individual ponds are provided as case studies in TRCA 2018, and highlight the need to assess the potential costs based on the individual pond.

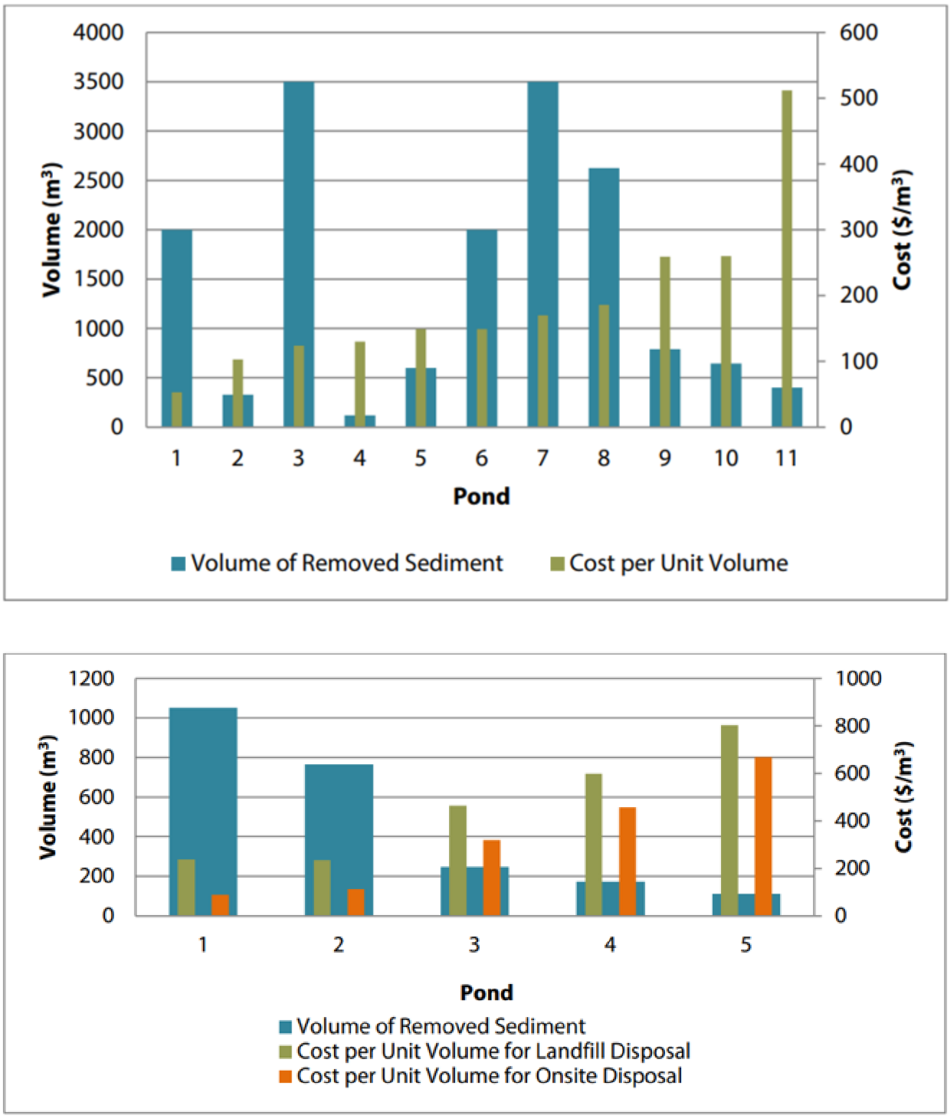
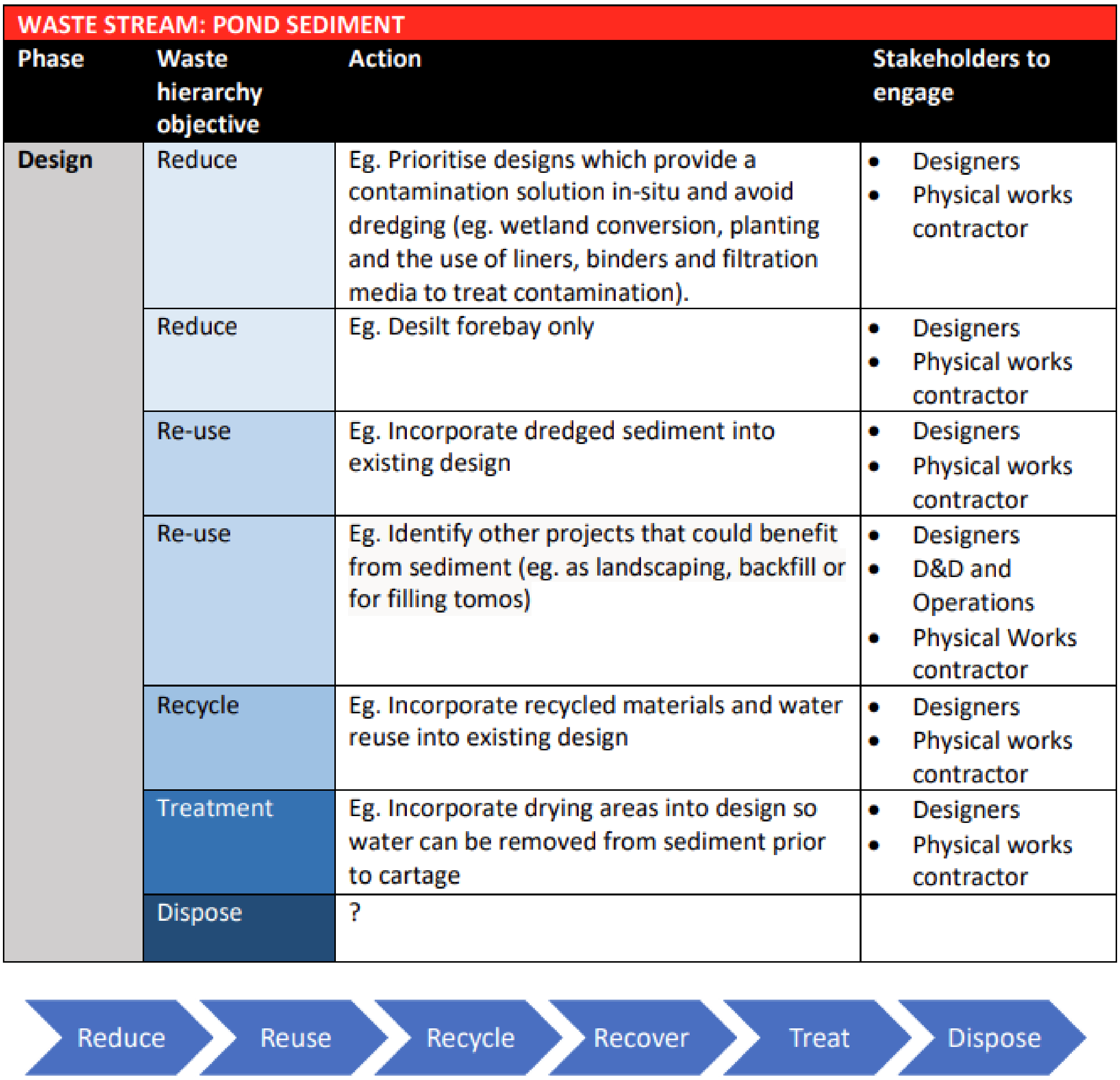


Figure 20. Range in sediment removal costs per cubic metre sediment removed and associated volume of sediment removed from ponds across the greater Toronto area (upper) and for the City of Guelph (lower), including a comparison of cost for landfill disposal compared to on-site 'disposal'. Source: TRCA 2018.

4.1.3 Workshops

Discussions and workshops were held with a range of contractors, Auckland Council staff, contractors, and consultants with expertise in pond renewal and physical works. The largest workshop (in March 2023) was facilitated by Healthy Waters and covered a wide range of pond sediment challenges and opportunities. Staff presented key challenges and the design solutions that applied waste hierarchy principles, as contained in the Auckland Council waste minimisation plan (2018): reducing sediment in ponds through sediment diversion (reuse, recycling, and/or recovery), waste treatment, with waste disposal being the least preferred option. Staff also presented a draft range of possible actions (Figure 21).



WASTE STREAM: POND SEDIMENT

Phase	Waste hierarchy objective	Action	Stakeholders to engage
Design	Reduce	Eg. Prioritise designs which provide a contamination solution in-situ and avoid dredging (eg. wetland conversion, planting and the use of liners, binders and filtration media to treat contamination).	• Designers • Physical works contractor
	Reduce	Eg. Desilt forebay only	• Designers • Physical works contractor
	Re-use	Eg. Incorporate dredged sediment into existing design	• Designers • Physical works contractor
	Re-use	Eg. Identify other projects that could benefit from sediment (eg. as landscaping, backfill or for filling tomos)	• Designers • D&D and Operations • Physical Works contractor
	Recycle	Eg. Incorporate recycled materials and water reuse into existing design	• Designers • Physical works contractor
	Treatment	Eg. Incorporate drying areas into design so water can be removed from sediment prior to cartage	• Designers • Physical works contractor
	Dispose	?	

Figure 21. Auckland Council draft design stage solutions, March 2023.

Auckland System Management (an Alliance with Waka Kotahi NZ Transport Agency that operates and maintains Auckland's motorways) has had experience beneficially reusing pond sediments as 'landscape ameliorants' where these are consistent with resource consent conditions, including for use as building bunds within landscaped areas.

Workshop participants identified solutions to improve sediment quality by reducing water content or contaminant concentrations, thereby increasing reuse options. These included the following.

- Ponds could be designed or retrofitted with:
    - a forebay (and/or second ponds) to facilitate dewatering and extend pond life by allowing regular, small-scale desilting, while noting that larger forebays with energy dissipation structures and/or treatment trains to maximise sediment capture provide the best outcomes, and that access to the forebay is required
    - dewatering pipes, although there was a difference of opinion on pipe design
    - adjacent dewatering areas of sufficient size, and with truck access and visual screening.
- A gross pollutant trap could be placed upstream of ponds to reduce contamination by buoyant/neutral materials such as plastics. Gross pollutants reduce the value of the sediment for surface landscaping and mean a cover of soil is usually needed.
- Flocculants could be selected that minimise pH drops to levels that challenge plants, thereby minimising the need for liming.
- Techniques to accelerate sediment drying could be used (e.g. windrowing with arborist mulch, wood chips or organic matter; opening and turning geobags/windrows). This method 'blends, binds and diminishes'. Time may be needed for compaction/settling, depending on land use. Staff from Watercare Service Ltd have suggested blending biosolids with pond sediment, but opportunities to do this will be limited to the cleanest sediments, as biosolids have elevated copper and zinc, as do some pond sediments. Sediment pond tests indicate that carbon, nitrogen and phosphorus levels are adequate for plant growth, so biosolids are unlikely to be needed for adequate plant growth, although they are likely to boost the growth rates of some plants.
- There would be a reduced biosecurity risk (such as from alligator weed) by composting, including composting within a geobag.
- Sediment removal and placement could be timed to occur before the planting season (i.e. in summer for autumn to spring planting). This would also help maintain staff throughout the year.

Workshop participants also suggested that 'transaction' or planning costs could be reduced by two actions: getting better estimates of sediment volume, because this affects the ability to collaborate with parks, which otherwise have to import soils; and developing standardised designs or aspects of design (and standardised responses) that could be used for resource consenting and consultation with land owners. Many of these factors are also discussed in TRCA 2018.

Closed landfill workshop

A workshop was also held that focused on the potential for using pond sediment at closed 'legacy' landfill sites, given the Portland Road / Waitaramoa Park case study was such a site. An initial analysis indicated there are other closed landfills with similar low-quality parks lacking funding to be upgraded (i.e. a thin soil cap and poor drainage, creating ponding and making it difficult to mow through winter, with consequent reduced community recreational value). The treeless flat surface also has low aesthetic value.

Using the Portland Road / Waitaramoa Park area to place sediment effectively funded a park upgrade. The new, higher contour provides interest and drainage, enhanced by a new public walkway with native amenity plantings that is more useable, and the adjacent Significant Ecological Area is also better buffered with native planting (and probably reduced leachate). Anecdotally the use of 5,000 m^3 of excavated sediment to create a new landscape feature at Portland Road / Waitaramoa Park saved approximately $750,000 in landfill fees.

There are over 200 closed landfills across Auckland. These were identified in 2010 when the councils were amalgamated to form Auckland Council. About 150 are small to medium, low-risk sites. They are not cleanfills as they can contain asbestos, hardfill (demolition waste) and/or organic materials. Sometimes the fill material is contaminated, as controls during construction were variable. Most of these sites have no formal liner, nor a clay/engineered cap, just a topsoil cover with mown grass.

Nearly all of these closed landfill surfaces are used for passive or active recreation. Local community boards sometimes want to upgrade their uses (e.g. adding planting or paths, or major upgrades such as sports-sand turfs with lighting). Key limitations to using these landfills include a paucity of information on what they contain (requiring sufficient lead time for investigations), time to design the park upgrade and consult the community and community boards, and ensuring space for sediment removal and construction while keeping space for community park use, especially if there is limited space to temporarily stockpile and/or a limited timeframe a site can be open. The number of closed landfills that may be suitable for this purpose may be small.

Three case studies can be used to refine the following draft requirements and considerations when investigating the use of closed landfills near sediment ponds: Portland Road / Waitaramoa, Te Atatū Peninsula, and Tahi Road, Waiheke Island.

Current processes for the beneficial use of pond sediments on closed landfill sites include:

- landowner approval from Auckland Council – Parks/Community Services and the Land Advisory Team determine what is in the best interests of the landowner, which may include constraints imposed by the Reserves Act 1977
- asset owner approval from the Closed Landfill Team, including identifying hazards
- resource consents from Auckland Council – closed landfills may need consents to ‘open’ them if placing soil/sediment on top of the landfill triggers consents (existing topsoil is likely to be stripped before placement of sediment) or if the landfill is dug up; consents may be triggered for works in a flood plain, wetland or coastal area
- regional rules, which may be triggered by earthworks volumes and include assessing potential hazards from contamination related to sediments and mitigation (e.g. capping, lining).

The land or asset owners are also likely to consider how the proposed sediment reuse fits with and benefits landfill performance and other activities on the landfills. For example, water should sheet off landfills to reduce leachate volumes, but many older landfills have an undulating contour due to differential settlement, so sediment placement that enhances contours can be beneficial by facilitating turf maintenance and playability. (Although note that sediment from ponds is also likely to settle over time, particularly when in geobags or with high organic contents.)

Similarly, sediment was used to mitigate problems at Tahi Rd on Waiheke Island. Here, risks associated with unstable lower landfill slopes and a poor interface between stream and landfill that was subject to tidal influence were ameliorated through sediment reuse. The addition of sediment to landfills can deliver benefits linked to raising the surface level above flood and coastal inundation. Sediment may offset the use of virgin excavated natural material (VENM) imported for landscaping parks, especially where suitable as a replacement for other soil products (and root zones), including bunds that are being used to enhance parks.

4.2 Sediment pond results

The primary focus for discussion on contaminant concentrations is metal and metalloid contaminants. Key contaminant concentrations (copper, lead, and zinc) are presented and compared to ecological soil guideline values (Eco-SGVs) in Figure 22. All sites had concentrations below the Eco-SGV for lead (290 mg/kg), while Eco-SGVs for copper and zinc (110 and 200 mg/kg, respectively) were exceeded at multiple sites. Typically, copper and zinc may be higher near transport corridors and in industrial areas as both of these trace elements are common roadway contaminants (linked to traffic intensity) and contaminants emitted by industrial activity (Clearwater et al. 2014; Kennedy & Sutherland 2008).

Elevated zinc is linked with the use of zinc roofing materials in industrial zones (Timperley et al. 2011) and zinc concentrations are increasing in Auckland marine sediments, while lead levels are decreasing. Zinc was the most commonly elevated trace element and was elevated in ponds across all land uses, excluding industrial/residential. While road and roof surfaces in residential urban areas are sources of zinc (Mosley & Peake 2001; Timperly et al. 2011), the high zinc concentrations at Parlane and Portland are more typical of industrial/motorway areas.

The Van Dammes Lagoon exceeded Eco-SGVs for both copper and zinc, with markedly high zinc concentrations (up to 1,730 mg/kg). The location of this pond in an industrial area renders this unsurprising. However, the relatively low trace element concentrations at Te Koiwi Park (industrial/residential) show that some stormwater pond sediments with some industrial inputs can contain contaminant concentrations below Eco-SGV triggers.

