Attachment D

Moturoa / Rabbit Island Consent Application - Biosolids Process Alternatives Assessment

Prepared for Nelson Regional Sewerage Business Unit (NRSBU)

Prepared by Beca Limited

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Contents

Appendices

Revision History

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Executive Summary

Nelson Regional Sewerage Business Unit (NRSBU) is responsible for managing and operating the Bell Island Wastewater Treatment Plant (WWTP). Biosolids produced at Bell Island WWTP are irrigated onto plantation forestry on Moturoa / Rabbit Island. The resource consent held by NRSBU for application of the biosolids expires on 8 November 2020 and NRSBU is seeking to obtain a new resource consent to continue land application of the biosolids.

As part of the consent application a review of process alternatives for biosolids treatment has been carried out and the findings are presented in this report. Alternative options were evaluated in the context of the project objectives which include provision of a solution which produces Grade A biosolids and continues to beneficially re-use 100% of the biosolids produced at Bell Island WWTP. The process options should be considered alongside the Moturoa / Rabbit Island Biosolids Application: Alternatives Assessment.

The WWTP at Bell Island has two liquid streams, one comprising primary settling, activated sludge and secondary settling and the second comprising facultative and maturation ponds. Primary sludge and waste activated sludge are thickened to approximately 5% dry solids (DS) and treated in an autothermal thermophilic aerobic digestion (ATAD) process, to produce biosolids suitable for application to land. Current biosolids production (in the year to 30 June 2020) is approximately 2,613 kg DS/d or 89 m^3/d at 3% DS as an annual daily average. Due to population increases expected through the duration of the consent, it is expected that the biosolids production will increase. It is estimated that, based on current operation the biosolids production could increase to approximately 3,020 kg DS/d, or 100 m^3/d at 3%DS over the duration of the consent. However, the actual future production could vary due to changes in trade waste discharges received at the plant and operational management to control the biosolids loads and associated nutrient loads.

The existing consent conditions prescribe pathogen reduction requirements and are based on the US EPA Guidelines, Part 503 guidelines. Key aspects are the temperature-time relationship required to demonstrate pathogen reduction and the options for meeting the vector attraction reduction (VAR) requirements for a "Class A sludge". Both of these aspects have been adopted in the NZ Biosolids Guidelines (2003).

The biosolids grading system is made up of two parts. The first part, which is denoted by a capital 'A' or 'B' represents the stabilisation grade. The second part, denoted by a lower case 'a' or 'b' represents the chemical contamination grade,

Operational records show that the ATAD process operates at sufficiently high temperature (>50 °C) and for sufficiently long retention times, a minimum of 48 hours per train and typically 19 days per train, that pathogens are effectively eliminated from the biosolids. The biosolids also meet the VAR requirements by holding the biosolids > 45 °C on average for a period of greater than 14 days. Hence, the biosolids produced at Bell Island WWTP meet the stabilisation requirements for a "Class A" sludge as defined by the US EPA and are classified as Ab according to the Biosolids Guidelines (2003).

A long list of process alternatives was identified that could be considered for use at Bell Island WWTP to achieve a Grade A biosolid product. The long list was screened during a collaborative meeting with NRSBU and the team carrying out the Moturoa / Rabbit Island Biosolids Application: Alternatives Assessment to identify a short list or process solutions for further consideration. The short-listed solutions were:

For application to land as a slurry, the following solutions were identified:

1. ATAD
2. Thermal pre-treatment + anaerobic digestion
3. Thermal pre-treatment + anaerobic digestion + post-aerobic digestion

For application to land as a dewatered cake, the following solutions were identified:

4. Thermal pre-treatment + anaerobic digestion + dewatering

For application to land as a dried product, the following solutions were identified:

5. Anaerobic digestion + dewatering + drying

For disposal to landfill, the following solution was identified:

6. Anaerobic digestion + dewatering

The shortlisted solutions were evaluated relative to each other using the following criteria:

- Technical risk/viability (operational complexity, operational flexibility, footprint, appropriate for future biosolids loads, etc.)
- Local environmental impacts (odour, organic contaminants, etc.)
- Greenhouse gas impacts (effectively energy - process and transport)
- Cost

Following the evaluation, it was identified that whilst there are alternative processes available that could produce a Grade A biosolid, for continued application to land as a slurry, they offer no significant net benefits over the existing ATAD process solution and would incur a significant investment cost to implement. None of the alternatives considered would produce a Grade Aa biosolid as they do not materially affect the metals concentrations.

If alternative re-use options are adopted in the future, that require a dewatered product, the ATAD would be less suitable as the digested biosolids are not amenable to dewatering, requiring significantly higher polymer consumption than an anaerobically digested product. Furthermore, a solution that includes anaerobic digestion would provide an opportunity for energy recovery through the generation and use of biogas in addition to a digested biosolid more amenable to dewatering.

In summary, for continued application of biosolids as a slurry on Moturoa / Rabbit Island, the ATAD process is the best practicable option and the preferred option. A move to an alternative biosolids reuse pathway could be the trigger for a change in process to open up opportunities for further resource recovery, e.g. energy recovery from biogas.

The existing process has already been validated as meeting the Grade A criteria. Should an alternative process be implemented during the term of the consent it would have to validated as meeting the Grade A criteria, as described in the NZ Biosolids Guidelines (2003). It is acknowledged that the biosolids produced at Bell Island WWTP comply with the limits for organic contaminants as outlined in the NZ Biosolids Guidelines (2003). However, the organic contaminants of concern may change as research into emerging organic contaminants continues. These two potential changes could be addressed through an appropriate monitoring and technology review condition.

1 Introduction

1.1 Project Background

Nelson Regional Sewerage Business Unit (NRSBU) is responsible for managing and operating the Bell Island Wastewater Treatment Plant (WWTP), which is jointly owned by the Nelson City and Tasman District Councils (NCC and TDC). Sludge from WWTP processes is stabilised in digesters at the WWTP and the resultant biosolids are then pumped to storage tanks at the Biosolids Application Facility (BAF) on Moturoa / Rabbit Island. From there the biosolids are sprayed onto plantation forestry on Moturoa / Rabbit Island via a heavy duty travelling irrigator.

NRSBU holds an existing resource consent, under the Resource Management Act 1991 (RMA), for the application of biosolids to forestry land on Moturoa / Rabbit Island (ref: NN940379V3). This consent, issued by TDC, expires on 8 November 2020. NRSBU is seeking to obtain a new resource consent to continue the application of biosolids to the forestry land on Moturoa / Rabbit Island and any additional resource consents as necessary to legally operate the Moturoa / Rabbit Island BAF under the RMA.

1.2 Project Objectives

The project objectives for the consent application are presented in the AEE. Within these overarching project objectives, there are a number that relate specifically to the treatment processes (current and alternatives) adopted for the biosolids generated at the Bell Island WWTP. These include:

- Provide a solution that continues the philosophy of beneficial re-use of biosolids and resource recovery,
- Provide a solution that is the Best Practicable Option (BPO) for the treatment and re-use of biosolids generated at Bell Island WWTP,
- Work with mana whenua, the community, and key stakeholders to ensure a biosolids treatment and reuse solution that:
  - Provides for current and future community well-being, health and safety,
  - Ensures acceptable environmental and cultural effects,
  - Provides for planned future population and industrial/commercial growth,
  - Achieves efficient use of existing infrastructure,
- Obtain long-term consents that provide certainty and security for the ongoing beneficial reuse of resources and continued investment in the WTTP infrastructure.

1.3 Report Objectives

This report presents a summary of the current operation of the biosolids treatment at Bell Island WWTP, the nature of the biosolids, the monitoring of the biosolids implemented and the findings of a review of alternative biosolids treatment technologies that could potentially be implemented at Bell Island WWTP. The alternative assessment (pursuant to the requirements of the Fourth Schedule of the RMA) covers solutions that would produce a biosolids product appropriate for continuation of the current land application and also for alternative re-use or disposal options that have been considered in the Moturoa / Rabbit Island Biosolids Application: Alternatives Assessment (Tonkin and Taylor, 2020). These alternative re-use/disposal options include application to land as a slurry, a dewatered sludge or a dried sludge; and disposal to landfill as either a dewatered sludge or a dried sludge.

1.4 Existing Operation

The WWTP treats municipal (mainly domestic) wastewater from the areas of Nelson City (Stoke and Tahunanui); and Tasman District (Richmond, Brightwater, Wakefield, and Mapua). Industrial wastewater is conveyed from Alliance Group Limited; ENZA Foods; and Nelson Pine Industries.

1.4.1 Liquid Stream Process

The treatment provided at Bell Island WWTP is summarised in the process flow schematic presented in Figure 1. The wastewater entering the WWTP passes through an inlet screen and a grit removal plant. Screenings and grit are disposed of to landfill. The wastewater is then settled in a primary clarifier before being split split between two streams. One stream comprises three parallel facultative ponds and two subsequent maturation ponds in series; and the other an activated sludge tank and a secondary clarifier.

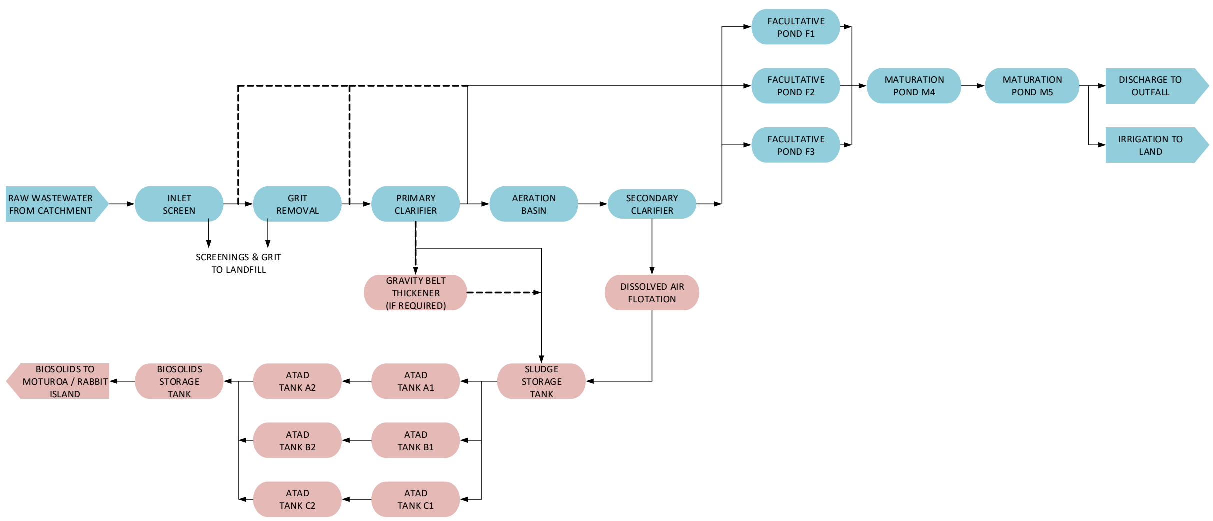


Figure 1 – Process flow schematic for Bell Island WWTP

1.4.2 Biosolids Processes

Sludge from the primary clarifier passes either through a belt thickener or is discharged directly to the sludge holding tanks. Waste activated sludge (WAS) is thickened using a dissolved air flotation (DAF) system and is then blended with the primary sludge in the sludge holding tanks. No sludge from the ponds is treated in the ATAD.

Blended primary and waste activated sludge is fed, to the autothermal aerobic digestion (ATAD) process. ATAD is a batch fed process in which thickened sludge is aerated and mixed. Under these conditions, aerobic microorganisms break down organic material into carbon dioxide, water and nitrogen. The reactions through which the organic material is broken down are exothermic i.e. heat is produced. By insulating the ATAD tanks, the heat is retained, meaning the process can maintain operating at temperatures in excess of 55 °C without the need for supplementary heating.

The existing ATAD process is operated as three trains; each with two tanks in series (Figure 1). The temperature in the second tank is higher than that in the first. The process is batch fed so that all sludge entering the tanks is held within each tank, at elevated temperature, for a minimum duration of 24 hours. The batching process operates as follows:

1. Decant biosolids from second tank in each train and discharge to the BAF. Only when this is complete;
2. Transfer biosolids from the first tank in each train to fill the second tank. Only when this is complete;

3. Transfer sludge from the sludge storage tank to fill the first tank in each train.

By following this approach, no biosolids can be transferred to the BAF without it having had at least 24 hours retention in the second tank of the ATAD train; and similarly, no biosolids can enter the second tank of each train without having had at least 24 hours retention in the first tank of that train.

Where maintenance of the ATAD is required, it is understood that NRSBU requires the ATAD to reprocess the discharge biosolids from any maintained train to ensure there is no possibility of reduced residence time or reduced exposure of all the biosolids to the full temperature.

The digested biosolids are transferred into a biosolids storage tank at Bell Island. From here, they are pumped to storage tanks at the Biosolids Application Facility on Moturoa / Rabbit Island. The biosolids are transported to forestry blocks in tankers and are then applied to land via a heavy-duty travelling irrigator.

2 Basis of Alternatives Assessment

2.1 Biosolids Production

2.1.1 Existing Biosolids Production

The biosolids generated at Bell Island WWTP for the period 1 July 2012 to 28 June 2020 are summarised as annual average daily loads on a dry solids (DS) basis in Table 1. From the table, it can be seen that the biosolids loads have increased over the eight year period considered.

Table 1 – Average biosolids loads generated at Bell Island WWTP, July 2012 to June 2020

Year	Feed to ATAD (kg DS/d)	Feed to ATAD (% DS)	Biosolids (kg DS/d)	Biosolids (% DS)
July 2012 – June 2013	2166	4.1	1602	2.4
July 2013 – June 2014	2328	4.3	1925	2.9
July 2014 – June 2015	3820	4.3	2341	2.8
July 2015 – June 2016	4381	4.6	2065	2.9
July 2016 – June 2017	4734	5.3	2227	3.4
July 2017 – June 2018	4334	5.1	2445	3.2
July 2018 – June 2019	3752	4.9	2288	3.0
July 2019 – June 2020	4417	4.7	2613	3.0

2.1.2 Estimated Future Biosolids Production

Future biosolids loads have been estimated for 2053 based on the growth projections in the Resource Consent application and AEE for the Bell Island WWTP (Stantec, 2017). The projected growth in population and the influent flows and loads, out to 2053, are summarised in Table 2.

Table 2 – Summary of growth projections and estimated future flows and loads at Bell Island to 2053 (Stantec, 2017)

Parameter	Unit	2018	2053
Total Population Served		44,751	56,832
Average Dry Weather Flow (ADWF)	m^3/d	15,456	18,549
Chemical Oxygen Demand (COD)	kg/d	19,798	21,498
Carbonaceous Biochemical Oxygen Demand ($cBOD_5$)	kg/d	9,899	10,749
Total Suspended Solids (TSS)	kg/d	7,499	8,443

The future biosolids loads, pre and post ATAD, have been estimated by increasing the solids loads for the year ending 30 June 2020 in proportion with the projected increase in influent $cBOD_5$ and TSS loads over the consent period as presented in Table 2. The measured annual daily loads for the year ending 30 June 2020 were 6,090 kg/d for $cBOD_5$ and 7,495 kg/d for TSS. The measured influent $cBOD_5$ load received at Bell Island WWTP has decreased from 7,904 kg/d in the year ending 30 June 2017 to 6,090 kg/d in the year ending 30 June 2020. The COD load has also reduced over the same period albeit, to a lesser extent. The reduction in the influent organic load is likely attributable to reduced trade waste which makes up a significant proportion of the load treated at Bell Island WWTP.

In estimating future biosolids loads and production, the $cBOD_5$ load was assumed to increase by 850 kg/d as per Table 2 (equivalent to approximately 14,000 PE based on domestic loads) rather than increasing from current loads to the 10,749 kg/d projected.

Based on the operation of the plant in the year to 30 June 2020, it is estimated that the combined primary and WAS feed to the ATAD process will increase to approximately 5,270 kg/d and that the biosolids generated at Bell Island WWTP after the ATAD process will increase to approximately 3,020 kg/d on a dry solids basis. For a dry solids content of 3.0% DS, the increased load would increase the average daily biosolids volume to approximately 100 m^3/d.

It should be noted that this is an indicative estimate only as the biosolids loads are not directly related to the influent loads as the Bell Island WWTP has the operational flexibility, e.g. by varying the split between the activated sludge plant and the ponds, to manage the biosolids loads. This is shown in the last 8 years of data for the plant (Table 3), which shows how the influent $cBOD_5$ and TSS loads; and the biosolids loads have varied.

Table 3 – Summary of influent cBOD5 and TSS loads and biosolids loads generated at Bell Island WWTP

Year	Influent cBOD5 (kg/d)	Influent TSS (kg/d)	Biosolids (kg/d)
July 2012 to June 2013	6,238	7,990	1,602
July 2013 to June 2014	6,304	8,491	1,925
July 2014 to June 2015	5,875	5,638	2,341
July 2015 to June 2016	7,349	6,681	2,065
July 2016 to June 2017	7,904	6,493	2,227
July 2017 to June 2018	7,198	6,495	2,445
July 2018 to June 2019	6,525	6,687	2,288
July 2019 to June 2020	6,090	7,499	2,613

The nutrient content of the biosolids is more important than the volume produced, particularly nitrogen load, as it is this that limits the quantity of biosolids that can be applied. The Bell Island plant can be managed to favour more or less nutrients in the biosolids in order to maintain the applied nitrogen loads within the consented limits.

2.2 Existing Biosolids Classification

2.2.1 Water New Zealand Biosolids Guidelines

In 2003, NZWWA (now Water NZ) produced a set of “Guidelines for the safe application of biosolids to land in New Zealand”, referred to in this report as the NZ Biosolids Guidelines (2003). Subsequently, in 2017 Water NZ (in association with other organisations) released a set of “Guidelines for Beneficial Use of Organic Materials on Productive Land” for public consultation, referred to in this report as the NZ Biosolids Guidelines (Draft 2017). This document is still watermarked “Draft for Public Comment” and as such, the NZ Biosolids Guidelines (2003) have been adopted as the current framework in this assessment. In terms of treatment required to produce biosolids from wastewater sludges, the requirements are similar in the two documents. There are some differences in the contaminant grading which are discussed in this section.

The NZ Biosolids Guidelines (2003) defines four grades of biosolids as summarised below (Figure 2). Each of the grades is a composite of a stabilisation grade and a contaminant grade. The NZ Biosolids Guidelines (2003) propose,

> *”that the discharge of Aa biosolids to land be handled by way of a permitted activity rule in regional plans and that these biosolids carry a registered Biosolids Quality Mark (BQM) as a means of providing independent third party accreditation that the biosolids meet all the relevant process and product standards (see section 5). It is proposed that the discharge of Ab, Ba or Bb biosolids to land be treated as a discretionary activity requiring a resource consent.”*

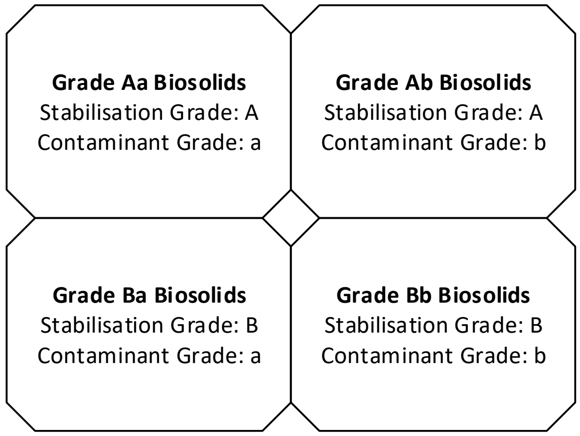
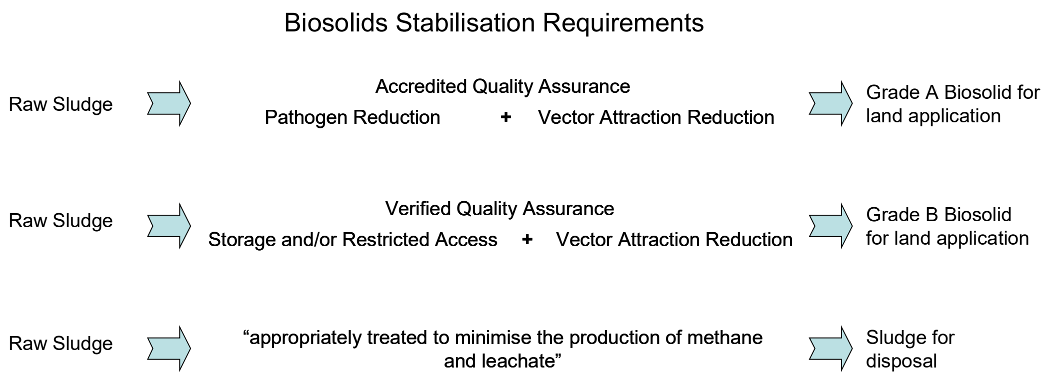


Figure 2 – Four grades of biosolids defined in The NZ Biosolids Guidelines (2003), (NZWWA,2003)

The stabilisation grade is defined by a combination of pathogen reduction and vector attraction reduction (VAR). The requirements for the different grades are summarised in Figure 3. Vectors include any animal or insect that is a potential carrier of disease, for example, birds, rats, flies. One of the aims of stabilisation processes is to reduce the attraction of vectors to the biosolids.



Note: Grade A and Grade B requirements are defined in NZWWA Guidelines. Any sludge not treated to achieve Grade A or B is classed as a sludge and not a biosolid. The treatment requirements are taken from the New Zealand Waste Strategy.

Figure 3 – Biosolids stabilisation requirements

To achieve a Grade A in terms of stabilisation the biosolids have to meet the pathogen reduction requirements outlined in Table 4.

Table 4 – Pathogen reduction processes to achieve Grade A biosolids (NZ Biosolids Guidelines, 2003)

Pathogen Reduction Requirements	Applicable Processes
Time Temperature Processes	
a) ≥ 7% DS $t = \frac{131,700,000}{10^{0.14T}}$; t = days, T = °C where T ≥ 50 °C and t ≥ 15 s	• thermal drying • thermal hydrolysis
b) < 7% DS $t = \frac{50,070,000}{10^{0.14T}}$; t = days, T = °C where T ≥ 50 °C and t ≥ 30 min	• pasteurisation • thermophilic anaerobic digestion • thermophilic aerobic digestion
c) Composting i) In vessel: T ≥ 55 °C for ≥ 3 days ii) Windrow: T ≥ 55 °C for ≥ 15 days (minimum 5 turnings)	• in vessel composting • windrow, aerated static pile composting
High pH – High Temperature Process pH >12 for ≥ 72 hours and maintain T > 52 °C for 12 consecutive hours within the 72 hours all from the same chemical application and drying to > 50% DS afterwards	• Lime stabilisation
Other Processes Demonstration by agreed comprehensive process and product monitoring that Grade A pathogen levels are met consistently	

In addition to the pathogen reduction methods outlined in Table 1, in order to achieve a Grade A biosolid, one of the approaches to VAR summarised in Table 5 also has to be demonstrated.

Table 5 – Vector attraction reduction methods for biosolids (NZ Biosolids Guidelines, 2003)

VAR Requirements (at least one required)	Typical Processes
1. Mass of volatile solids reduce by at least 38%	• mesophilic anaerobic digestion • partially aerated lagoons • aerobic digestion
2. Biosolids ≥ 90% DS if heat dried at T > 80 °C	• thermal drying
3. T ≥ 40 °C for ≥ 14 days and T_{ave} ≥ 45 °C	• composting
4. SOUR* @ 20 °C ≤ 1.5 gO_2/m^3 for liquid sludges from aerobic processes	• aerobic digestion • extended aeration
5. pH ≥ 12 for at least 2 hours and pH ≥ 11.5 for at least 22 more hours	• lime stabilisation
6. Soil incorporation	• sub-surface injection of liquid sludge • ploughing in immediately after application

*SOUR – standard oxygen uptake rate

The contaminant grade (a or b) is determined based on the concentrations of specific heavy metals and organic compounds. The requirements for the contaminant grades and the soil limits for application are summarised in Table 6 for heavy metals. The values stated are as 95th percentile values with no individual sample to exceed the limits by more than 20%. The NZ Biosolids Guidelines (Draft 2017) proposed not having different grades for metal limits but instead having a "compliance limit" which is based on the NZ Biosolids Guidelines (2003) Grade b limits. Grade A biosolids which meet the compliance limit would be a "Type A1" organic product.

There is a requirement in the existing consent for Moturoa / Rabbit Island to measure the metals outlined in Table 6 in the biosolids (3 monthly), in the groundwater (yearly) and in the soils (3 yearly) with the soil limits being included as a consent condition.

Table 6 – Metal limits for re-use of biosolids by land application (NZ Biosolids Guidelines, 2003)

Metal	Soil limit or ceiling concentration (mg/kg dry weight)	Biosolids Limits	
		Grade a Concentration limit (mg/kg dry weight)	Grade b Concentration limit (mg/kg dry weight)
Arsenic	20	20	30
Cadmium	1	1	10
Chromium	600	600	1500
Copper	100	100	1250
Lead	300	300	300
Mercury	1	1	7.5
Nickel	60	60	135
Zinc	300	300	1500

The contaminant limits for organic compounds in the NZ Biosolids Guidelines (2003) are summarised in Table 7. There are no limits for any of these in the existing consent conditions, however, there is a condition to screen the biosolids five yearly for persistent organochlorine and organophosphate compounds. Sampling carried out in 2013 and 2018 for compliance with this condition showed that the concentrations of these compounds were below the limit of detection, for the analytical method used, in the biosolids applied on Moturoa / Rabbit Island. As such the biosolids meet the Grade a requirement for the organic compounds specified.

The NZ Biosolids Guidelines (Draft 2017) do not include limits for any of the same organic compounds, on the basis that these are substances that were banned some time ago and should no longer be present in wastewater or biosolids. The draft guidelines do however include limits for a number of emerging organic contaminants, based on EU guidance, with a note that contaminants and concentration limits applicable to New Zealand need to be developed.

Table 7 – Organic compound limits for re-use of biosolids by land application (NZ Biosolids Guidelines, 2003)

Metal	Soil limit or ceiling concentration (mg/kg dry weight)	Biosolids Limits	
		Grade a Concentration limit (mg/kg dry weight)	Grade b Concentration limit (mg/kg dry weight)
DDT/DDD/DDE	0.5	0.5	0.5
Aldrin	0.02	0.02	0.2
Dieldrin	0.02	0.02	0.2
Chlordane	0.02	0.02	0.2
Heptachlor & Heptachlor epoxide	0.02	0.02	0.2
Hexachlorobenzene (HCB)	0.02	0.02	0.2
Hexachlorocyclohexane (Lindane)	0.02	0.02	0.2
Benzene hexachloride (BHC)	0.02	0.02	0.2
Total polychlorinated biphenyls (PCBs)	0.1	0.2	0.2
Total dioxin TEQ	0.00001	0.00003	0.00005

2.2.2 Biosolids Applied on Moturoa / Rabbit Island

The existing consent conditions prescribe pathogen reduction requirements and are based on the US EPA Guidelines, Part 503 guidelines. Key aspects are the temperature time relationship required to demonstrate pathogen reduction and the options for meeting the VAR requirements for a “Class A sludge”. Both of these aspects have been adopted in the NZ Biosolids Guidelines (2003) so the stabilisation requirements in the existing consent are consistent with the NZ Biosolids Guidelines (2003).

Figure 4 shows the temperatures in the first tank of each ATAD train for the seven year period 01 July 2013 through until 30 June 2020. The temperature is always above 40 °C when the tanks are in operation, however, it is not always above the minimum temperature required for pathogen reduction (50 °C). The time temperature relationship has therefore been reviewed based on the second tank of each train alone.