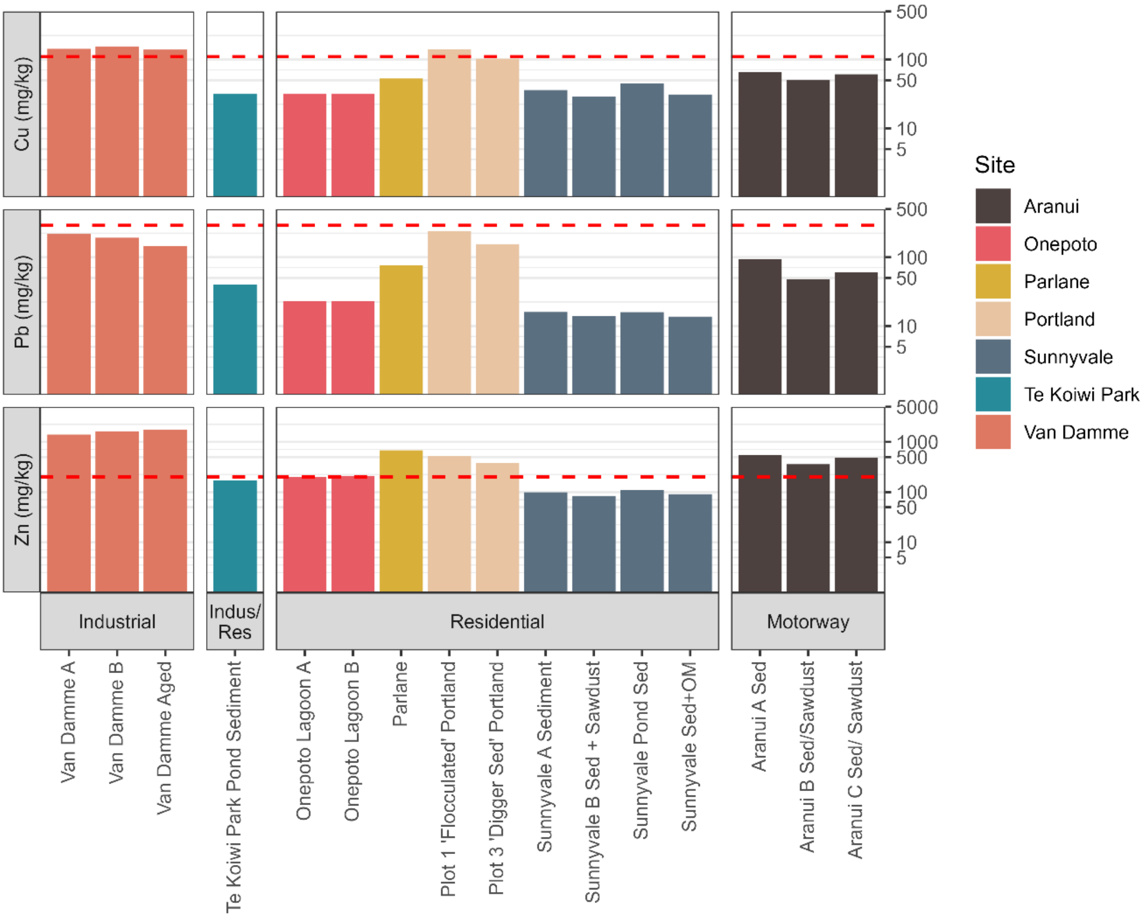


Figure 22. Trace element concentrations in sediment samples at stormwater ponds.
Red dashed lines represent Eco-SGVs that provide protection for 95% of species in typical soil (Cavanagh & Harmsworth 2023).
Notes: Cu = copper, Pb = lead, Zn = zinc, Indus/Res = industrial/residential, Sed = sediment, OM = organic material.

General soil properties relevant to plant growth for the digger-excavated and flocculated sediment samples are presented in Figure 23. Digger-excavated samples that contained added organic matter (a range of sizes from sawdust to wood peelings and chip) had higher carbon content and carbon:nitrogen ratios as a result of the added carbon contained in organic matter. Samples from Van Damme also contained high carbon, although the carbon:nitrogen ratios of these samples were within a more typical range for soil/sediment. Generally, a carbon:nitrogen ratio between 7 and 30 is considered optimal for environmental conditions (Sparling et al. 2008). A carbon:nitrogen ratio above this range indicates that low nitrogen availability may limit plant growth, while a ratio below 7 indicates excess available nitrogen, which is likely to be lost through leaching.

Carbon amounts between 3 and 12% are generally considered sufficient for productive soils (LMF 2009), but elevated carbon concentrations at depth risk stimulating aerobic microbes, which then deplete soil oxygen (with the depth and carbon content influenced by soil drainage/permeability). The Olsen P (phosphorus) concentrations >50 mg/kg at Aranui, Van Damme, Parlane, and Portland (flocculated sediment only) indicate an abundance of plant-available phosphorus in these sediments. With the exception of Onepoto (possibly marine influenced, with high carbonate content), flocculated sediments tended to have acidic to strongly acidic pH, exacerbated at Portland Road by the use of an acidic flocculant. Digger-excavated sediments tended to be less acidic than flocculated sediments, but many were nonetheless acidic, with Portland Road the most acidic.

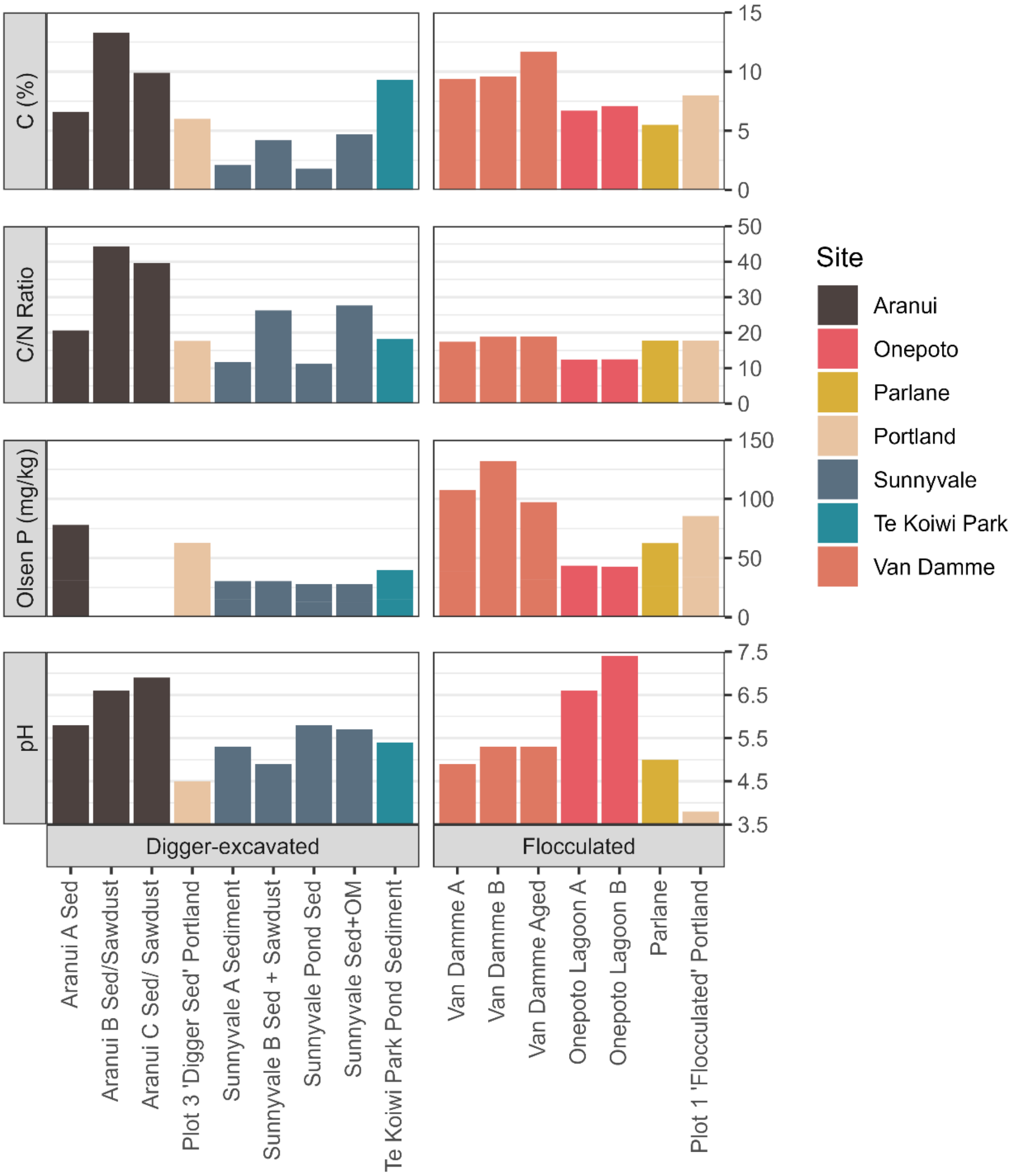


Figure 23. Summary of general soil properties for digger-excavated or flocculated sediments. Notes: Olsen P was not measured in Aranui B and C sediment/sawdust samples, Sed = sediment, OM = organic material.

Data from extended analysis of the Portland and Sunnyvale stormwater ponds showed marked differences in anaerobically mineralisable nitrogen (AMN) and sulphate concentrations (Table 2). Portland sediment samples contained high sulphate concentrations (2,120–3,140 mg/kg) and low AMN concentrations (16–26 µg/g), while the opposite was true for Sunnyvale sediment (sulphate 9–49 mg/kg, AMN 156–239 mg/kg).

While it may be hypothesised that the high AMN at Sunnyvale is due to an increased abundance of microbes, hot-water-extractable carbon (HWEC) and estimates of the microbial biomass were higher for the Portland Road flocculated and digger-excavated sediments. Thus, an alternative interpretation may be that the microbial community at Portland Road is functioning poorly (potentially due to the low pH) in comparison to that present at Sunnyvale. The lower AMN in the Sunnyvale sample with added organic material may reflect either dilution of the AMN or a change in the availability of AMN as a result of adding organic material – or simply variability between samples. All data from analysed samples are presented in Appendix 2.

Table 2. Extended chemical properties (carbon, nitrogen, and sulphur) for Portland Road and Sunnyvale stormwater pond sediments

Site	Sample name	SO_4-S (mg/kg)	AMN (mg/kg)	AMN/TN (%)	OM (%)	HWEC (mg/kg)	MBC (est.) (mg/kg)
Portland Road	Plot 1 'Flocc' Portland	3,140	26	0.6	13.8	843	136
Portland Road	Plot 2 'Topsoil' Portland	139	60	3.8	4	475	88
Portland Road	Plot 3 'Digger Sed' Portland	2,120	16	—	10.3	774	127
Sunnyvale	Sunnyvale Pond Sed	9	239	14.8	3.1	374	75
Sunnyvale	Sunnyvale sed + OM	49	156	9.3	8.1	419	80

SO_4 = sulphate, S = sulphur, AMN = anaerobically mineralisable nitrogen, TN = total nitrogen, OM = organic matter, HWEC = hot-water-extractable carbon, MBC (est.) = microbial biomass carbon (estimated from HWEC).

4.3 Portland Road beneficial reuse trial

4.3.1 Slurry and leachate samples

Negligible dissolved metal concentrations were present in the inlet and outlet (leachate) samples (Table 3). The high total concentrations in the inlet samples reflect the high solids content of the sample, while the low total concentrations in the outlet samples reflect the visibly reduced sediment load in these samples (Figure 24). However, some metals may be mobilised as the sediments 'ripen' and aerate, and due to changes in the chemistry of the sediments.

Figure 24. Samples of inlet to geobags before flocculation (left bottle), and leachate from geobags after flocculation (right bottle).

Table 3. Total and dissolved concentrations for selected metals in replicate samples going into the geobags (inlet) and leachate from the geobags (outlet)

Sample	Dissolved Cu (mg/L)	Total Cu (mg/L)	Dissolved Pb (mg/L)	Total Pb (mg/L)	Dissolved Zn (mg/L)	Total Zn (mg/L)
Portland Road Inlet R1	<0.0005	1.4	0.00027	3.1	<0.0010	6.2
Portland Road Inlet R2	0.0005	1.78	0.00058	4.1	0.0011	7.7
Portland Road Outlet R1	<0.0005	0.00137	<0.00010	0.0035	0.0018	0.0053
Portland Road Outlet R2	<0.0005	0.0009	<0.00010	0.0023	<0.0010	0.0037

Cu = copper, Pb = lead, Zn = zinc

4.3.2 Soil chemistry

Both flocculated and digger-excavated sediments have adequate macro-nutrients, but a highly acidic pH in flocculated sediments is probably the main reason for poor growth of planted seedlings and for preventing the establishment of plants from seeds.

Excavated sediments had more than double the total carbon (6–8%) and nitrogen (0.3–0.4%) content of site-won topsoil (total carbon 2.3% and nitrogen 0.16%). The higher carbon content provides a larger chemical buffer, and is reflected in much higher cation and anion exchange capacities than site-won topsoils (Appendix 2). Similar carbon:nitrogen ratios of c. 18 and 15, respectively, mean that the growth of high-nitrogen-demanding plants may be limited, although the growth of most native plants is unlikely to be limited at these ratios, as reflected in the growth rates of *Carex* in topsoil and digger-excavated sediment.

Available phosphorus of excavated sediment was abundant (Olsen P over 20) and at the levels of fertile pastures, much higher than in most native ecosystems. Legumes are usually favoured in such soils, but here the growth of most legumes in the excavated sediments (even *Lotus*) would be limited by the low pH, which increases the availability of contaminants – most notably copper and zinc, as well as soil-derived aluminium (Morton & Moir 2018), all of which may be toxic to legumes.

The growth medium that is most favourable is the digger-dug sediment. Despite being strongly acidic, planted native seedlings grew well, and this was the only plot in which self-established native species were able to grow (section 4.3.3). The flocculated sediment from this site requires amendment to raise the pH above 5 to facilitate the growth of a wider range of (primarily exotic) plants, including grass. A soil pH above 5 also reduces the concentration of metals in solution and so helps reduce metal leaching. The 'control' (the local topsoil removed from the site) has a favourable chemistry but contained weeds that smothered native plants (until they were released by weeding), and prevented the establishment of new native species from outside the plots.

Of particular note is the marked decrease in soil zinc concentration between May 2022 and May 2023 (Figure 25) in both the flocculated sediment and digger-excavated sediments. Both of these sediments also had low pH (typically <4.5), which increases the likelihood of leaching of zinc (and also copper, although the observed soil concentration changes were much lower). Therefore leaching losses are the most likely explanation for this marked decrease in soil concentrations, although plant uptake of zinc may also account for some reduction (see section 4.3.4).

The similar soil concentrations of zinc and copper between the May and September 2023 samples, which still had low pH, suggests that residual zinc and copper were probably more tightly adsorbed on the soil particles and further leaching losses are likely to be low. Lead concentrations were elevated compared to expected background concentrations, but were below Eco-SGVs and were reasonably constant over the different sampling time points, suggesting no significant movement of soil particles with adsorbed metal contaminants. Arsenic concentrations were also elevated (20–42 mg/kg, Appendix 2) compared to background concentrations, but were below the soil contaminant standard for protection of human health for recreational settings (80 mg/kg).

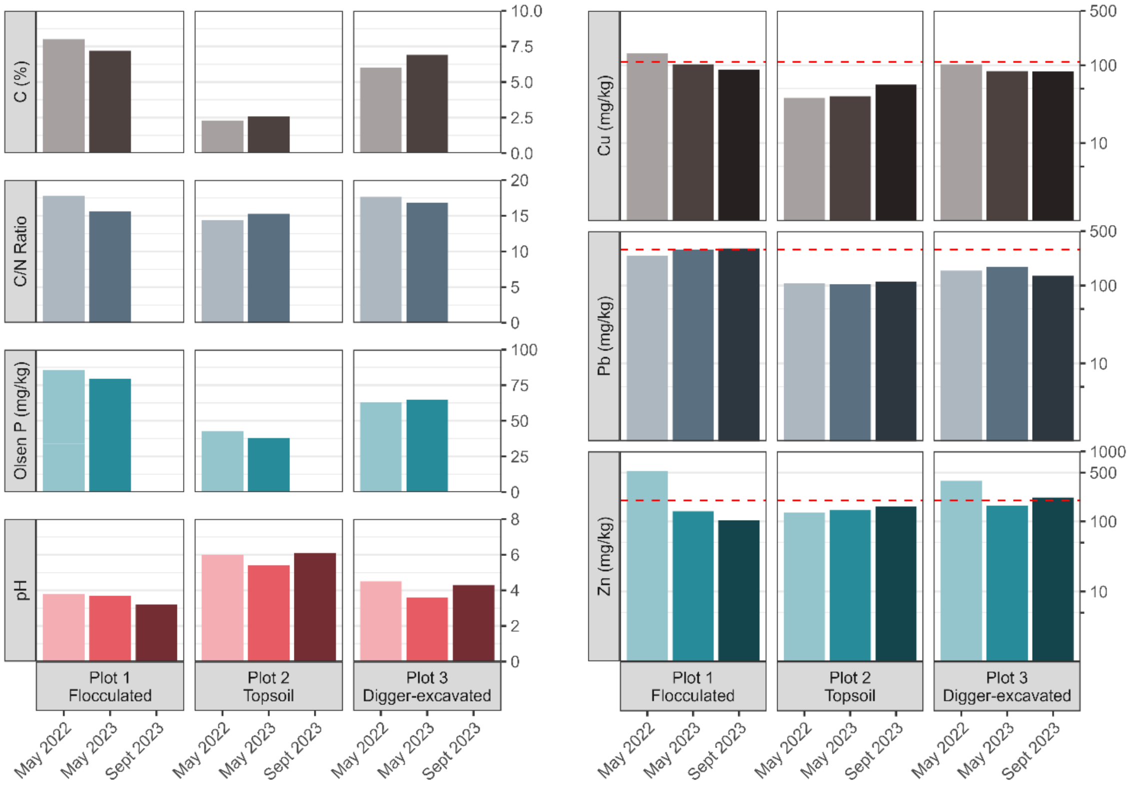


Figure 25. Changes in key soil properties in the different plots at Portland Road: Plot 1 – dredged and flocculated sediment; Plot 2 – site-won soil; Plot 3 – digger-excavated soil.

Figure 26. Left: Portland Road soil cores from the surface 100 mm of the three trial plots. All have signs of anaerobic conditions: slate grey and bright orange iron nodules in both sediments (left core digger dug, and right core flocculated), and pale yellow mottles in the site-won topsoil (centre core). Right: planted *Coprosma repens* in dug sediment soil with small, self-established *Coprosma robusta* and *Metrosideros excelsa* (pōhutukawa) seedlings, February 2023.

4.3.3 Soil physical properties

Both dredged and digger-excavated sediments are physically better growing media than the topsoil due to 2 to 3 times more total available water (Table 4); this is equivalent to 120 mm over 300 mm depth (design depth) compared to 45 to 60 mm in the clay loam soils. This increased available water translates to less vulnerability to drought stress in summer if both have similar rooting depths: plants in the topsoil become stressed about 20 days earlier than those in sediment (assuming evapotranspiration c. 3 mm/day). The higher available moisture is probably driven by the high organic content (c. 7% carbon in sediments, cf. 3% in soil), which increases water stored at field capacity, as there is little difference at permanent wilting point (1,500 kPa tension) and no impact of flocculant.

Table 4. Key soil physical attributes of the three treatments at Portland Road / Waitaramoa Reserve site, mean plus std deviation

Treatment	Dry bulk density (g/cm^3)	Air-filled pore volume (% v/v)	Field capacity (% v/v)	Readily available water (% v/v)	Total available water (% v/v)	Water at permanent wilting point (% v/v)
Digger-dug sediment: plot	0.60 ± 0.09	11 ± 3	65 ± 3	9 ± 4	42 ± 5	22 ± 1
Flocculated sediment: plot	0.58 ± 0.04	13 ± 1	64 ± 2	8 ± 2	44 ± 2	20 ± 1
Local site-won topsoil: plot	1.15 ± 0.05	10 ± 3	46 ± 1	4 ± 2	22 ± 1	24 ± 2
Bund topsoil	0.97 ± 0.11	27 ± 1	36 ± 3	7 ± 1	15 ± 3	21 ± 0

Both sediments and site-won topsoil are highly vulnerable to compaction levels that restrict root growth. The vulnerability to compaction of site-won topsoil is shown by comparing the uncompacted site topsoil in the bund, which has a weak, nut/crumb structure and 27% large, air-filled pore volume (Table 4), with that in Plot 2 (site-won topsoil). Here the large pore volume drops to 10% v/v, a level considered just adequate for the growth of a range of common plants (Table 4). This marked change is much less observable when looking at bulk density for these samples, which only increases from 0.97 to 1.15 g/cm^3, and is typical of the range of bulk densities for Ultic Soils. In contrast, the bulk density of both sediments is about 0.60 g/cm^3, while the air-filled pore volumes is only slightly higher than for the site-won soils.

However, the sediments are more resistant to compaction than the site-won topsoil. Resistance is indicated by a relatively stable bulk density in response to applied compaction as moisture content is increased (Figure 27), and a penetration resistance (strength) exceeding 3,000 kPa at high moisture contents (i.e. 50% w/w). This resistance and strength are probably linked to the elasticity provided by the coarse organic root fibres in these sediments.

In contrast, the site-won topsoil rapidly loses strength as soil moisture exceeds 30% w/w (pink line on Figure 27 below). The bulk densities in the graphs below are different to those measured in the field because the laboratory test applies a standard compactive pressure (a defined weight dropped from a defined height a specific number of times) that was higher than used to place the sediments and topsoil in the bund. Figure 27 also illustrates the difference in water held by the sediments and topsoil: these organic-rich sediments can contain up to 70% water-filled pores, or about 20% more than the site-won topsoils.

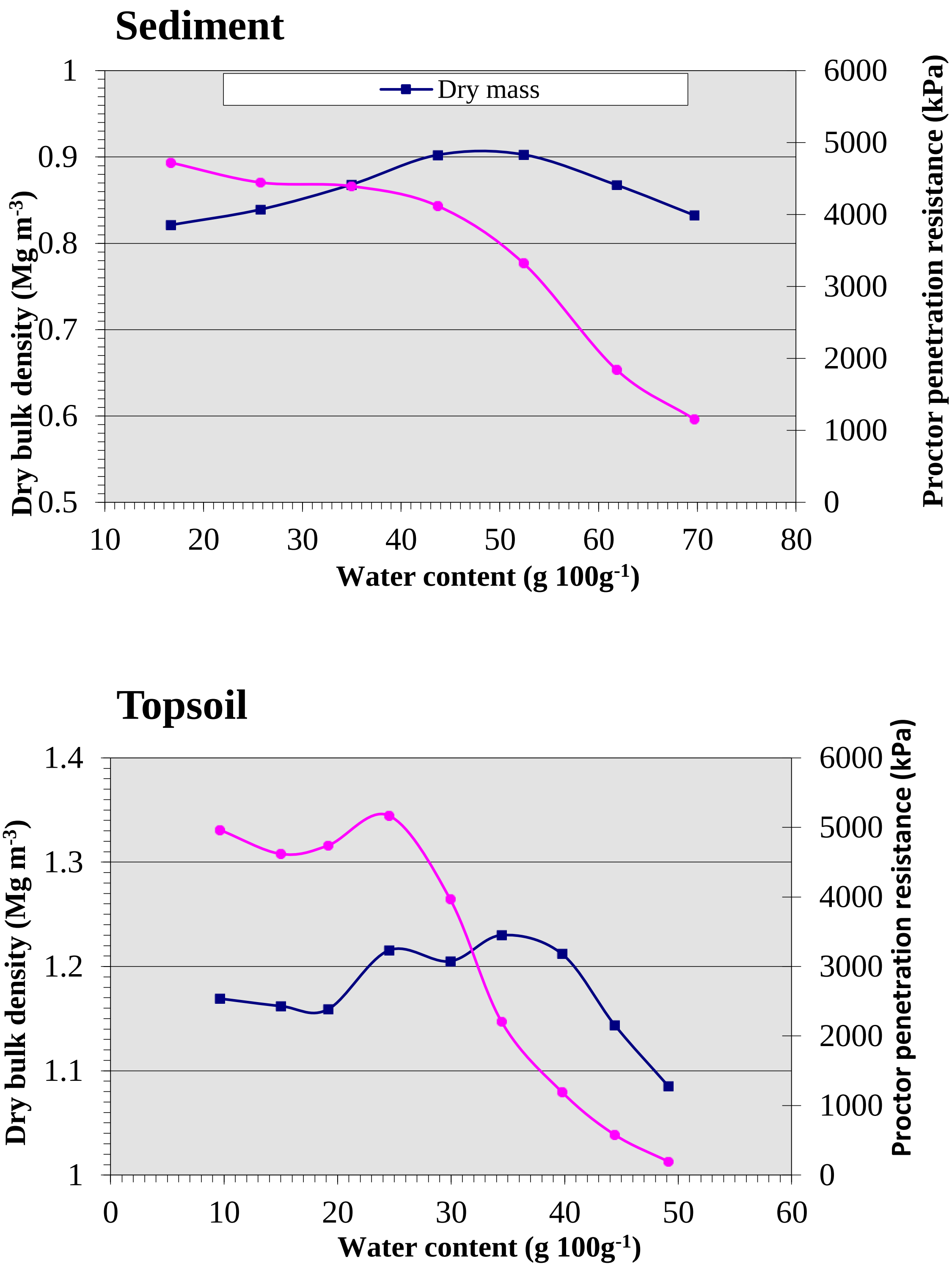


Figure 27. The vulnerability of sediments and topsoil to compaction changes with changing moisture content. Compaction is measured by bulk density (black line) and by penetration resistance (pink line).

Notes: bulk densities below c. 1.2 Mg/m^3 and resistances below 3,000 kPa are considered non-limiting to root growth.

4.3.4 Plant mortality, cover, and growth

Summer 2022/23 provided unusually good growing conditions for plants that were above flood zones and adapted to imperfectly to poorly drained soils, as summer moisture deficits were small and temperatures warm (Figure 28). All individuals of the green *Carex testacea* survived the first year without irrigation in all plots, as did the brown form and *Coprosma repens* in the digger-excavated sediment (Table 5). However, many of the brown *Carex* and all the *Coprosma* were smothered by weeds in the site-won topsoil plot. Several of the brown *Carex* in the flocculated sediment plot died and all were unhealthy, as were the coprosmas.

Table 5. Survival of planted seedlings, July 2023

Plot	*Carex testacea* (green) (%)	*Carex testacea* (brown) (%)	*Coprosma repens* (%)
1 Flocculated sediment	100	57	100
2 Site-won topsoil	100	42	0
3 Digger-excavated sediment	100	100	100

Total plant cover differed between treatments. It was 100% in digger-excavated sediment and site-won topsoil (Table 6), but cover in site-won topsoil was dominated by tall, self-established weeds that smothered the planted sedges (although some were still alive) and *Coprosma*. In contrast, the flocculated sediment was hostile to the establishment of adventive plants, so the planted species were the only plants delivering cover. The best outcomes occurred in the digger-excavated sediment plot, where plants were able to self-establish but competition with planted seedlings was low.

Weeds were removed in February 2023, May 2023, and July 2023. This allowed the cover of native planted species in the site-won topsoil plot to increase from 10% to 60%, reaching 80% in July 2023. This was dominated by the taller, green *Carex testacea*, with the brown form having just 5% cover and *Coprosma* absent. The cover of native planted species also increased in the digger-excavated sediment, doubling from 40 to 80% by May and remaining at 80% in July 2023. The cover of non-native weeds decreased over time in both site-won topsoil and digger-excavated sediment plots.

Although the site-won topsoil plot maintained full cover with consistent weed growth (dominated by wire-weed, willow-weed, lotus and kikuyu grass), the digger-excavated sediment plot had 15% bare surface in July 2023 as the weeds were not as vigorous and were easier to completely remove from the friable surface, meaning weeding efforts were more effective and longer-lasting. The bare area in the digger-excavated plot favoured the natural establishment of native species from adjacent shrublands. The tallest of these were individual tī kōuka (*Cordyline australis*), 45 cm height); mānuka (*Leptospermum scoparium*), 20 cm; karamu (*Coprosa robusta*), 15 cm; and tree hebe (*Veronica parviflora*), 15 cm.

However by far the most numerous native seedlings were pōhutukawa (*Metrosideros robusta*), which were mostly 10 to 15 cm high. Most pōhutukawa showed myrtle rust infection – semi-mature pōhutukawa trees were within 10 m of the plots, probably the source of both seed and rust spores. In contrast, only one pōhutukawa seedling persisted in the flocculated sediment (and was very close to the stem of a planted *Coprosma*, so potentially in retained potting mix), and no native species self-established into the site-won topsoil (all space was quickly shaded by weeds or planted *Carex*).

Figure 28. Portland Road trial, 9 Aug 2022, about 2 months after planting, showing 100% initial survival and no visual differences in growth or leaf colour between treatments; all of the green form of *Carex* have yellowed. Left = dredged, flocculated, and geobagged sediment (ex geobag); centre = site-won topsoil (the 'control' growing medium); right = digger-excavated sediment .

In February 2023 the height and spread of planted green *Carex testacea* were similar between treatments (Figures 29 and 30), although plants in the flocculated sediment had a higher proportion of dead leaves. However, by July 2023 plants in the site-won topsoil and digger-excavated sediment had grown substantially, while those in the flocculated sediment showed large variation in growth and some die-back; on average, plants in the flocculated sediments grew just 2 cm higher and 1 cm wider over the period (Figures 29 and 31, Table 7).

Plant height and spread growth were greatest in the site-won topsoil. As the cover of sedges increases to c. 90%, the average spread (118 ± 8 cm in topsoil and 100 ± 10 cm in digger-excavated sediment) will stabilise unless dieback occurs (e.g. as a result of summer droughts) or plants taller than the 50 to 70 cm sedges smother the sedges. Some weeds have the potential to smother, including kikuyu, some *Senecio* species, and wattles (*Acacia* species).

In the digger-excavated plot, both planted and self-established native coprosmas (*C. repens* and *C. robusta*) and pōhutukawa have the greatest potential to smother some sedges, although this is not necessarily an unwanted outcome. Lime or dolomite amendment at rates that raise soil pH within the root zone is required to allow an adequate native plant cover in the flocculated sediment plot. As of July 2023, kikuyu grass stolons were beginning to establish within the plot from source plants along three plot edges.

Table 6. Plant cover in February 2023 (before weeding) and May 2023

Plot	Total cover %	Planted cover %	Weed cover %
February 2023			
1 Flocculated sediment	40	40	0
2 Site-won topsoil	100	10	90
3 Digger-excavated sediment	100	40	60
May 2023			
1 Flocculated sediment	40	40	0
2 Site-won topsoil	100	60	40
3 Digger-excavated sediment	100	80	20

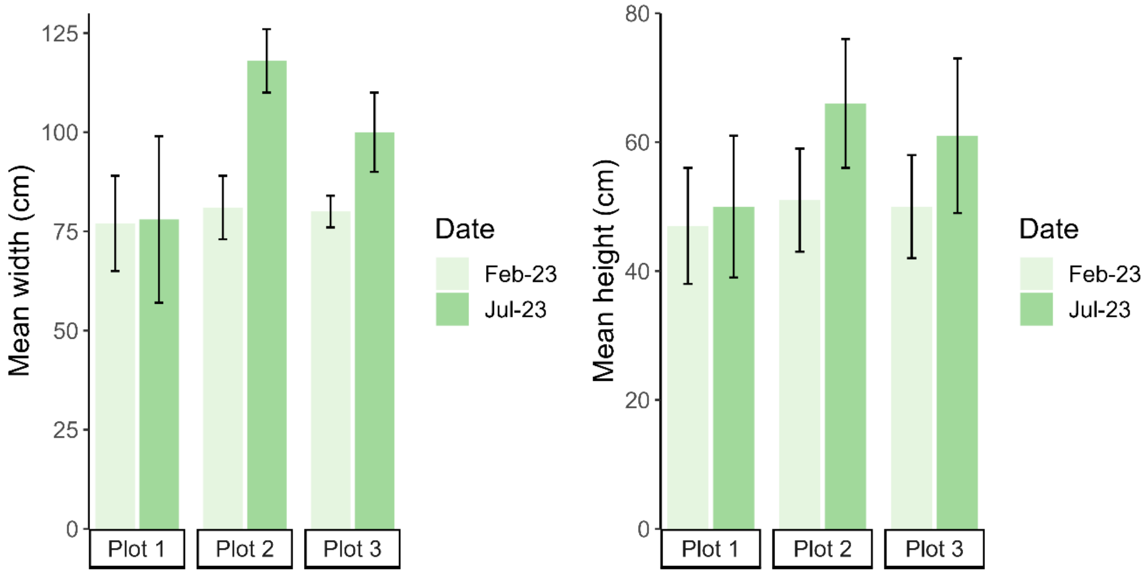


Figure 29. Width (left) and height (right) of *Carex testacea* (green form) in February and July 2023 in the three plots. Plots show mean height/width of plants in each plot; error bars represent standard deviation.