Figure 5 shows the temperatures in the second tank of each ATAD train for the seven year period 01 July 2013 through until 30 June 2020. For the periods when the ATAD trains are in operation, the temperature is maintained above 50 °C, as required for pathogen reduction. For most of the period shown, the temperatures were in the 60 – 70 °C range.

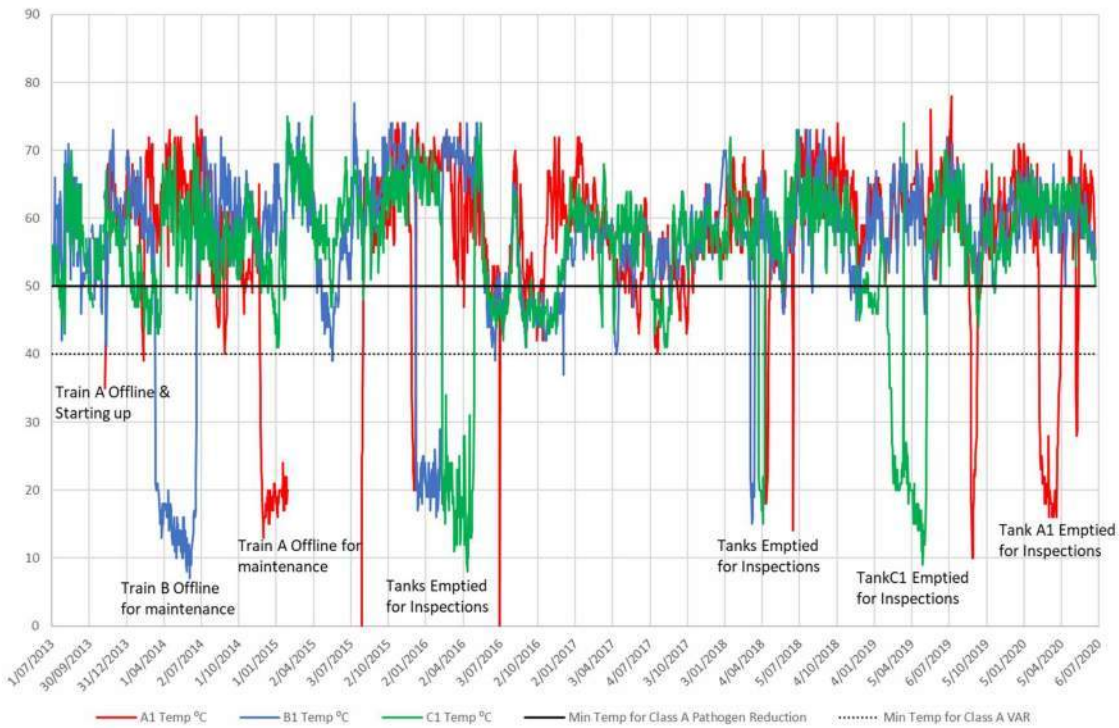


Figure 4 - Temperature in 1st tank of each ATAD train (01 July 2013 to 30 June 2020)

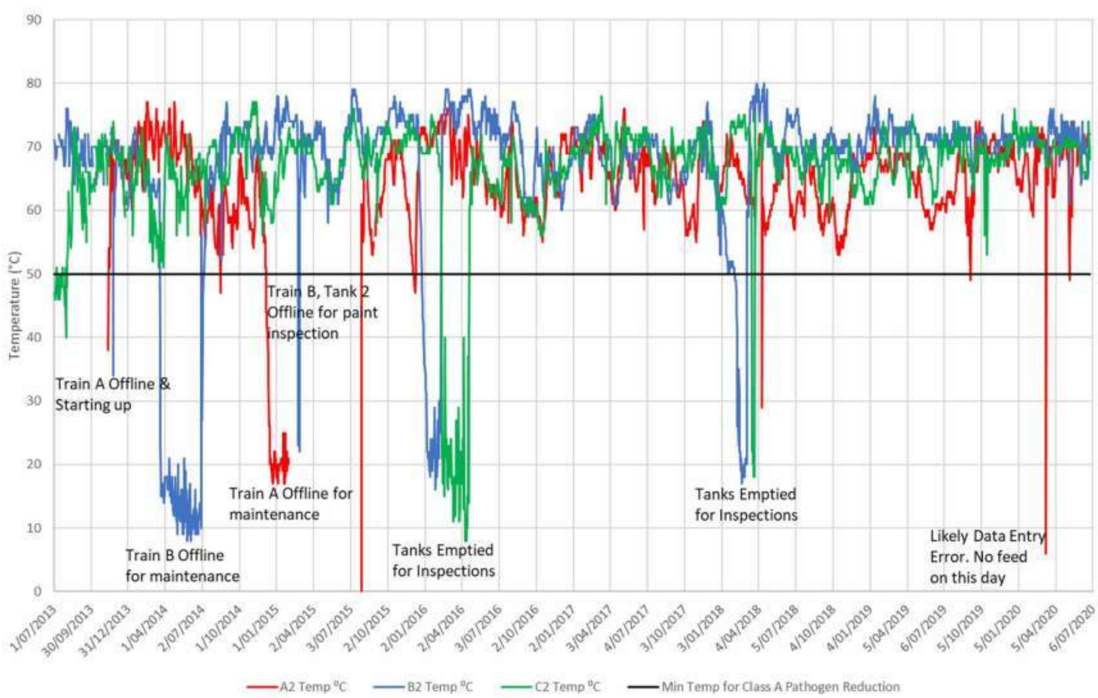


Figure 5 - Temperature in 2nd tank of each ATAD train (01 July 2013 to 30 June 2020)

Figure 6 shows the time-temperature time relationship based on the equation b) in Table 4 as a blue line (NB this is the same equation as that in the existing consent conditions). To comply with the pathogen reduction requirements, the retention time in the tank needs to be above the blue line for any given temperature. In this case, it is clearly demonstrated that for the period considered, the ATAD plant at Bell Island WWTP always complies with the time-temperature requirements for Grade A biosolids based on the second tank only.

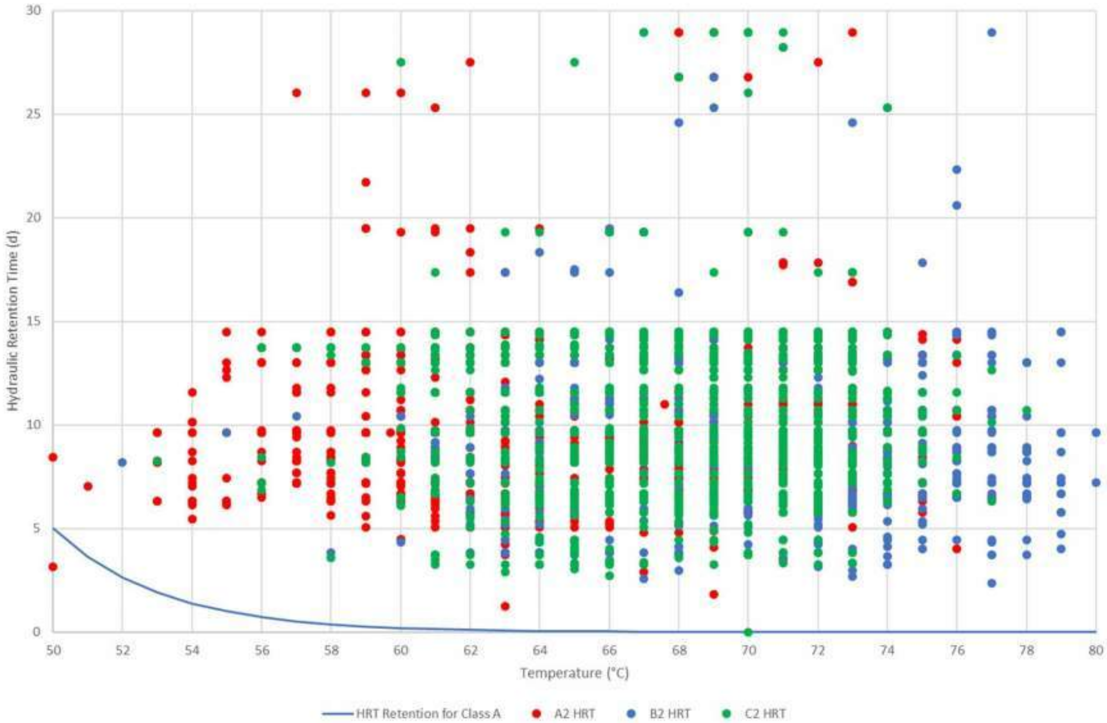


Figure 6 - Temperature and retention in 2nd tank of each ATAD train relative to retention required to achieve a Grade A biosolid (01 July 2014 to 30 June 2020)

In terms of VAR methods, the existing ATAD process should achieve methods 1,3 and 4 identified in Table 5. For the period 01 July 2014 to 30 June 2020, the average temperature in all tanks when in operation was greater than 50 °C and the average retention time within each train was 19 days, 19 days and 19 days respectively for train A, train B and train C of the ATAD. As such the existing ATAD process achieves the VAR requirements of the NZ Biosolids Guidelines (2003). Furthermore, the volatile solids reduction is generally greater than 38%, with the average for the July 2019 – June 2020 period being 43% reduction.

As noted previously, the biosolids produced at Bell Island WWTP meet the requirements for a contaminant Grade a for persistent organic compounds as specified in the NZ Biosolids Guidelines (2003). The metals concentrations recorded for the Bell Island WWTP biosolids are reported in Table 8 with a comparison against the concentration limits in the NZ Biosolids Guidelines (2003) (NRSBU, 2015). Since the concentrations of cadmium, copper, mercury and zinc exceed the Grade a limits, the biosolids produced at Bell Island are a contaminant Grade b.

Table 8 – Heavy metals concentrations in biosolids produced at Bell Island WWTP

Qaulity of biosolids	Heavy metal concentration mg/kg							
	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Bell Island	13.5	3.1	103.0	533.0	1.1	48.0	50.0	1020.0
NZ Guideline Grade a	20.0	1.0	600.0	100.0	1.0	60.0	300.0	300.0
NZ Guideline Grade b	30.0	10.0	1500.0	1250.0	7.5	135.0	300.0	1500.0

In summary, the biosolids produced at Bell Island WWTP meet the stabilisation requirements for a "Class A" sludge as defined by the US EPA and therefore comply with the existing consent conditions. The Bell Island biosolids that are currently applied to land on Moturoa / Rabbit Island are classified as Grade Ab according to the NZ Biosolids Guidelines (2003) and therefore have a restricted use requiring a Resource Consent to apply them to land. Under the NZ Biosolids Guidelines (Draft 2017), the biosolids produced at Bell Island WWTP would be Grade A and compliant for metals, however, current monitoring for organics does not analyse the same compounds that have limits imposed under the NZ Biosolids Guidelines (Draft 2017) so it cannot definitively be identified as a Type A1 organic material.

2.3 Future Biosolids Requirements

The requirements will be dictated by the end use.

2.3.1 Land Application of Biosolids as a Slurry (as per the current status quo biosolids operation)

For application to land as a slurry, we have assumed the biosolids will need to be:

- Grade A stabilised and compliant with the Grade b contaminant limits in the NZ Biosolids Guidelines (2003)
- A liquid or slurry that can be pumped and distributed in a tanker

2.3.2 Land Application of Dewatered Biosolids

For application to land as a dewatered cake, we have assumed the biosolids will need to be:

- Grade A stabilised and compliant with the Grade b contaminant limits in the NZ Biosolids Guidelines (2003)
- Have a dry solids content > 20% DS

2.3.3 Land Application of Dried Biosolids

For application to land as dried biosolids, we have assumed the biosolids will need to be:

- Grade A stabilised and compliant with the Grade b contaminant limits in the NZ Biosolids Guidelines (2003)
- Stabilised and dry solids content > 90% DS

2.3.4 Disposal to Landfill

For disposal to landfill, we have assumed the biosolids will need to be:

- Grade B stabilised – not strictly required but some degree of stabilisation will reduce the volume for disposal and reduce the nuisance odour potential during transportation.
- Dry solids content > 20%

2.4 Evaluation Criteria

2.4.1 Long List Evaluation

For evaluation of the long list, treatment alternatives were considered on the basis of whether they were technically feasible, technically viable, and consistent with the NRSBU objectives. For the purposes of this report and the context for assessment of "Feasible Options" the following definitions have been adopted:

- *Technically Feasible*

"That a process or equipment can be made or is possible"

"Capable of being done"

In the context of this study *"technically feasible"* treatment processes are those that are proven and commercially available in the marketplace.

- *Technically Viable*

Technically viable technologies are technically feasible technologies that have been successfully applied in the treatment of municipal wastewater biosolids at a scale commensurate with the Bell Island WWTP operation.

Consistency with NRSBU project objectives was assessed on the basis of the treatment process being able to:

- Produce biosolids of the appropriate grade for the alternative uses being considered, by doing so this should
  - Provide for current and future community well-being, health and safety;
  - Achieve acceptable environmental effects;
- Be sufficiently flexible to be expanded or adapted to alternative re-use routes, and by doing so
  - Provide for planned future population and industrial/commercial growth;
  - Achieve efficient use of existing infrastructure
- Provide a solution that continues the philosophy of 100% reuse of nutrients
- Provide a solution that could provide additional resource recovery, e.g. energy, etc.

2.4.2 Short List Evaluation

The shortlisted solutions have been evaluated on a qualitative basis against the following criteria:

- Technical risk/viability (operational complexity, operational flexibility, footprint, appropriate for future biosolids loads, etc.)
- Local environmental impacts (odour, organic contaminants, etc.)
- Greenhouse gas impacts (effectively energy - process and transport)
- Cost

3 Long List of Process Alternatives

3.1 Introduction

The long list identifies a range of treatment process alternatives that could be considered for use at Bell Island WWTP to treat sludge to produce biosolids for re-use or recover resources in an alternative way. The processes are described in terms of how they function, the advantages and disadvantages, and the relevance to the Moturoa / Rabbit Island consent application. A high level screening of the alternative treatment processes has been carried out to select a shortlist of treatment solutions for further evaluation. This initial screening was carried out through group discussions with NRSBU and the team carrying out the Biosolids Options Assessment. During these discussions, the long list of possible solutions was revised to a short list of the best candidate options based on technical merits and consistency with the project objectives identified in Section 2.4.1.

3.2 Mechanical Pre-treatment

3.2.1 Sludge Thickening

Sludge thickening processes remove water from dilute sludges to increase the dry solids content. This results in lower volumetric loading to the following processes. A range of processes can be used including dissolved air flotation, gravity belt thickeners, drum thickeners, gravity thickeners, etc.

3.2.2 Solids Disintegration

Solids disintegration technologies, aim to increase volatile solids reduction of sludge, particularly WAS, in subsequent digestion processes, by making the more easily degraded solids available to the digestion bacteria. The most commonly applied technology is ultrasonic technology.

3.3 Thermal Pre-treatment

3.3.1 Pasteurisation

Thickened sludge is batch fed into a reactor where the temperature is held at 65 – 70 °C for 30 minutes to 60 minutes. By holding the sludge at this elevated temperature for the minimum retention time (calculated as for the existing ATAD facility), pathogen reduction is achieved that meets the requirements for a Grade A product. If the pasteurisation is used together with a digestion process to reduce the volatile solids, a Grade A biosolid can be produced.

3.3.2 Thermal Hydrolysis

Thermal hydrolysis is a batch fed process that holds pre-dewatered sludge very high temperatures (150 – 170 °C) and pressures (827 kPa) for 30 minutes. The high temperature disinfects the sludge, meeting the pathogen reduction requirements for Grade A biosolids. When the sludge is de-pressurised, the cell walls of the microorganisms in the WAS are ruptured making the WAS volatile solids more available for digestion. This results in greater volatile solids reduction being possible in subsequent digestion processes.

3.4 Biological Stabilisation

3.4.1 Aerobic Digestion (Ambient)

Aerobic digestion is the biochemical oxidative stabilisation of wastewater sludge. The process involves microbes that break down biological waste in the presence of air.

The process is conducted in open or closed tanks by agitating sludge with air or oxygen, which is supplied by surface aerators or diffusers. Aerobic conditions are maintained at residence times ranging from 60 days at 15°C, to 40 days at 20°C. As food is depleted, the microbes enter the endogenous phase and cell tissues are aerobically oxidised. Volatile solids reduction of at least 38% is typically achieved.

3.4.2 Autothermal Thermophilic Aerobic Digestion

Autothermal thermophilic aerobic digestion (ATAD) is a batch fed process in which thickened sludge is aerated and mixed. Under these conditions, aerobic microorganisms break down organic material into carbon dioxide, water and nitrogen. This breakdown of organic material is through exothermic reactions, i.e. heat is produced. By retaining the heat in insulated tanks, the elevated temperature required for pathogen reduction can be maintained without supplementary heating.

3.4.3 Mesophilic Anaerobic Digestion

Mesophilic anaerobic digestion is carried out in a closed, mixed tank, in the absence of oxygen, and with the temperature maintained typically around 35 °C. Microorganisms that thrive under these conditions break down organic material to methane and carbon dioxide. The process involves a number of metabolic steps to hydrolyse volatile solids to soluble organic substances that are then converted to organic acids which in turn, are converted to methane gas and carbon dioxide. The process can be carried out in a single tank or in sequential tanks as an acid-gas phased digestion with hydrolysis and acid formation taking place in the first, shorter “acid” phase, and methane formation taking place in the second longer “gas” phase.

Other products of the digestion process include hydrogen, hydrogen sulphide, ammonia and phosphates. The biogas produced is around 60-70% methane which can be burned in boilers or combined heat and power engines to generate heat, or heat and power, recovering some of the energy from the biosolids. Although there is some pathogen reduction, it is not sufficient to achieve a Grade A product without an additional thermal step.

3.4.4 Thermophilic Anaerobic Digestion

Thermophilic anaerobic digestion involves the biochemical break down of wastewater sludge using stimulated microbes, in the absence of air. Useful biogas is produced as an output, with methane as the primary constituent.

The process is conducted with a residence time of approximately 15 days, at upwards of 45°C, with volatile solid reduction of at least 38%. Thermophilic anaerobic digestive processes operate at greater temperatures than equivalent mesophilic processes, leading to higher metabolic rates and higher consequent specific growth rates. The process is also effective against pathogenic bacteria.

3.4.5 Temperature Phased Anaerobic Digestion

Uses a combination of thermophilic and mesophilic anaerobic digestion to achieve a high degree of volatile solids reduction. If retention in thermophilic stage is controlled, can achieve pathogen reduction required for Grade A biosolids.

3.4.6 Aerobic In-vessel Digestion (Dry)

Generally, digestion of wastewater sludges is “wet digestion”. If biosolids are co-digested with other organic feedstocks with a high dry solids content (15-20% DS) a dry digestion process could be considered.

3.4.7 Composting

Composting is an aerobic process in which stabilised, dewatered sludge is blended with another product such as green waste, sawdust, or wood chips. The addition of the other material provides a carbon source for the microbial reactions and increases porosity of the blend to assist in oxygen transfer. The breakdown of organic matter is exothermic, resulting in elevated temperatures within the composting mix which destroys pathogens. If the process is controlled to provide appropriate time temperature conditions, a Grade A biosolid is produced.

3.4.8 Vermicomposting

Vermicomposting uses worms to break down organic material in a blend of stabilised, dewatered sludge and another solid waste such as pulp and paper solids. The vermicast generated can achieve the requirements of a Grade A biosolid and can be used as a fertiliser.

3.5 Thermal & Chemical Processes

3.5.1 Torrefaction

Organic material is heated in the absence of oxygen, at temperatures in the range 250-350°C to enhance the fuel properties of the material.

3.5.2 Pyrolysis

Organic material is heated in the absence of oxygen, at temperatures in the range 400-800°C to convert the carbon to a char, bio-oils and syngas.

3.5.3 Gasification

By heating dried biosolids at temperatures in excess of 600°C in a controlled environment with respect to oxygen it is possible to maximise the conversion of carbon to syngas (hydrogen and carbon monoxide) which can be used for energy generation.

3.5.4 Wet Air Oxidation

Wet oxidation is a form of hydrothermal oxidative treatment using oxygen as the oxidizer. It is referred to as "Wet Air Oxidation" (WAO) when air is used. The oxidation reactions occur in superheated water at temperatures of 210 – 240 °C. The system must be maintained under pressure to avoid excessive evaporation of water.

A 4% dry solid slurry can be processed in a WAO system where it is disinfected, and the treated effluent can be dewatered to 55% dry solids using a filter press. Wet oxidation has been used commercially for around 60 years for treating wastewater. It is often referred to as Zimpro process.

3.5.5 Incineration

Biosolids are burned at temperatures between 760°C and 930°C giving near complete combustion of all organic material to carbon dioxide and water. If the solids are sufficiently dewatered prior to combustion no supplementary fuel is required and excess energy may be recovered; depending on the nature of the incoming material, e.g. there is less residual energy in digested biosolids than undigested.

3.5.6 Lime Stabilisation

The addition of lime to dewatered sludge increases the pH to > pH 12 and destroys pathogens. To achieve a Grade A biosolid, the lime addition has to raise the pH to greater than pH 12 for a minimum of 72 hours and be sufficient to raise the temperature to > 52°C for 12 consecutive hours within the 72 hours and the dry solids content has to be > 50% DS afterwards.

3.6 Dewatering

3.6.1 Mechanical Dewatering

Mechanical dewatering is a reduction of the moisture content within the biosolids, typically to around 75-80%, to reduce the volume of the biosolids. This results in a biosolids "cake" with a solids content of 20-25% dry solids. A number of processes are commonly used in New Zealand to achieve this, including belt filter presses, centrifuges and screw presses.

3.6.2 Thermal Drying

Dewatered sludge is dried by direct or indirect contact with heat which is used to evaporate the water content. The dried product can have a dried solids content of > 90% DS, giving a very low volume for transporting to point of use. Thermally dried solids are Grade A in terms of pathogen reduction and VAR. The dried product can be used as a fertiliser, fuel or soil conditioner. Some dried biosolids are marketed in New Zealand (New Plymouth), however, due to the metals content, there are sites which produce a dried product which is landfilled (e.g. Hutt Valley).

3.6.3 Solar Drying

Solar drying is a form of thermal drying that relies on solar energy and air movement to evaporate water from the biosolids to achieve a dried product with a solids content of 75 – 90 %DS. In order to achieve the higher dry solids content, more drying time is required, hence a larger footprint. The target dry solids content will be dictated by the end use requirements. Solar driers typically consist of a concrete pad with low walls and a greenhouse type structure. The biosolids are spread over the concrete pad and a mobile turning device periodically turns the biosolids to expose more surface area for evaporation. Ventilation is controlled to provide optimum drying conditions.

3.7 Screening of Long List Options

A high level screening of the alternative treatment processes has been carried out to select a shortlist of treatment solutions for further evaluation. This initial screening was carried out through group discussions with NRSBU and the team carrying out the Biosolids Options Assessment. During these discussions, the long list of possible solutions was revised to a short list of the best candidate options based on technical merits and consistency with the project objectives identified in Section 2.4.1.

The outcome of this screening process is summarised in Table 9 which summarises the advantages and disadvantages of the processes and the consistency with the project objectives. Where processes have been identified for further consideration, this could be as part of an overall solution and not necessarily as a standalone process.

Table 9 – Screening of long list options

Process	Advantages	Disadvantages	Consistency with Project Objectives	Considered Further
Sludge Thickening	• Reduce capacity of downstream processes – cost savings	• Ongoing maintenance costs • Chemical costs for polymer addition	Already implemented Bell Island WWTP. Any alternative solution is also likely to require thickening of the sludge prior to further processing.	✓
Solids Disintegration	• Increased volatile solids reduction in subsequent digesters resulting in less biosolids and higher gas production • Contributes to VAR when combined with anaerobic digestion	• Does not provide temperature/time requirements for Grade A stabilisation when paired with conventional anaerobic digestion • High capital cost • High energy input • Mixed performance at full scale (different approaches installed at Mangere and Rosedale WWTPs in Auckland and neither is still operational)	Does not produce Grade A biosolid when used with anaerobic digestion Poor track record in New Zealand.	✗
Pasteurisation	• Achieves the pathogen reduction required for a Grade A biosolid • Relatively simple process	• Does not reduce volatile solids • Does not increase volatile solids reduction in digester • Energy input to raise temperature	Could be used together with anaerobic digestion to achieve a Grade A biosolid for re-use.	✓
Thermal Hydrolysis	• Higher breakdown of WAS in subsequent digestion processes • Lower viscosity of biosolids, better mixing in digesters allowing higher solids concentrations to be digested – smaller digesters required • Allows higher volatile solids loading to digesters • Increased volatile solids reduction in digesters • Better dewatering biosolids – can be 8% higher dry solids content	• Odour potential at processing site • Highly corrosive process conditions requiring exotic materials (titanium) • High energy input • Require dewatering in addition to thickening prior to thermal hydrolysis • Need a subsequent digestion step to reduce volatile solids • Need to dilute back to 10% DS prior to digestion – for Grade A product, need disinfected dilution water to maintain pathogen reduction • Increased residual organics and nitrogen in centrate (if biosolids dewatered) can impact liquid stream processes, particularly if UV disinfection used	Could be used together with anaerobic digestion to achieve a Grade A biosolid for re-use. Would reduce the volume of the anaerobic digester. Further benefit if future re-use requires a dewatered biosolid as higher DS content achieved, reducing volume of product to be re-used.	✓
Aerobic Digestion (Ambient)	• Achieves vector attraction reduction requirement for Grade A biosolid	• Does not achieve Grade A product as no pathogen reduction process • High energy input	Does not produce Grade A biosolids. Could be used post thermal treatment + anaerobic digestion for additional volatile solids reduction and nitrogen removal.	✓
Autothermal Thermophilic Aerobic Digestion	• Generates a Grade A biosolid • Relatively simple process	• High energy input for aeration • Odour potential due to elevated temperatures • Biosolid produced is not amenable to dewatering – high consumption of coagulation chemicals is typically required to enhance dewatering	This is the current treatment process to generate Grade A biosolids for beneficial re-use on Moturoa / Rabbit Island. Business as usual case. Not appropriate for any scheme requiring dewatering.	✓
Mesophilic Anaerobic Digestion	• Biogas generation – can be used to generate heat and power • Reduction of organic material in sludge – less volume for re-use or disposal • Biogenic carbon if biogas burned – positive from a carbon footprint perspective	• Pathogen reduction does not meet Grade A requirements • Need an additional process step, e.g. a thermal pre-treatment, to achieve the pathogen reduction requirement for Grade A biosolids • Any methane emissions increase carbon footprint of plant • Biogas pre-treatment required if used in gas engine (H_2S, siloxane removal)	Could be used together with a thermal pre-treatment to achieve a Grade A biosolid. Benefit if a dewatered product is required as anaerobically digested biosolids dewater better than aerobically digested biosolids.	✓
Thermophilic Anaerobic Digestion	• Can achieve a Grade A product if operated as a batched process to achieve the time temperature requirements • Biogas generation/utilisation - is there enough to heat digesters? Any residual? • Reduction of organic material in sludge – less volume for re-use or disposal	• Odour risk due to elevated temperatures • May need external heat source for start-up	Could be used as an alternative to ATAD to achieve a Grade A product as meets the VAR and pathogen reduction requirements.	✓
Temperature Phased Anaerobic Digestion	• Achieves high degree of volatile solids reduction • Can achieves pathogen reduction required for Grade A biosolids if thermophilic phase operated as a batch process	• More complex temperature control between the phases • Additional tanks	Could be used as an alternative to ATAD to achieve a Grade A product as meets the VAR and pathogen reduction requirements.	✓
Aerobic In-vessel Digestion (Dry)	• None identified	• Need solids content >10% DS	More suited to co-digestion with another solid waste.	✗
Composting	• Carbon source can reduce metals content on a mg/kg basis • Produces a Grade A product	• Need to find a sustainable carbon source/bulking agent • Increase mass and volume of solids for re-use if carbon source cannot be recovered • New Zealand experience is that there is limited market for the product • Large land area required for composting operation	With no readily available bulking agent identified, and historically poor market for the product in New Zealand, would be risk to NRSBU.	✗