Table 7. Growth of *Carex* (mean and std dev.) and the main self-established plants, February 2023

Plot	*Carex* height (cm)	*Carex* spread (cm)	Main self-establishing plants
1	47 ± 9	77 ± 12	Nil
2	51 ± 8	81 ± 8)	Polygonum, Persciaria, Lotus, Pennisetum, Senecio
3	50 ± 8	80 ± 4	Polygonum, Persicaria, Senecio, Pennistemon, Conyza

Notes: Conyza = *Conyza sumatrensis* (fleabane); Lotus = *Lotus pedunculatus, L. corniculatus* (lotus, birds-foot trefoil); Polygonum = *Polygonum aviculare* (wireweed or knotweed); Pennistemon = *Pennisetum clandestinum* (kikuyu grass); Persicaria = *Persicaria maculosa* (willow weed); Senecio =*Senecio vulgaris* (groundsel), *S. bi-pinnnastisectus* (fireweed) and other species).

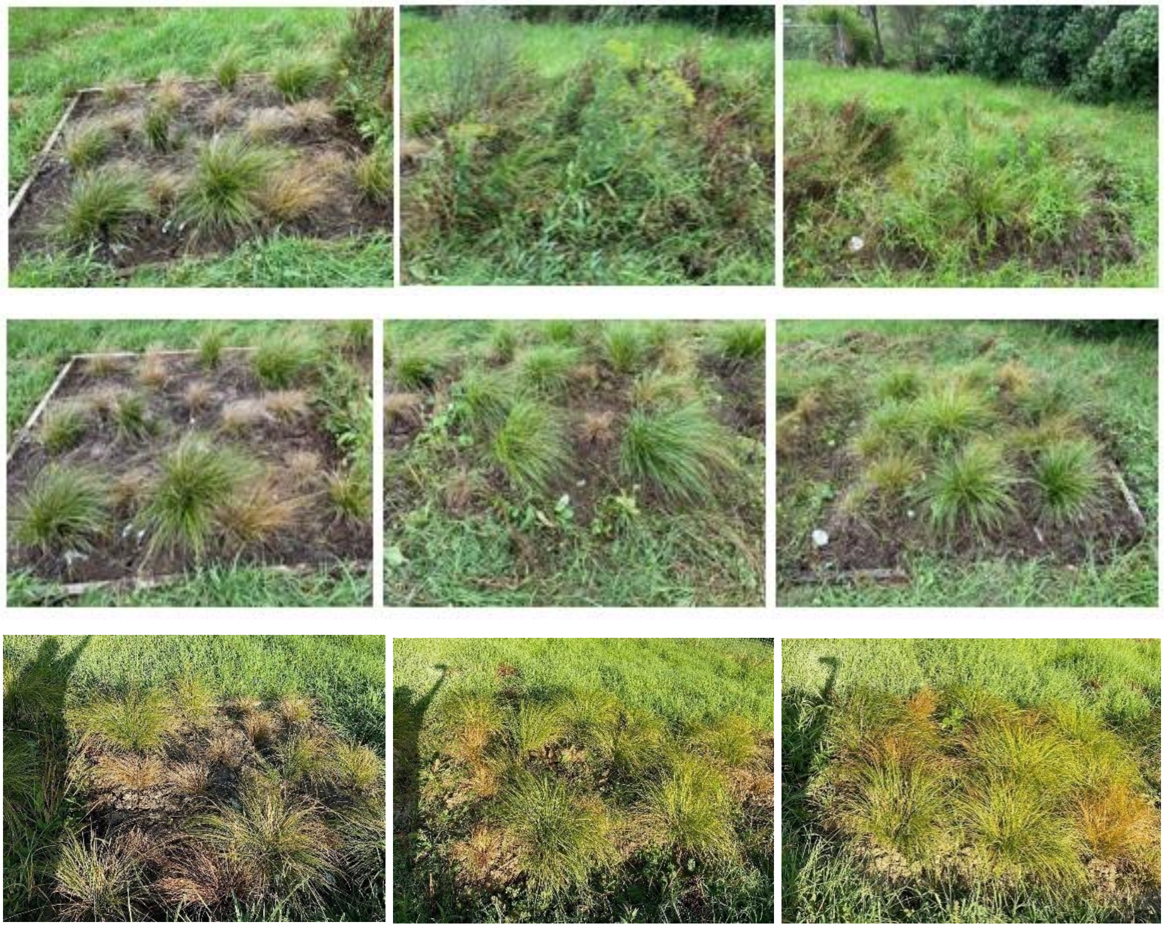


Figure 30. Portland Road trial. Left = dredged, flocculated, and geobagged sediment (ex geobag); centre = site-won topsoil (the 'control' growing medium); right = digger-excavated sediment. Top row: 3 February 2023 before weeding, showing large weed biomass on site-won topsoils smothering some planted sedges and the absence of any weeds on flocculated sediment. Centre row shows plots after weeding, 3 February 2023. Bottom row shows plots after recovery from shading, 22 Feb 2023.

Flocculated & dredged sediment Site-won Soil Digger dug sediment

July 2023

Figure 31. Portland Road trial, July 2023, showing taller sedges in the central topsoil plot and high cover of planted species in the digger-excavated sediment plot (right).

4.3.5 Foliar chemistry

Foliar samples indicate that *Carex* growing in the flocculated plot are deficient in phosphate, despite soil results showing moderate phosphate availability (Table 8). Elevated zinc concentration in leaves of plants growing in both digger-excavated and flocculated sediments reflect the elevated zinc in these sediments. The pH less than 5 in both sediments also favours mobilisation of zinc into a dissolved form, whereas the pH around 6 of the site-won topsoil (Figure 25, Appendix 2) supresses the desorption of zinc and therefore its uptake into plants. The foliar samples did not show elevated copper in plant tissues.

Table 8. Concentrations of nitrogen, phosphorus, zinc, and copper in *Carex testacea* leaves and associated sediment samples, collected in May 2022 and May 2023.

Plot	Foliage total N, %	Foliage total, P %	Foliage Zn, (in sediment May 2022, May 2023) mg/kg	Foliage Cu (in sediment May 2022,May 2023) mg/kg
1 Flocculated sediment	1.5	0.08	164 (520, 140)	12 (141, 103)
2 Site-won topsoil	1.1	0.15	46 (134, 145)	11 (38, 40)
3 Digger-excavated sediment	1.1	0.13	85 (380, 169)	10 (103, 84)

Notes: N = nitrogen, P = phosphorus, Zn = zinc, Cu = copper.

5 Developing a decision-making flow chart

5.1 Considerations for the beneficial reuse of sediment

5.1.1 Stormwater pond site considerations

Some site-specific factors influence what and how sediments are removed from stormwater ponds. Detailed consideration of these was beyond the scope of the current project, but factors include:

- the presence of weeds in or surrounding the stormwater pond (creating opportunities through co-disposal, but also requiring consideration of biosecurity risks where weeds can invade terrestrial environments)
- access to the pond for desilting
- the area available for sediment dewatering and/or reuse.

A number of design and operational elements were also discussed at the March 2023 workshop that would facilitate desilting processes and potentially improve the quality of sediment removed. These included:

- the construction of forebays that can be easily accessed, dewatered, and sediment removed
- the installation of gross pollutant traps upstream of the stormwater ponds (to reduce gross contaminants)
- the installation of draw-down pipes to facilitate dewatering of ponds for maintenance.

Some of these factors were also specified in TRCA 2018, along with guidance on other aspects of inspection and maintenance of stormwater ponds and constructed wetlands. Perhaps a key point of difference between TRCA 2018 and the current operations is that systematic sampling is undertaken *prior* to desilting operations in Canada, rather than primarily grab or composite samples being collected during desilting operations (which might be needed to inform disposal to landfill).

5.1.2 Recipient site characteristics

The location and characteristics of the site/s that receive the sediment influence both the costs associated with beneficial use and the extent to which the added sediment provides beneficial properties, or at least ensures that soil quality at the site is not degraded. The soil quality at the recipient site should be assessed using the same parameters as for sediment to help predict the effects of sediment addition in relation to the desired land use (mown pasture for recreation and native shrubland/forest are common uses), and how to enhance outcomes as an overall package. This includes considering land topography:

- slopes, contours, and consequent drainage, especially in relation to mowable areas and potential for erosion
- overland flow paths and flood plains

- the value of bunds for visual and noise buffers, as well as for enhancing deeper root zones within (degraded) recreational areas.

The economic feasibility of beneficial reuse is primarily influenced by the cost of transport to the location of beneficial reuse. Other factors include any requirements for disposal (e.g. vehicle access, liners, defined capping or surfaces), and, in public recreational areas, the cost of having the area temporarily unavailable and providing fencing to ensure public safety during construction. It may also be influenced by the cost of importing soils and/or fill that would otherwise be required to deliver the desired improvements at the site.

Economic evaluation should be considered on a case-by-case basis, where there is space for dewatering, zinc concentrations are amendable/acceptable, and a nearby beneficial use has been identified, and at a sub-regional level when there is no nearby beneficial use but material could be beneficial and is being trucked anyway. This may include transport to a temporary site for processing and or stockpiling.

5.1.3 Removal methods

The most common sediment removal methods in Auckland currently appear to be dredging and flocculation into geobags, or excavation via digger with (or without) mixing with sawdust or wood waste. Some smaller volumes may be vacuum-dredged directly into trucks. The additional of sawdust or woodwaste is used to increase solid content to allow disposal to landfill. The removal method can influence the texture of the sediment, with smaller, homogeneous chunks of vegetation typically present in dredged sediments, and larger, heterogeneous chunks present in digger-excavated sediment, which may also have sawdust/wood chips added.

In both cases the organic material provided by vegetation or wood chips improves texture as well as the organic matter content of sediments. The quantity and type of vegetation incorporated with sediment matters. Woodier material (e.g. willow, alder or mangrove roots) lasts longer before breaking down because it has a higher C:N ratio; perennial sedges, reeds, and rushes (including raupō and *Glyceria*) have a shorter life but can be more fibrous (delivering a more open sediment) compared to grasses (kikuyu), waterlilies, and knotweeds.

Dewatering of sediment is a critical component because it enables transport and beneficial reuse of the sediment. This mainly occurs via dewatering in geobags with the aid of flocculants, or through additional sediment bulking with sawdust or wood chip, but can also be delivered by evaporation in summer for ponds that can be effectively dewatered. With a greater focus on beneficial reuse of the sediment, dewatering via gravity may have increased potential, particularly for sediments bound with plants. This requires additional land area but may be relevant in the context of using specific sites for ‘processing’ removed sediments. Such an approach may also require thinking differently about removal options (e.g. using smaller ‘sucker’ trucks better suited to the transport of more liquid slurries).

A further aspect of sediment removal not often explicitly discussed is the ‘ripening’ of the sediments: the transition of the sediments from an anaerobic state to an aerobic state, visibly observed as a colour change from grey/black to brown and the development of regular cracks that create structure and enhance permeability to air and water movement. This transition results in chemical changes of the sediments that can influence leaching processes and the plant-availability of nitrogen (the maximum benefit to plant growth is obtained through the use of ripened sediment). Further evaluation of the changes in zinc and copper concentrations (through leaching) as sediments ripen is required to fully inform the appropriate handling of removed sediments for beneficial reuse.

Flocculants

There was limited discussion with council staff or contractors on the flocculants used for dewatering; Crystalfloc B400 and B500, and IXOM Superfloc 400 or 500 were mentioned. A previous report for Auckland Regional Council (TP226) reviewed the effects of residual flocculants on aquatic systems, noting that the range of materials used included aluminium coagulants such as aluminium sulphate (alum) and polyaluminium chloride (PAC); synthetic polyelectrolytes including polyacrylamides, which can be in several charge states (cationic, anionic, and non-ionic); and various cationic products, mainly polyamines.

A difference in the toxicity of cationic and anionic flocculants was noted, although the report concludes, while acknowledging the limited availability of data, that the likelihood of the release of unbound flocculant is low and hence the risk to aquatic systems is low. However, the report does not consider the potential environmental effects of flocculants on the sediment or soil, which becomes more relevant in the context of beneficial use of flocculated sediments.

TRCA 2018 notes the use of polymer flocculants, primarily anionic polyacrylamides, for the consolidation of wet sediment, and the availability of guidance on the use of anionic PAM for sediment management applications (TRCA 2013, cited in TRCA 2018). Anionic polyacrylamides are also widely used in the US for erosion control (Sojkal et al. 2007; USDA 2020). In all cases, anionic PAM is preferred to cationic PAM or other commonly used flocculants, given the lower toxicity and demonstrated efficacy (Sojkal et al. 2007; Rocha & Van Seters 2013 in TRCA 2018).

A stocktake and evaluation of flocculants commonly used during desilting operations would be relevant to ensure compatibility with beneficial use of sediments – noting the results from the Portland Road trial, which showed flocculated sediment sustained a low pH that was unsuitable even for native plants, which can normally grow in strongly acidic soils.

5.1.4 Sediment characteristics

Sediment texture influences the beneficial use options of sediments. For example, coarser (sand) and lower-organic content sediments are likely to be more geotechnically suitable for load-bearing purposes (e.g. areas to be maintained by tractor-mowers). Finer silt and clay sediments can be useful to provide additional nutrient storage, chemical buffering, and to some extent increased water-holding capacity.

Sediment textures can vary across a pond (see Figure 18), and ponds can be located in catchments that supply different-textured sediments. This can also vary over time (e.g. coarser material entering when roads are re-surfaced or a catchment contains unpaved light-industrial areas, and finer material entering when bulk earthworks are occurring). Pond sediment in the Auckland region is mainly composed of clay and/or silt fractions, with scattered pockets of sand and gravel generally located nearer inlets. Sediment also contains small but significant amounts of organic material. Organic content is increased when sediment is removed together with aquatic or riparian vegetation. Ponds closer to coastal areas (such as Akoranga or Portland Road) have higher sand fractions, and areas adjacent to or reclaimed from the coast can contain shells (i.e. calcium carbonate).

Soil texture also influences drainage (and therefore sediment trafficability, the ability to cultivate, rate of drying and ripening, and risk of dust generation), the supply and exchange of water and air, and the nutrient-supplying ability of soil materials, which combined influence plants and soil animals. New Zealand experience re-establishing pasture on deeper (>30 cm) and finer, flood-deposited sediments is relevant to pond sediment (McKee & Graham 1952, Wilson & Valentine 2005[5]). Focusing on flooded areas with finer-textured deeper sediments, this experience highlights the value of quickly establishing plants (cereals or pasture species) before sediments dry, and the value of cultivation to help aerate anaerobic sediments.

Different sediment types have their advantages and disadvantages. Silty sediments are vulnerable to generating dust. Clay sediments are generally more vulnerable to short-term crusting and/or surface ponding, both of which impede plant establishment. A complementary approach is to mix or blend sediment with suitably textured natural soils. This is advocated in USACE 2015, which targets a final texture of the mixture of dredged material and marginal soil that approximates a loam soil (USDA classification). For example, mixing a fine-textured dredged material (silt and clay) with a coarse-textured marginal soil (sand) to the proportions of a loam (roughly equal proportions of silt, clay, and sand) should improve its physical and chemical characteristics. An alternative approaches may be to apply an organic mulch, as a hydromulch with added seed.

The pH of the sediment can influence suitability for use. For example, at Portland Road the very low pH of the dredged (flocculated) sediments did not support healthy native sedges or non-native weeds, while moderately acidic, digger-excavated sediments were suitable for native plant growth, allowed self-establishment of native plants, and minimised weed growth. Site-won soils with a slightly higher pH had considerable weed growth.

Removed sediments typically have higher macro-nutrient status and may have higher water storage capacity (particularly with organic plant material incorporated) than *in situ* soils present at potential reuse sites. Sediment characteristics are likely to change with

---

[5] Also see Cyclone Gabrielle guidance: Soil Repair after Cyclone Gabrielle - LandWISE - Promoting sustainable land management. A difference between the sediments from Auckland ponds that were tested and flood sediments is that the ponds generally have higher concentrations of organic matter and available phosphorus; hence fertiliser is probably not required to establish plants in pond sediments, although liming may be needed, depending on the site and flocculant used.

dewatering and ripening (Figure 32), and this process can be accelerated with cultivation, so assessment of the sediment's characteristics *before* reuse will better inform beneficial use options.

Figure 32. Cross-section of a geobag reveals an aerobic (brown) layer overlying a (grey/black) anaerobic layer at c. 20 cm depth. The aerobic zone will deepen with disturbance or further drying through cracking and plant roots extracting water.

Potential for acid-sulphate soils

The high sulphate concentrations in the Portland Road sediments (Table 2) may have arisen from the oxidation of high concentrations of sulphide (G. Corban, Hill Laboratories, pers. comm.), which, combined with the markedly low pH, suggests that the sediments removed may have included acid-sulphate soils. These soils are formed under waterlogged conditions in the presence of no or minimal oxygen (Simpson et al. 2018). Under these anaerobic conditions, sulphate-reducing bacteria in the soil convert dissolved sulphate in the pore water into reduced inorganic sulphur (Figure 33). The reduced inorganic sulphur then reacts with metals, particularly iron, resulting in the formation of metal sulphides (principally pyrite). A supply of easily decomposable organic matter (such as decaying vegetation) is also required to provide sufficient energy for the bacteria to convert the sulphate into reduced inorganic sulphur.