		• High odour risk during composting operation • Would require a change of application approach if applied to land, redundant assets and investment in new plant required		
Vermicomposting	• For some wastes, e.g. pulp mill solids the blend has appropriate carbon (from pulp waste) to nitrogen (from wastewater sludge) ratio – mutually beneficial • Resource recovery of nutrients that can be re-used	• Large land area required • Reliable carbon source required • Odour generation • Need to develop a market for the product • Increased volume for application	With no readily available bulking agent identified, and historically poor market for the product in New Zealand, would be risk to NRSBU.	✘
Torrefaction	• Resource recovery as a solid fuel – energy production • Biochar – application as beneficial soil remediation and sequestering carbon	• Typically need dried product as a starting point • No nutrient recovery • High energy input	More applicable to wood waste than biosolids.	✘
Pyrolysis	• Production of char, syngas and bio-oils • Conversion of carbon only, little solids for disposal • Potential use of biochar product • Beneficial application of biochar to land – carbon credit (in Australia) and potential agronomic benefits	• Need dried biosolids as feed stock • High energy input • Liquid residues to be managed – limited use for aqueous pyrolysis liquid generated • Syngas and bio-oils need further processing to be useful as a product or fuel source	No beneficial re-use of nutrients, not consistent with biosolids application to land. Need to have a use/market for the biochar and the syngas to obtain any benefit from resource recovery.	✘
Gasification	• Only inert ash for disposal – lowest residual • Conversion to syngas • Maximise calorific value recovered from biosolids	• Need dried biosolids as feed stock • High energy input • Liquid residues (tar) to be managed	No beneficial re-use of nutrients, not consistent with biosolids application to land. Need to have a use/market for the syngas to obtain any benefit.	✘
Wet Air Oxidation	• Can recover a range of products with commercial value	• High TKN waste stream • Highly odorous waste stream • Highly corrosive environment within the process – materials selection issues • Despite promising trials, not proven at a commercial scale	Not sufficiently well developed and reliable for application at this stage.	✘
Incineration	• Can be autothermal if dry solids content is high enough > 35%DS • Inert ash only for disposal – high metals content • Can be energy positive once running – excess heat – is there a use?	• Public perception – seen more as a disposal option than resource recovery • To maximise energy recovery, no stabilisation but need to dewater and dry – complex flow scheme • Emissions control needs to be effective to prevent air pollution	Whilst there is resource recovery, in the form of energy, there would be no nutrient recovery and re-use. Typically considered as a disposal option.	✘
Lime Stabilisation	• Can meet Grade A stabilisation requirements • Dilute metal concentrations	• Increases total solids for re-use or disposal • High chemical consumption for Grade A product • Requires dewatering to achieve Grade A • High odour potential from release of ammonia, particularly as pH falls after application • H&S risks around handling lime – dust inhalation • High carbon footprint due to high usage of lime • Regrowth of biological activity with pH reduction	Whilst a Grade A biosolid can be achieved, the disadvantages of this process do not fit with the objectives of NRSBU.	✘
Mechanical Dewatering	• Lower volumes for re-use or disposal • Could pump liquid biosolids to Moturoa / Rabbit Island and dewater there if there is a benefit to application to land as a solid product on Moturoa / Rabbit Island	• Chemical costs associated with polymer consumption • Would require a change of application approach if applied to land, redundant assets and investment in new plant required	Would be required for an alternative re-use (or disposal) pathway that requires a dewatered biosolids cake or a dried product.	✓
Thermal Drying	• Grade A product • Dried product - low volume for re-use or disposal • Opportunities for sale as product, e.g. New Plymouth, would require change in biosolids guidelines around metal contamination • Could be applied to land	• High energy input to drier, if insufficient biogas could require supplementary fuel. If no reticulated gas, could use biomass boiler • Biosolids need to be dewatered to minimise water to be evaporated, additional plant and chemical consumption • Would require a change of application approach if applied to land, redundant assets and investment in new plant required	Grade A biosolids and appropriate for 100% reuse. Could be considered for an alternative re-use (or disposal) that requires a dried product.	✓
Solar Drying	• Dried product – low volume • Can be certified Grade A but if not certified, have to monitor for pathogens to demonstrate compliance as Grade A product. • Low energy input	• Large footprint • Odour risk at plant • Multiple handling of biosolids, requiring additional plant • Would require a change of application approach if applied to land, redundant assets and investment in new plant required	Grade A biosolids and appropriate for 100% reuse. Could be considered for an alternative re-use (or disposal) that requires a dried product.	✓

3.8 Short List of Solutions for Evaluation

Based on the high-level screening of the long list of alternative processes and the alternative final use options being evaluated by Tonkin and Taylor (2020), a number of solutions have been identified for further evaluation. In order to leave some flexibility in the final implementation, some of the technologies have been left as generic, e.g. “anaerobic digestion” and “drying” within which there are multiple options that are able to achieve the required biosolids standards. This is to leave some flexibility in the final implementation.

For application to land as a slurry, the following solutions were identified:

Option 1 ATAD

Option 2 Thermal pre-treatment + anaerobic digestion

Option 3 Thermal pre-treatment + anaerobic digestion + post-aerobic digestion

For application to land as a dewatered cake, the following solutions were identified:

Option 4 Thermal pre-treatment + anaerobic digestion + dewatering

For application to land as a dried product, the following solutions were identified:

Option 5 Anaerobic digestion + dewatering + drying

For disposal to landfill, the following solution was identified:

Option 6 Anaerobic digestion + dewatering

4 Evaluation of Shortlisted Alternative Solutions

4.1 Option 1 – ATAD

The ATAD is a proven, relatively simple process that produces a Grade Ab biosolid. Given the retention times currently used, there should be capacity to treat increased loads within the existing footprint. For producing a liquid product, the ATAD is very effective.

Monitoring of groundwater and soils on Moturoa / Rabbit Island shows that after applying the biosolids for the last 24 years, the concentrations of contaminants are within the relevant guidelines. Although there have been some odour complaints, an alternative stabilisation process is not likely to improve this.

This is likely to be the lowest cost solution on a whole of life cost basis due to not having an initial capital outlay. This was the finding of a previous comparison of options carried out by NRSBU (2015).

4.2 Option 2 – Thermal Pre-treatment + Anaerobic Digestion

Anaerobic digestion provides the opportunity for further resource recovery in the form of biogas which can be used to generate heat and power. A thermal pre-treatment (or batch fed thermophilic anaerobic digester) would be required to achieve the pathogen reduction for a Grade A biosolid. A detailed heat balance would have to be carried out to confirm whether the biogas produced would be sufficient to provide all the heating requirements. This would be a more complex plant than the existing ATAD although all processes are proven. The footprint would have to factor in gas storage and handling, hazardous areas, etc.

There would be potential for struvite formation in the transfer pipeline to Moturoa / Rabbit Island. Potential for biogas venting at air valves could result in risk of odour complaints.

As sulphur will be reduced in the anaerobic process, it is likely to be present in the slurry as H_2S giving a higher risk of odour complaints due to venting at air valves, open storage tanks on Moturoa / Rabbit Island and application of a liquid anaerobically digested biosolid.

4.3 Option 3 – Thermal Pre-treatment + Anaerobic Digestion + Post-aerobic Digestion

This is a similar solution to Option 2 but includes a post-aerobic digestion stage. The aim of the post digestion is to increase the volatile solids reduction, reduce the odour risk through oxidation of H_2S, precipitate struvite in the biosolids to reduce risk of the transfer pipe blocking and potentially to reduce the nitrogen in the biosolids.

The combination of anaerobic and aerobic process could remove more odorous compounds than either aerobic or anaerobic treatment alone, so there is potential for reduced odour emissions from the applied biosolids.

4.4 Option 4 – Thermal Pre-treatment + Anaerobic Digestion + Dewatering

Similar to Option 2 but includes a dewatering plant and solids loadout for a dewatered biosolid. The final dewatered product could have a higher odour potential than the ATAD biosolids, depending on the dewatering equipment used and the polymer requirements. By trucking dewatered biosolids off site, there could be impacts on the local community through increased vehicle movements and potential for odour complaints over a wider area. Truck movements to cart product will have a negative impact on greenhouse gas emissions.

4.5 Option 5 –Anaerobic Digestion + Dewatering + Drying

4.5.1 Technical Risk / Viability

Anaerobic digestion provides the opportunity for further resource recovery in the form of biogas which can be used to generate heat and power. The subsequent drier should achieve the pathogen reduction for a Grade A biosolid. A detailed heat balance would have to be carried out to confirm whether the biogas produced would be sufficient to provide all the heating requirements.

This would be a more complex plant than the existing ATAD although all processes are proven. The footprint would have to factor in gas storage and handling, hazardous areas, etc.

A thermal drier would require a significant energy input. There could be an opportunity with this solution to use biogas, however it is unlikely that there would be sufficient for the digester heating and a drier. A detailed energy balance would be required to confirm this. A solar drier could be more appropriate however, this would have a significant footprint.

Higher odour potential at Bell Island WWTP. The dried product should have a relatively low odour potential. Additional truck movements at Bell Island to cart biosolids and deliver chemical.

Potential for methane emissions to offset energy savings from ATAD. Additional power consumption for dewatering facility and drier. Truck movements to cart product are likely to result in increased GHG emissions relative to ATAD.

4.6 Option 6 – Anaerobic Digestion + Dewatering

4.6.1 Technical Risk / Viability

Anaerobic digestion provides the opportunity for further resource recovery in the form of biogas which can be used to generate heat and power and a stabilised biosolid that can be relatively easily dewatered. The product produced is however, not a Grade A product and this solution has been included to produce biosolids for a landfill disposal alternative to land application.

There would be additional truck movements at Bell Island to cart biosolids and deliver chemical which would impact the local community and contribute to higher greenhouse gas emissions.

4.7 Odour Potential of Solutions

All of the solutions identified have a high level of stabilisation. As such, there should be minimal further breakdown of organic material following application of the biosolids to land which should in turn reduce the potential for nuisance odours. WEF (2010) notes the degree of attenuation of putrefaction and odour potential for both ATAD and anaerobic digestion to be “good”. Fisher, et al. (2019) carried out a review of the effects of stabilisation processes on odour emissions. Some of the key findings included:

- For dewatered anaerobically stabilised biosolids, the dewatering method can significantly affect the odour concentration – high shear processes, e.g. centrifuge increase odour potential, more so if the solids are stored following dewatering
- Some evidence that an aerobic stage following anaerobic digestion might reduce the concentration of some odorous compounds by reducing the protein levels in the biosolids
- High polymer doses during dewatering appeared to increase odour intensity and concentration
- Biosolids from ATAD considered less odorous than from conventional aerobic digestion.

It is difficult to categorically say one solution will generate less odour complaints than another as there are many variables that affect the outcome. It is expected that aerobic digestion processes would produce a low odour product, although Fisher et al. (2019) noted that that was not necessarily reported in the literature.

Anaerobically digested sludges have been documented as having odour emission risks although a post aerobic stage could improve the odour potential from the biosolids.

4.8 Impact of Solutions on Emerging Organic Contaminants

Clarke and Smith (2011) reviewed emerging organic contaminants (EOCs) in biosolids and made a risk-based prioritisation of chemicals of concern. The highest priority was given to perfluorinated chemicals (PFOS & PFOA) followed by polychlorinated alkanes (PCAs), although a wide range of different organic contaminants were identified as being present in biosolids. In Australia in 2017, following sampling of biosolids which revealed the presence of PFOS and PFOA in the majority of samples, a PFOS limit for biosolids was proposed for Australia (ANZBP, 2017) with a recommendation that monitoring be implemented for PFOS.

Effect of long-term application of biosolids on soil residual PFAS levels at Rabbit Island, Xue (Scion 2020) reported negligible levels of PFOS and PFOA in soil samples from Moturoa/Rabbit Island indicating that 'long-term repeated application of biosolids have not caused appreciable accumulation in the forest soil ecosystem'.

Research into the removal of EOCs in biosolids treatment processes is largely inconclusive with often conflicting findings being found. This is due to a combination of uncertainty about their adverse effects, particularly at the concentrations that might be found in the receiving environment, the high cost of analysis, the wide range of substances being considered and a variety of treatment processes and operating conditions at different plants. On balance and based on the monitoring completed to date the NRSBU approach to EOCs is in line with other WWTP in NZ.

Further research is ongoing and once work is implemented to identify the compounds of concern in New Zealand, it is likely that there will be limits and monitoring requirements for some of these compounds in the future. Once such limits are implemented through an updated version of the NZ Biosolids Guidelines, it would be reasonable to expect that NRSBU would implement best practice for monitoring and managing the biosolids, in line with the current operation.

4.9 Comparative Evaluation of Solutions

The shortlisted solutions have been evaluated relative to each other using the criteria identified in Section 2.4.2. The outcome of this is summarised in Table 10. The colour coding adopted relates to the relative level of effect for each option as follows:

(green)	Low effects	Most beneficial
(orange)	Medium effects	to
(red)	High effect	Least beneficial

The costs included in the Table 10 are based on the information included in Appendix A (capital costs) and Appendix B (operating costs). The costs presented are indicative only and are intended to be for comparison of options. These estimates are not suitable for establishing capital cost budgets for any future projects.

The comparative operating costs only consider the net energy consumption of major process units and polymer consumption associated with dewatering. Other operational costs such as staffing, compliance monitoring, etc. are expected to be similar for all options. For operational costs relating to biosolids use, refer to the "Moturoa / Rabbit Island Biosolids Application: Alternatives Assessment" (Tonkin and Taylor, 2020).

Table 10 – Comparative evaluation of options relative to Option 1 (ATAD)

Option		Grade A Biosolids	100% Reuse of Biosolids	Technical Risk / Viability	Local Environmental	GHG Impacts	Operating Cost	Capital Cost
1	ATAD	✓	✓	• Demonstrated at Bell Island for 25 years	• Some odour complaints • No effects on soil or groundwater	• Energy	• Energy – aeration & biosolids pumping • Biosolids application	• Renewals as plant reaches end of life
2	Thermal Pre-treatment + Anaerobic Digestion	✓	✓	• Proven technology installed on many sites around the world • More complex plant than ATAD • Hazardous area requirements • Potential for struvite formation in the transfer pipeline to Moturoa / Rabbit Island	• Potentially higher risk of odour complaint due to H_2S in liquid sludge • Potential for biogas venting at air valves - risk of odour complaints • Likely to be less effective at removal of EOCs	• Net energy consumption • Fugitive methane emissions at Bell Island • Fugitive methane emissions from storage tanks on Moturoa / Rabbit Island	• Energy – heating, digester mixing, hot water pumping & biosolids pumping • Additional plant maintenance • Biosolids application • Energy recovery from biogas • 250% lower than Option 1	• Thermal pre-treatment • Boiler • Anaerobic digester • Gas storage & handling • Cogen engine (if recovering power) • Indicative capital cost $3.8 million
3	Thermal Pre-treatment + Anaerobic Digestion + Post-aerobic Digestion	✓	✓	• Proven technology • Post-aerobic digestion should – Improve VSR – Reduce odour risk as H_2S oxidised – Less risk of pipe blockage as struvite precipitated in biosolids – Reduce nitrogen in biosolids	• Lower odour risk than Option 2 • Likely better removal of EOC's than Option 2	• Net energy consumption • Fugitive methane emissions at Bell Island	• Energy – heating, digester mixing, hot water pumping, aerobic digester aeration & biosolids pumping • Additional plant maintenance • Biosolids application • Energy recovery from biogas • 150% lower than Option 1	• Thermal pre-treatment • Boiler • Anaerobic digester • Gas storage & handling • Cogen engine • Post-aerobic digester – repurpose ATAD tanks • Indicative capital cost $3.8 million
4	Thermal Pre-treatment + Anaerobic Digestion + Dewatering	✓	✓	• Proven technology installed on many sites around the world • More complex plant than ATAD • Hazardous area requirements • Potential for struvite formation in dewatering equipment & pipework	• Dewatered product may be less prone to odour complaints as odorous compounds remain in filtrate • High shear dewatering processes have higher risk of odour complaints • Polymer addition can contribute to odours	• Net energy consumption • Fugitive methane emissions at Bell Island • Truck movements for hauling biosolids	• Energy – heating, digester mixing, hot water pumping & dewatering • Chemical costs – polymer for dewatering • Additional plant maintenance • Biosolids hauling • Energy recovery from biogas • 180% lower than Option 1	• Thermal pre-treatment • Boiler • Anaerobic digester • Gas storage & handling • Cogen engine • Dewatering plant • Polymer storage and handling • Dewatered solids loadout facility • Indicative capital cost $5.3 million
5	Anaerobic Digestion + Dewatering + Drying	✓	✓	• Proven technology installed on many sites around the world • More complex plant than ATAD • Hazardous area requirements – gas and dust • Potential for struvite formation in dewatering equipment & pipework	• Dried product should be less prone to odour complaints • Potential for dust nuisance during application	• Net energy consumption • Fugitive methane emissions at Bell Island • Truck movements for hauling biosolids	• Energy –heating, digester mixing, hot water pumping & dewatering, drier • Chemical costs – polymer for dewatering • Additional plant maintenance • Biosolids hauling • Energy recovery from biogas • 200% higher than Option 1	• Anaerobic digester • Gas storage & handling • Cogen engine • Dewatering plant • Polymer storage and handling • Dewatered solids conveyance • Drier, incl. dried biosolids handling, storage and loadout • Indicative capital cost $8.6 million
6	Anaerobic Digestion + Dewatering	✗	✗	• Proven technology installed on many sites around the world • Hazardous area requirements	• Risk of odour complaints if dewatered biosolids moved through built up areas	• Net energy consumption • Fugitive methane emissions at Bell Island • Truck movements for hauling biosolids	• Energy – heating, digester mixing, hot water pumping & dewatering • Chemical costs – polymer for dewatering • Additional plant maintenance • Biosolids hauling • Energy recovery from biogas • 180% lower than Option 1	• Anaerobic digester • Gas storage & handling • Cogen engine • Dewatering plant • Polymer storage and handling • Dewatered solids loadout • Indicative capital cost $5.0 million

5 Conclusions and Recommendations

From the above assessment, it can be concluded that:

- The existing ATAD process achieves the pathogen and VAR requirements of Grade A biosolids as per the NZ Biosolids Guidelines (2003) and the NZ Biosolids Guidelines (Draft 2017); and produces Class A biosolids as defined by the US EPA and required under the existing consent conditions.
- The heavy metal concentrations in the biosolids, specifically cadmium, copper and zinc, exceed the concentration limits for a contaminant Grade a but are within those for a Grade b product as per the NZ Biosolids Guidelines (2003). The biosolids would meet the Grade A1 requirements for metals as outlined in the proposed NZ Biosolids Guidelines (Draft 2017) which is currently out for consultation.
- The existing biosolids produced at Bell Island WWTP are Grade Ab as per the NZ Biosolids Guidelines (2003).
- The biosolids are currently applied as a slurry to land in forested areas of Moturoa / Rabbit Island.
- There are alternative processes that could also produce a Grade Ab biosolid, however, for continued application to land as a slurry, they offer no significant net benefits over the existing ATAD solution and would incur a significant investment cost to implement.
- None of the alternatives considered would produce a Grade Aa biosolid as they do not materially affect the metals concentrations.
- If alternative re-use options are adopted in the future, that require a dewatered product, the ATAD would be less suitable as the digested biosolids are not amenable to dewatering, requiring significantly higher polymer consumption than an anaerobically digested product.
- If a dewatered or dried product is required in the future, a solution that includes anaerobic digestion would provide an opportunity for energy recovery through the generation and use of biogas in addition to a digested biosolid more amenable to dewatering.
- In summary, for continued application of biosolids as a slurry on Moturoa / Rabbit Island, the ATAD process is the preferred option. A move to an alternative biosolids reuse pathway could be the trigger for a change in process to open up opportunities for further resource recovery, e.g. energy recovery from biogas.
- A monitoring and technology review condition will be included in the consent application that would provide for:
  - a validation monitoring period, should any change of process be implemented, and
  - any future change to the guidelines (or replacement of the current guidelines) that results in different limits for the organic compounds, or limits for different organic compounds.
  - NRSBU continuing to implement best practice for biosolids management in accordance with the applicable guidelines.

6 References

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A

Appendix A – Indicative Capital Costs

Memorandum

To:	N. Berry	**Date:**	14 May 2020
From:	Ulrich Kornmueller	**Our Ref:**	3257053
Copy:			
Subject:	**Bell Island WWTP – Anaerobic Digestion Options Overview**		

Introduction

As part of the application for a resource consent relating to the disposal of Biosolids from the Nelson Wastewater Treatment Plant (NWWTP) a series of alternatives for the treatment of the sludges derived at the plant were examined. This memo outlines options relating to the anaerobic digestion (AD) of the primary sludge and waste activated sludge (WAS).

This memo outlines a comparative cost study of the following four options which had been previously identified for inclusion in the comparison.

- Thermal Pre-treatment + AD (including gas utilisation)
- Thermal Pre-treatment + AD (including gas utilisation) + dewatering
- AD + dewatering + drying
- AD + dewatering

Assumptions

The following assumptions have been made in relation to this cost comparison

- The future load estimate is representative
- The improvements to the settling of WAS are implemented and the approximate ratio of 70%:30% of primary sludge to WAS is attained
- Existing thickening equipment is adequate and will continue to be used.
  The existing gravity belt thickener will be in constant operation to achieve
- Natural gas is available and piped to the plant to fuel the dryer (option 3)
- See section entitled "Cost Estimates" for limitations and assumptions relating directly to the cost estimates

Anaerobic Digester – Key Parameters

The key process parameters for the Anaerobic digester plant are outlined in this section.

The sludge load on the anaerobic digester plant would be as shown in table 1.

Memorandum

Table 1: Sludge load

	Present WAS Settling regime			Improved WAS Settling regime		
Current Sludge Load		**4800**	DS kg/d		**6520**	DS kg/d
Primary Sludge	90%	4500	DS kg/d	70%	4500	DS kg/d
Secondary Sludge	10%	300	DS kg/d	30%	2020	DS kg/d
Future Sludge Load		**5274**	DS kg/d		**7370**	DS kg/d
Primary Sludge	90%	5230	DS kg/d	70%	5070	DS kg/d
Secondary Sludge	10%	1307	DS kg/d	30%	2300	DS kg/d

An operational volume of 2500m^3 was selected for the digester.

This provides some flexibility in the need to thicken the feed sludge initially. Some indicative (approximate) Hydraulic Retention Times for various sludge parameters are:

- Sludge load 5500 kg/d feed DS at 5.5% HRT 25 days
- Sludge load 6500 kg/d feed DS at 5.5% HRT 21 days
- Sludge load 7500 kg/d feed DS at 6.0% HRT 20 days

Options Description

Each of their options addressed in this study is described briefly below. None of these options has been optimised with a view to selecting the most cost-effective unit processes and equipment. It is possible (in fact highly likely) that alternatives can be found for various unit processes that require a different capital cost outlay. The approach taken in selecting the equipment for this study was to select unit process equipment that experience has shown to work effectively, is reasonably easy to operate and is generally cost effective. Cost optimization has not been carried out and this would be a future second step.

Option 1 – Thermal Pre-treatment + AD (including gas utilisation)

The primary sludge and waste active sludge is thickened at the existing primary settling tank (to approx. 5%) and at a DAF unit (to approx. 5.5%). An existing gravity belt thickener is available and this should be used to target 7% DS. From these facilities the thickened sludge will be pumped to the anaerobic digester facility for further treatment. The first step in this process is thermal pre-treatment. In developing the indicative cost estimates, the thermal pre-treatment process has been assumed to be pasteurisation. Alternative processes could be considered and would change the costs.

Pasteurisation will be carried out in a battery of three 3 vessels. On an hourly basis the feed flow is sequentially cycled to the vessels so that they each progress through the steps of the pasteurisation process as follows.

- Filling and heating
- Holding for one hour at 70°C
- Emptying and cooling to 37°C

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Sludge screening has been included. This is a recommended step as it removes any small plastics and other contraries from the sludge. This process also helps combat ragging which may occur due to the presence of hair or other fibres which can become problematic in the digester.

As small shed is provided to contain both pasteurisation system and the sludge screen. The sludge screen would be mounted on a raised platform so that the contraries may be discharged directly into a small hook bin which is to be regularly removed and trucked way to dispose of the contents.

Anaerobic Digestion is in a simple steel tank erected on a dished concrete slab. It is recommended that the tank be constructed of either stainless steel or laminated stainless panels. The digester is to be covered by means of a double membrane gas storage cover. The outer membrane is inflated with air to provide structural support. This system is provided with under / over pressure gas relief valves. The inner membrane is prevented from sagging into the sludge when the biogas levels are low by a net. This net also can serve to facilitate H_2S removal.

Digester mixing is achieved by an inclined, large diameter, slow mixer which is supported by an external independent support system. This is an effective mixing system and requires little internal maintenance.

The gas utilisation system consists of a 300KW_e Cogeneration system. The heat is to be used to heat both pasteurisation and maintenance heating for the digester. The sort of co-generation system envisaged here is a containerised unit which has built in emergency cooling systems and is essentially a plug and play unit. Note that the unit must be selected to conform to the limitation of the H_2S removal capability of the gas storage cover net system.

An enclosed flare is provided as an emergency biogas consumer to prevent methane being emitted to the atmosphere. As it is intended only as an emergency device, a high-performance flare is considered to be unnecessary.

No reserve heating capacity has been considered at this stage. It is thought that the existing sludge handling facility will provide emergency / standby capacity in the event of failure of or major maintenance to critical process equipment. This will also allow a slow/cold start-up of the new AD plant without having to provide equipment specifically for just this occasion. Alternatively, start-up equipment could be hired.

After digestion, the sludge is pumped to existing facilities for disposal in a similar fashion to the current disposal process to Rabbit Island.

Option 2 - Thermal Pre-treatment + AD (including gas utilisation) + dewatering

This option is identical to option 1 except for the disposal step.
Here the digested sludge is pumped to new centrifuges located with the pasteurisation and sludge screening processes.

Two centrifuges have been considered, in duty / standby mode. They are mounted on elevated platforms to allow them to discharge directly into hook bins located below. Duty is changed over if a bin is full and removed for emptying. This avoids a complicated bin changeover system. Typically, the digested sludge is dewatered to between 22% and 25% DS which can be trucked away for disposal or utilisation.

An alternative would be to provide only one centrifuge, retaining the existing sludge system to provide reserve holding capacity and treatment in the event of maintenance / failure. However, a more elaborate bin change-over mechanism would be required for day to day use.

Memorandum

Option 3 - AD + dewatering + drying

This option is similar to option 2 above except that:

- There is no co-generation, instead a dual fuel boiler is provided
- after the centrifuges, the dewatered sludge is sent to a dryer.

Thermal pre-treatment has been removed from the process as the sludge is heat treated in the dryer to achieve grade A classification. However, we do not recommend the omission of the thermal pre-treatment step as this introduces health risks to plant operations and maintenance staff and renders any dewatered sludge that may be produced in the event of dryer maintenance or failure unusable.

A drum dryer has been considered for this process as it produces easily handed, small compact round granules. The drum dryer will be housed in a simple building which would also accommodate the pasteurisation, the sludge screen and dewatering unit processes.

Silos are provided alongside this building to store both dewatered sludge and dried product.

As the quantity of biogas that is produced is unlikely to be sufficient for both digester heating and the dryer, there is no point in having a co-generation plant. Instead a dual fuel boiler is to be installed to provide heat for the digesters. The alternative or secondary fuel would be either LP gas or diesel. The dryer would be the preferential user of the biogas.

Option 4 - AD + dewatering

This is essentially option 2 without the thermal pre-treatment.
As explained in option 3 above, it is not recommended to omit the thermal pre-treatment step.

Cost Estimate

Limitations

Due to the high-level conceptual nature of the design, this concept estimate is indicative only (and is to be within an expected accuracy range of +-50%) (including the design development contingency). These estimates are not suitable for establishing capital cost budgets for the project. A more detailed cost estimate based on developed design would from part of the scope for the next stage of the project definition.

Basis of Estimate

- The attached cost estimate is to be read in conjunction with the brief descriptions of the four options above. There is no in-depth concept design as the basis of the estimate as the purpose is order of magnitude comparative only.
- The scope of the works is limited to the physical works associated with the secondary processing of the waste and excludes the following:
  - Demolition, siteworks, paving, access control, site services, etc.
  - Biofilter structures and associated mechanical and electrical works
  - Underground services and connections
  - Client management costs

Pricing

- This estimate is based on a combination of high-level factored rates, historical pricing, experience and elemental rates based on current market pricing.

Memorandum

- The estimate is based upon rates and prices gathered over the previous two years and no allowance has been included for increases in labour, materials or plant beyond the present.
- No allowance has been made for any potential effects of the COVID pandemic
- No allowance has been made for pre-contract or contract escalation.
- A provision has been included for costs which can be anticipated during design development. This does not include design scope and/ or construction risk which should be assessed in the risk analysis process in the next stage of the project definition.

Further Assumptions

This estimate is based on the following assumptions:

- The works are competitively tendered and contractors have unimpeded access to the site to carry out the works
- Any works requiring integration with existing services and facilities are undertaken under maintenance shut conditions and have been drained, cleaned and made safe by operational staff prior to any works are undertaken under this contract.
- Ground conditions a suitable for conventional foundations and that no ground improvement or piling works are required

Exclusions

The following items are excluded from the estimated cost:

- *General exclusions:*
  - GST
  - Owner Costs
  - Operating costs, spares, etc.
  - Escalation
  - Provision for foreign exchange fluctuations
  - Specific Risk contingency (a general risk contingency of 20% has been applied)
- Specific Exclusions:
  - Geotechnical investigation
  - Resource consent applications and other local authority costs.
  - Relocation or diversion of existing services (if required)
  - Siteworks, paving and underground services
  - Treatment or removal of contaminated materials
  - Ground improvement and/or piling to buildings and structures
  - Upgrade to capacity of existing services
  - Office accommodation, control room, amenities, DG storage, sampling rooms, etc.
  - Furniture, fittings, equipment, vehicles, etc.

Ulrich Kornmueller
Senior Project Manager

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BELL ISLAND WWTP
ESTIMATE of COSTS for
OPTIONS ASSOCIATED WITH ANAEROBIC DIGESTION OF WASTE SLUDGE

				OPTIONS			
				2 & 3	4	5	6
Item			Major Process Units and Structures	Pasteurisation + AD	Pasteurisation + AD + Dewatering	AD + Dewatering + Drying	AD + Dewatering
	1		**Pasteuristation**				
	1.1		3x pasteurisation tanks	150,000.00	150,000.00		
			heat exchangers, valves & piping local				
			pumps (to AD)				
	1.2		Thickened sludge feed Pipeline to AD complex	30,000.00	30,000.00	30,000.00	30,000.00
	1.3		Thickened sludge feed Pumps (from GBT to AD complex)	30,000.00	30,000.00	30,000.00	30,000.00
	2		**Sludge pretreatment**				
	2.1		Strainpress	90,000.00	90,000.00	90,000.00	90,000.00
	2.2		Supports, Piping and valves	50,000.00	50,000.00	50,000.00	50,000.00
	2.3		Bins	15,000.00	15,000.00	15,000.00	15,000.00
	3		**Digester**				
	3.1		Concrete base	200,000.00	200,000.00	200,000.00	200,000.00
			Stainless Steel digester	450,000.00	450,000.00	450,000.00	450,000.00
	3.2		Digester mixing	75,000.00	75,000.00	75,000.00	75,000.00
	3.3		Digester cover - double membrane complete with support blower, O/U safety valves	150,000.00	150,000.00	150,000.00	150,000.00
	3.4		Piping and valves	50,000.00	50,000.00	50,000.00	50,000.00
			pumps	30,000.00	30,000.00	30,000.00	30,000.00
	3		**Dewatering**				
	3.1		Centrifuges (2x)		600,000.00	600,000.00	600,000.00
	3.2		Supports, Piping and valves		150,000.00	150,000.00	150,000.00
	3.3		bins		80,000.00	80,000.00	80,000.00
	3.4		Floculant Dosing		15,000.00	15,000.00	15,000.00
			ICB extraction pump				
			dilution panel				
			Dosing pump				
	4		**Dryer**				
	4.1		dryer plant - Drum Dryer			1,500,000.00	
	4.2		Silos				
			wet sludge silo			100,000.00	
			dry product silo			100,000.00	
			Product hall (Alternative)				
			concrete base			40,000.00	
			steel frame building			75,000.00	
	4.3		Feed pump to dryer			75,000.00	

BELL ISLAND WWTP
ESTIMATE of COSTS for
OPTIONS ASSOCIATED WITH ANAEROBIC DIGESTION OF WASTE SLUDGE

Beca

Item	Major Process Units and Structures	Pasteurisation + AD	Pasteurisation + AD + Dewatering	AD + Dewatering + Drying	AD + Dewatering
5	**Gas System**				
5.1	Storage (included in digester)				
5.2	Cogen unit 300 kWe	600,000.00	600,000.00		600,000.00
	Boiler (dual fuel biogas / diesel) +fuel storage			250,000.00	
5.3	Piping, blowers and fittings	30,000.00	30,000.00	30,000.00	30,000.00
5.4	Flare	100,000.00	100,000.00	100,000.00	100,000.00
5.5	HEX	30,000.00	30,000.00		30,000.00
6	**Buildings**				
	for Pasteurisation and Sludge prep				
	Steel Frame, simple cladding, concrete Floor	200,000.00	200,000.00		200,000.00
	for Dryer				
	Steel Frame, simple cladding, concrete Floor			700,000.00	
7	**Odour System**	50,000.00	75,000.00	175,000.00	75,000.00
8	**Electrical Infastucture**				
	Electrical	75,000.00	125,000.00	200,000.00	125,000.00
	Controls	50,000.00	75,000.00	150,000.00	75,000.00
	SUB TOTAL	2,455,000.00	3,400,000.00	5,510,000.00	3,250,000.00
	Contactor P&G (10%)	245,500.00	340,000.00	551,000.00	325,000.00
	Commissioning	49,100.00	68,000.00	110,200.00	65,000.00
	SUB TOTAL	**2,749,600.00**	**3,808,000.00**	**6,171,200.00**	**3,640,000.00**
	Design (12%)	329,952.00	456,960.00	740,544.00	436,800.00
	Construction Monitoring (4%)	109,984.00	152,320.00	246,848.00	145,600.00
	SUB TOTAL	**3,189,536.00**	**4,417,280.00**	**7,158,592.00**	**4,222,400.00**
	Contingency (20%)	637,907.20	883,456.00	1,431,718.40	844,480.00
	TOTAL	**3,827,443.20**	**5,300,736.00**	**8,590,310.40**	**5,066,880.00**
		$ 3,515,635	$ 4,988,928	$ 8,590,310	$ 4,755,072

B

Appendix B – Comparative Operational Costs

Beca

Calculation Sheet

Job Name	Moturoa/Rabbit Island Consent Application	**Job No.**	3257053	**Rev**	A
Project Component	Opex Estimate	**Page No.**	1	**of**	1
Calc Set Title	Digester heat requirements & energy availability				
		Prepared By:	NDB	**Date**	15/05/2020
		Checked By:		**Date**	
		Reviewed By:		**Date**	

Unit Costs

Power	0.15	$/kWh
Polymer	12	$ per kg of active emulsion polymer
Diesel	1.5	$/L

Inputs	**Option 1**	**Option 2**	**Option 3**	**Option 4**	**Option 5**	**Option 6**	Unit	**Comments & Assumptions**
Feed Sludge	6540	6540	6540	6540	6540	6540	kg/d	
Digested Sludge	3742	3597	3303	3597	3597	3597	kg/d	90% VS, ATAD 45% VSR, AD 50% VSR, AD+AerD 55% VSR
Ave Sludge Volume	119	119	119	119	119	119	m^3/d	
Peak Sludge Volume	178	178	178	178	178	178	m^3/d	
Sludge heating		336	336	336	133	133	kW	
Heat recovery cooling sludge		-152	-152	-152			kW	Assume 50% recovery cooling from 70 to 35 deg C
Digester heat losses		36	36	36	36	36	kW	See Digesters & CHP sheet
Heat recovery from Biogas		345	345	345	638	345	kW	
Additional Energy required for heating digester		-125	-125	-125	-469	-176	kW	Surplus of heat energy
Electrical Energy from Biogas		293	293	293		293	kW	
ATAD Volume	1695		1695				m^3	
Digester Volume		2854	2854	2854	2854	2854	m^3	
Decanter Motor sizing	0	0	0	41	41	41	kW	GEA pro 5000 (UCT 466)
Decanter Run time	0	0	0	40	40	40	hrs/week	Based on 8 hours, 5 days/week
Polymer consumption	0	0	0	36	36	36	kg/d	Based on 10 kg/tDS
Dewatered Sludge Volume				18	18	18	m^3/d	Based on 20% DS
Drier Thermal Energy	0	0	0	0	0.92	0	kWh/L	
Drier Electrical Energy	0	0	0	0	0.15	0	kWh/L	
Drier Thermal Energy	0	0	0	0	689	0	kW	
Net Drier Thermal Energy, using surplus heat from Cogen	0	0	0	0	220	0	kW	
Drier boiler diesel consumption					607		L/d	
Drier Electrical Energy	0	0	0	0	2698	0	kWh/d	

	Option 1	**Option 2**	**Option 3**	**Option 4**	**Option 5**	**Option 6**	
Energy Cost for ATAD	$ 228,987	$ -	$ 228,987	$ -	$ -	$ -	Based on 105W/m3 effective volume (EPA report on ATAD)
Supplementary Energy to heat sludge for pasteuriser/digester	0	0	0	0	0	0	
Mixing energy for Digester	$ -	$ 37,499	$ 37,499	$ 37,499	$ 37,499	$ 37,499	Based on 10W/m3
Decanter energy consumption	$ -	$ -	$ -	$ 12,792	$ 12,792	$ 12,792	
Decanter polymer consumption	$ -	$ -	$ -	$ 157,549	$ 157,549	$ 157,549	
Drier Electrical Energy Consumption					$ 147,702		
Boiler diesel consumption					$ 332,434		Assumes heat provided by dual fuel burner with biogas & diesel
Sub total - Major Energy Users + Chemicals	$ 228,987	$ 37,499	$ 266,486	$ 207,840	$ 687,976	$ 207,840	
Value of Electrical Energy Recovered	$ -	-$ 384,885	-$ 384,885	-$ 384,885	$ -	-$ 384,885	
Net Operating Costs	$ 228,987	-$ 347,386	-$ 118,399	-$ 177,045	$ 687,976	-$ 177,045	
Opex relative to ATAD	0%	-252%	-152%	-177%	200%	-177%	

Limitations:

This opex estimate only considers the power and heat requirements of the major process units and polymer consumption for options including dewatering.
The costs are intended to be comparative to the current operation and as such elements common to all schemes, such as sludge storage tanks and pumping are excluded.
These estimates are for the treatment solutions only and do not include costs associted with end use, e.g. pumping to Rabbit Island, trucking biosolids, landfill costs, cost of application to land, etc.
The cost estimates do not include maintenance costs or renewals costs.

REPORT

Attachment E

Tonkin+Taylor

Moturoa / Rabbit Island Biosolids Application: Alternatives Assessment

Prepared for
Nelson Regional Sewage Business Unit
Prepared by
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1 Introduction

Tonkin & Taylor Ltd (T+T) has been engaged by the Nelson Regional Sewerage Business Unit (NRSBU) to prepare a technical assessment of actual and potential effects of the application of biosolids on groundwater at Moturoa / Rabbit Island. This report details the results of our assessment and has been undertaken in accordance with our Professional Services Brief dated 23 March 2020.

This report will be used as part of the Assessment of Effects on the Environment (AEE) for resource consent renewal in conjunction with a number of other specialist technical reports prepared by other members of the consenting project team.

1.1 Background

Nelson Regional Sewerage Business Unit (NRSBU) is responsible for managing and operating the Bell Island Wastewater Treatment Plant (WWTP), which is jointly owned by the Nelson City and Tasman District Councils (NCC and TDC). The operation of the WWTP and associated discharges to land, air and water is subject to resource consents that have recently been renewed through to February 2040.

Sludge from WWTP processes is stabilised in digesters at the WWTP and the resultant biosolids are then pumped to storage tanks at the Biosolids Application Facility (BAF) on Moturoa / Rabbit Island. From there the biosolids are transported in tankers and sprayed onto plantation forestry on Moturoa / Rabbit Island via a heavy-duty travelling irrigator. Biosolids have been applied to the forest in this way, since 1996.

NRSBU holds an existing resource consent under the Resource Management Act 1991 (RMA), for the application of biosolids to land (forestry blocks) on Moturoa / Rabbit Island (ref: NN940379V3). This consent, issued by TDC, expires on 8 November 2020.

The following document has been prepared as a high-level alternatives assessment which evaluates the existing biosolids activity relative to other potential locations and methods.

1.2 Scope

The scope of this report is to identify and assess potential end uses of biosolids produced by the WWTP. This includes the use of the current biosolids product (1-3% solids slurry) and also other potential products including dewatered biosolids (around 20% dry solids) and dried biosolids (around 95% dry solids).

This report should be read alongside Moturoa / Rabbit Island Consent Application - Biosolids Process Alternatives Assessment, prepared for the NRSBU by Beca Limited, May 2020 (the Beca Process Alternatives Assessment) Further information is provided in Section 6 of the AEE (Moturoa / Rabbit Island biosolids Reconsenting, Tonkin & Taylor Ltd 2020).

1.3 Resource consent to apply biosolids to land

Discharge permit NN940379V3 authorises the discharge of biosolids to the commercial forestry area at Moturoa/ Rabbit Island. The discharge permit is subject to key consent conditions which manage environmental effects via:

- Limiting the depth, rate and timing of the discharge (conditions 4.1-4.6),
- Excluding certain areas from the discharge (5.1-5.4 and 6.1-6.2),
- Regular monitoring of biosolid quality (7.1), groundwater quality (7.2), soils (7.3), and the coastal marine area (7.4-7.7),
- Implementation of a contingency and management plan (9.1), and

- A range of reporting and notification requirements.

1.4 Biosolids production

The Bells Island WWTP operation is described in the Beca Process Alternatives Assessment. Biosolids production in the 2018/19 year was around 80 m^3 per day with volumes predicted to rise to around 125 m^3/day. The Assessment also comments on the characteristics of the biosolids produced as follows.

> *In summary, the biosolids produced at Bell Island WWTP meet the stabilisation requirements for a "Class A" sludge as defined by the US EPA and therefore comply with the existing consent conditions. The Bell Island biosolids that are currently applied to land on Moturoa / Rabbit Island are classified as Grade Ab according to the NZ Biosolids Guidelines (2003) and therefore have a restricted use requiring specific consents for discharge. Under the NZ Biosolids Guidelines (Draft 2017), the biosolids produced at Bell Island WWTP would be Grade A and compliant for metals, however, current monitoring for organics does not analyse the same compounds that have limits imposed under the NZ Biosolids Guidelines (Draft 2017) so it cannot definitively be identified as a Type A1 organic material.*

1.5 Application to forestry land

Biosolids from the WWTP have been applied to the Pinus Radiata plantation on Moturoa / Rabbit Island since 1996 via spraying from a heavy-duty travelling irrigator. Forward planning of biosolids and the staging of application in set "blocks" of the forest is prescribed in the Biosolids Management Plan. Biosolids application can continue with limited/no interruption of recreational activities on Moturoa/ Rabbit Island.

Moturoa/ Rabbit Island is made up of predominantly low nutrient and organic level sand[1]. Application of biosolids at Moturoa / Rabbit Island is intended to eliminate the need for application of nitrogen on the forestry plantation located on the Island. In coastal forest areas such as Moturoa / Rabbit Island which are subject to nitrogen deficiency, a response in diameter growth would be expected following the application of nitrogen fertilizer and this has been continuously observed in the biosolids research trials completed at the site[2]. In general, biosolids application has been observed to be beneficial to trees growing on this site and has transformed a low productivity forest site to one of moderately high productivity.

Application rates vary depending on the age of the trees in a specific block with current consent conditions specifying nitrogen loading rates in kg of nitrogen per hectare (kg N / Ha). The application rates can be averaged over three (3) years and range from 150 kg N / Ha in the first 12 years of tree growth and 100 kg N / Ha after the first 12 years of growth.

The average nitrogen content of the biosolids produced at Bells Island is 2 kg per m^3. This equates to over 58,000 kg in 2018/19. At an application rate of 100 kg N / Ha each year almost 600 Ha is required for land application. This reduces to almost 400 Ha if the application rate is 150 kg N / Ha.

2 Potential Biosolids Management Options

2.1 General comments

The objective for biosolids management is to minimise the quantity of material requiring management, control potential nuisance (odour/insects) and/or to generate a product with value. This may involve:

[1] Report, The Rabbit Island Biosolids Project, Peter Wilks, Hailong Wang.
[2] Report, 2012 Annual Report on the Biosolids Research Trial at Rabbit Island, Jianming Xue and Mark O. Kimberley (SCION).

- Digestion, with aeration (aerobic) or without oxygen (anaerobic) including consideration of advanced (pre-treatment) options
- Mechanical dewatering, using presses or centrifuges
- Thermal drying (with a range of technologies available)
- Vermi-composting or composting
- Thermal destruction
- Use of the stabilised product (for example dewatered biosolids, dried biosolids, compost)
- Landfilling the product.

The NRSBU targets 100% beneficial reuse of biosolids from the WWTP. This is currently achieved through the application of biosolids at Moturoa / Rabbit Island.

2.2 Options assessments from the 1994 consent application

An assessment of alternative disposal or end use options was undertaken as part of the original consent application undertaken by the then NRSA (Nelson Regional Sewage Authority) for the discharge of biosolids to land[3]. The options that were considered in the 1994 consent application are summarised in Table 2.1.

Table 2.1: Options considered as part of original 1994 consent application

Option considered	Key conclusions
1 Disposal to landfill	Investment in dewatering would be required and Eves Valley Landfill (now closed) was not considered an appropriate disposal location due to the need to have an appropriate refuse to sludge ratio. A dedicated landfill was considered as an option but was identified as difficult to achieve due to the need to obtain resource consent.
2 Ocean disposal	Was not considered further due to strong opposition that would likely have occurred.
3 Composting	Composting was identified as feasible however it was recognised that there would need to be investment in dewatering and a significant amount of capital expenditure to begin operations. The potential for odour was identified but acknowledged that with good management odour could be minimised. Conclusions were that this could be a viable option for the future if a market for the product and an alternative disposal option could be identified.
4 Incineration	Incineration was evaluated as costly and complicated and generally only to be considered when alternatives are limited.
5 Disposal to agricultural land	There were significant issues highlighted with disposal to agricultural land including the leaching of nutrients or heavy metals, land use, public access and aerosols leading to the conclusion that these challenges would be difficult to overcome without NRSA owning the land.
6 Disposal to forest	Disposal to forest was considered the preferred option and the content of the resource consent applications. Major advantages identified included assured disposal due to Tasman District Council owning the land, beneficial use of the waste product, forestry identified as a suitable land use application and the forest canopy was predicted to reduce the impact of some aerosols.

[3] Report, Disposal of Biosolids to Rabbit Island, Prepared for Nelson Regional Sewerage Authority, Beca Steven, November 1994

Option considered	Key conclusions
7 Bio augmentation	Bio-augmentation is the addition of certain types of micro-organisms to the WWTP ponds with the aim to significantly reduce the amount of sludge. It was not deemed a feasible solution for long term, sustained biosolids management.

2.3 Process options

While the focus of this report, and the NRSBU resource consent application, is on the end use of biosolids produced at the WWTP, the treatment processes employed define the characteristics of the biosolids that are available for use or disposal. The Beca Process Alternatives Assessment considers a range of processes that could be employed to treat solids from the wastewater treatment process.

The report considered a range of process options with various combinations of raw solids pre-treatment, biological stabilisation, thermo and chemical processing and dewatering. The report identified a shortlist of combinations for more detailed evaluation. The options were

For application to land as a slurry, the following solutions were identified:

1 ATAD
2 Thermal pre-treatment + anaerobic digestion
3 Thermal pre-treatment + anaerobic digestion + post-aerobic digestion

For application to land as a dewatered cake, the following solutions were identified:

4 Thermal pre-treatment + anaerobic digestion + dewatering

For application to land as a dried product, the following solutions were identified:

5 Anaerobic digestion + dewatering + drying

For disposal to landfill, the following solution was identified:

6 Anaerobic digestion + dewatering

The assessment concluded the following.

- The existing ATAD process achieves the pathogen and VAR requirements of Grade A biosolids as per the NZ Biosolids Guidelines (2003) and the NZ Biosolids Guidelines (Draft 2017); and Class A biosolids as defined by the US EPA and required under the existing consent conditions.
- The heavy metal concentrations in the biosolids, specifically cadmium, copper and zinc, exceed the concentration limits for a contaminant Grade a but are within those for a Grade b product as per the NZ Biosolids Guidelines (2003).
- The existing biosolids produced at Bell Island WWTP are Grade Ab as per the NZ Biosolids Guidelines (2003).
- The biosolids are currently applied as a slurry to land in forested areas of Moturoa / Rabbit Island.
- There are alternative processes that could also produce a Grade Ab biosolid, however, for continued application to land as a slurry, they offer no significant net benefits over the existing ATAD solution and would incur a significant investment cost to implement.
- None of the alternatives considered would produce a Grade Aa biosolid as they do not materially affect the metals concentrations.
- If alternative re-use options are adopted in the future, that require a dewatered product, the ATAD would be less suitable as the digested biosolids are not amenable to dewatering, requiring significantly higher polymer consumption than an anaerobically digested product.

- If a dewatered or dried product is required in the future, a solution that includes anaerobic digestion would provide an opportunity for energy recovery through the generation and use of biogas in addition to a digested biosolid more amenable to dewatering.
- In summary, for continued application of biosolids as a slurry on Moturoa / Rabbit Island, the ATAD process is the preferred option. A move to an alternative biosolids reuse pathway could be the trigger for a change in process to open up opportunities for further resource recovery, e.g. energy recovery from biogas.

The outcome of the treatment process will be one of several potential products that could be produced using various combinations of process steps. These are:

a A Class Ab biosolids slurry - from aerobic digestion (the existing situation). anaerobic digestion or a anaerobic digestion followed by aerobic digestion.

b A Class Ab or Class Bb dewatered biosolid, around 20% dry solids - most likely from anaerobic digestion due to challenges dewatering aerobic digested sludge.

c A Class Ab dried biosolid - produced by drying biosolids to around 95% dry solids using a supplementary energy (wood, gas) or solar energy.

2.4 End use options identified

The focus of this assessment and the companion Beca Process Alternatives Assessment is on identifying proven approaches that are potentially technically viable. This means technologies or uses that have been demonstrated at a similar scale, processing similar materials and have evidence of successful commercial application. Emerging technologies or solutions that are at an early stage of commercial implementation, termed technically feasible, have not been considered for inclusion in the shortlist. Those that are technically feasible but not considered technically viable in Nelson/Tasman are considered but not carried through to more detailed analysis in Section 4.

A range of options for biosolids products exist. These may involve additional processes, for example composting of dewatered biosolids. Potential pathways for use are illustrated in Figure 3.1. Options are discussed further in the remainder of Section 3.4.

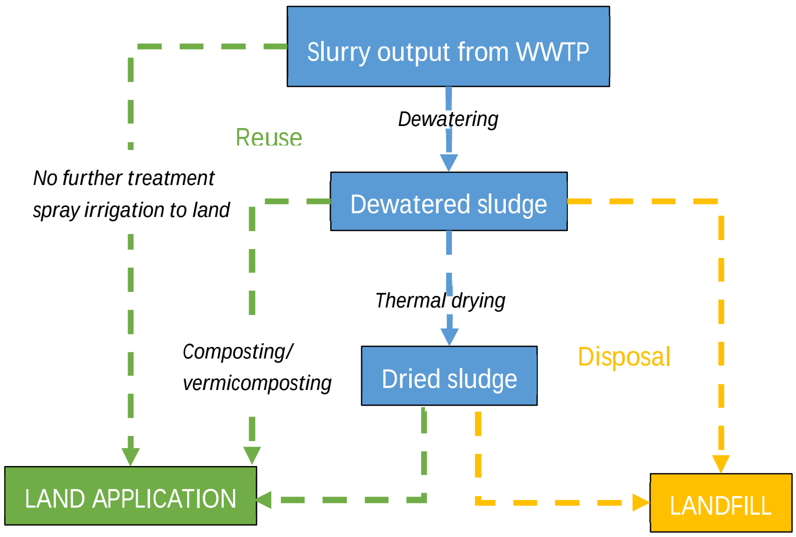

Figure 2.1: End use options for biosolids from various process outputs

2.4.1 Land application - general comments

Only a small portion of biosolids are applied to land in New Zealand (approximately 16 %[4] [5]). In comparison the UK and Australia apply approximately 80 % of biosolids to land. Biosolids can be applied to land in multiple forms. Examples include:

- in liquid form as a slurry (with less than 3% dry solids)
- as a dewatered 'cake' (around 20% dry solids)
- as a dried product (typically around 95% dry solids)
- in a compost or vermi-compost product

Application on land that is accessible by public or used for production requires biosolids that meet Grade A (pathogen reduction, reducing vector attraction) requirements. Even with demonstrated pathogen reduction potential end users may be concerned about the use of sewage derived products. Examples include restrictions on the use of biosolids on dairy grazing land and unclear requirements in the EurepGap standards (which primarily address food quality and safety) for primary producers exporting to the EU.

There are some locations where the application of wastes of human origin such as biosolids (regardless of grade) is unacceptable to Maori. Best practice requires that relevant tribal authorities to a potential application site be consulted on biosolid management, experience would suggest that potential issues may arise and require negotiation.

2.4.2 Land application of slurry

2.4.2.1 Description

Application of biosolids in slurry form involves irrigation, in some cases with soil incorporation. The only example of land application of a biosolids slurry in New Zealand is the application of biosolids to forestry at Moturoa / Rabbit Island in Nelson. There are many examples of the application of wastewater solids slurry from food processing (meat, dairy) in multiple locations around New Zealand.

Slurry can be applied to the surface or injected into soil. Slurry application is likely to be viable where:

- The biosolids meets quality requirements - for example pathogen reduction and contaminant levels.
- It is straightforward and cost effective to transport the biosolids from the wastewater treatment plant where they are generated to the location for application.
- It is possible to apply the slurry safely and in a way that minimises adverse environmental effects, for example avoiding the potential for liquid biosolids to flow into waterways.
- The nutrients provided by the biosolids provide value, for example offsetting fertiliser inputs.

2.4.2.2 Biosolids quality requirements

Input materials of high water content (up to 3 % solids). Unless access to the application area is carefully controlled the biosolids should meet pathogen reduction requirements (Grade A in the NZ Biosolids Guidelines (2003)).