Seawater typically contains higher sulphate concentrations than freshwater, and mangroves are specifically identified as areas where acid-sulphate soils may be found. Hence, removal of sediment from any stormwater ponds that are tidally influenced or have evidence of self-established mangroves surrounding the area (e.g. Portland Road) should be evaluated for the potential for acid-sulphate soils. Roberts and McConchie (2017) have developed a preliminary map of the potential for acid-sulphate soils in the Auckland region. The field determination of the pH of a soil–water paste, and the pH in a soil (30% H_2O_2 mixture), can enable the identification of acid-sulphate soils on-site (Sullivan et al. 2018).

Simpson et al. (2018) provide guidance on the dredging of acid-sulphate soil sediments and associated dredge spoil management, including a case study of the removal of material from a stormwater treatment wetland. This document may be useful for Healthy Waters to refer to when developing further stormwater pond sediment protocols.

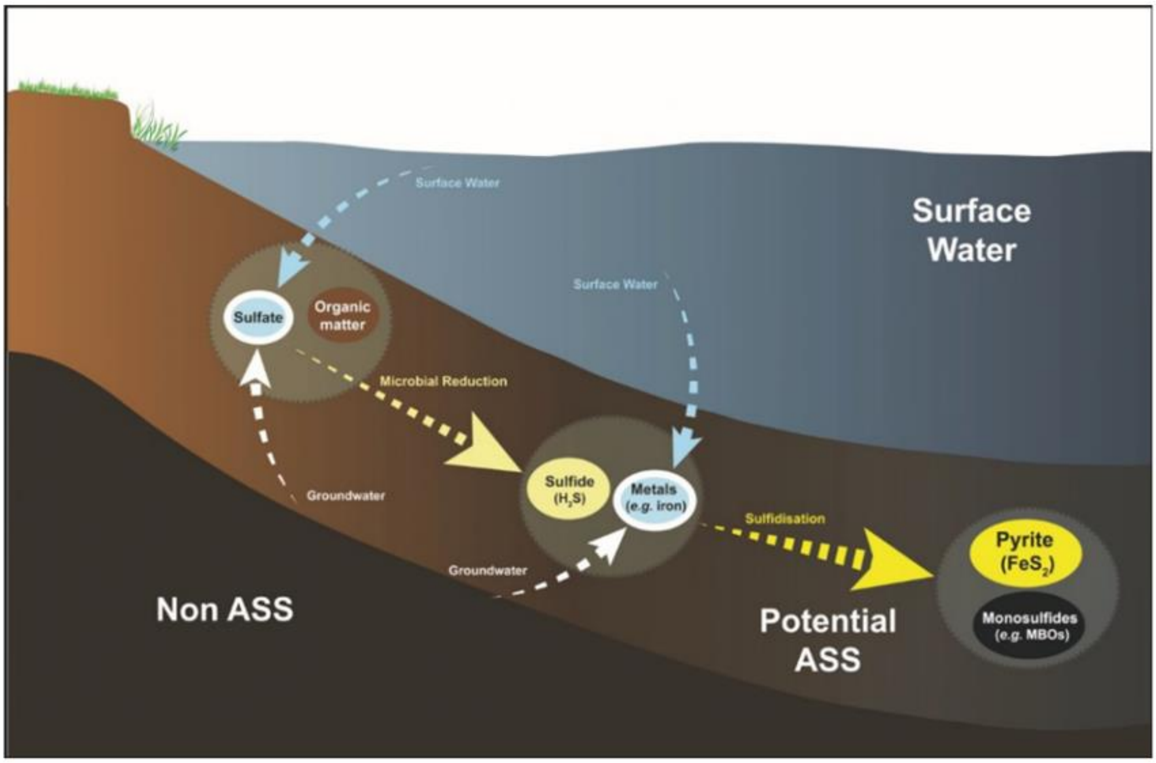


Figure 33. Formation and accumulation of acid-sulphate materials.
Source: Simpson et al. 2018
Notes: ASS = acid-sulphate soils; MBOs = monosulphidic bland ooze

5.1.5 Contaminants

Contaminant concentrations in sediment will be a key factor influencing the beneficial use of removed sediments. For stormwater ponds in urban areas, the primary contaminants in the sediment are expected to be copper, lead, and zinc, derived from a variety of sources including galvanised roofing, copper piping, brake pads, tyre wear (e.g. Kennedy & Sutherland 2008) and petroleum hydrocarbons (e.g. Mayson et al. 2010; Timperley et al. 2011). New Zealand studies on road-derived sediments (e.g. Mayson et al 2010; Depree et al. 2010; Depree 2011), and Canadian studies on stormwater ponds (e.g. Kelly-Hooper et al. 2022) also highlight the common occurrence of organic contaminants such as total petroleum hydrocarbons, and polycyclic aromatic hydrocarbons (commonly expressed as a benzo(a)pyrene-equivalent [BaP-eq] concentration) in stormwater pond sediments.

A summary of the different soil guideline values that are relevant to consider for the beneficial reuse of sediments is given in Table 9, with specific numerical values for key contaminants of concern provided in Table 10. A more detailed description of the basis of the different guideline values is provided below.

The available guideline values have been developed for different purposes, including protection of human health and protection of soil biota (soil microbes, plants, soil invertebrates), and for regulatory purposes. Waste acceptance criteria may also be relevant to consider when disposing of sediment to landfill: these may be set by the individual landfill, or may be those outlined in WasteMINZ (2022) for the different classes of landfill.

In the first instance the key criterion is whether the sediment is sufficiently solid for disposal, which is a key reason that amendments such as woodchips and sawdust may be used when sediments are removed. Dewatering in geobags also increases the solids content, and geobags can be disposed directly to landfill.

From a regulatory perspective, in the Auckland region the discharge of sediments to land will need to be compliant with Auckland Unitary Plan section E30 – contaminated land, which defines permitted activities and activities that may require consent in relation to contaminant concentrations in the sediment. Section E30.6.1.4 is most relevant and covers conditions for the discharge of contaminants onto or into land from land not used for rural production activities, which is most likely to be the case for the beneficial use of stormwater sediments. Under this section, the concentrations of contaminants (relevant to the site's history) in soil or fill material must not exceed (a) the criteria specified in Table E30.6.1.4.1 'Permitted activity soil acceptance criteria' or the background concentration ranges of trace elements specified in Table 3 of TP153. The only organic contaminants included under the permitted activity criteria are benzo(a)pyrene (equivalent) and total DDT. For other hydrocarbon contaminants, the criteria outlined in Table 4.20 'Soil acceptance criteria for protection of groundwater quality' in the *Guidelines for Assessing and Managing Petroleum Hydrocarbon Contaminated Sites in New Zealand* (MfE 2011) need to be considered. Additional documents are specified in the Auckland Unitary Plan, section E30.6.1.4, for other contaminants present.

Table 9. Summary of various guideline values for soil contaminants

Soil guideline value	Purpose	Source document
Auckland permitted activity criteria	Define permitted activities or where consent may be required in relation to the discharge of contaminants, including onto or into land.	Auckland Unitary Plan, section E30 (Table E30.6.1.4.1)
Auckland background concentrations (selected trace elements)	Relevant in the context of identifying when concentrations are above background; the movement of sediment with concentrations below background is effectively unrestricted from a contaminant perspective	TP153:2001 Background concentrations of inorganic elements in soils from the Auckland Region Auckland Unitary Plan, section E30 (Table E30.6.1.4.2)
Ecological soil guideline values	Protection of soil biota and plants	Cavanagh & Harmsworth 2023
Soil contaminant standards	Protection of human health. Referred to in the National Environmental Standard for Assessing and Managing Contaminants in Soil to Protect Human Health	MfE 2011
Waste acceptance criteria	Determining suitability of sediment for disposal	WasteMINZ 2022 Individual landfill criteria

Table 10. Summary of various soil guideline values (mg/kg) for key contaminants of concern

Land-use scenario / % protection	Arsenic (mg/kg)	Lead (mg/kg)	Copper (mg/kg)	Zinc (mg/kg)	BaP- eq (mg/kg)	DDTs (mg/kg)
Auckland permitted activity criteria	100	250	325	400	20	12
Auckland background concentrations: [a]						
non-volcanic	0.4–12	<1.5–65	1–45	9–180	NA	NA
volcanic			20–90	54–1,160	NA	NA
Ecological soil guideline values: [b]						
95% protection	20	290	110[c]	200[c]	2.8[d]	2.4
80% protection	60	900	245[c]	320[c]	22 [d]	4.8
60% protection	150	2,500	430[c]	510[c]	47 [d]	11
Soil contaminant standards						
Standard residential: assumes that 10% of all produce consumed is home-grown	20	210	>10,000	NA	10	70
Parks/recreation	80	880	>10,000	NA	40	400
Commercial industrial	70	3,300	>10,000	NA	35	1,000
Waste acceptance criteria: [e]						
Class 1 Landfill [f]	5	5	5	10	NS	NS
Class 3 – Managed fill [g]	140	460	280	1,200	125	2
Class 4 – Controlled fill[h]	17	160	220	190 or background concentration if higher	2.8	2

Sources: documents are shown in Table 9

NA – not available, NS – not specified

[a] ARC 2001.

[b] Values are based on the lowest median background concentration for individual contaminants.

[c] Values for a typical soil. Additional values are also available for sensitive and tolerant soils (refer to source documents).

[d] Benzo-a-pyrene concentration only

[e] WasteMINZ 2022. Different waste acceptance criteria may be used by different landfills, depending on their consent conditions.

[f] Criterion is the maximum allowable TCLP concentration in mg/L (Appendix C& D, WasteMINZ 2022).

[g] Criterion is based on protection of the groundwater drinking-water and aquatic environment (Appendix C& F, WasteMINZ 2022).

[h] Criterion is based on the lowest of criterion for soil ecology protection, human health protection for agricultural or rural residential use, drinking-water protection or protection of aquatic environments (Appendix C& G, WasteMINZ 2022).

Auckland permitted activity criteria

These criteria are used in a regulatory context to define whether consents are required for the activity occurring on-site. The values are based on ANZECC[6] sediment quality criteria (ANZG 2018), which are in turn based on the assumption that no more than 20% of the soil is likely to be in fine particles, which have the potential to enter surface water (A. Kalbarzcyk, Senior Specialist – Contaminated Land, Auckland Council, pers. comm.). Thus the permitted activity criteria are sediment default guideline value multiplied by 5 (except for zinc, which is multiplied by 2).

These criteria are based on protecting biota associated with aquatic sediments and are most relevant when there is a potential discharge to a stream. It is important to note that they *do not* consider the protection of on-site ecological receptors (i.e. soil biota, plants). This is most relevant in the context of copper and zinc, for which the permitted activity criteria are higher than the Eco-SGVs that provide protection for 80% of soil species.

Background concentrations

Regional background soil concentrations of various trace elements in non-volcanic and volcanic soils have been determined across the Auckland region by ARC 2001 (TP153) and Cavanagh, McNeill et al. 2023. As noted above, background concentrations in TP153 are specified in the E30 of the Auckland Plan and thus hold regulatory weight. However, caution is recommended before accepting background concentrations of zinc in volcanic soils that are higher than the 80% protection Eco-SGV (320 mg/kg for a typical soil) or the permitted activity criterion of 400 mg/kg. The background concentration ranges for zinc in volcanic soils in TP153 indicate an upper concentration of 1,160 mg/kg. However, while such concentrations may be true naturally occurring concentrations in some volcanic soils, the spatial extent of such elevated concentrations is likely to be highly limited. There should, therefore, be verification of the zinc concentrations at the site in question to determine whether such elevated concentrations are acceptable in sediment to be used on that site.

Ecological soil guideline values

Ecological soil guideline values (Eco-SGVs) were developed to protect terrestrial biota (soil microbes, invertebrates, plants, wildlife, and livestock) from the negative effects of contaminants, and they provide a useful way to readily assess potential environmental impact. The methodology for deriving these values considers that it is the anthropogenic addition of contaminants to soil that results in negative effects, which means that Eco-SGVs can be modified to take into account varying background concentrations.

Default generic Eco-SGVs have been developed by Cavanagh and Harmsworth (2023) using the median background concentration for different levels of protection for ecological receptors: 95%, 80%, and 60%. In modified environments such as urban

---

[6] Australian and New Zealand Environment and Conservation Council.

recreational reserves and roadside plantings, protection levels of 80% for copper and zinc would be acceptable, given that these elements are also essential for the growth of plants and terrestrial animals.

Waste acceptance criteria

Different waste acceptance criteria are used by different landfills, depending on their consent conditions. Waste acceptance criteria are also specified in the *Technical Guidelines for the Disposal to Land* (WasteMINZ 2022).

The waste acceptance criterion (WAC) for Class 1 landfills is based on TCLP (a leaching test using an acidic extract) and so is not included here. Class 2 landfills are for construction and demolition waste only, and so are not relevant to the disposal of sediment from stormwater ponds. WAC for managed fills (Class 3 landfills) are primarily based on the protection of groundwater from leaching, while WAC for controlled fill (Class 4 landfills) are based on the lowest of the values protective of ecological receptors in the fill, people exposed to the fill, users of groundwater, and aquatic receptors in nearby streams. The *Technical Guidelines* specify the use of regional values (or national values if regional values are unavailable) for soil background concentrations of trace elements as the WAC for cleanfills (Class 5 landfills).

Soil contaminant standards for the protection of human health

Soil contaminant standards for the protection of human health have been developed using agreed generic exposure scenarios, which are discussed in detail in MfE 2011. The exposure scenarios for the primary land uses potentially relevant for beneficial reuse of sediments are described below (the most relevant scenario is the parks/recreation scenario).

Parks/recreation scenario

This scenario includes residential reserves where children play frequently, playing fields, and public green area reserves and gardens used for passive recreation. This scenario assumes a frequency of visitation of 200 days per year, with soil ingestion associated with active recreation (e.g. rugby) used as the default.

Standard residential

This exposure scenario is based on a typical separate house with gardens, including a vegetable garden. The exposure scenario assumes that home-grown produce comprises 10% of all produce consumed by residents.

Commercial/industrial (outdoor worker or unpaved)

This scenario represents an outdoor worker who carries out maintenance activities involving soil exposure to surface or near-surface soil through gardening and other landscaping activities, and occasional shallow excavation for routine underground service maintenance activities. Exposure to soil is less intensive and/or less frequent than would occur during construction or extensive excavation works, but occurs over a longer period.

5.2 Beneficial use options

The range of potential beneficial uses of pond sediment includes:

- as a growing medium, either as topsoil or rootzone material (where organic levels and drainage will sustain aeration) or as an amendment to *in situ* surface soils or subsoils to improve suitability for plant growth or water infiltration
- raising the surface level above flood and coastal inundation
- improving amenity value and usability[7] through addition to landscaping bunds/contouring.

The latter two activities may be particularly valuable where they were already planned and require importing additional materials, and/or the costs to undertake these activities were previously marginal, or they provide the opportunity to improve amenity value when previously no improvements were being considered.

Care needs to be taken to ensure the proposed use of the sediment is beneficial, and is not simply being undertaken to avoid transport and landfill disposal costs. For example, though burial of entire geobags containing excavated sediment within a landscaping bund may be considered beneficial in that it:

- does not incur the costs (and associated emissions) of transport and disposal to landfill
- can offset the import of materials to the site
- may contribute to the geotechnical stability of the landscaping bund

it is arguably just disposal in a different location, because the sediment cannot be accessed (e.g. by plant roots to release available nutrients, etc.), and natural water flow pathways are disrupted. If the sediment is removed from the geobag, or at least geobags are slit open to allow plant roots to access the sediment and provide less disruption to water flow, then this use of sediment can be considered to be beneficial. However, the retention of intact geobags may enhance early trafficability and could reduce settling; the relative merits need to be assessed on a case-by-case basis.

5.3 Decision-making flowchart

Three decision-making flow charts were developed. The first of these (Figure 34) provides a general overview of the various factors that influence decisions on how the sediment may be removed, and general considerations for beneficial reuse. In evaluating potential beneficial use options it is helpful to assess potential reuse within or adjacent to the areas

---

[7] For example, improving drainage and removing hollows to enhance maintenance and use of mown grass.

from which the sediment is extracted; spatial information provides a useful approach to assess potential options (e.g. Figure 35).

The second and third flow charts (Figures 36 and 37) are based on the characteristics of the removed sediment and have been developed for use at *recipient sites* that have non-volcanic or volcanic soils, respectively.

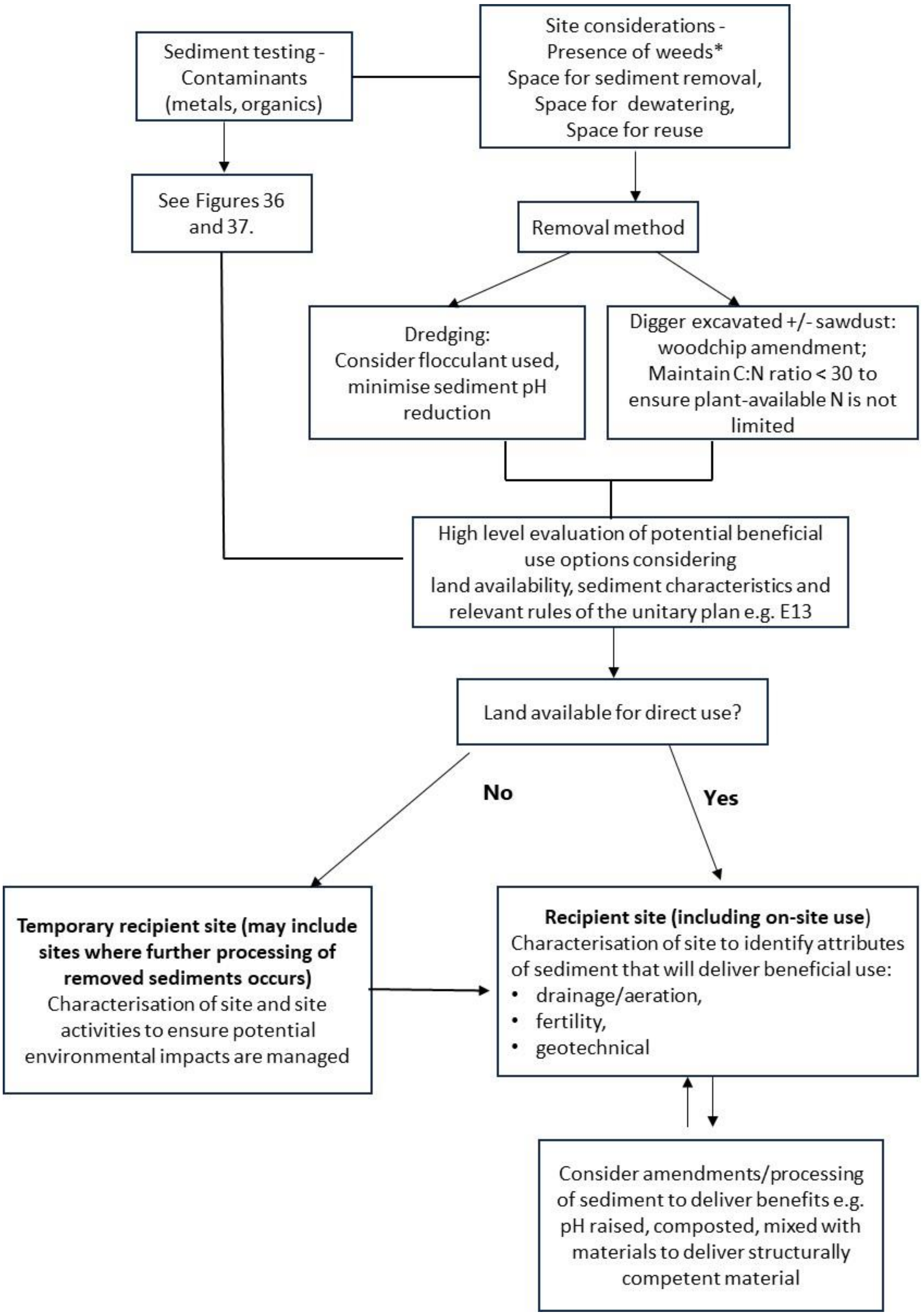


Figure 34. Overview of factors contributing to determining beneficial use options for sediment.
*** The presence of weeds/pest plants in or around the pond may require additional treatment (e.g. composting) or specific treatment (e.g. covering with a 'clean' material to a depth that prevents plant regeneration) of removed sediment.**

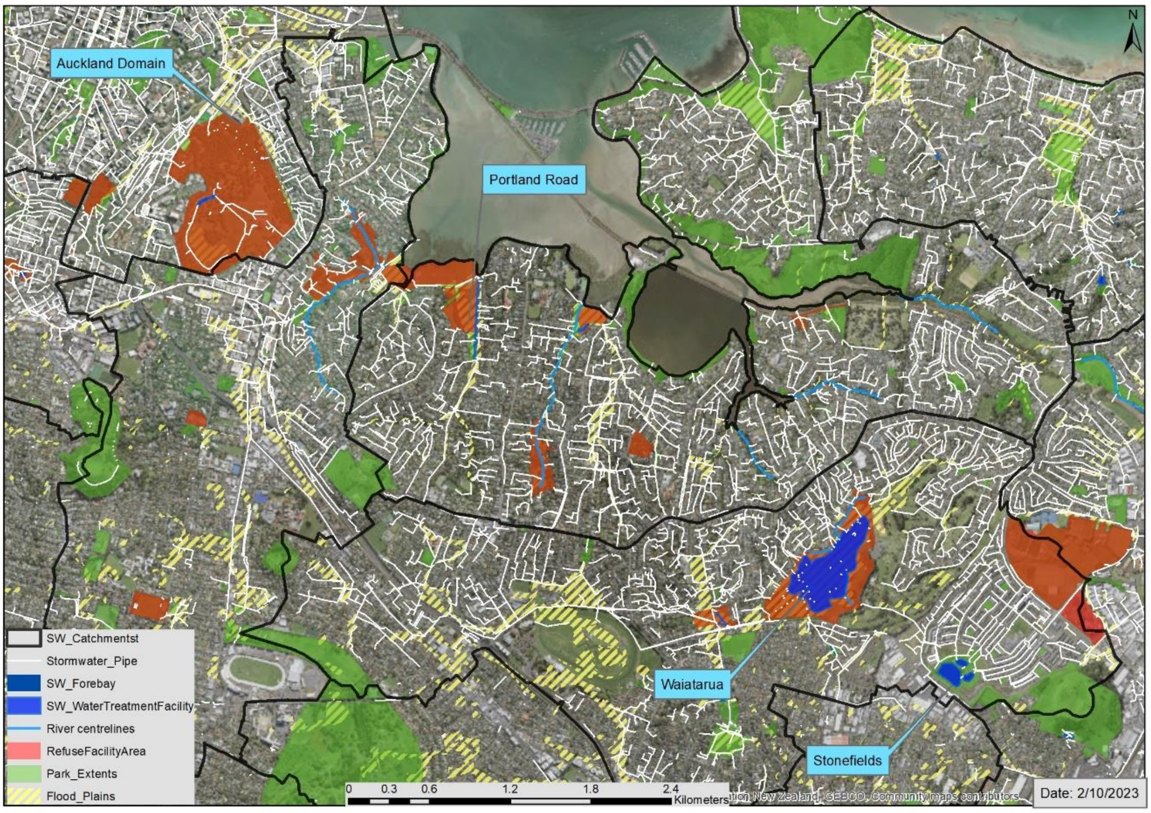


Figure 35. This map illustrates information that is useful as part of an initial assessment of beneficial reuse of sediment. It indicates potential reuse within or adjacent to the parks within which the sediment is extracted. The map shows central Auckland sites draining into Hobson Bay / Waitaramoa from a catchment extending from Auckland Domain (top left of map) to Stonefields Reserve (bottom right of map). Sediment ponds (blue, labelled in the legend as 'SW_WaterTreatmentFacility') are all located within parks (green), many of which are also closed refuse facilities(orange). Variable proportions of these parks and refuse facilities are mapped as flood plains (yellow hatching).
Notes: Using excavated sediment to raise surface levels will be constrained in many potential parks and refuse facilities by the need to preserve flood volume, as shown at the Portland Road site. The use of sediment to enhance old landfills was also demonstrated at the Portland Road site. This catchment has a concentration of closed refuse facilities along streams and coastal areas. However, the refuse facility layer appears to include wider areas so needs to be validated (e.g. the whole of the Auckland Domain and Waitaraua Reserve, bottom right of map).

The sediment characteristic flow charts (Figure 36 and Figure 37) use zinc concentrations as the primary contaminant to determine decision-making pathways for sediment. This is because zinc is widely recognised as the primary contaminant in urban sediments, frequently co-occurring with hydrocarbons (i.e. sediments that contain high concentrations of zinc are also likely to contain high concentrations of hydrocarbons). Thus, managing sediments based on zinc concentrations will also manage organic contaminants in most cases. However, analyses of organic contaminants such as polycyclic aromatic hydrocarbons, or asbestos (primarily in stormwater ponds receiving run-off from catchments containing older buildings that may have used asbestos) may be required to meet council requirements for the application of sediment to land.

The ability of microbial communities to degrade organic contaminants is also limited by high concentrations of metals, which means that metal concentrations need to be 'right' in order to provide conditions for ongoing degradation of organic contaminants. Asbestos may need to be considered separately if there is some likelihood of occurrence, although the frequency of detection in stormwater pond sediments in unknown.

These flow charts also highlight the need to consider the pH of the sediment in evaluating potential beneficial use. Specifically:

- a pH over 5.5 allows for largely unrestricted beneficial use of removed sediment
- a pH between 4 and 5.5 is suitable for growing many native species, but may be restrictive for grass and other exotic species
- a lower pH also increases the potential for leaching of metals, and below a pH of 4 liming of the sediments will be required to reduce leaching potential and increase suitability for plant growth.

Sediment characteristics may change with dewatering and ripening, so verification of the characteristics of any stockpiled sediment prior to confirmation of beneficial use is advisable. The soil characteristics of the receiving site should also be assessed to confirm that the sediment does provide beneficial properties – or at least doesn't degrade soil quality at the site. This is particularly relevant for zinc concentrations and sites with volcanic soils that may contain naturally elevated zinc concentrations, in which case sediment with higher zinc concentrations may be acceptable for use. It is recommended that sediments with elevated zinc (above 400 mg/kg) undergo leachate assessment and the potential leaching risk is evaluated. Sediments with highly elevated zinc (i.e. >1,200 mg/kg need to undergo treatment to reduce zinc concentrations, or simply be disposed to landfill.

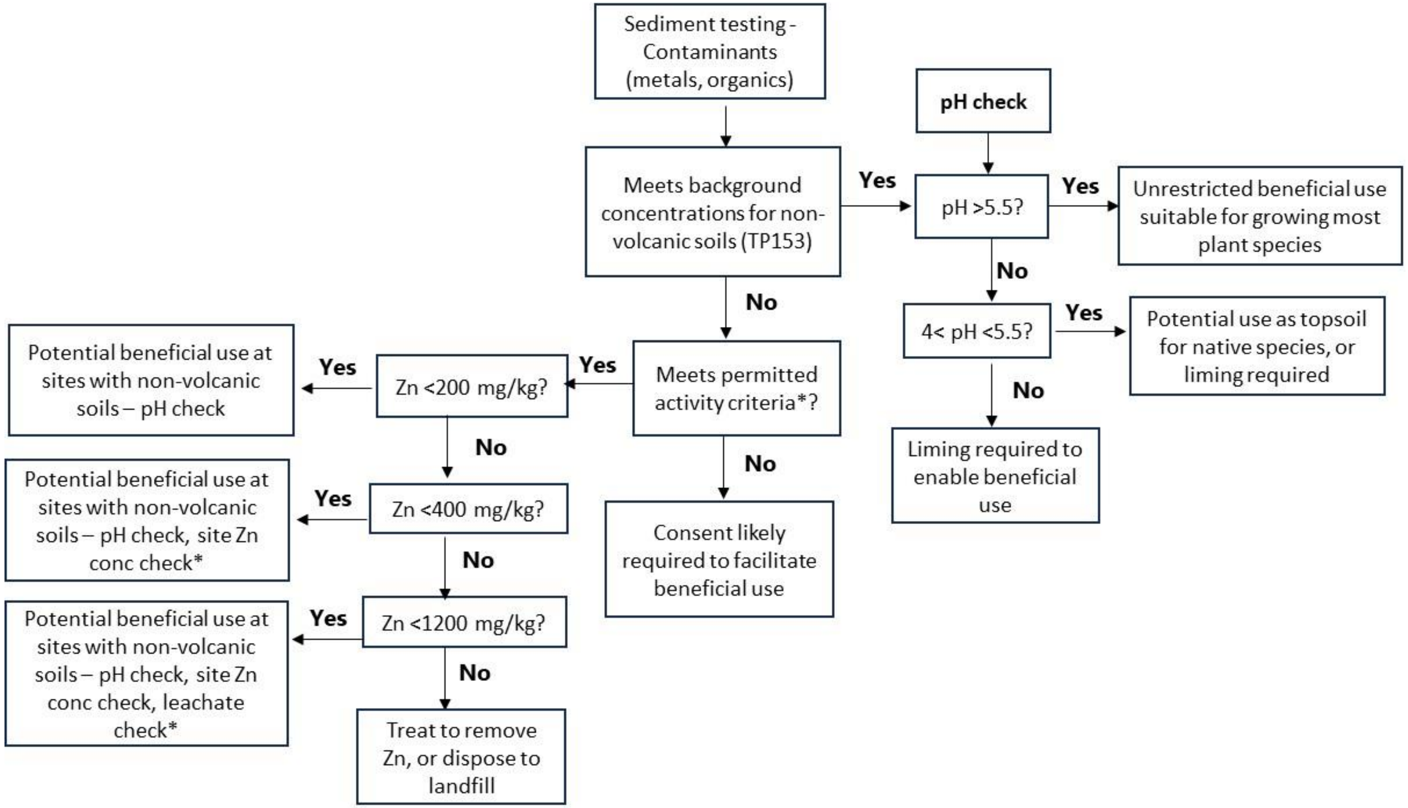


Figure 36. Flow chart for decision-making on potential beneficial use of sediments for recipient sites with non-volcanic soils, based on sediment characteristics and understanding of the current regulatory requirements.

Notes: Background concentrations for non-volcanic soils are specified in TP153 as well as Auckland Plan E30.1.6.4. Permitted activity criteria are specified in E30.1.6.4. When sediment concentrations are above background concentrations, zinc is used as the key determinant for beneficial use considerations (see main text). The zinc concentrations are the 95% protection level Eco-SGV (200 mg/kg), permitted activity criteria (400 mg/kg), and the waste acceptance criteria for Class 3 landfills (1,200 mg/kg). Asbestos may also need to be considered separately. Compliance with Auckland Plan E13 should also be evaluated.
*** 'Site zinc conc check' refers to assessment of the zinc concentrations present at the receiving site, which may allow for deviation from the zinc concentration triggers shown here. 'Leachate check' refers to assessment of metals present in leachate from the sediments.**