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[4] Report, The Value of Biosolids in NZ-An Industry Assessment, Prepared for WasteMINZ 2019, Rob Tinholt, 2019.
[5] The remainder is disposed of to landfill (around 80% or incinerated

2.4.2.3 Comments

There is only one example in New Zealand (Moturoa / Rabbit Island). The situation at Moturoa / Rabbit Island is unique, because the wastewater treatment plant is located within close proximity of the nutrient deficient forestry block.

2.4.3 Land application of dewatered biosolids

Subject to appropriate processing to meet Grade A requirements it is possible to apply dewatered biosolids to land. This is a common approach internationally with a large proportion of biosolids applied to land in Australia and the USA being dewatered biosolids. Processing needs to provide assurance of adequate pathogen reduction through elevated temperature, extended processing time and/or other means. Examples include:

- Thermophillic anaerobic or aerobic digestion
- Thermal hydrolysis (typically pre-digestion)
- Pasteurisation per or post digestion
- Addition of lime (increased temperature and high pH).

There are no current examples of the land application of dewatered biosolids in New Zealand. Christchurch City Council completed a land application trial at Bottle Lake Forest in the early 2000's and holds resource consent[6] to discharge dewatered biosolids to selected forestry sites around Canterbury, although it is understood that this is no longer in use. Christchurch now dry biosolids at their Bromley wastewater treatment plant (see Section 2.4.4).

2.4.3.1 Biosolids quality requirements

Dewatered biosolids (15-20 % solids). Processing providing pathogen reduction to meet the Grade A requirements in the NZ Biosolids Guidelines (2003).

2.4.3.2 Comments

Dewatered biosolids are unlikely to meet Grade a contaminant thresholds.

Dewatered biosolids can be odorous and difficult to handle with conventional fertiliser spreading equipment.

Land application of dewatered biosolids is common internationally (Australia, United States of America) using manure spreading equipment.

2.4.4 Land application of a dried biosolids

2.4.4.1 Description

Adequate drying of biosolids can result in Grade A pathogen reduction, potentially making the product suitable for application to land. There are several locations where dried biosolids are produced in New Zealand.

In New Plymouth dewatered solids are dried using gas heated drum drying technology to produce a hard granule fertilizer. The product is marketed under the brand name *Bioboost*. Bioboost has successfully developed a local end market in general garden use (commercial and residential), lawns, broad acre cropping, turf and forestry.

Solar drying of biosolids has been successfully implemented in Selwyn. Solar air drying results in a biosolid product that is 93 % solids. The land surrounding the Pines Wastewater Treatment Plant has

[6] Resource consent CRC964299.3, expiry October 2028

been consented to allow the disposal of Grade Aa biosolids. Currently dried solids are being trucked off site for disposal at landfill. Disposal to adjacent pasture land is anticipated in the future once testing has been undertaken to see if biosolids can achieve a Grade Aa standard.

The Biosolids drying facility Christchurch City Council's Bromley Wastewater Treatment Plant is a large scale wood fired belt drying plant resulting in biosolids that are over 95 % solids. The product is able to meet the class Ab classification for biosolids, which means that it is suitable for reuse on land. Christchurch City Council has a relationship with the operators of Stockton Mine on the West Coast and biosolids are beneficially reused to rehabilitate areas at the Mine.

Biosolids at the Hutt Valley Wastewater Treatment Plant (Lower Hutt) are dried to around 95% solids in a gas fired dryer. The biosolids are largely disposed of to landfill but have been used on forestry land in the Manawatu.

2.4.4.2 Biosolids quality requirements

Dried biosolids (over 90 % solids). The drying process meets pathogen reduction requirements to meet the Grade A requirements in the NZ Biosolids Guidelines.

2.4.4.3 Comments

Dried biosolids are unlikely to meet Class a contaminant thresholds.

There are challenges associated with matching the quality of the output with a suitable land application arrangement. This matching can be reliant on the success of identifying opportunities and building relationships (i.e. CCC and Stockton Mine willing to take Class Ab biosolids).

Application to farmland or forestry may be appropriate but there can be challenges in identifying appropriate locations, and with maintaining appropriate land area for application within a practical distance of the treatment facility.

The dried product is easier to handle with conventional equipment, for example fertiliser spreaders, compared to dewatered biosolids or biosolids slurry.

2.4.5 Land application of compost/vermi-compost containing biosolids

2.4.5.1 Description

Dewatered sludge can be used as feedstock for composting to produce a soil amendment product. Key to the success of this process is achieving a suitable carbon to nitrogen ratio to facilitate the process and achieve a suitable nutrient balance in the product. For biosolids this requires the use of a carbon rich bulking agent, generally at a 2 - 4:1 blending ratio.

Potential end users for a biosolids derived compost within the Tasman/ Nelson Region include the two Councils and application to the parks and reserves under their control, local golf courses, schools or members of the public/ operators who wish to apply the product for gardening fertilisation or soil improvement purposes. The agriculture industry (excluding food crop or stock grazing) could also potentially use the product for soil amendment of fertiliser.

There have been several examples of biosolids composting occurring in New Zealand although none of those currently operating produce compost for general use. Palmerston North City Council compost biosolids and green waste with the resulting product used to build up a topsoil layer on a closed landfill (Awapuni Landfill).

Typically, a biosolids composting operation will employ enclosed composting technology including the ability to treat odours generated during handling and composting. A key challenge for these operations has been securing sustainable markets for the compost product. Between 1999 and 2008 dewatered sludge from Wellington City Council's Moa Point wastewater treatment plant was composted by the Living Earth Joint Venture plant at the Southern Landfill site. The operation was an enclosed tunnel composting facility with materials handling and process areas vented to atmosphere via a biofiliter. The facility cost $17M to build but struggled to develop and maintain a sustainable market for the compost product and generated a significant number of odour complaints from nearby properties.[7]

Thames Coromandel District Council ran a biosolids composting trial that was unsuccessful and decommissioned in October 2017. The Council acquired an aging asset with high maintenance costs that were not offset by fuel, transport and landfill disposal costs that did not increase as predicted.

Similarly, Rotorua District Council built and ran a biosolids composting facility that eventually was closed down.

2.4.5.2 Biosolids quality requirements

Input materials are ideally dewatered solids (>15% dry solids). The input biosolids and technology selected will determine the bulking agent requirements. The inclusion of bulking agent dilutes trace contaminants and can assist in meeting contaminant thresholds.

2.4.5.3 Comments

Composting of putrescible materials such as dewatered biosolids carries a relatively high odour risk. This can be managed by minimal turning or enclosed systems with treatment of process air.

Ideally processing sites are also well removed from residential or other sensitive land uses.

Securing appropriate bulking agent can be challenging as typically a 2 - 4:1 blending ratio is required. Green and wood waste is often in demand for general composting operations and bioenergy. There are commercial green waste composting and bioenergy operations in the Nelson/Tasman area that compete for these materials.

Compost produced with biosolids and suitable bulking agents are designed for land application. Potential uses include top dressing (pasture, turf), during re-sowing (pasture, turf), horticulture (during crop establishment) and for landscaping/home gardening. With the addition of bulking agent the biosolids derived product is typically several times the volume of the biosolids.

Composting of appropriate processed biosolids can produce a Grade A biosolid. The addition of bulking agent may reduce contaminant levels to enable biosolids to meet the Grade a criteria.

Identifying and securing markets for product can be challenging with some land uses resistant to using sewage derived products.

Compost and vermi-compost products are complementary to, rather than direct replacements for, conventional fertiliser. Effectively communicating the benefits of including these products in a growing system is an ongoing challenge.

2.4.6 Land application of vermi-compost

2.4.6.1 Description

Vermi-composting has similar opportunities and barriers as conventional composting in that achieving a suitable carbon to nitrogen ratio through the secure supply of a bulking agent is crucial.

A number of biosolid vermicomposting sites exist in New Zealand ranging from small communities with onsite small scale systems (i.e. Maketu) to full scale centralized vermi-composting operations

[7] http://www.scoop.co.nz/stories/AK0712/S00069.htm

(i.e. those managing biosolids from Rotorua, Hamilton and Taupo[8]). All of the larger large sites have access to pulp mill solids which are used as the bulking agent. Some also combine sludge from local milk processing plants as a feedstock. Sludge is generally anaerobically digested and dewatered before being vermi-composted. Vermicast has a number of end markets in the central north island including land application to maize crops, orchards, forestry and pasture.

2.4.6.2 Biosolids quality requirements

Similar to composting, biosolids are ideally dewatered solids (>15% dry solids).

2.4.6.3 Comments

Vermi-composting carries a relatively high odour risk. Ideally processing sites are also well removed from residential or other sensitive land uses.

Vermi-composts produced with biosolids and suitable bulking agents are designed for land application. Potential uses include top dressing (pasture, turf), during re-sowing (pasture, turf), horticulture (during crop establishment) and for landscaping/home gardening. With the addition of bulking agent the biosolids derived product is typically several times the volume of the biosolids.

The Central North Island vermi-compost operations are unique in having access to significant quantities of high carbon feed source (pulp mill wastewater treatment sludge).

Identifying and securing markets for product can be challenging.

Compost and vermi-compost products are complementary to, rather than direct replacements for, conventional fertiliser. Effectively communicating the benefits of including these products in a growing system is an ongoing challenge.

2.4.7 Potential land application locations in Nelson/Tasman

2.4.7.1 Description

In addition to Moturoa / Rabbit Island, it may be possible to apply biosolids in other locations. Examples include:

- Horticultural land - compost is often used in tree and vine based horticulture applications for weed suppression and sustained nutrient delivery. Compost can also be used to maintain soil structure and health for heavy rotation cropping systems. Subject to meeting appropriate quality requirements there is potential for other biosolids products to be used in a similar way. Possibilities include:
  - Dewatered biosolids incorporated during soil preparation, but this would be subject to stand down periods that are likely to make this impractical.
  - Dried biosolids as a compost replacement, potentially viable subject to market acceptance of the product.
  - Compost containing compost or vermi-compost, potentially viable subject to market acceptance of the product.
- Other forestry land. Use of biosolids on forestry land would most likely be viable at re-sowing, i.e. incorporate biosolids (dewatered, dried, compost or vermi-compost) prior to planting. With a general trend to eliminate pruning it has become less practical to apply biosolids throughout the crop rotation. This means that a large area would be required with a 20-30 year rotation of blocks requiring biosolids application once per rotation.

[8] Vermicomposting of Biosolids and Beneficial Reuse – New Zealand Commercial Case Studies from 4 communities over 8 year. Michael Quintern Max Morley 2017.

It could also be possible to sell a biosolids derived product on the open market. Bioboost (dried biosolids) from New Plymouth is a current example of this approach. Biosolids compost produced in Wellington was sold to landscapers and the general public while the facility operated.

Key considerations when evaluating potential locations include:

- Total land area required - 600 Ha per year or more[9].
- Location - proximity to the Bell Island WWTP to minimise transport costs, adjacent land use.
- Land use - in general land used in a way that avoids public access or allows access to be controlled immediately after biosolids application will be preferred.
- Produce - while it is technically feasible to manage risks associated with biosolids, applying biosolids to land used for food production is unlikely to be preferred.
- Topography - flat to gently rolling land is likely to be preferred to steep country.
- Ownership - sites controlled by the biosolids producer are likely to be preferred due to the ability to control land use and access.

These factors can be considered making use of existing spatial datasets including land use, topography and ownership. Maps of forestry land (noting forests owned by Councils) and agricultural/horticultural land are included in Appendix A. Key points to note include:

- There is approximately 100,000 Ha of planted production forest in the Nelson and Tasman Regions. This tends to be on steep country on the hills surrounding the Waimea Plains.
- Council owned forestry land comprises over 3,000 Ha[10], all on relatively steep country.
- There is around 23,000 Ha of horticultural land in the Nelson and Tasman Regions, predominantly on the Waimea Plains[11].

2.4.7.2 Comments

While there is a significant amount of potentially suitable land for the application of biooslids in the Nelson and Tasman Regions it is unlikely to be suitable for slurry or dewatered product. This is due to a combination of:

- Transport costs.
- Current land use - biosolids is unlikely to be suitable for application to land used for growing crops for human or animal consumption.
- Land ownership (very little of the land is owned by the Councils).
- Surrounding land use that is likely to be sensitive to potential odour impacts.
- Topography, making access and management of run-off difficult.

2.4.8 Landfill disposal of dewatered biosolids

2.4.8.1 Description

It is estimated that 27 % of biosolids in New Zealand are placed directly into Class 1 landfills[12]. An additional 4% is used for landfill cover, 5% is stored at wastewater treatment plants and 45% is used for quarry rehabilitation in a biosolids mono fill in Auckland. Dewatering is undertaken to reduce

[9] Refer to Section 1.5 for discussion on nitrogen content of the biosolids and application rates. Application rates are normally based total nitrogen applied, this doesn't change with water content i.e. the same area is required for slurry, dewatered biosolids and dried biosolids.
[10] 500 Ha owned by Nelson City Council, 2,500 Ha owned by Tasman District Council. There is an additional 7,000 Ha of Crown owned land in plantation forestry.
[11] 9,000 Ha for fruit and berry, 14,000 Ha for grain,
[12] Report, The Value of Biosolids in NZ-An Industry Assessment, Prepared for WasteMINZ 2019, Rob Tinholt, 2019.

sludge volume, reducing handling, transport and landfill gate fee costs. In comparison to international trends (Europe, Australia and the U.S.) New Zealand has maintained high landfill disposal rates. This is due to a range of factors that are likely to include:

- Potential user concerns about sewage derived products.
- Relatively low cost landfill disposal in most parts of New Zealand.

Reasons to consider alternatives to landfill disposal in New Zealand have become more compelling in recent times. Significant factors include:

- Increasing cost of disposal due as new landfill facilities are developed.
- The need to blend dewatered biosolids with general waste to meet typical consent conditions and maintain the stability of the landfill.
- Recognition of the nutrient value of biosolids
- Policy incentives to divert waste from landfill and prioritise reuse including the Emissions Trading Scheme charges and the landfill levy[13].

Watercare Services Limited disposes of limed, dewatered biosolids at Puketutu Island in Mangere. The disposal process will ultimately restore an area that has been quarried. There also examples of sludge 'mono fills' associated with pulp and paper manufacturing sites in New Zealand.

2.4.8.2 Biosolids quality requirements

Input material characteristics depend on the dewatering method used, around 20 % solids can be achieved through traditional dewatering. Landfill acceptance criteria typically require a cake rather than flowing material.

2.4.8.3 Comments

Even at 20% dry solids biosolids or dewatered wastewater sludge needs to be blended with general waste to maintain the stability of the landfill. The appropriate blend ratio is dictated by biosolids properties.

Dewatered sludge is typically treated as a special waste, requiring immediate burial and careful handling. This means disposal rates are often 1.5 - 2 x rates for general waste.

Landfilling is generally not viewed in NZ as best practice biosolid management as the value of biosolids is not optimized. However, some regions continue to be constrained by lack of economic alternatives and for that reason landfill disposal continues. This may however change if the increase in the landfill levy is progressed. During consultation in early 2020, mid 2020 was noted as the likely timing for deciding on any changes to the waste levy. This has been delayed due to COVID-19 with no clear signal from government on when a decision will be made.

In Tasman / Nelson the only landfill that could potentially accept biosolids is York Valley Landfill (Market Road, Nelson).

2.5 Preliminary option evaluation

This section presents a range of technically feasible end use or disposal options. To develop a short-list of options for further consideration, the viability in Nelson/Tasman has been evaluated. This involves looking at potential links from the product provided at the WWTP through to an end use or disposal options.

[13] NZ is currently undertaking a landfill levy review with a look to increase the price of landfill gate fee, this may further incentivise the diversion of biosolids from landfill.

The technically feasible options are summarised in Table 2.2 with comment on the technical viability.

Table 2.2: Product - End use combination viability

Biosolid product	End use/disposal	Comment	Viable
Grade A slurry	Moturoa /Rabbit Island	Current approach	ü
	Other forestry/horticulture	There are no suitable alternative locations close to Bell Island, slurry is unlikely to be suitable for horticulture due to stand down period after application. Soil injection could be possible on NRSBU or other farm land with 600 Ha or more required.	û
Grade A dewatered	Moturoa /Rabbit Island	Requires new application approach and investment in new processing at Bell Island (digestion, pasteurisation, dewatering). Potential for odour issues similar to slurry.	ü
	Other forestry/horticulture	Requires new processing at Bell Island (digestion, pasteurisation, dewatering). There are no suitable alternative locations close to Bell Island, dewatered biosolids are unlikely to be suitable for horticulture due to stand down period after application.	û
Grade B dewatered	York Valley Landfill	Requires dewatering at Bell Island, transport and disposal charges are likely to be significantly more expensive than the current costs.	ü
Grade A dried	Moturoa /Rabbit Island	Potential to spread dried biosolids with conventional fertiliser spreader and existing tracks. Low odour product. Requires investment in new processes at Bell Island (dewatering and dryer).	ü
	Other forestry/horticulture	Potentially suitable locations (horticulture) but likely to be concerns about sewage derived product. Potentially viable to transport dried product to suitable forestry block. Requires investment in new processes at Bell Island (dewatering and dryer).	ü
	Open market	Contaminant levels likely to preclude general sale. Likely to be concerns about sewage derived product. Requires investment in new processes at Bell Island (dewatering and dryer).	û
Grade A compost/ vermi-compost	Moturoa /Rabbit Island	Requires new application approach, requires investment in new processing at Bell Island (dewatering, enclosed composting or vermi-composting). Requires a source of bulking agent (for example green waste or sawdust). Addition of bulking agent means there will be significantly more material to apply i.e. Moturoa / Rabbit Island may not be large enough.	û
	Other forestry/horticulture	Requires new application approach, requires investment in new processing at Bell Island (dewatering, enclosed composting or vermi-composting). Requires a source of bulking agent (green waste, sawdust, ...). Potentially suitable locations (horticulture) but may to be concerns about sewage derived product. Potentially viable to transport compost/vermi-compost product to suitable forestry block.	û

Biosolid product	End use/disposal	Comment	Viable
	Open market	Requires new application approach, requires investment in new processing at Bell Island (dewatering, enclosed composting or vermi-composting). Requires a source of bulking agent (green waste, sawdust, ...). Potentially suitable locations (horticulture) but may to be concerns about sewage derived product. Potentially viable to transport compost/vermi-compost product to suitable forestry block.	û

2.6 Options shortlist

The options evaluation will only focus on options that are proven and technically viable for potential Moturoa/ Rabbit Island application. A number of end use options discussed in the sections above, although technically feasible, have been discounted from further analysis for the following reasons:

- Land application of biosolids slurry at another forestry or horticulture location: although feasible no potentially viable locations have been identified. Key requirements include proximity to the Bell Island wastewater treatment plant (to enable pumping of the slurry), topography, land ownership (Council preferred) and adjacent land use.
- Land application of dewatered biosolids: Although feasible, is not widely practiced in NZ and no viable alternatives to Moturoa / Rabbit Island have been identified. Key requirements include proximity to the Bell Island wastewater treatment plant (to minimise transport costs), topography, land ownership (Council preferred) and adjacent land use. While there is a large amount of forestry land the combination of steep topography and largely private ownership means biosolids application on forestry is not an attractive option for NRSBU.
- Sale of dried biosolids to the public: although feasible, it would require significant investment in new processing steps with an uncertain market for the product.
- Composting/vermicomposting of dewatered sludge: Although viable it would be high cost, produce a large amount of product which may require additional land for disposal and would require development of new processing steps and markets for processed product.

Of the end use / disposal options described in Section 2.5, five have been identified as viable and worthy of further assessment. These are:

1. Class Ab biosolid slurry to Moturoa / Rabbit Island
2. Class Bb dewatered biosolid to York Valley Landfill
3. Class Ab dewatered biosolids to Moturoa / Rabbit Island
4. Class Ab dried biosolid to Moturoa / Rabbit Island
5. Class Ab dried biosolid to Other forestry/horticulture

3 Short-list evaluation

3.1 Evaluation approach

Assessing options for biosolids management from the WWTP requires consideration of a wide range of factors. Options were assessed against evaluation criteria that were developed with project stakeholders and can be referred to in Table 3.1.

Table 3.1: Chosen evaluation criteria for assessing biosolids management options

Criteria	Description
Technical risk/viability	A qualitative assessment of the comparative technical risk associated with the option i.e. what are the chances of failure due to technical issues. Look for options with demonstrated success in New Zealand or similar.
Market risk	A qualitative assessment of the market risk associated with the option i.e. what are the chances of failure due to difficulties with the final disposal or reuse component of the option.
Resilience risk	A qualitative assessment of the resilience of the option to various disruptions including low probability, high impact events, for example forest fire on Moturoa / Rabbit Island.
Local environment impacts	A qualitative assessment of likely net local environmental impact of the option (i.e. odour, groundwater, coastal water). In this context local refers to the activity site and surrounding land uses.
Greenhouse gas impacts	A high level qualitative assessment of potential greenhouse gas emissions from each option, considering processing, transport and disposal.
Community impacts	A qualitative assessment of likely community support or opposition for the option, likely associated with local environmental impacts but also considering cultural impacts.
Cost	Comparative costs

For each criteria options are ranked as high, medium or low and colour coded accordingly. This scale reflects 'risk or impact of cost' of each option. Low (risk, impact of cost) is preferable to medium or high, reflected by the green colour coding.

The evaluation should not be interpreted as a determination of the magnitude of effect on the environment under the Resource Management Act 1991 (RMA). Rather the intention is to compare and contrast the short listed options to, on balance, identify the preferred option.

A detailed assessment of the cost of each option is beyond the scope of this evaluation. The focus of the cost criteria is on comparing the relative cost of the options under consideration. Where an option is anticipated to cost more it is qualitatively evaluated as high.

3.2 Short-list evaluation

The short-list of end use/ disposal options identified in Section 2.6 have been combined with the process options identified in the Beca Process Alternatives Assessment (refer to Section 3.3). The options evaluated are:

1a ATAD - Class Ab biosolid slurry to Moturoa / Rabbit Island

1b Thermal pre-treatment, anaerobic digestion - Class Ab biosolid slurry to Moturoa / Rabbit Island

1c Thermal pre-treatment, anaerobic digestion, aerobic digestion - Class Ab biosolid slurry to Moturoa / Rabbit Island

2 Anaerobic digestion, dewatering - Class Bb dewatered biosolid to York Valley Landfill

3 Thermal pre-treatment, anaerobic digestion, dewatering - Class Ab dewatered biosolid to Moturoa / Rabbit Island
4 Thermal pre-treatment, anaerobic digestion, drying - Class Ab dried biosolid to Moturoa / Rabbit Island
5 Thermal pre-treatment, anaerobic digestion, drying - Class Ab dried biosolid to other forestry/horticulture

3.2.1 Technical risk/viability

Considering technical risk, options that are proven at commercial scale and in New Zealand are generally considered lower risk than those that are novel in a New Zealand context. Multiple process steps or those that have the potential to introduce risk in other areas are also considered higher risk.

Table 3.2: Technical risk summary

	1a ATAD + Slurry (Moturoa)	1b Thermal + Anaerobic Digestion + Slurry (Moturoa)	1c Thermal + Anaerobic Digestion + Aerobic Slurry (Moturoa)	2 Anaerobic digestion + landfill	3 Thermal + Anaerobic digestion + Dewater (Moturoa)	4 Anaerobic Digestion + Drying (Moturoa)	5 Anaerobic Digestion + Drying (Moturoa)
Proven at scale	ü	~	~	ü	ü	ü	ü
Proven in New Zealand	ü	û	û	Landfill may not be available	~	ü	~

3.2.2 Market risk

Options that have secure market, location for application or disposal location are considered low risk. This favours end use or markets that are controlled by NRSBU or one of the owner Councils. Options that apply biosolids at Moturoa / Rabbit Island present a lower market risk than those that apply biosolids elsewhere. Landfill is considered medium risk because there is an objective to reduce the disposal of organic waste at York Valley Landfill.

3.2.3 Resilience risk

Resilience risk favours options that allow for a range of process, application and/or disposal options. In this context application of sludge or dewatered biosolids at Moturoa / Rabbit Island presents a higher resilience risk when compared with disposal of dewater sludge at York Valley Landfill or application of dried biosolids. Dried biosolids are relatively easy to transport to alternative locations.

3.2.4 Local environment impacts

Local environmental impacts are being evaluated in detail for the AEE. Based on experience to date with the application of aerobically digested biosolids slurry at Moturoa / Rabbit Island the local impacts are considered low risk. Anaerobically digested slurry has the potential to generate odour during application. Transporting dewatered sludge to landfill will generate multiple heavy vehicle movements to/from Bell Island which is accessed via a causeway across the estuary, accessible only at low tide.

3.2.5 Greenhouse gas impacts

From the perspective of greenhouse gas generation the status quo is relatively energy efficient. Introducing thermal treatment and anaerobic digestion increases the energy requirement but also generates biogas that can be used to generate energy.

Transporting dewatered biosolids to landfill generates transport related impacts and contributes to landfill gas generation at York Valley Landfill.

Drying biosolids requires considerable energy with the demand more than can be supplied by biogas.

3.2.6 Community impacts

The evaluation of community impacts is preliminary and will be informed by ongoing community engagement. The benefits of using the nutrients present in the biosolids are balanced by potential community concerns about the application of biosolids to land.

3.2.7 Cost

The cost for each option can be compared on the basis of different process components and operational costs. Table 3.3 summarises key contributors to cost for each option, indicative costs are presented in Figure 3.1 and Figure 3.2.