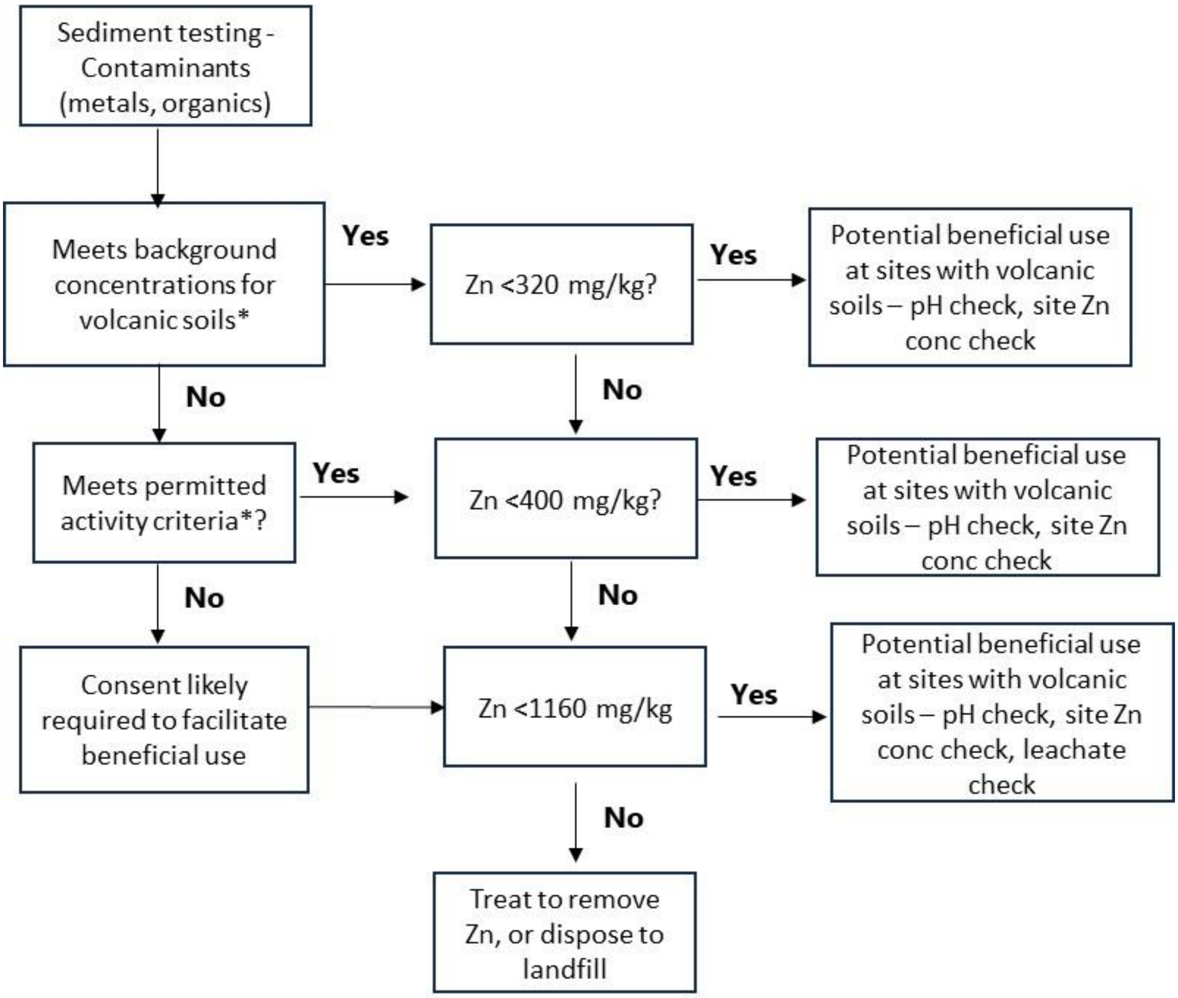


Figure 37. Flow chart for decision-making on potential beneficial use of sediments for recipient sites with volcanic soils, based on sediment characteristics and understanding of the current regulatory requirements.
*** Background concentrations for volcanic soils are specified in TP153, as well as in Auckland Plan E30.1.6.4. Permitted activity criteria are specified in E30.1.6.4. Zinc is used as the key determinant for beneficial use considerations (see main text). Asbestos may also need to be considered separately. Compliance with Auckland Plan E13 should also be evaluated.**
Notes:
'pH check' refers to assessment of sediment pH, as illustrated in Figure 36.
'Site Zn conc check' refers to characterisation of zinc concentrations at the recipient site to validate whether sediment zinc concentrations are not markedly higher than recipient site concentrations. The 80% protection level Eco-SGV (rather than the 95% protection value) is used as a trigger value for volcanic soils in recognition that zinc concentrations in volcanic soils are anticipated to be elevated and soil ecosystems are more adapted to elevated zinc. Other zinc concentrations are the permitted activity criteria of 400 mg/kg, and the upper background concentration range for volcanic soils in TP153 (1,160 mg/kg); this is similar to the waste acceptance criteria for Class 3 landfills (1,200 mg/kg).
'Leachate check' refers to assessment of the concentrations of zinc (and copper) in leachate from the removed sediments.

6 Conclusions

Analysis of sediments from a cross-section of pond types in the Auckland region showed that excavated sediments generally contain soil properties beneficial for plant growth, and in some cases contain greater nutrients than *in situ* or imported topsoils. Specifically, available phosphorus was often similar to that found in fertile pastures and more than sufficient for native plant species. Sufficient nitrogen for plant growth was generally present in sediments, although the addition of sawdust or woodchips to solidify sediments could result in an excess of carbon, resulting in short to medium limitation of available nitrogen for plants (and overcome by supplying nitrogen fertiliser).

The sediments were predominantly silt, with variable organic content, which is also influenced by the removal method. Larger and heterogeneous chunks will be present in digger-excavated sediment, which may also have sawdust/woodchips added to increase solids content. Smaller homogeneous chunks are typically present in dredged sediments, although in both cases the organic matter improves texture as well as the organic matter content of sediments.

Contaminant concentrations were sometimes low and were variable across ponds with similar surrounding land uses, although only a small number of ponds were sampled. Canadian studies also demonstrate high variability of contaminants in individual ponds, which suggests that sediments in individual ponds need to be assessed. Over time, with continued data collection, stronger trends may emerge, or the characteristics of individual ponds may be better recognised. Nonetheless, it is expected that ponds that receive greater input from roads, and sealed areas (particularly industrial areas with zinc roofing) will have higher contaminant loads, although the sediment (and contaminant load) also depends on what is happening in the stormwater catchment area. For example, source control is increasing (particularly for copper and zinc roofing materials), and any increased stormwater treatment closer to source (e.g. swales, raingardens, greenroofs, detention tanks) helps reduce contaminant loads, while the presence of bare soil in the catchment may lead to greater sediment input, albeit this is likely to have lower contaminant concentrations.

The Portland Road beneficial use trial demonstrated the potential for excavated sediment to be beneficially used within a root zone as a substitute topsoil, with higher macro-nutrient status and higher plant water storage and supply than site-won soils. This trial also highlighted that the use of flocculant may lead to sustained low pH of sediments, which has a negative impact on plant growth, including on native species that normally prefer acidic soils.

However, digger-excavated sediment also had a low pH, indicating that flocculant use is not the only reason for a low pH. The high sulphate content of sediments from Portland Road, combined with the low pH, may indicate that acid-sulphate soils were present in these sediments.

The Portland Road trial also highlighted a marked reduction in zinc concentrations of the soil over the first year, which is likely to be due to leaching of zinc from the soil, given the low pH of both flocculated and digger-excavated sediments. However, this leaching appears to have stablished after 12 months (and perhaps earlier), as soil concentrations of zinc and copper at 18 months were similar to those at 12 months.

Clarity in relation to what is considered beneficial use is required. For example, the burial of entire geobags containing excavated sediment within a landscaping bund is effectively disposal in a different location, as the sediment cannot be accessed (e.g. by plant roots) and natural water flow pathways are disrupted. However, geobags can be removed, or at least slit open to allow plant roots to access the sediment.

This project and development of the decision-making flow chart focused on inorganic metal and metalloid contaminants, in particular zinc, rather than organic contaminants such as hydrocarbons. There are two reasons for this.

- Metal contaminants, unlike organic contaminants such as hydrocarbons, cannot be degraded through biological or abiotic processes. Further, the ability of microbial communities to degrade organic contaminants is limited by high concentrations of metals, so metal concentrations need to be 'right' in order to provide the conditions for ongoing degradation of organic contaminants. However, it is noted that information (e.g. concentration data) on organic contaminants will probably be required to meet regulatory requirements.
- Zinc is widely recognised as the primary contaminant in urban sediments, frequently co-occurring with hydrocarbons (i.e. sediments that contain high concentrations of zinc are likely to also contain high concentrations of hydrocarbons). Thus, managing sediments based on zinc concentrations will also manage organic contaminants in most cases.

While not within the scope of the current project, logistics around the processing – including dewatering and 'ripening' (aeration of anaerobic sediments) – of removed sediments arguably remains the key challenge to overcome to facilitate the beneficial use of pond sediments. Aside from this, there are similar considerations for the beneficial use of sediments removed from stormwater ponds and the beneficial use of 'surplus' soils – soils disturbed through land development processes that are unable to be beneficially used on-site. These considerations include the nature of beneficial use, contaminant concentrations identified as acceptable for reuse, and appropriate characterisation of the sediments or soils to match identified beneficial use.

Arguably the beneficial use of stormwater pond sediments is more complicated than for surplus soils due to the additional requirement for dewatering (and 'ripening') of the sediments to enable beneficial use. Nonetheless, in both cases perhaps the key challenge is linking the source site with an appropriate recipient site to achieve beneficial use. The use of an intermediary site to stockpile, and, where appropriate, process (e.g. dewater and ripen sediments) is seen as the most likely potential solution.

Economic evaluation is required, probably on a case-by-case and sub-regional basis, to identify where cost savings can be made through the beneficial use of the removed sediments compared to landfill disposal. Key factors influencing cost are transportation distances and landfill disposal costs. From an environmental perspective, reducing transport emissions and the requirement for landfill space, alongside the value of the beneficial use (which can include enhanced amenity value of green space and reducing flood-prone areas) are additional factors to consider in identifying the best option for beneficial reuse.

7 Recommendations

Further information is required to ensure environmental risks are appropriately managed. Specifically, further evaluation is required to assess:

- the potential leaching of metals during sediment 'ripening' processes (including of dewatered, flocculated geobag sediments) to ensure that any associated risk to ground- or surface water is appropriately managed.
- the potential for ponds to contain acid-sulphate soils
- whether the flocculants used are compatible with the proposed beneficial use (in the first instance this would simply involve a stock-take and literature review of flocculants commonly used in desilting operations).

Additional recommendations are as follows.

- The pH of removed sediments should be routinely measured. This is a critical measure to assess suitability of the sediment for use, particularly to identify when lime addition may be required to facilitate beneficial plant growth and reduce potential for leaching of metals.
- Geotechnical suitability may need to be assessed to inform some beneficial uses; for example, the use of sediments in a landscaping bund.
- Sediments should be sampled *in situ*, prior to desilting operations, to provide a greater lead-time to assess potential beneficial use options. This information should be systematically captured to build a greater understanding of the beneficial and constraining characteristics of sediments in stormwater ponds across Auckland.
- The Canadian *Inspection and Maintenance Guide for Stormwater Management Ponds and Constructed Wetlands* (TRCA 2018) provides wider information on practices for the management and maintenance of stormwater treatment facilities that may be useful for Healthy Waters to consider, alongside an evaluation of existing design, maintenance, and desilting operations. Similarly, the Australian guidance on the dredging of acid-sulphate soil sediments and associated dredge spoil management (Simpson et al. 2018) may be useful to consider if the potential occurrence of acid-sulphate soils in stormwater ponds is identified.
- It would be helpful to systematically capture costs and volumes of sediment removed from different ponds to build a better picture of what items create the greatest cost, and to consider that alongside costs and benefits of beneficial use.
- Efforts to facilitate the beneficial reuse of stormwater pond sediments should be coordinated with efforts to facilitate the beneficial reuse of surplus soils.

8 Acknowledgements

A huge thanks to Ollie Ferrick, Michael Cole and the wider Glasgow Contractors team for facilitating the Portland Road beneficial use trial and assisting with the logistics of sample collection. Various current or former Auckland Council staff, including Arash Farjood, James Corbett, Andrew Kalbarcyk, Leighton Gillespie, Santiago Carrillo Trivino, Tom Stephens, and Leigh Steckler, are thanked for their discussions on various aspects related

to beneficial reuse of pond sediments. Participants in the March 2023 workshop provided additional insights into factors influencing management or beneficial reuse of sediments. Oshadhi Samarasinghe is thanked for undertaking the mapping of stormwater ponds.

9 References

ANZG (Australian and New Zealand Guidelines) 2018 [modified 2020]. Australian and New Zealand Guidelines for Fresh and Marine Water Quality. https://www.waterquality.gov.au/anz-guidelines/guideline-values/default/sediment-quality-toxicants

ARC (Auckland Regional Council) 1992. TP10 [Technical Publication No. 10]: Stormwater management devices: design guidelines manual (2nd edn). Auckland, Auckland Council.

ARC (Auckland Regional Council) 1999. TP90 [Technical Publication No. 90]: Erosion & sediment control: guidelines for land disturbing activities in the Auckland Region. http://www.aucklandcity.govt.nz/council/documents/technicalpublications/TP90%20Erosion%20and%20sediment%20control%20guidelines%20for%20land%20disturbing%20activities%20in%20the%20Auckland%20Region%20Part%20A%201-4%20-%201999.pdf

ARC (Auckland Regional Council) 2001. Background concentrations of inorganic elements in soils from the Auckland Region. Technical Publication No. 153. Auckland, Auckland Regional Council.

ARC (Auckland Regional Council) 2003. TP10 [Technical Publication No. 10]: Stormwater management devices: design guidelines manual (2nd edn). Auckland, Auckland Council. http://www.aucklandcity.govt.nz/council/documents/technicalpublications/TP10%20Stormwater%20management%20devices%20design%20guideline%20manual%202003.pdf

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

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, Simcock R, Thompson-Morrison H, Harmsworth G 2023. Sustainable management of surplus soils: consultation draft. Manaaki Whenua – Landcare Research Contract Report LC4326. Envirolink Tools Grant C09X2206.

CEDA (Central Dredging Association) 2019. Position paper: assessing the benefits of using contaminated sediments. CEDA. http://www.dredging.org/media/ceda/org/documents/resources/cedaonline/2019-05-BUCS-pp.pdf

Charters FJ, Cochrane TA, O'Sullivan AD 2014. Modelling stormwater management options in established urban areas. 2014 Stormwater Conference. https://ir.canterbury.ac.nz/server/api/core/bitstreams/49676d22-05d6-400f-a3ba-f80b2c3d2c24/content

Charters FJ, Cochrane TA, O'Sullivan AD 2016. Untreated runoff quality from roof and road surfaces in a low intensity rainfall climate. Science of the Total Environment 550: 265–272.

Charters FJ, Cochrane TA, O'Sullivan AD 2021. The influence of urban surface type and characteristics on runoff water quality. Science of the Total Environment 755: 142470–142478.

Charters FJ, O'Sullivan AD, Cochrane TA 2022. Influences of zinc loads in urban catchment runoff: roof type, land use type, climate and management strategies. Journal of Environmental Management 322: 116076.

Clearwater SJ, Thompson KJ, Hickey CW 2014. Acute toxicity of copper, zinc, and ammonia to larvae (Glochidia) of a native freshwater mussel *Echyridella menziesii* in New Zealand. Archives of Environmental Contamination and Toxicology 66: 213–226. https://doi.org/10.1007/s00244-013-9972-7

Depree C 2011. Street sweeping: an effective non-structural best management practice (BMP) for improving stormwater quality in Nelson? NIWA Client Report No: HAM2011-043. NIWA.

Depree C, Rijkenberg M, McNeill S 2010. Reusing road sweepings and stormwater sediments: reducing heavy metal leaching. 2010 Stormwater Conference.

Fassman E 2012. Stormwater BMP treatment performance for sediment and heavy metals. Separation and Purification Technology 84: 95–103. https://researchspace.auckland.ac.nz/handle/2292/17962

Fassman E, Liao M, Hellberg C, Easton H 2009. Monitoring of the treatment train at the Albany Park n Ride. 2009 Stormwater Conference. https://www.stormwater360.co.nz/assets/Uploads/Session1-2-M.-Liao.pdf

Henry M, Haouche L, Lemière B 2023. Mineral processing techniques dedicated to the recycling of river sediments to produce raw materials for construction sector. Mining 3: 54–76.

Hewitt A 1998. The New Zealand Soil Classification. Addendum in: The Living Mantle, Soils in the New Zealand Landscape. The New Zealand soil classification (landcareresearch.co.nz)

Kelly-Hooper F, Barfoot K, Dela Cruz L, Pike G F 2022. Challenges, opportunities for beneficial reuse of stormwater management pond sediment. Environmental Science and Engineering Magazine October: 44–49.

Kennedy P, Sutherland S 2008. Urban sources of copper, lead and zinc. Prepared by Organisation for Auckland Regional Council. Auckland Regional Council Technical Report 2008/023.

LMF (Land Monitoring Forum) 2009. Land and soil monitoring: a guide for SoE and regional council reporting. Hamilton, Land Monitoring Forum.

Mayson A, Depree C, Simcock R 2010. Road derived sediments (RDS) and vegetative material reuse feasibility study. Report prepared for NZTA.

McKee JG, Graham GJ 1952. Pasture establishment on flooded areas of Gisborne Flats. NZ Journal of Agriculture 84(3): 197.

MfE (Ministry for the Environment) 2011. Guidelines for assessing and managing petroleum hydrocarbon contaminated sites in New Zealand (Revised 2011). Ministry for the Environment. https://environment.govt.nz/assets/publications/Files/modules-final-jun99.pdf

Moores J, Hunt J, Pattinson P 2009a. Quantification of catchpit sediments and contaminants. Auckland Regional Council Technical Report 2009/123.

Moores J, Pattinson P 2008. Performance of a sediment retention pond receiving chemical treatment. Prepared by NIWA for Auckland Regional Council. Auckland Regional Council Technical Report 2008/021.

Moores J, Pattinson P, Hyde C 2009b. Enhancing the control of contaminants from New Zealand's roads: results of a road runoff sampling programme. New Zealand Transport Agency Research Report 395.

Morton JD, Moir JL 2018. Soil aluminium toxicity in New Zealand pastoral farming: a review. Journal of New Zealand Grasslands 80: 129–138.

Mosley LM, Peake BM 2001. Partitioning of metals (Fe, Pb, Cu, Zn) in urban run-off from the Kaikorai Valley, Dunedin, New Zealand. New Zealand Journal of Marine and Freshwater Research 35(3): 615–624.

Roberts RC, McConchie J 2017. Preliminary assessment of the acid sulphate soils hazard in the Auckland region. In GJ Alexander, CY Chin eds. Proceedings of the 20th NZGS Geotechnical Symposium, Napier.

Semadeni-Davies AF 2013. Classification of stormwater-borne solids: a literature review. Prepared by the National Institute of Water and Atmospheric Research (NIWA) for Auckland Council. Auckland Council Technical Report TR2013/017.

Simpson SL, Mosley L, Batley GE, Shand P 2018. National acid sulfate soils guidance: guidelines for the dredging of acid sulfate soil sediments and associated dredge spoil management. Canberra, ACT, Department of Agriculture and Water Resources.

Sojka RE, Bjorneberg DL, Entry JA, Lentz RD, Orts WJ 2007. Polyacrylamide in agriculture and environmental land management. Advances in Agronomy 92: 75–162.

Sparling GP, Lilburne L, Vojvodic-Vukovic M 2008. Provisional targets for soil quality indicators in New Zealand. Landcare Research Science Series No. 34.

Sullivan L, Ward N, Toppler N, Lancaster G 2018. National acid sulfate soils guidance: national acid sulfate soils sampling and identification methods manual. Canberra, ACT, Department of Agriculture and Water Resources.

Timperley M, Jayaratne R, Davis MD, Skeen M 2011. An overview of version 2 of the contaminant load manual. 2011 Stormwater Conference. https://www.waternz.org.nz/Attachment?Action=Download&Attachment_id=1202

TRCA (Toronto and Region Conservation Authority) 2018. Inspection and maintenance guide for stormwater management ponds and constructed wetlands. TRCA and CH2M.

Trowsdale SA, Simcock R 2011. Urban stormwater treatment using bioretention. Journal of Hydrology 397(3-4): 167–174.

USACE (United States Army Corps of Engineers) 2015. Engineer manual: dredging and dredged material management. EM 1110-2-5025. USACE.

USDA (United States Department of Agriculture) 2020. Conservation practice standard anionic polyacrylamide (PAM) application code 450. Natural Resources Conservation Service, United States Department of Agriculture.

US EPA (United States Environmental Protection Agency) 2020. Beneficial use of dredged material decision tool: Reses project report. EPA/600/R-20/409.

WasteMINZ 2022. Technical guidelines for disposal to land (Land disposal technical guidelines). http://www.wasteminz.org.nz/pubs/technical-guidelines-for-disposal-to-land-april-2016/ (accessed March 2022).

Williams K, Margeson K, Paczuski S, Clarke R, Auker K, Hoffman J 2020. Beneficial use of dredged material decision tool. Duluth, MN, US Environmental Protection Agency. EPA/600/R-20/409.

Wilson MD, Valentine 2005. Regrassing flood damaged pastures. Proceedings of the NZ Grassland Association 67, p. 117.

Zanders J 2005. Road sediment: characterization and implications for the performance of vegetated strips for treating road run-off. Science of the Total Environment 339: 41–47.

Appendix 1 – Sampling strategy for stormwater ponds

Auckland Council indicated the need for a sampling strategy to assist with the future management of the pond sediments in their region. However, there needs to be a clear purpose for this sampling, because this will determine how the sampling and/or analyses are undertaken. We have assumed the primary purpose is to determine spatial (surface and depth) variability in sediment characteristics that would influence beneficial use (including contaminant load).

Ideally, any sampling would be undertaken on dewatered ponds. Sampling of sediments in ponds with water requires more specialised equipment and personnel.

The pond inlets need to be identified, and (ideally) sampling undertaken on a gradient from forebay overflow to high-flow outlet (noting if any short circuiting is occurring). Forebays should be sampled separately. A minimum of five locations (four points of a cross and one in the centre of the pond) should be sampled to start to build a picture of spatial variability. This strategy also allows for sampling of three points along the water-flow path.

Sampling points should be at least 1 m, and ideally 1.5 to 2 m, from the edge and beyond the pond's 'apron' (the shallow edge that is usually included to help people who fall in to get out more safely and not fall into deep water; this edge may have dense vegetation).

To consider depth distribution and gain a better understanding of the properties of all the sediment that will be removed, sediment cores are needed. The depth of cores is related to the anticipated depth of sediment being removed. Note that more specialised equipment and personnel would be required to collect cores greater than about 30 cm or for sediments under water.

Cores should be cut in increments that are appropriate for the core length (and relevant to the desilting methods). The spatial distribution and number of cores collected depends on the size and shape of the pond and the anticipated 'direction' of inputs; but, as noted above, a minimum of five locations should be sampled.

It is probably useful to sample a few ponds more intensively to get a better sense of how spatially variable the contaminants are. However, this needs to be considered in the context of the methods used for desilting, as there is no point in obtaining a fine delineation of contamination/texture gradients if this can't be utilised in the desilting process. For example, it may not be worth the effort/is too difficult to separate more highly contaminated sediment or fine vs coarse sediment during desilting of a smaller pond .

Samples should be analysed for pH, total carbon and nitrogen, Olsen phosphorus, and total phosphorus, these being the minimum analytes to help inform the beneficial properties of the sediment.

The results from sediment cores could also provide an understanding of changes that have occurred in the catchments/pond over time, although that would require more detailed information about the pond and the surrounding land use over time.

For the value of this sampling and analyses to be fully realised, it is important to be starting to build a picture of what factors contribute to the 'representativeness' of a pond, and to start to assess those factors across the ponds in the Auckland region.

Appendix 2 – Sediment chemical data

Table A1. Sample description and key chemical properties of stormwater pond sediment samples

Site	Sampling date	Pond age	Pond type	Sample name	Soil/sediment description	pH	Olsen P (mg/kg)	Total P (mg/kg)	C (%)	N (%)	C:N ratio	Zn (mg/kg)	Cu (mg/kg)	Cr (mg/kg)	As (mg/kg)	Pb (mg/kg)	Ni (mg/kg)	Cd (mg/kg)	Hg (mg/kg)	Volume weight (g/mL)
Aranui	May-23	Old	Motorway	Aranui A Sed	Digger-excavated	5.8	47	1307	6.6	0.32	21	550	66	49	9	94	50	0.31	—	0.66
Aranui	May-23	Old	Motorway	Aranui B Sed/Sawdust	Digger-excavated, sawdust added	6.6	—	1110	13.3	0.3	44	360	50	40	8	48	38	0.24	—	1.26
Aranui	May-23	Old	Motorway	Aranui C Sed/ Sawdust	Digger-excavated, sawdust added	6.9	—	1134	9.9	0.25	40	480	61	48	10	60	44	0.34	—	1.27
Onepoto	Jan-23	Old	Residential	Onepoto Lagoon A	Flocculated	6.6	27	1029	6.7	0.54	12	200	32	34	18.3	23	43	0.25	—	0.64
Onepoto	Jan-23	Old	Residential	Onepoto Lagoon B	Flocculated	7.4	26	1105	7.1	0.57	12	210	32	32	19.7	23	43	0.25	—	0.66
Parlane	May-23	Young	Residential	Parlane	Flocculated	5	37	852	5.5	0.31	18	680	53	31	8	76	20	0.31	—	0.71
Portland Road	May-22	Old	Residential	Plot 1 'Flocculated' Portland	Flocculated	3.8	52	907	8	0.45	18	520	141	38	27	240	28	0.48	0.19	0.66
Portland Road	May-22	Old	Residential	Plot 2 'Topsoil' Portland	Site-won soil	6	22	771	2.3	0.16	14	134	38	31	38	107	41	0.21	—	0.97
Portland Road	May-22	Old	Residential	Plot 3 'Digger Sed' Portland	Digger-excavated	4.5	36	1148	6	0.34	18	380	103	38	27	155	51	0.31	0.19	0.75
Portland Road	May-23	Old	Residential	Plot 1 'Flocculated' Portland	Flocculated	3.7	47	858	7.2	0.46	16	140	103	38	31	290	18	0.12	—	0.71
Portland Road	May-23	Old	Residential	Plot 2 'Topsoil' Portland	Site-won soil	5.4	19	755	2.6	0.17	15	145	40	26	31	104	38	0.18	—	1
Portland Road	May-23	Old	Residential	Plot 3 'Digger Sed' Portland	Digger-excavated	3.6	37	973	6.9	0.41	17	169	84	42	29	173	45	0.14	—	0.76
Portland Road	Sept-23	Old	Residential	Plot 1 'Flocculated' Portland	Flocculated	3.2	—	—	—	—	—	104	88	37	28	300	17	< 0.10	—	—
Portland Road	Sept-23	Old	Residential	Plot 2 'Topsoil' Portland	Site-won soil	6.1	—	—	—	—	—	164	56	27	42	113	44	0.22	—	—
Portland Road	Sept-23	Old	Residential	Plot 3 'Digger Sed' Portland	Digger-excavated	4.3	—	—	—	—	—	220	83	42	20	133	69	0.19	—	—
Sunnyvale	Apr-22	Young	Residential	Sunnyvale A Sediment	Digger-excavated	5.3	15	492	2.1	0.18	12	99	36	62	6.8	16	15.5	0.1	—	0.97
Sunnyvale	Apr-22	Young	Residential	Sunnyvale B Sed + Sawdust	Digger-excavated, sawdust added	4.9	16	407	4.2	0.16	26	84	29	24	6.4	13.9	11.1	0.1	—	0.85
Sunnyvale	Aug-22	Young	Residential	Sunnyvale Pond Sed	Digger-excavated	5.8	15	552	1.8	0.16	11	110	45	33	6.3	15.9	13.6	0.09	—	0.88
Sunnyvale	Aug-22	Young	Residential	Sunnyvale Sed+OM	Digger-excavated, sawdust added	5.7	16	427	4.7	0.17	28	91	31	33	6.2	13.7	15.6	0.08	—	0.76
Te Koiwi Park	May-22	Old	Industrial/ residential	Te Koiwi Park bund	Site-won soil	5.3	9	—	2.6	0.19	14	50	35	155	3.6	16.6	50	0.1	0.12	0.86
Te Koiwi Park	May-22	Old	Industrial/ residential	Te Koiwi Park imported soil	Imported soil	6.1	9	—	6.7	0.58	12	83	40	32	22	31	7.2	0.22	0.41	0.78
Te Koiwi Park	May-22	Old	Industrial/ residential	Te Koiwi Park pond sediment	Digger-excavated	5.4	25	—	9.3	0.51	18	169	32	25	7.6	40	10.7	0.79	0.3	0.6
Van Damme	Sep-22	Old	Industrial	Van Damme A	Flocculated	4.9	69	2560	9.4	0.54	17	1400	143	104	16.2	220	69	2.1	0.17	0.57
Van Damme	Sep-22	Old	Industrial	Van Damme B	Flocculated	5.3	83	2370	9.6	0.51	19	1630	155	92	15.6	192	71	2	0.14	0.59
Van Damme	May-23	Old	Industrial	Van Damme Aged	Flocculated	5.3	65	2040	11.7	0.62	19	1730	139	70	19	145	47	0.8	—	0.49

Notes: P = phosphorus, C = carbon, N = nitrogen, Zn = zinc, Cu = copper, Cr = chromium, As = arsenic, Pb = lead, Ni = nickel, Cd – cadmium, Hg = mercury

Table A2. Anion sorption capacity and cation-exchange capacity measures for Portland Road, Sunnyvale, and Te Koiwi Park stormwater pond sediment and soil samples

Site	Sampling date	Pond age	Pond type	Sample name	Soil/sediment description	ASC (%)	K (me/ 100 g)	Ca (me/ 100 g)	Mg (me/ 100 g)	Na (me/ 100 g)	CEC (me/ 100 g)	Base Sat (%)
Portland Road	Aug-22	Old	Residential	Plot 1 'Flocc' Portland	Flocculated	78	0.99	11.6	8.21	1.16	45	49
Portland Road	Aug-22	Old	Residential	Plot 2 'Topsoil' Portland	Site-won soil	35	0.61	10.9	6.31	0.99	23	82
Portland Road	Aug-22	Old	Residential	Plot 3 'Digger Sed' Portland	Digger-excavated	61	1.81	13.2	7.47	1.95	39	62
Sunnyvale	Aug-22	Young	Residential	Sunnyvale Pond Sed	Digger-excavated	63	0.5	8.8	3.02	0.37	22	58
Sunnyvale	Aug-22	Young	Residential	Sunnyvale Sed+OM	Digger-excavated, organic matter added	48	0.5	11.4	3.17	0.37	22	69
Te Koiwi Park	May-22	Old	Industrial/ Residential	Te Koiwi Park bund	Site-won soil	68	0.68	2.3	1.55	0.25	13	37
Te Koiwi Park	May-22	Old	Industrial/ Residential	Te Koiwi Park imported soil	Imported soil	—	0.65	9.6	1.23	0.34	20	58
Te Koiwi Park	May-22	Old	Industrial/ Residential	Te Koiwi Park pond sediment	Digger-excavated	88	0.45	6.2	2.41	0.57	28	35

Notes: ASC = anion sorption capacity, K = potassium, Ca = calcium, Mg = magnesium, Na = sodium, CEC = cation exchange capacity, Sat = saturation.

Table A3. Extended chemical properties (carbon, nitrogen, and sulphur) for Portland Road and Sunnyvale stormwater pond sediments

Site	Sampling date	Pond age	Pond type	Sample name	Soil/sediment description	SO_4-S (mg/kg)	AMN (µg/g)	AMN/TN (%)	OM (%)	HWEC (mg/kg)	MBC (est.) (mg/kg)	Organic S (mg/kg)
Portland Road	Aug-22	Old	Residential	Plot 1 'Flocc' Portland	Flocculated	3,140	26	0.6	13.8	843	136	—
Portland Road	Aug-22	Old	Residential	Plot 2 'Topsoil' Portland	Site-won soil	139	60	3.8	4	475	88	5
Portland Road	Aug-22	Old	Residential	Plot 3 'Digger Sed' Portland	Digger-excavated	2,120	16	—	10.3	774	127	—
Sunnyvale	Aug-22	Young	Residential	Sunnyvale Pond Sed	Digger-excavated	9	239	14.8	3.1	374	75	7
Sunnyvale	Aug-22	Young	Residential	Sunnyvale Sed+OM	Digger-excavated, organic matter added	49	156	9.3	8.1	419	80	3

Notes: SO_4 = sulphate, S = sulphur, AMN = anaerobically mineralisable nitrogen, TN = total nitrogen, OM = organic matter, HWEC = hot-water-extractable carbon, MBC (est.) = microbial biomass carbon (estimated from HWEC).

Appendix 3 – GIS layers

Table A4. GIS data layers used for the mapping

Layer name	Source	Description
SW_catchments	Auckland Council – through Jean Pierre Gallet.	Consolidated stormwater catchment
SW_WaterTreatmentFacility	Auckland Council- through Jean Pierre Gallet. Can be viewed on Auckland Council GeoMaps	Stormwater ponds are used for both water quantity (retention) and quality control and are designed to contain a permanent pool of water known as the water quality volume. These ponds detain runoff and discharge it at a specified rate, reducing the potential for flooding and stream erosion by slowing the rate of stormwater discharged to the receiving environment. Lakes are important natural habitats where stormwater runoff flows into the lakes and eventually evaporates. An aquifer is defined as a single geological formation, or a group of geological formations, that transmits and yields a significant volume of water.
SW_Forebay	Auckland Council- through Jean Pierre Gallet. Can be viewed on Auckland Council GeoMaps	A small pool located near the inlet of a storm basin or other stormwater management facility for the purposes of pre-treatment.
Stormwater_Pipe	Auckland Council – Open Data	Pipelines form part of a reticulated stormwater network that includes pipes, culverts, and subsoil drains to drain stormwater runoff from roads, property, and open areas to receiving environments.
River_centrelines	Topo150k	
Highways	NZTA	State highways
Roads	NZTA	All other roads
RefuseFacilityArea	Auckland Council – through Jean Pierre Gallet.	Closed landfills
Park_Extents	Auckland Council – Open Data	All lands that are owned and/or maintained by Auckland Council Community Facilities department, and in some cases by other Council-owned and controlled organisations; they are generally parks and open spaces.
Flood_Plains	Auckland Council – Open Data	The flood plains indicate the area of land inundated by runoff in a storm event that has a 1% or greater probability of occurring in any given year