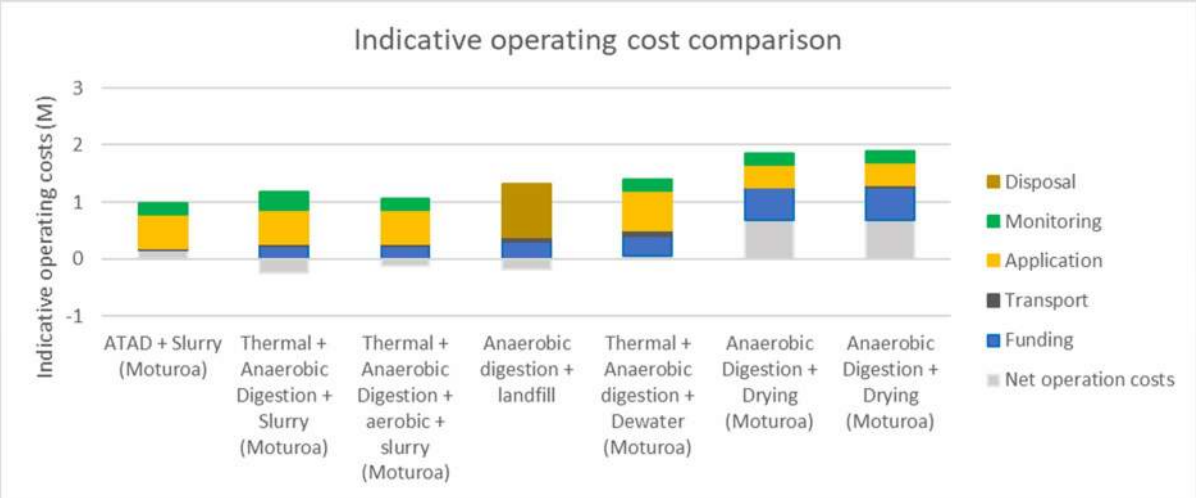

Figure 3.1: Indicative annual operating costs including funding

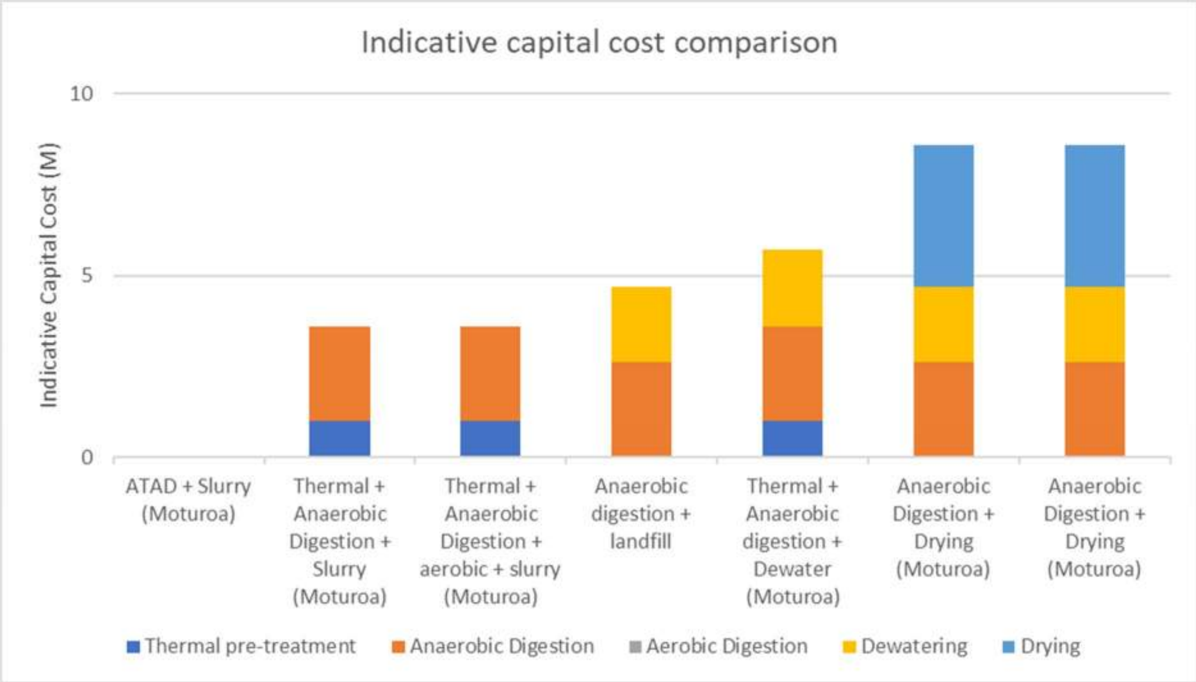

Figure 3.2: Indicative capital costs by process component[14]

[14] Refer Appendix A of the Beca Process Alternatives Assessment

Table 3.3: Cost items for each option

	1a ATAD + Slurry (Moturoa)	1b Thermal + Anaerobic Digestion + Slurry (Moturoa)	1c Thermal + Anaerobic Digestion + Aerobic Slurry (Moturoa)	2 Anaerobic digestion + landfill	3 Thermal + Anaerobic digestion + Dewater (Moturoa)	4 Anaerobic Digestion + Drying (Moturoa)	5 Anaerobic Digestion + Drying (Moturoa)
Process	ATAD	Thermal pre-treatment + Anaerobic digestion	Thermal pre-treatment + Anaerobic digestion + aerobic digestion	Anaerobic digestion + Dewatering + Additional nutrient removal requirements at WWTP[15]	Anaerobic digestion + Dewatering + Additional nutrient removal requirements at WWTP[15]	Thermal pre-treatment + Anaerobic digestion + Dewatering + Drying + Additional nutrient removal requirements at WWTP[15]	Thermal pre-treatment + Anaerobic digestion + Dewatering + Drying + Additional nutrient removal requirements at WWTP[15]
End use/ disposal	Slurry to Moturoa / Rabbit Island	Slurry to Moturoa / Rabbit Island	Slurry to Moturoa / Rabbit Island	Dewatered biosolid to York Valley Landfill	Dewatered biosolid to land at Moturoa / Rabbit Island	Dry granule applied to Moturoa / Rabbit Island	Dry granule applied to other forest or horticulture

[15] The liquid removed during dewatering will be returned to the wastewater treatment plant, increasing the loading of nutrients requiring removal.

	1a ATAD + Slurry (Moturoa)	1b Thermal + Anaerobic Digestion + Slurry (Moturoa)	1c Thermal + Anaerobic Digestion + Aerobic Slurry (Moturoa)	2 Anaerobic digestion + landfill	3 Thermal + Anaerobic digestion + Dewater (Moturoa)	4 Anaerobic Digestion + Drying (Moturoa)	5 Anaerobic Digestion + Drying (Moturoa)
Operations costs	ATAD aeration + Slurry pumping + Biosolids application	Thermal pre-treat heating (can use gas from anaerobic digestion) + Anaerobic digestion pumping + Slurry pumping + Biosolids application - Power generation from excess biogas.	Thermal pre-treat heating (can use gas from anaerobic digestion) + Anaerobic digestion pumping + Aerobic digestion + Slurry pumping + Biosolids application - Power generation from excess biogas.	Anaerobic digestion pumping + Dewatering + Energy cost for nutrient removal + Transport to York Valley + Landfill disposal charges incl landfill levy and emissions trading - Power generation from excess biogas.	Anaerobic digestion pumping + Dewatering + Revised Biosolids Application + energy cost for nutrient removal - Power generation from excess biogas.	Thermal pre-treat heating (can use gas from anaerobic digestion) + Anaerobic digestion pumping + Dewatering + Drying + Transport to Moturoa / Rabbit Island + Biosolids application + energy cost for nutrient removal	Thermal pre-treat heating (can use gas from anaerobic digestion) + Anaerobic digestion pumping + Dewatering + Drying + Transport to Moturoa / Rabbit Island + Biosolids application + energy cost for nutrient removal

3.2.8 Short-list evaluation summary

Evaluation results are summarised in Table 3.3 with commentary against each evaluation criteria provided in Table 3.4. Each of the options were scored against each of the options assessment criteria set out in Table 3.1. For each criteria options are ranked as high, medium or low and colour coded accordingly. Low (risk, impact of cost) is preferable to medium or high, reflected by the green colour coding.

Table 3.4: Options assessment summary matrix for biosolids treatment and end use /disposal.

	1a ATAD + Slurry (Moturoa)	1b Thermal + Anaerobic Digestion + Slurry (Moturoa)	1c Thermal + Anaerobic Digestion + Aerobic Slurry (Moturoa)	2 Anaerobic digestion + landfill	3 Thermal + Anaerobic digestion + Dewater (Moturoa)	4 Anaerobic Digestion + Drying (Moturoa)	5 Anaerobic Digestion + Drying (Moturoa)
Technical risk/viability	Low	Medium	Medium	High	Low	low	Medium
Market risk	Low	Low	Low	Medium	Low	Low	Medium
Resilience risk	*High*	*High*	*High.*	*Medium*	*High*	*Low*	*Low*
Local environmental impacts	Low	Medium	Low	Medium	Low	Medium	Low
Greenhouse gas impacts	Low	Medium	Medium	High	Low	High	High
Community impacts	Medium	Medium	Low	Medium	Low	Medium	Medium
Cost	Medium	Medium	Medium	High	High	High	High

Table 3.5: Options assessment matrix for biosolids treatment and end use /disposal.

	Option 1a	Option 1b	Option 1c	Option 2a
Description	Processing: ATAD End use: Slurry to Moturoa / Rabbit Island	Processing: Thermal pre-treatment, anaerobic digestion End use: Slurry to Moturoa / Rabbit Island	Processing: Thermal pre-treatment, anaerobic digestion plus Aerobic Digestion End use: Slurry to Moturoa / Rabbit Island	Processing: Anaerobic digestion, dewatering Disposal: Cake to York Valley Landfill
Technical risk/viability	Low *Proven process at Moturoa / Rabbit Island*	Medium *Land application of slurry is relatively novel to NZ, this process has potential for odour issues due to sulphide generation under anaerobic conditions resulting in hydrogen sulphide emissions (rotten egg odour). Potential for struvite formations to block slurry pipeline.*	Medium *Process options individually proven but no experience in NZ with the combination of processes.* *Reasonably unique process configuration.*	High *Conventional process and end use in New Zealand.* *Nelson Tasman Regional Landfill Business Unit is actively working to reduce their emission profile, and therefore discouraging organic material acceptance. It is unclear whether this waste would be accepted.*
Market risk	Low *Land controlled by TDC*	Low *Land controlled by TDC.*	Low *Land controlled by TDC*	Medium *Landfill disposal (controlled by Nelson Tasman Regional landfill Business Unit).*
Resilience	High *Risk to system if Moturoa /Rabbit Island is not accessible for biosolids application, for example due to forest fire[16]. Due to difficulty in transporting Slurry.*	High *Risk to system if Moturoa /Rabbit Island is not accessible for biosolids application, for example due to forest fire. Due to difficulty in transporting Slurry.*	High *Risk to system if Moturoa /Rabbit Island is not accessible for biosolids application, for example due to forest fire. Due to difficulty in transporting Slurry.*	Medium *Reduced risk because dewatered biosolids can be transported more easily than slurry if required but the nearest landfill if York Valley is not available is in Blenheim.*

[16] An example of a 'black swan' event, an unpredictable event that is beyond what is normally expected of a situation and has potentially severe consequences. Black swan events are characterized by their extreme rarity, their severe impact, and the widespread insistence they were obvious in hindsight.

	Option 1a	Option 1b	Option 1c	Option 2a
Description	Processing: ATAD End use: Slurry to Moturoa / Rabbit Island	Processing: Thermal pre-treatment, anaerobic digestion End use: Slurry to Moturoa / Rabbit Island	Processing: Thermal pre-treatment, anaerobic digestion plus Aerobic Digestion End use: Slurry to Moturoa / Rabbit Island	Processing: Anaerobic digestion, dewatering Disposal: Cake to York Valley Landfill
Local environmental impacts	Low 25 year experience shows this has not caused any significant adverse effects. *Potential for odour issues*	Medium *Increased Potential for odour issues from the anaerobically digested sludge.*	Low *Process performance expected to be better than current. Similar biosolids product to the current slurry.*	Medium *Biosolids no longer applied at Moturoa / Rabbit Island, multiple transport movements.*
Greenhouse gas impacts	Low *No additional energy required, application location close to generation.*	Medium *Energy required for thermal pre-treatment (biogas)*	Medium *Energy required for thermal pre-treatment (biogas) and for aerobic digestion. Possible improve energy efficiency over all compared to current system.*	High *Dewatering, transport, and landfill gas emissions.*
Community impacts	Medium *Application of biosolids has been in service for 24 years.* *Increase tree growth, improves economics from TDC forest.* *Potential adverse effects from odour.*	Medium *Application of biosolids with nutrient recovery but potential for odour impacts.*	Low *Current impacts low, this option likely to reduce further. Due to expected improvements in effects from odour.*	Medium *Risk that the NTRLBU landfill will not accept the material, and biosolids would need to be carted to Kate Valley landfill.*
Cost	Medium cost *Business as usual, no capital investment required, med-high operation cost*	Medium cost *Investment in thermal pre-treatment and anaerobic digestion required, lower net operation cost.*	Medium cost *Investment in thermal pre-treatment and anaerobic digestion required. Ongoing costs for aerobic digestion.*	High cost *Investment in anaerobic digestion and dewatering required. Landfill disposal cost.*

	Option 3	Option 4	Option 5
Description	Processing: Anaerobic digestion, dewatering Disposal: Cake to Moturoa / Rabbit Island	Processing: Thermal pre-treatment, anaerobic digestion, dewatering, drying End use: Dry granule applied to Moturoa / Rabbit Island	Processing: Thermal pre-treatment, anaerobic digestion, dewatering, drying End use: Dry granule applied to other forest or horticulture
Technical risk/viability	Low *Relatively novel combination of processes, but all proven. Application of dewatered product would require alternative machinery and operational requirements in the forest.*	Low *Relatively novel combination of processes, but all proven, and therefore technically viable with low risk.*	Medium *Relatively novel combination of process options, but all proven technologies. Risks are present for ongoing acceptance by third party land owners due to the sewage origin of the material*
Market risk	Low *Land controlled by TDC*	Low *Land controlled by TDC*	Medium *Land application of dried biosolids is novel in NZ*
Resilience	High *Risk to system if Moturoa /Rabbit Island is not accessible for biosolids application, for example due to forest fire. Dewatered biosolids are easier to transport to alternative locations for application if required. New location would need to be developed.*	Low *Reduced risk to system if Moturoa /Rabbit Island is not accessible for biosolids application, for example due to forest fire. Dried biosolids are straight forward to transport to alternative locations for application if required.*	Low *Reduced risk to system if Moturoa /Rabbit Island is not accessible for biosolids application, for example due to forest fire. Dried biosolids are straightforward to transport to alternative locations for application if required. However risk of events occurring is higher due to reliance on third party land.*

	Option 3	Option 4	Option 5
Description	Processing: Anaerobic digestion, dewatering Disposal: Cake to Moturoa / Rabbit Island	Processing: Thermal pre-treatment, anaerobic digestion, dewatering, drying End use: Dry granule applied to Moturoa / Rabbit Island	Processing: Thermal pre-treatment, anaerobic digestion, dewatering, drying End use: Dry granule applied to other forest or horticulture
Local environmental impacts	Low Application of Slurry to land has shown no significant adverse effects and this option reduces the potential for adverse effects further by reducing potential for run-off or odour.	Medium *Reduced odour risk compared to slurry, significantly less benefit from fertiliser effect of the application.*	Low *Biosolids no longer applied at Moturoa / Rabbit Island*
Greenhouse gas impacts	Low *Biogas production will allow improved energy efficiency but may result in increased calculated emissions.* *Less energy required and disposal close to generation.*	High *Energy required for thermal pre-treatment and drying (biogas)*	High *Energy required for thermal pre-treatment and drying (biogas), transport*
Community impacts	Low *New application methods increases risk, but overall impacts reduce.* *Tree growth benefits reduced TDC economic benefits.*	Medium *Application of biosolids to land but beneficial reuse.*	Medium *Application of biosolids to land but beneficial reuse.*
Cost	High cost *Investment in thermal pre-treatment and anaerobic digestion and new application vehicles required.*	High cost *Investment in in anaerobic digestion, dewatering, thermal drying required. High operational costs.*	High cost *Investment in in anaerobic digestion, dewatering, thermal drying required. High operational costs.*

3.3 Summary of evaluation

Options with a high proportion of green are preferable to those with a higher proportion of orange and red coding. There is no weighting of the criteria. The evaluation of community impacts is preliminary only and should be tested through engagement with key stakeholders.

Option 1a (application of slurry from the existing ATAD process) is the preferred option. This reflects a secure 'market', relatively low energy inputs and relatively low cost. This option requires careful management of odour risk. The evaluation considers community impacts are low and reflects 24 years of experience with land application of biosolids, no significant adverse effects and balanced by the positive view of beneficial use of the nutrients present in the biosolids.

Option 1b (application of slurry from a new process involving thermal pre-treatment and anaerobic digestion of wastewater solids) is not preferred. This reflects the additional capital cost (for thermal pre-treatment and anaerobic digestion), additional energy for processing and minimal changes to the product being applied to land at Moturoa / Rabbit Island. Anaerobically digested slurry also presents an increased risk of odour during application due to the presence of sulphides. The evaluation considers community impacts are medium reflecting potential concerns about the increased odour potential from anaerobic material and while this is somewhat balanced by the positive view of beneficial use of the nutrients present in the biosolids, there is an increased risk.

Option 1c (application of slurry from a new anaerobic digestion with post aerobic digestion of wastewater solids) is not preferred. This reflects the additional capital cost (for thermal pre-treatment and anaerobic digestion), additional energy for processing and minimal changes to the product being applied to land at Moturoa / Rabbit Island. The evaluation considers community impacts are low reflecting lower concerns about the odour potential from aerobic material. This option is unproven in NZ and the performance improvement is unclear.

Option 2 (application of dewatered anaerobic digestion sludge at York Valley Landfill) is not preferred. This reflects the fact that the Nelson Tasman Regional Landfill business unit is actively working to reduce its carbon emissions, and one of the aspects being worked on in the Nelson Region is organics diversion from the landfill. This option would also incur additional costs (for anaerobic digestion, dewatering, transport and landfill charges including landfill levy and Emissions Trading Scheme Charges) and greenhouse gas impacts (associated with transport and landfill disposal). These factors are potentially offset by reduced local environmental impacts (although there are limited impacts known at this time) as a result of no application on Moturoa / Rabbit Island. The evaluation considers community impacts are high reflecting potential concerns about the landfill disposal of biosolids, these are exacerbated by reducing the beneficial reuse of nutrients.

Option 3 (application of anaerobically digested and dewatered sludge at Moturoa/Rabbit Island) is not preferred. This option would also incur additional costs (for anaerobic digestion, and dewatering) but would reuse a significant portion of the current infrastructure. An alternative application vehicle would need to be used for the application. This option would significantly reduce the nutrient concentration in the biosolids being applied and therefore increase the mass able to be applied to the land area. These factors are offset by reduced local environmental impacts as a result of less odour potential on Moturoa / Rabbit Island. The evaluation considers community impacts are similar to Option 1b but reflect less potential for odour related concerns. A dewatered product is less beneficial as a reuse fertiliser leading to less benefit realised from increased tree growth. Cost for operations would increase but would be capable of reusing a significant portion of the current infrastructure.

Option 4 (application of dried biosolids at Moturoa / Rabbit Island) is not preferred. This reflects the high cost (for thermal pre-treatment, anaerobic digestion and drying) and additional energy for processing. A dried product is less beneficial as a reuse fertiliser leading to less benefit realised from increased tree growth. These factors are offset by access to a secure market and reduced odour risk during application. The evaluation considers community impacts are medium reflecting potential concerns about the land application of sewage derived material and balanced by the positive view of beneficial use of the nutrients present in the biosolids.

Options 5 (application of dried biosolids at another forestry or horticulture location) is not preferred. This reflects the high cost (for thermal pre-treatment, anaerobic digestion and drying), additional energy (processing, transport) and lack of secure markets. A dried product is less beneficial as a reuse fertiliser leading to less benefit realised from increased tree growth. These factors are offset by reduced local environmental impacts as a result of no application on Moturoa / Rabbit Island. The evaluation considers community impacts are medium reflecting potential concerns about the land application of sewage derived material and balanced by the positive view of beneficial use of the nutrients present in the biosolids.

Other comments from the evaluation include:

- Thermal pre-treatment is required alongside anaerobic digestion to achieve a Grade A product, this is required for land application.
- Thermal pre-treatment is not required for Option 2 (dewatered sludge to landfill) but there may be benefits through the improved solids reduction associated with thermal pre-treatment reducing the quantity of material requiring disposal and associated disposal costs.
- Thermal pre-treatment and drying will require energy input with the potential to use biogas from anaerobic digestion to provide part of the required energy.
- There is no other immediately alternative apparent forestry option available, that is in reasonably close proximity, has an appropriate buffer from neighbouring land uses and that exhibits suitable terrain, that would be suitable for slurry application.
- Landfill disposal costs are likely to rise due to proposed changes in the Landfill Levy and Emissions Trading Scheme costs.

3.4 Best Practicable Option

The RMA requires that the discharge of a contaminant be undertaking utilising the Best Practicable Option. This is defined in Section of the RMA as:

> *best practicable option, in relation to a discharge of a contaminant or an emission of noise, means the best method for preventing or minimising the adverse effects on the environment having regard, among other things, to—*
>
> a *the nature of the discharge or emission and the sensitivity of the receiving environment to adverse effects; and*
>
> b *the financial implications, and the effects on the environment, of that option when compared with other options; and*
>
> c *the current state of technical knowledge and the likelihood that the option can be successfully applied*

Regarding the nature of the discharge or emission and the sensitivity of the receiving environment to adverse effects (a), the application of biosolids at Moturoa / Rabbit Island can be managed to minimise potential adverse impacts including

- Odour during application - through careful application, appropriate buffer zones and excluding the public from areas where biosolids are being applied.
- Elevated nutrients or contaminants in soil or groundwater - through working within defined application rate thresholds based on applying nitrogen at a level that will be used by the

growing pine trees. These application rates also limit the trace contaminants applied, avoiding the potential to accumulate trace contaminants in solids to an unacceptable level.

This is discussed in detail in the Assessment of Effects on the Environment.

Regarding the financial implications, and the effects on the environment, of the application of slurry to land at Moturoa / Rabbit Island when compared with other options (b), this report evaluates a range of options considering cost and effects on the environment alongside risk (technical, market, resilience). The conclusion of that assessment is that Option 1a (aerobic digestion of wastewater solids, application of biosolids slurry at Moturoa / Rabbit Island) is the preferred option (Best Practicable Option).

Regarding the current state of technical knowledge and the likelihood that the option can be successfully applied (c) the evaluation included consideration of a wide range of options for processing (documented in the Beca Process Alternatives Assessment) and end use or disposal. This considered the technical feasibility and viability of a range of options. Options identified technically feasible options (that have been demonstrated at full scale) and short-listed those evaluated as technically viable (operate at a similar scale, process similar materials and operating commercially). The preferred option is proven in operations at Bell Island wastewater treatment plant and Moturoa / Rabbit Island.

4 Conclusions and recommendations

This report outlines an evaluation of potential end uses of biosolids produced by the Bell Island WWTP. The evaluation has considered a range of factors in identifying a preferred option. The factors are:

- Technical risk/viability
- Market risk
- Resilience
- Local environment impacts
- Greenhouse gas impacts
- Community impacts
- Cost

The evaluation concluded that aerobic digestion of wastewater solids to produce a biosolids slurry followed by the application of the slurry to land at Moturoa / Rabbit Island is the preferred and best practicable option.

The evaluation results also suggest that If Moturoa / Rabbit Island is no longer an option for land application then landfill disposal or application of a dried biosolids elsewhere are the most viable options. It should be noted however that:

- Landfill will be expensive and increasingly so with anticipated increases in the Landfill Levy and emissions trading costs.
- Drying will be more attractive if low cost energy can be accessed (e.g. solar) and secure markets are available or can be developed over time.

The evaluation also noted that a change from the current approach would increase costs with funding of capital investment, transport of biosolids to alternative disposal or land application sites and operating costs all considered.

Given the changing nature of biosolids management in New Zealand and globally it is recommended that end use options for biosolids produced at the Bell Island WWTP are periodically re-evaluated.

5 Applicability

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

We understand and agree that our client will submit this report as part of an application for resource consent and that Tasman District Council as the consenting authority will use this report for the purpose of assessing that application.

Tonkin & Taylor Ltd

Report prepared by:

....

Chris Purchas

Senior Consultant

Authorised for Tonkin & Taylor Ltd by:

....

Neville Laverack

Project Director

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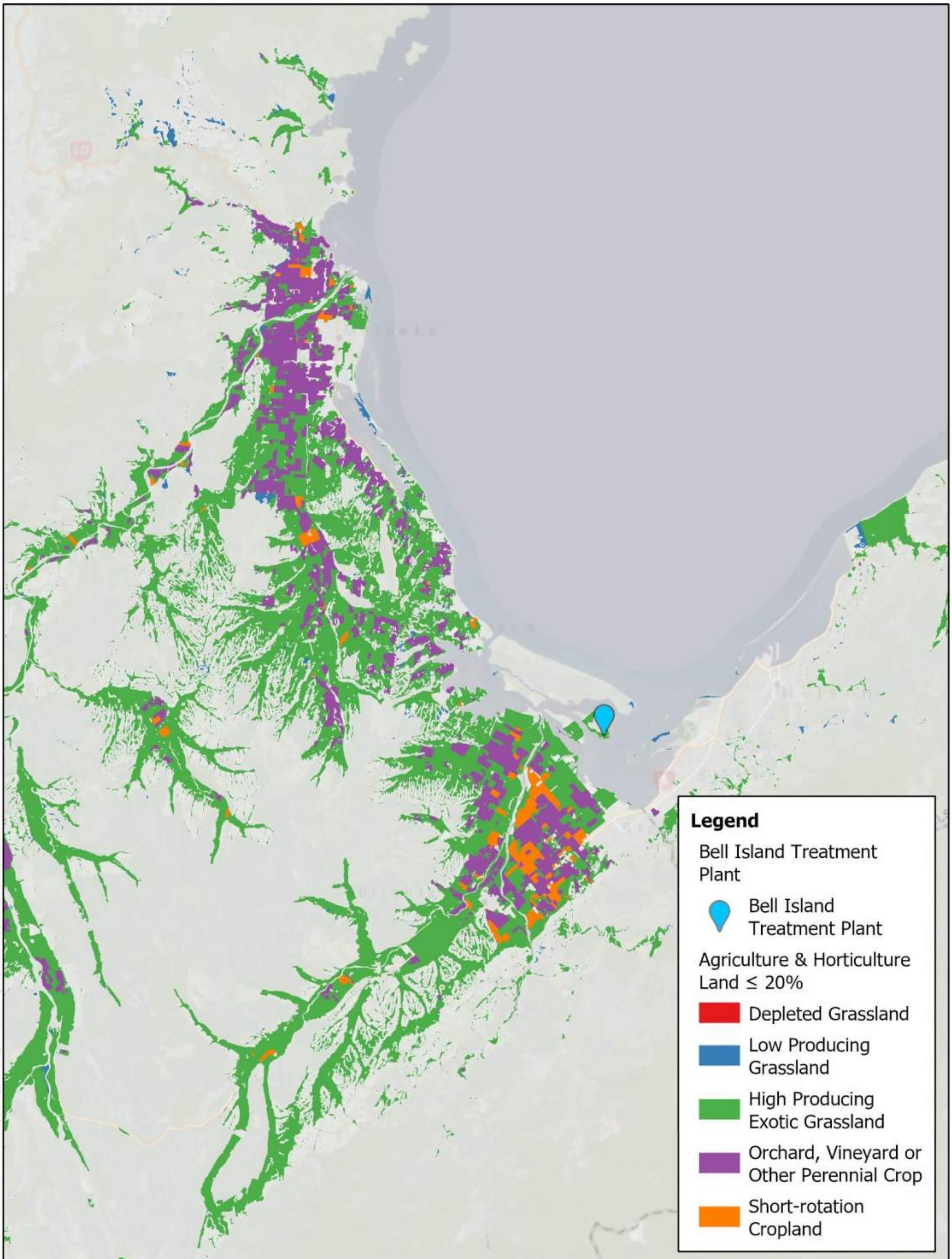
Appendix A: Land use maps - Nelson and Tasman



Sourced from the LINZ Data Service and licensed for re-use under the Creative Commons Attribution 4.0 New Zealand licence , Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community, Land Information New Zealand, Eagle Technology Contains data sourced from LRIS.

Map Scale @ A4: 1:250,000

0 2 4

Kilometres

DRAFT

Title: **Biosolids**

Agriculture and Horticulture Land

FOR INTERNAL PURPOSES ONLY YET TO BE VERIFIED.

Client: NRSBU

Project: Rabbit Island Resource Consent

Beca

Discipline: GIS

Drawing No: GIS-3323048-11

Attachment F

Nelson Regional Sewerage Business Unit

BIOSOLIDS MANAGEMENT PLAN

Distribution:

Malcom Furness (NM Waste)
Sam Nuske (PF Olsen)
Mark Johannsen (TDC)
Brad Nixon (NRSBU)
Nathan Clarke (NRSBU)
Allan Jones (Nelmac)

Updated:
July 2020

Table of Contents

1. INTRODUCTION

In 1996 a joint venture was set up to spray biosolids at Rabbit Island. The joint venture is between the Tasman District Council (TDC) as the land owner and the Nelson Regional Sewerage Business Unit (NRSBU) as the entity managing the biosolids business. NRSBU has engaged NM Waste to carry out the spraying, and PF Olsen to manage the spraying sites and spraying quality.

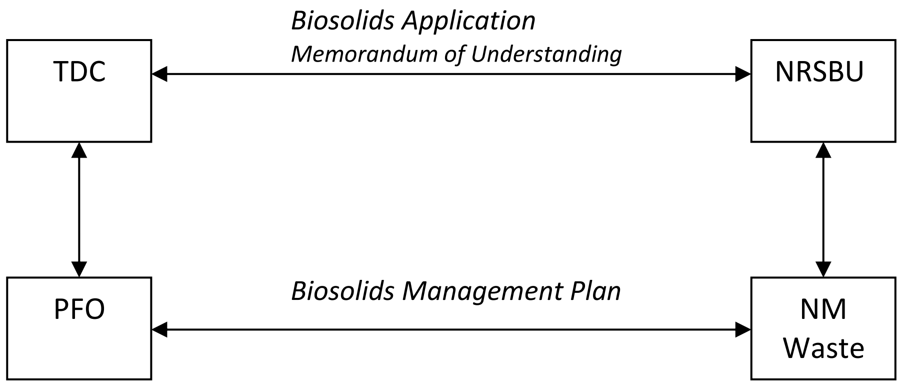
This Management Plan is a working document of the relationship between the above parties and will be reviewed at least annually.

The current Resource Consent (RM940379V3) expires 8 November 2020.

2. STRUCTURE

2.1 Organisational

The structure of the contract is illustrated below.



2.2 Operational

The resource consents (including variations) and discharge permit governing the application of biosolids to Rabbit Island are included as Appendix A.

Contact phone numbers of all personnel involved in the biosolids disposal programme are listed in Appendix B.

Specific operational responsibilities are detailed in the respective contracts between each party. In summary these responsibilities are as follows:

NM Waste

- Application volume calculations
- Rainfall recording
- Health and Safety of NM Waste staff
- Protection and safety of public and visitors in their work sites
- Fire Prevention
- Spillage
- Equipment Failure
- Application maps and records

PF Olsen

- Maintenance of tracks and access
- Forest security
- Spray block schedule
- Audits of spraying and protection of forest infrastructure and tree-crop
- Public safety
- Fire risk management

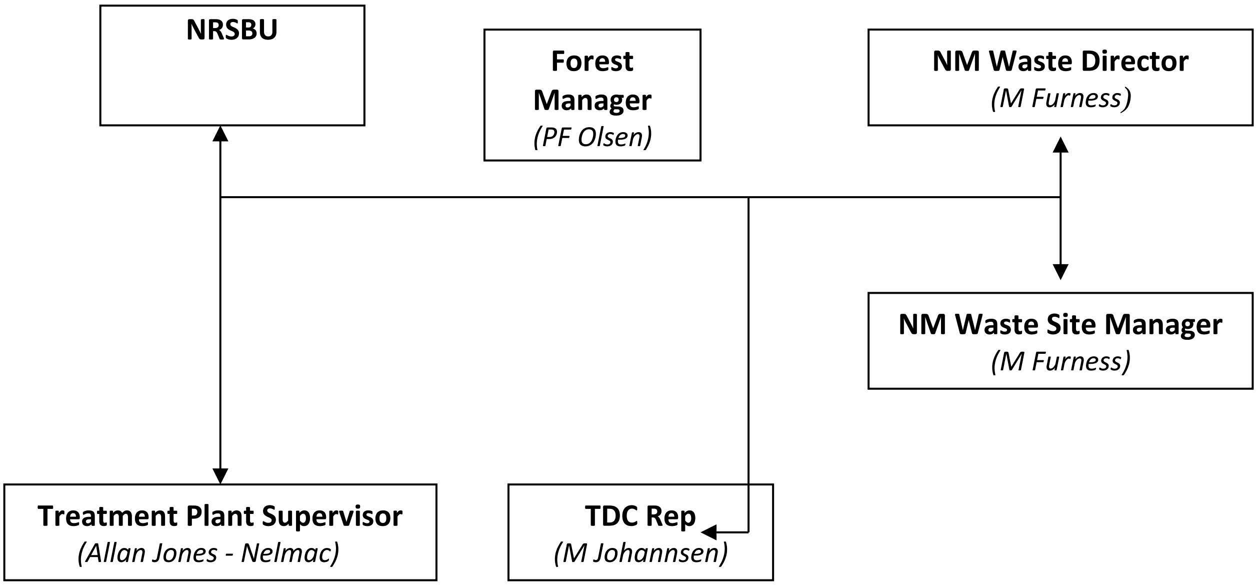
NCC

- Resource Consents Compliance
- Health and Safety audits of BioSpraying operations

Nelmac

- Biosolids Concentration and Quality

STRUCTURE


NRSBU
Forest Manager
(PF Olsen)
NM Waste Director
(M Furness)
NM Waste Site Manager
(M Furness)
Treatment Plant Supervisor
(Allan Jones - Nelmac)
TDC Rep
(M Johannsen)

3. PROCEDURES

3.1 Daily

NM Waste:

- Provide operators with loading rate instructions and data sheets
- Collate sampling data from Bells Island staff
- Storage tanks to be thoroughly mixed to ensure uniform application
- Apply biosolids to the forest areas as per application schedule provided by PF Olsen
- Monitor spray progress and notify PF Olsen two weeks from moving spray blocks. Ongoing liaison with PF Olsen required if spray rates change significantly following the initial notification.
- Confirm weather conditions. Record details
- Select appropriate open application site based on wind direction & velocity

Treatment Plant Supervisor (Bell Island):

- To provide NM Waste with biosolid:
    - quality
    - concentrations (solids and %N)
    - volumes

3.2 Monthly

NW Waste:

- Reconciliation of the quantity of biosolids pumped to Rabbit Island to that disposed
- Review any road maintenance required
- Along with PF Olsen, review access tracks or any opening up of stands required
- Install signage (500x300mm and placed 100m apart) at least one month prior to disposal
- Remove signage at expiry of exclusion period (1-month)
- Restrict public access to disposal areas for 1 month.
- Complete biosolids application records (refer 9.2) for each stand.
- On completion of stand, or as requested, forward map to PF Olsen and the NRSBU. Maps to state area sprayed (in hectares) and application dates and nitrogen rate applied.
- Complete Site Audits (post-spray checks) fortnightly and submit in the monthly report or direct to PF Olsen

PF Olsen:

- Supply NM Waste with updated plan of disposal areas 12 months in advance of spraying to allow signage installation, as per RC
- Complete pre-check spray sheet with NM Waste minimum 6 months prior to spraying operations
- Plan, along with NM Waste, access to blocks and re-establishment (slash-raking, planting spacings, earthworks for sprayer access) to maximise sprayable area (subject to other operational and financial constraints).
- Carry out own quality control within 2-weeks of spraying and complete post spray check sheets during and after completion of block. Arrange remediation or other action where necessary
- Advise TDC when cycleways are affected during spraying operations
- Maintain maps showing:
    - Restricted areas
    - koiwi
    - Gravel lenses
    - Water sampling bores
    - Archaeological sites
    - Cycleways
    - Planned harvesting areas

Continued on next page...

...continued

NRSBU:

- Review site audits and action as necessary
- Review long-term area availability for disposal and to ensure sustainability of applications
- Submit monitoring reports to TDC for Consents listed in Appendix A

The above items will largely form the agenda items for the monthly meeting. This to be chaired by and minutes taken by the NRSBU (or representative) and attended by representatives of NM Waste, Bell Island Operator, and PF Olsen.

3.3 Annual

Activities to be completed by the NRSBU are as follows:

- Survey of additional features identified or included over past year and entering onto maps
- Three Year Strategic Plan (Based on projected loads from the treatment plant)
- Accumulated loadings of heavy metals and nutrients in soils in accordance with resource consents
- Review of monitoring and resource consents conditions for 6-yearly review
- Review Management Plan and update as necessary
- Health and Safety Audit

3.4 Pre-Spray checks

Prior to spraying a pre-check sheet must be completed and signed off by PF Olsen and NM Waste. This check sheet covers:

- Tanker / sprayer access
- Signage
- Public access/cycleways
- Exclusion zones (eg trials, koiwi etc)
- Buffer zones
- Any other areas of concern

A copy of the pre-spray check sheet is attached – Appendix H.

3.5 Post-Spray checks

Regular quality control during the spraying operation is to be carried out by PF Olsen and a post-spray check sheet completed. This sheet covers:

- Tree damage
- Excessive ponding (Engineer to be notified if after 1- 2 weeks ponding subsists)
- Rubbish
- Even coverage
- Damage to infrastructure (signs, roads etc)

A copy of the post-spray check sheet is attached – Appendix I

Once the block is completed a final post-spray check sheet is to be completed and signed off by PF Olsen and NM Waste.

4. RECREATIONAL LAND

TDC shall give the NRSBU notice (as per resource consent conditions or license agreement) of their intention to exclude further land from biosolids disposal areas for recreational uses. This procedure will be governed by the Effluent (Biosolids) Dispersal Licence 1997.

5. HEALTH and SAFETY

5.1 Public Information

A notice board will be erected at the corner of Bullivant Road and Ken Beck Drive. This notice board will be used to inform the public about the biosolids application.

The NRSBU will ensure that the notice board is updated as required.

5.2 Public Access

PF Olsen will liaise with the TDC Reserves managers, and NM Waste to coordinate signage, access, and spraying to minimise the risk to the public.

Public access ways will require closure when spraying machinery needs to operate on the access way. This includes tracks that intersect with operational tracks.

NM Waste will set up and maintain public cycleway closure signage and barriers. NM Waste will endeavour to open cycleways on weekends when it is safe to do so.

5.3 Weekend work

In the event NM Waste need to work on either a Saturday, Sunday or Public holiday, they will need to advise PF Olsen and the NRSBU at least 2 working days prior.

Should PF Olsen consider that undue difficulties will arise because of, for example, conflict with other activities on the Island, then they are to notify NM Waste and the NRSBU immediately.

PF Olsen will, where possible, advise NM Waste of any weekend activities requiring public access within the forest.

5.4 Access to Operational area

Any non-NM Waste personnel requiring access to the immediate operational spray area when spraying is taking place shall notify and obtain the approval of the NM Waste site manager before entry.

Entry to an active spraying area where physical contact of biosolids or inhalation of spray aerosols is likely will require the person to be inoculated with appropriate shots (refer NM Waste H&S manual for more detail).

5.5 Incident and Accident Reporting

All accidents and incidents in NM Waste operations shall be firstly reported to the NRSBU. Any such reports that are concerned with use of vehicles on forest roads, spraying in the forest, or public safety, are also to be notified to PF Olsen.

The NRSBU will notify the TDC of any accidents involving injury or incidents that could have resulted in serious harm. For other non-injury accidents/minor incidents the NRSBU will carry out its own investigation and report to the TDC if appropriate.

For clarification the TDC is the landowner, NW Waste is the contractor, NRSBU are the Principal, and PF Olsen are the forest manager for TDC.

6. EXCLUSION ZONES

Exclusion zones comprising Koiwi, flax, manuka, kanuka and archaeological areas identified in the resource consents in Appendix A, are to be shown on forest application maps.

Prior to application of biosolids the NRSBU is to appoint a suitably qualified person to identify gravel areas within the disposal area. Once these areas are identified, the NRSBU is to have them surveyed to fix the co-ordinates. The site is to be clearly marked by NM Waste, in a manner approved by the NRSBU, and entered onto the forest map.

NM Waste is to ensure that operators are trained to identify gravel areas and objects of archaeological interest. If such area or objects are identified during disposal operations the NRSBU is to be notified immediately. The NRSBU will then:

- Notify the relevant parties to conduct an inspection
- Survey the area to fix co-ordinates
- Instruct NM Waste to fence the area off
- Ensure the site (if to be permanently excluded form spraying) is recorded on forest maps

7. TRIAL SITES

PF Olsen have set up a trial in Cpt 11.04 to evaluate the effects on tree growth of varying nitrogen loadings. This is approved under the resource consent. As of 2015 spraying of the trial is to be ceased due to the trail intersecting a marked koiwi area. Measurement and sampling of this trail will remain unchanged.

PF Olsen will be responsible for all "above ground" monitoring of trial sites (tree growth). NRSBU will be responsible for "below ground" monitoring of trial sites (soil and groundwater). This responsibility extends to costs as well.

8. APPLICATION PLAN

- **Forest Operations**

  Planting
  For any stand, planting is carried out during the winter immediately following completion of harvesting. Consideration should be taken by PF Olsen in planning slash-raking and planting (row direction/spacing) to facilitate access by biosolid spraying vehicles and trucks.

  Tending
  Stands are left until age 5-6 years, when they are pruned to 2.5 metres and thinned to a final crop stocking of 350-400 stems per hectare. Trees will be then second pruned to a minimum of 5.6 metres. From this time on, trees are left through to harvest, generally at age 28-30 years.

  Where possible, subject to maintaining sufficient future spray areas, no spraying shall take place in stands within 1-month of first pruning and until 1-month after the final prune and thin. This will minimise the risk of damage to trees during the most vulnerable stage.

  Generally thinning to waste prevents the access of biosolid sprayers for 1-2 years due to felled trees blocking vehicle movements. To allow the spray schedule to continue undelayed, PF Olsen where practical will look to thin blocks in a manner that leaves one row every 40 metres which is clear of thinnings for the biosolids sprayers to use as access.

- **Age Classes Excluded from Spraying**

  An exclusion period of 3 years prior to the harvesting of any stand.

- **Nutrient Requirements of P.radiata**

  In areas subject to nitrogen deficiency, such as Rabbit Island, a response in diameter growth can be expected following application of nitrogen fertiliser. This has been proven in nitrogen trials already existing on Rabbit Island. The nitrogen demands of P.radiata are generally constant from planting through to maturity. A slight reduction in the amount required occurs after canopy closure.

  Application of biosolids will effectively eliminate the need for nitrogen but applications of phosphate and boron may still be necessary. Regular foliage sampling will confirm the need for supplementary fertilisers. Nitrogen fertiliser may still be required where biosolids has not been applied.

- **Buffer Zones**

  A significant number of stands are affected by buffer zones adjacent to public access ways, archaeological sites and around the coastal margin of Rabbit Island. Buffer requirements are detailed in the consent.

8.1 Spray Schedule

The available disposal areas and anticipated date of application will be maintained and kept up to date in a Schedule by PF Olsen and provided to NM Waste in advance of application. Due to the frequency with which changes are made to the schedule this is not attached to this Management Plan but available on request. The biosolids discharge regime allowed for under the current Resource Consent (NN940379V3) is specified in Table 1 of that consent. This specifies the allowable rate and timing of application.

8.2 Records to be kept

NW Waste:

- Application details: stand, rate, area, depth, volume, application date. Data to be shown on maps as appropriate.
- Daily weather data (including rainfall)
- Allowable solids loading rate for each disposal area
- Metered volumes of biosolids discharged from Rabbit Island holding tanks
- Operational and/or safety problems and responses
- Accidental spillage (refer to procedure in Appendix E)
- Vehicle, machinery and plant maintenance records (monthly)

NRSBU:

- Biosolids and Environmental monitoring as required by Consent- refer Appendix C
- Minutes of monthly meetings
- Register of odour complaints from external parties

PF Olsen:

- Maintain spray records and maps.
- Maintain updated spray schedule
- Tree trial growth data

9. CONTINGENCY PLANS

Contingency plans to be included are:

- Fire Fighting Co-ordination (Appendix D)
- Spillage or Contamination by Biosolids (Appendix E)

Appendix A: Resource Consents

Note: only the most recent consent for Rabbit Island is attached:-

Rabbit Island Variation (450kg/ha)	NN 940379V3

Other relevant documents:

• Resource Consent	RM 940534
• Discharge Permit	NN 940379D
• Nickel Variation to Consent	NN 940379D
• Effluent Dispersal Licence	

Appendix B: Contact Phone Numbers

NRSBU		
Brad Nixon *Operations Manager*	539 5570 (b/h)	Mob: 022 010 8471
Nathan Clarke *General Manager*	546 0370 (b/h)	Mob: 022 013 4808
NELMAC		
Bells Is Duty Operator:	021 301 391 (24hrs)	
Allan Jones *Operations Manager - Treatment*	Mob: 021 845 810	
PF OLSEN		
Sam Nuske *Branch Manager*	544 0066 (b/h)	Mob: 029 773 0935
TDC		
Mark Johannsen	543 8400 (b/h)	
NW WASTE		
Malcolm Furness *Director*	021 074 4185 (24 hours)	

Appendix C: Resource Consents Monitoring

BIOSOLIDS APPLICATION MONITORING PROGRAMME
NN 940 379V3

Biosolids					Groundwater			Soils#		Coastal		
Microbes		pH, N, P,K and Metals	Organo - Cl and P	Temp (>50C)	Levels	pH, N, Cl & Conductivity	Heavy Metals and Al	pH, N, P, K, Ca, Mg & Na	Heavy Metals & Al	Full	Visual	Benthic Algae
Refer consent: only required at start up unless non-compliance with temperature	Amended by agreement December 2011. Sampling to be monthly, or more frequently if levels approach USEPA Class A faecal coliform limits of 1000/gram. i.e 100,000/100g	3 Monthly	5 yearly	Continuous	3 monthly	3 monthly	Annually	3 yearly following initial application to the stand	3 yearly following initial application to the stand	6 yearly inc transects	Initially 6 monthly, then 3 yearly	6 Yearly

\# Soil to be tested every 3 years: 0-20cm, 20-40cm. Two samples per 10ha applied.

Appendix D: Fire Fighting Co-ordination

(Adapted from NM Waste Safety Plan)

Fire suppression to take priority over all other activities on Rabbit Island.

All NM Waste employees will comply with the requirements for fire training and access to protective clothing as stipulated in their contract with NRSBU.

Every reasonable effort shall be made to put out any unattended fires and report these fires to the Forest Manager immediately, and to dial 111 for emergency services.

When requested, employees and biosolid disposal equipment will be made available to the Forest Managers or Waimea Rural Fire Authority for firefighting.

Appendix E: Spillage and Contamination by Biosolids

(Adapted from NM Waste Safety Plan)

EMERGENCY PLAN

The purpose of the emergency plan is to provide a means of minimising the effects of accidental spillage, discharge or creation of materials which are environmentally damaging. This plan should be displayed prominently for all site personnel to read.

IN CASE OF ACCIDENTAL SPILLAGE:

- Do what you can to prevent it from spreading if it is a large spill. If outside, use earth to build a dam or retaining wall. If inside, use pieces of timber to prevent it from spreading. Small spills will be spread out to prevent concentrated infiltration of waste into the ground.
- Warn others in the area of the problem.
- Advise the foreman immediately.
- Remove all plant and material from the area of the spillage.
- Clean up the area affected as soon as possible.

THE MAJOR PROBLEM AREAS REGARDING THE PROJECT ARE:

- Contamination of groundwater.
- Contamination of coastal waters.
- Work being done that does not meet the requirements of permits and approvals.
- Failure to observe NM Waste Safety Rules

Appendix F: Material Safety Data Sheet

NELSON REGIONAL SEWERAGE SCHEME

MATERIAL SAFETY DATA SHEET

Statement of Hazardous Nature:
Not classified as hazardous according to the criteria of NZ legislation.

Company Details:

Company:	Nelson Regional Sewerage Business Unit
Address:	110 Trafalgar Street, Nelson
Telephone:	(03) 546 0200 (all hours) (03) 546 0239

INDENTIFICATION

Product Name:	Biosolids
Other Names:	Stabilised Sludge; Treated Sludge
Manufacturer's Product Code:	Not Relevant
U.N. Number:	Not Relevant
Dangerous Goods Class:	Not Relevant
Hazchem Code:	Not Relevant
Toxic Substance Schedule:	Not Relevant
Uses:	Irrigation, Applied via spray nozzles and Compost

Physical Description

Appearance:	Dark brown liquid with a solids concentration of approximately 3.5%. Liquid has a lingering humus like odour which is offensive immediately after application but is barely noticeable after a period of approximately 2 days
Boiling/Melting Point:	As for water
Vapour Pressure:	As for water
Specific Gravity:	1.0 to 1.1 SG
Flash Point:	As for water
Flammability:	As for water
Solubility in Water:	As for water

Other Properties

pH	8.1
Total Solids	35000 g/m^3 (3.5%)
Fixed Solids	9500 g/m^3
Volatile Solids	25500 g/m^3
Pathogens	< 100,000 MPN faecal coliforms per 100g (<1,000 per gram) (Class A, USEPA Standards) Typical levels less than 2,000/100g.
(following treatment exceeding 50ºC)	< 3 salmonella spp/g VSS < 1 plaque-forming virus unit/g VSS < 1 protozoan organism/g VSS < 1 Helminth egg/g VSS

Ingredients

Chemical Entity	Cas No	Proportion
Ammonia-N		1000 g/m^3
Total Kjeldahl Nitrogen		2200 g/m^3
Total Phosphorus		440 g/m^3
Potassium		100 g/m^3
Arsenic		0.24 g/m^3
Cadmium		0.06 g/m^3
Chromium		1.5 g/m^3
Copper		8.8 g/m^3
Lead		1.6 g/m^3
Nickel		1.0 g/m^3
Zinc		20 g/m^3
Mercury		0.02 g/m^3

HEALTH HAZARD INFORMATION

Health Effects:

Swallowed: Gastroenteritis, diarrhoea and vomiting. If immunisations are not up to Date hepatitis, tetanus or polio could be contracted.

Eye: Could cause a burning sensation if sprayed directly into eye.

Skin: No known effects unless there is an open wound (refer to infection).

Inhaled: Could cause a mild headache if inhaled in a confined space.

Infection:

I. Prompt treatment of wounds will prevent infection. Any wound which has not begun to heal properly within 48 hours may be infected and dirt, dead tissue, foreign bodies and/or bacteria may still be present.

II. If infection develops, it can have serious consequences. It may enter the blood system and subsequently spread to other parts of the body permanently destroying tissue and occasionally leading to death.

III. If any of the following symptoms appear, seek medical aid immediately. The symptoms of infection are:
- increased pain and soreness in the wound
- increased swelling and redness of the wound and surrounding parts with a feeling of heat
- ooze of pus from the wound
- fever, sweating, thirst, shivering and lethargy (if the infection is severe)
- swelling and tenderness in glands
- faint red trails on the surface of the inside of the arms or legs (infected lymph vessels leading towards the lymph glands)

First Aid:

Swallowed: Rinse mouth out with clean water

Eye: Flush eye with clean water

Skin: Dilute with clean water (refer to infection)

Inhaled: Do not work in confined areas for extended periods

Infection:

I. There are several illnesses that can be caught from exposure to wastewater. If an illness may have been caused by contact with wastewater, seek medical treatment immediately.

II. In particular, flu-like symptoms (nausea, dizziness, stiff joints and/or lassitude) should be referred to a doctor within a week of exposure to wastewater.

III. Ensure the doctor is aware that contact with wastewater occurred recently.

Facilities: Ensure an adequate supply of clean, fresh water at biosolids storage facility

Advice to Doctor: Contact: National Poisons and Hazardous Chemicals Information Centre
PO Box 913, Dunedin
Phone: (03) 479 1200 (9am – 5pm)
(03) 474 0999 (emergencies)

PRECAUTIONS FOR USE

Exposure Standards: Wastewater Treatment Standards (**Work place exposure standards and biological exposure – OHS)**

Engineering Controls: Biosolids to be stored outdoors, in open tanks enclosed by a fence to prevent access by unauthorised personnel

Personal Protection

Personal Hygiene: The best defence against viral and bacterial infections is the practice of good personal hygiene as follows:

I. Hands and fingers should be kept away from the nose, mouth, eyes and ears.
II. Rubber gloves should be worn when performing tasks involving direct contact with wastewater or sludge.
III. Hands should be washed thoroughly with soap and hot water before eating, smoking and after work.
IV. Fingernails should be kept short and foreign materials should be removed from the nails with a stiff, soapy brush.
V. Smoking should be avoided when handling sewage.
VI. Door knobs and other building fixtures should not be contaminated by dirty hands.
VII. Work clothes worn in hazardous areas should not be worn or taken into areas used for the preparation or consumption of food. Neither should food be consumed in hazardous areas.
VIII. Tools and equipment used in hazardous areas should be thoroughly cleaned before being put away to avoid putting others at risk.
IX. Street clothes and clean clothes should be stored in a locker separate from used work clothes.
X. All cuts and scratches should be treated with antiseptic and covered immediately.
XI. A shower should be taken as soon as practicable after each work day.
XII. Gauze type aspirators should be used in high aerosol areas.
XIII. It is recommended that personnel in regular direct contact with sewage should have current tetanus, hepatitis A and hepatitis B immunisations.

Protective Clothing: The following are applicable:

I. Gumboots – to protect from contaminated soil, wastewater and effluent.
II. Ear muffs – in noisy environments.
III. Gauze type aspirators – in high aerosol areas.
IV. Safety glasses or goggles – to protect eyes from being sprayed.
V. Rubber gloves – to avoid contact with harmful liquids.

Flammability Not Relevant

SAFE HANDLING INFORMATION

Storage and Transport	To be stored in open tanks and transferred in tankers or pipelines.
Spills and Disposal	If a large spill occurs, contain the liquid and dispose of it in forests. If the spill is small, spread it out over the immediate area to ensure that a point source of contamination is not created.
Fire/Explosion Hazard	N/A

OTHER INFORMATION:

CONTACT POINT:

NM Waste:	**Malcolm Furness**	**021 079 4185**
NRSBU:	**Brad Nixon**	**022 010 8471**
PF Olsen Ltd:	**Sam Nuske**	**029 773 0935**

Appendix G: USEPA Class A Guidelines

SCHEDULE

The USEPA Guidelines, part 503.32 provide guidelines required to be met to produce a Class A sludge with respect to pathogens based on exposure to a temperature above 50°C for a set time governed by the following equation:

For a %Dry Solids (DS) of <7% (expected) the sludge shall be held at 50°C or higher for a minimum duration as determined by the equation:

$$Minimum\ Duration = \frac{50,070,000}{10^{0.14t}} \quad (days)$$

where t = temperature in °C and is greater than 50°C

TABLE 3: DURATION VS TEMPERATURE OF A SLUDGE WITH <7% DS

TEMPERATURE °C	RETENTION TIME (Days)
50°	5 days
55°	1 day
60°	5 hours
65°	1 hour
67°	30 minutes

USEPA microbiological standards for Class A Sludge are:

- ≤ 1000 MPN (Most Probable Number) faecal coliforms/g Total Solids (dry weight)
- ≤ 3 Salmonella spp./g VSS (Volatile Suspended Solids)
- ≤ 1 plaque forming virus unit/g VSS
- ≤ 1 protozoan organism/g VSS
- ≤ 1 helminth egg/g VSS

Table 5-2 lists several requirements that must be met for all six of the Class A alternatives. Perhaps the most significant of the requirements is to avoid regrowth of bacteria as indicated by the results of a fecal coliform or *Salmonella* test.

Alternative 1 for Meeting Class A: Thermally Treated Biosolids

This alternative applies when specific thermal heating procedures are used to reduce pathogens. Equations are used to determine the length of heating time at a given temperature needed to obtain Class A pathogen reduction (i.e., reduce the pathogen content to below detectable levels). The equations take into consideration the solid-liquid nature of the biosolids being heated, along with the particle size and how particles are brought into contact with the heat. The equations also take into consideration that the internal structure of the mixture can inhibit mixing. For example, a safety factor is included in the equation for Regime C (see Table 5-3) that adds more time for heating because less information is available about operational parameters that could influence the degree of pathogen destruction per unit of heat input. The rule identifies and provides equations for four different acceptable heating regimes.

The minimum indicated boundary conditions (i.e., solids content, mixing with the heat source, time of heating, and operating temperature) are given

TABLE 5-2
Pathogen Requirements for All Class A Alternatives

The following requirements must be met for *all* six Class A pathogen alternatives.

Either:

the density of fecal coliform in the biosolids must be less than 1,000 most probable numbers (MPN) per gram total solids (dry-weight basis),

or

the density of *Salmonella* sp. bacteria in the biosolids must be less than 3 MPN per 4 grams of total solids (dry-weight basis).

ie Max. 10/kg 100g

Either of these requirements must be met at one of the following times:

- when the biosolids are used or disposed;
- when the biosolids are prepared for sale or give-away in a bag or other container for land application; or
- when the biosolids or derived materials are prepared to meet the requirements for EQ biosolids (see Chapter 2).

Pathogen reduction must take place before or at the same time as vector attraction reduction, except when the pH adjustment, percent solids vector attraction, injection, or incorporation options are met.

Appendix H: Pre-Spray Check Sheet

PRE-SPRAY BLOCK CHECK:

Block ID		Nitrogen Application Rate	Kg/ha

Buffer Zones	
• 50m from mean high water	☐
• 15m from areas where the public has unrestricted access	☐
• Whichever is greater for areas bordering the Domain:	
○ 20m in from forest canopy; or	☐
○ 30m in from domain canopy; or	☐
○ 100m in from edge of forest canopy between November & March	☐
• Koiwi zone/Archaeological sites	☐
• Trial areas	☐
• Other ______________________________	☐

Map Attached Showing	
○ Spray area	☐
○ Cycle ways/Public Access Areas	☐
○ Turn-around areas	☐
○ Access tracks for tankers	☐

COMMENTS:

____

____

____

Signed	
Forest Manager:	
Biosolids Applicator:	
Date:	

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Appendix I: Post-Spray Check Sheet

POST-SPRAY CHECK:

Date Check: **Rework Required: Y/N** **Final Check? Y/N**

Block ID	
Spray Start	
Spray Completed	
Spray Rate	
Sign Removal Date	

	ACCEPTABLE	NOT ACCEPTABLE	ACTION
Ponding	❑	❑	
Tree Damage	❑	❑	
Over-spray	❑	❑	
Missed Areas	❑	❑	
Road Damage	❑	❑	
Other	❑	❑	

COMMENTS:

Signed	
Forest Manager:	
Biosolids Applicator:	
Date:	

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Attachment G

Assessing the impact of land application of biosolids on planted pine forest and soil properties at Moturoa / Rabbit Island

Jianming Xue and Graham Coker

Report information sheet

Report title	Assessing the impact of land application of biosolids on planted pine forest and soil properties at Moturoa / Rabbit Island
Authors	Jianming Xue and Graham Coker Scion
Client	Nelson Regional Sewerage Business Unit (NRSBU)
PAD output number	ID: 25586248
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Date	July 2020

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Executive summary

Background

This study was commissioned by Nelson Regional Sewerage Business Unit (NRSBU) to assess the actual and potential impact of land application of biosolids on planted pine forests and soil properties at Moturoa / Rabbit Island. NRSBU require this information to prepare a new Resource Consent application for application of biosolids to land on Moturoa / Rabbit Island in Nelson.

This report provides a summary of tree growth and nutrition, predicted annual and cumulative nitrogen (N) uptake and soil property monitoring from the biosolids research trial at Moturoa / Rabbit Island over the past 22 years. This report also provides an analysis of operational soil data to serve as a cross-check to the research trial site.

Conclusions

<u>Biosolids Research trial</u>

- Repeated applications of biosolids to a radiata pine plantation on a low fertility sandy soil significantly increased soil total C, N and P and their availabilities, which, however, showed downward movement in soil profile.
- Enhanced pine growth due to biosolids application was mainly a result of improved soil N supply and tree N nutrition.
- Although a small reduction (5-7%) in wood quality (density and stiffness) was observed due to application of biosolids, the considerable increase in tree stem volume more than compensated for the value loss in reduced wood quality.
- Repeated applications of biosolids, especially the High treatment (600 kg N ha^{-1}), was associated with a reduction in soil pH and the slow accumulation of Cu, Zn, Pb, As, Cd and As in the litter layer and the top 50 cm of the soil.
- Overall concentrations of these heavy metals were well below the soil contaminant limits defined by the Guidelines for the Safe Application of Biosolids to Land in New Zealand, NZWWA 2003 (the NZ Biosolids Guidelines 2003) and the consent limits i.e. Public Health Guidelines for the Safe Use of Sewage Effluent and Sewage Sludge on Land (Department of Health 1992).
- Ecotoxicological assessment in 2010 after 13 years of biosolids application showed no significant adverse effect on soil quality and health caused by repeated applications of biosolids.
- There was no evidence that long-term repeated applications of biosolids had resulted in accumulation of perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA) in the surface soil (0-25 cm).
- In consideration of the positive effect on tree growth and the potential risk of N leaching, application of 300 kg N ha^{-1} per 3 years was justified as an appropriate application rate at Moturoa / Rabbit Island.
- Biosolids-derived heavy metals were strongly retained in the litter layer. The mobility and long-term fate of these heavy metals in the receiving environment need to be monitored.
- In consideration of the relatively uniform soils across Moturoa / Rabbit Island and the same forest management practices (by PF Olsen), we believe the research trial reflects the wider scheme of operational areas, and it is therefore justified to extrapolate findings from this research trial to operational sites.

<u>Operational areas</u>

- Repeated applications of biosolids improved soil fertility, by increasing soil organic matter and available nutrients (e.g. N, P) over time, especially in the top soil.
- Overall, soil pH was maintained above 5, although it gradually decreased with repeated applications of biosolids over time and dropped below 5 at some sites.
- The concentrations of Cd, Cr, Cu, Pb, Hg and Zn were below the soil limits defined in the NZ Biosolids Guidelines 2003 and the National Environmental Standard for Assessing and Managing Contaminants in Soil to Protect Human Health (MFE 2012).
- The average concentrations of As and Ni were lower than the NZ Biosolids Guidelines 2003 soil limits but the maximum values for As and Ni were higher than those soil limits at certain times and locations.
- Some changes in soil monitoring regime are recommended to safeguard the receiving environment (e.g. soil and groundwater).
- The existing application rates of 300 or 450 kg N ha^{-1} every 3 years depending on the stand age have been justified as appropriate and should be retained.

In conclusion, repeated applications of biosolids have not resulted in significant adverse effects on soil quality and health but have improved the nutrition and growth of radiata pine stands. This has shifted the forest site from one of relatively low productivity to an average or above average productivity site and improved forest profitability considerably.

Recommendations

- Soil from sites to which biosolids have been applied should be sampled using an unbiased pattern such as a grid or rectangle to capture the GPS location of the sample collection site. Using a standardized soil sampling methodology will ensure the soil monitoring is both reliable and accurate. Consistent analyses can help detect the spatial and temporal changes of soil properties caused by biosolids application which will inform the consent holders ongoing operations.
- Conditions of consent relating to soil monitoring for heavy metal concentrations should be updated to align with the soil limits recommended in the NZ Biosolids Guidelines 2003.
- Sites that have minimum buffers or a longer season of application, and sites with a greater risk of leaching or run-off, require greater monitoring both pre- and post-application.
- There are two discrete areas where additional monitoring may be warranted to safeguard the receiving environment. We suggest that an independent Monitoring and Technology Review Report be imposed as a condition of consent to investigate:
    a. PFAS (per- and poly-fluoroalkyl substances) levels in influents, effluents and biosolids of the Bell Island WWTP. If PFAS exists in biosolids we recommend that the NRSBU investigate whether it is necessary to develop a monitoring plan to assess PFAS concentrations in the soil and groundwater from representative areas of biosolids application on Moturoa / Rabbit Island; and
    b. the impacts of harvesting disturbance and pine reestablishment on provision of benefits and potential risks (e.g. fate of nutrients (N, P), heavy metals and emerging organic contaminants in the receiving environments) of biosolids land application on Moturoa / Rabbit Island. This can further reassure the sustainability of long-term biosolids application on forested land.

Assessing the impact of land application of biosolids on planted forest and soil properties at Moturoa / Rabbit Island

Table of contents

Introduction

The use of biosolids as a fertiliser and soil amendment for improvement of low fertility soils and reclamation of degraded land is a common management option in many parts of the world[1-3]. Land application of biosolids can enhance carbon (C) sequestration in soils[4], provide nutrients to plants[5], and improve overall soil fertility[6]. In New Zealand, application of biosolids onto forest land is often preferred to agricultural land because the biosolids can increase tree growth and subsequent economic returns[7-9] without the risk of contaminants entering the human food chain[3, 10].

Treated biosolids (Class A as defined by Biosolids Guidelines[11]) from the Bell Island wastewater treatment plant have been applied to radiata pine forest at Moturoa / Rabbit Island in Nelson since 1996, at the rates of 300 or 450 kg N ha-1 every 3 years depending on the stand age. To investigate whether this practice would be sustainable long-term, a research trial was established in 1997. Since establishment, this trial has been used to regularly monitor tree growth, nutrition and wood quality as well as environmental indicators, such as soil and groundwater quality. Several reports have been prepared to collate and interpret the monitoring data from the biosolids research trial[12-14].

This independent technical report was commissioned by Nelson Regional Sewerage Business Unit (NRSBU) to assess the actual and potential impact of land application of biosolids on planted pine forests and soil properties at Moturoa / Rabbit Island. NRSBU require this information to prepare new Resource Consent applications for future application of biosolids to land on Moturoa / Rabbit Island in Nelson.

The data underpinning this report was derived predominantly from the long-term biosolids research trial established by Scion in 1997. A brief analysis of soil quality in operational forest areas outside the research trial is also included to provide a comparison with the results from this trial. The report will cover the assessment of soil physical, chemical and biological properties and forest nutrition and growth, including nitrogen (N) uptake by pine plantation forests.

Materials and methods

Operational biosolids application at Moturoa / Rabbit Island

The Nelson Regional Sewage Business Unit (NRSBU) is a joint committee comprising representatives of Tasman District Council and Nelson City Council, an independent board member, an iwi representative and a member representing the three major industrial contributors. The NRSBU oversees a wastewater scheme which serves parts of Nelson City, Richmond, Wakefield, Brightwater and Mapua. NRSBU currently holds a resource consent (NN940379V3) for the discharge of biosolids to land, namely forestry blocks, on Moturoa / Rabbit Island, which will expire on 8 November 2020.

Site conditions

Moturoa / Rabbit Island (41°16′15″S 173°08′51″E) lies across the southernmost part of Tasman Bay, at the top of South Island. The Island has a flat topography with a maximum elevation of 10m. The soil type is classified as a sandy raw soil[15] with naturally low nutrient and organic matter levels. In particular, the low soil nitrogen (N) supply considerably limits radiata pine growth. The soil is permeable and provides free root access to the shallow ground water levels, which are 2-4 m below the surface depending on the time of the year. Annual rainfall is approximately 900mm based on the 30 years average.

Soil quality monitoring

To meet the compliance reporting under the existing consent, intensive monitoring of soil and groundwater quality change has been carried out since biosolids application commenced in 1996. The resource consent conditions for biosolids application require that soil samples be taken at an average of two samples every 10 ha in areas where biosolids have been applied. In practice, sampling is carried out in all stands that have been treated on an on-going basis and every 6 months samples are taken at some locations. Two samples are taken at each point (topsoil at 0-20 cm and subsoil at 20-40 cm). The soil samples are analysed for:

- pH
- organic matter
- nutrients: N, P, K, Ca, Mg and Na
- heavy metals: As, Ca, Cr, Cu, Pb, Hg and Ni

For investigating the effect of biosolids application on soil chemical properties, the research data set collected from 1999 to 2019 was analysed and the results are presented in the following section of this report. In addition, a selection of the soil data from the operational biosolids application areas have been analysed and are included in this report as a cross-check against the biosolids research trial data.

Research trial site

Trial design and establishment

To investigate whether the continued application of biosolids to land at Moturoa / Rabbit Island would be sustainable long-term, a research trial was established in October 1997, one year after the application of biosolids commenced. The resource consent conditions provided for the research trial to occur and the NRSBU engaged Scion to carry out the monitoring and assessment.

The research trial ran for 15 years and concluded in 2013. Biosolids are no longer applied to the research trial site however monitoring of soil properties and tree growth continue to assess the long-term effects of biosolids application on Moturoa / Rabbit Island.

A pine stand planted in 1991 was selected as the research trial site. The stand was established at a stocking rate of 1000 stems ha^{-1}, and all trees in the trial were pruned in four lifts up to 6 m height during the period November 1996 - August 2001.

Three biosolids treatments have been used in a split-plot, randomised block design with four replicates. Treated biosolids from the Bell Island wastewater treatment plant were applied in 1997, 2000, 2003, 2006, 2009 and 2012 at three application rates: 0 (Control), 300 (Standard) and 600 kg N ha^{-1} (High).

In this research trial, three stocking density treatments (subplots) were established, i.e., 300, 450 and 600 stems ha^{-1} within each biosolids treatment main-plot (Fig 1).

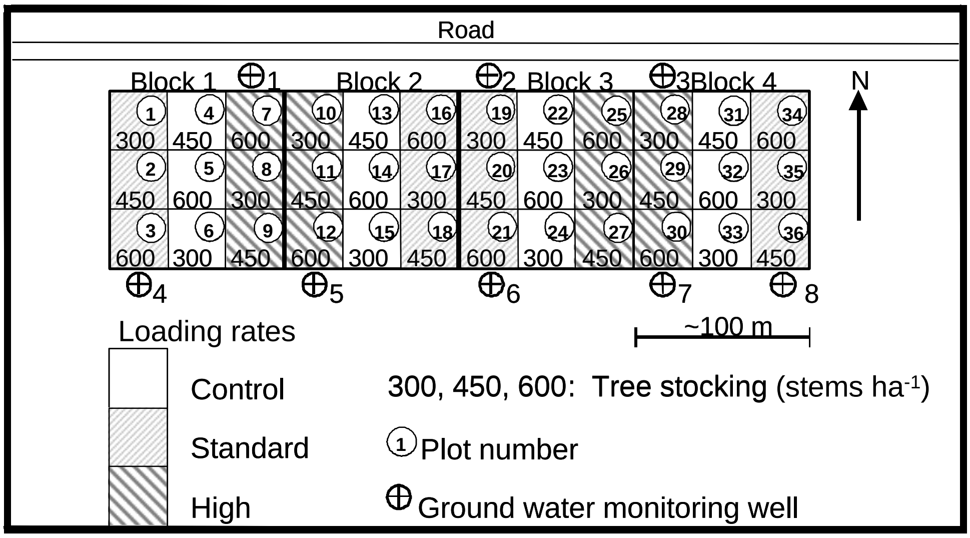

Fig 1. Biosolids trial plot layout at Moturoa / Rabbit Island.

Trial monitoring

Tree growth and economic analysis

Height and diameter at breast height (DBH) of all trees in each plot were measured annually in the winter from 1997 to 2015. Visual observations of each tree were recorded (e.g., stem form and health). All data was entered into the Scion's Permanent Sample Plot System. Stocking, mean top height (MTH, mean height of the largest 100 trees per hectare), basal area (BA) and stem volume were determined for each plot.

An analysis of the economic effects of applying biosolids to the Moturoa / Rabbit Island plantation was performed, taking account of both the effects of biosolids on tree growth and wood quality. Economic returns expressed as internal rate of return (IRR) and net present value (NPV) were calculated for each biosolids treatment using the Radiata Pine Calculator[16], costs were detailed in the previous report[9].

In June 2006 at age 15 years, one tree in each subplot was selected for destructive sampling. There were generally sourced from the plot buffer areas. Each tree was felled and then cross cut into 5 m logs, and the resonance velocity of each log was measured using the HM200, a resonance acoustic tool widely used in the New Zealand forest industry for segregating logs on the basis of stiffness. Acoustic velocities of 4 standing trees per subplot were also measured using a 'time-of-flight' acoustic velocity tool.

Tree nutrition and N uptake

To assess tree nutritional changes due to biosolids application, the current-year needles were sampled from the youngest second-order branches in the top third of crown of selected trees in each plot annually in March 1998 to 2011 and every two years after 2011 (i.e. 2013 and 2015). The samples were bulked between stocking density treatments within the same biosolids loading rates and analysed using an ICP-MS for a range of nutrients, including N, P, K, Ca, Mg, Na, Mn, Zn, Cu, B and Fe after being oven-dried (70 ^{o}C) and ground to <2 mm.

The nutrient balance model (NuBalM) developed by Scion was used to estimate annual N uptake by the live biomass, and cumulative N uptake by the live biomass plus forest floor of pine stands. The model has been published by Smaill et al[17] and undergone further development to link the model with the Forest Carbon Predictor (FCP)[18]. Thereafter specific functions for both N and P concentrations of biomass (live and forest floor) components were developed. The version of NuBalM used in this study is FCP_5_2. The data used to parameterise NuBalM include location, average mean annual temperature, soil fertility (soil C/N), stand management and tree species. The NuBalM predictions are improved with tree growth measurements (300 index) from the research biosolids trial at Moturoa / Rabbit Island.

Soil quality

The impact of biosolids applications on soil properties was assessed every three years (in line with the consent condition requirements), with the most recent samples being taken in November 2019. Samples were collected from the forest floor litter layer, topsoil (0-25 cm) and subsoil (25-50, 50-75 and 75-100 cm). Samples were taken from all subplots within each biosolids treatment main-plot and bulked, resulting in four replicate samples per biosolids treatment, i.e. 12 samples in total.

The litter samples were oven-dried (70 ^{o}C) and ground for chemical analysis. Soil samples were air-dried and ground to pass a 2-mm sieve. Soil pH was measured at a soil:water ratio of 1:2. Total C, N and S in soil and litter samples were determined by dry combustion using a LECO CNS 2000 Analyzer. Concentrations of soil exchangeable Ca, Mg, K, and Na were measured using the ammonium acetate method[19]. Extractable soil P was determined using the Olsen P method. Acid digestion was used to extract heavy metals in biosolids and soil samples[20]. Flame atomic absorption spectrometry was used to determine concentrations of As, Cd, Cr, Cu, Pb, Ni, and Zn in the acid digestion samples. Mercury was analysed using cold vapour atomic absorption spectrometry[21]. Foliage and litter samples were digested with concentrated HNO_3/H_2O_2, and the concentration of nutrients and heavy metals in the digest were determined using the inductively coupled plasma optical emission spectrometry (ICP-OES)[22].

The subset of soil samples (0-25 cm) were also sent to Asure Quality Limited for PFAS (per- and poly-fluoroalkyl substances, mainly PFOS and PFOA) analysis. Briefly, the test portions were fortified with internal standards and digested with sodium hydroxide. The digested samples were then extracted with methanol. A portion of the extract was acidified and cleaned up by dispersive SPE (solid-phase extraction). The extracts were concentrated prior to analysis. Selected perfluorinated alkyl acids in the extracts were determined by liquid chromatography-mass spectrometry (LC-MS/MS).

Statistical analysis

Two-way mixed model (split-plot design) analysis of variance (ANOVA) and least significant difference (LSD) tests were used to determine the statistical significance of the biosolids loading rate (main plot) and tree stocking rate (subplot) effects on tree growth. The biosolids loading rate and tree stocking rate were treated as fixed effects and block effect were treated as a random effect. In this report, we only present the results of biosolids main effect on tree growth (averaged across three stocking rates).

One-way mixed model (randomised complete block design) ANOVA and least significant difference (LSD) tests were used to determine the statistical significance of the biosolids loading rate effect on tree nutrition and soil properties. All data were analysed using the MIXED Procedure (SAS/STAT Version 9.3).

Results and discussion

Research trial site

Effects of biosolids application rate on tree growth

Stem diameter and basal area

In treatments with biosolids applied, diameter at breast height (DBH) and basal area (BA) remained significantly greater than the untreated Control in 2015 (Figs 2 and 3). At age 24 years, the average BA of the High treatment was 23% greater than the Control while the average BA of the Standard treatment was 20% greater than the Control (Fig 3).

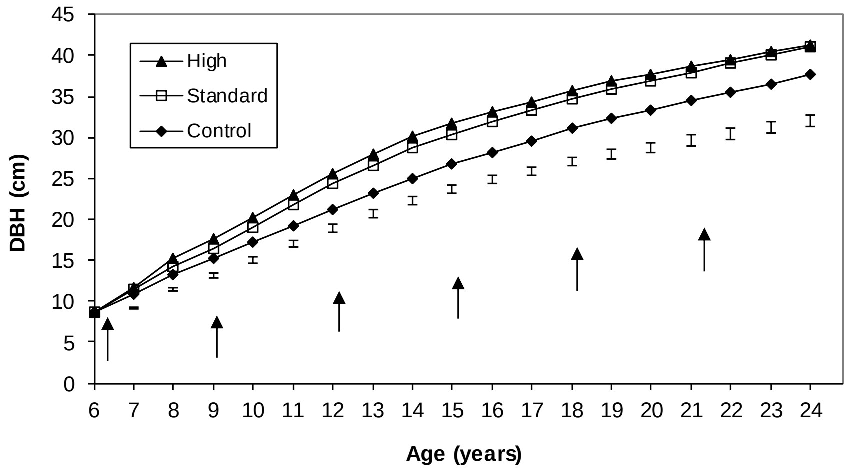

Fig 2. Effect of biosolids application on diameter at breast height (DBH) since the initial biosolids application at age 6 years. The bars show least significant differences (LSDs) calculated for each age. Treatment differences greater than the LSD are statistically significant (p = 0.05). The arrows show when biosolids treatments were applied (i.e. 1997, 2000, 2003, 2006, 2009 and 2012).

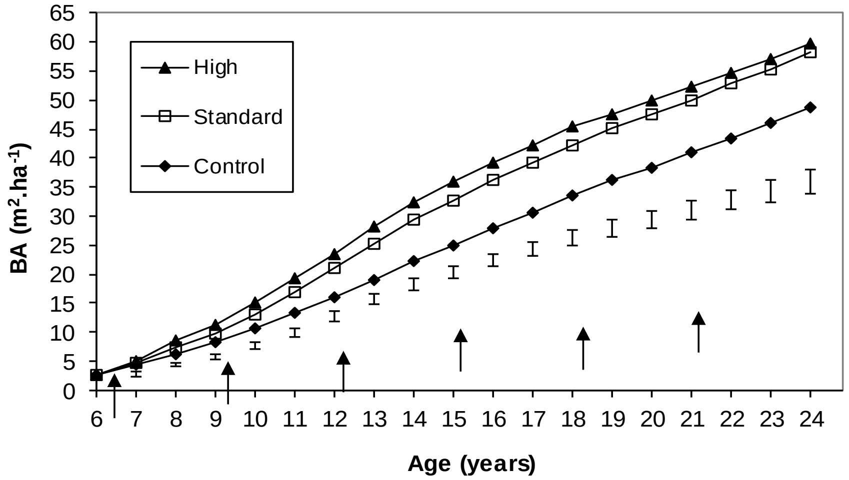

Fig 3. Effect of biosolids application on basal area (BA) since the initial biosolids application at age 6 years. The bars show LSDs calculated for each age. Treatment differences greater than the LSD are statistically significant (p = 0.05). The arrows show when biosolids treatments were applied (i.e. 1997, 2000, 2003, 2006, 2009 and 2012).

Stem height and volume

Mean top height (MTH) in both Standard and High biosolids treatments has shown a slight but statistically significant divergence from the Control treatment since 2001 (age 10 years) (Fig 4).

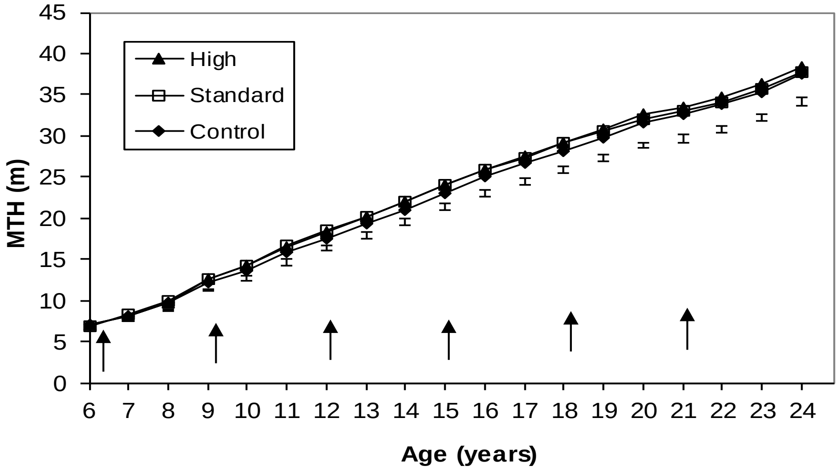

Fig 4. Effect of biosolids application on mean top height (MTH) since the initial biosolids application at age 6 years. The bars show LSDs calculated for each age. Treatment differences greater than the LSD are statistically significant (p = 0.05). The arrows show when biosolids treatments were applied (i.e. 1997, 2000, 2003, 2006, 2009 and 2012).

Stem volume remained significantly greater in plots with biosolids applied than those with no biosolids application (Fig 5). In 2015 at age 24 years, stem volume of the High treatment (725 m^3 ha^{-1}) was 25% greater than the Control (582 m^3 ha^{-1}), and stem volume of the Standard treatment (697 m^3 ha^{-1}) was 20% greater than the Control, indicating a substantial gain in productivity. The maximum growth differential between treated and untreated trees occurred between ages 10-14 years (Fig 5). Importantly, the increased stem volume achieved over these years appears to be firmly locked in. Although the difference in growth rate (data not shown) is now narrowing, there is no indication that the difference in total volume is closing.

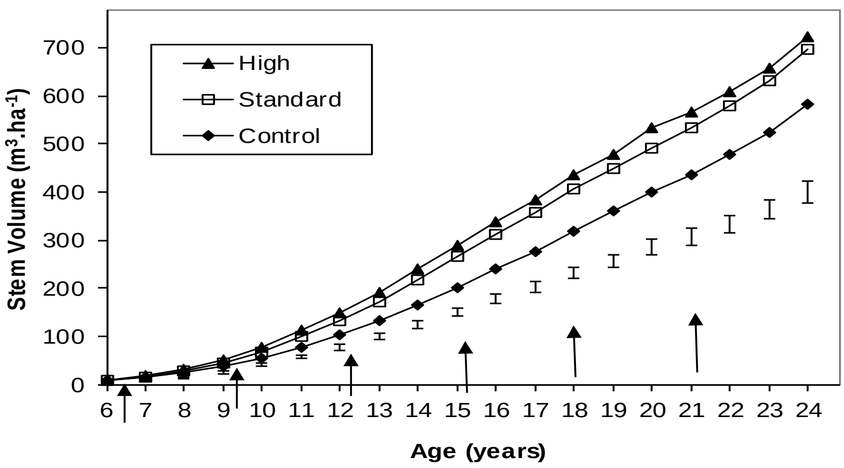

Fig 5. Effect of biosolids application on stem volume since the initial biosolids application at age 6 years. The bars show LSDs calculated for each age. Treatment differences greater than the LSD are statistically significant (p = 0.05). The arrows show when biosolids treatments were applied (i.e. 1997, 2000, 2003, 2006, 2009 and 2012).

Effects of biosolids application rate on wood quality and economic return

Wood quality is typically described by attributes such as wood density and stiffness. Wood density represents timber strength and is usually assessed by taking density cores from standing trees. Stiffness is an important indicator of timber suitability for structural applications and commonly assessed by measuring the acoustic velocity of standing trees using acoustic tool tools. Two earlier studies (age 12 and 15 years) evaluating responses of tree growth and wood properties to biosolids application at mid-rotation have both shown a 5-7% reduction in wood density and stiffness of radiata pine standing trees caused by application of biosolids at Rabbit Island[23-24].

The predicted values in each grade and the overall stumpages at harvest (age 30 years) are shown in Table 1. Overall the high and standard biosolids treatments are predicted to increase the net stumpage value of logs by 24% and 16% respectively at harvesting, providing a large positive impact on the forest owner's economic return. This analysis takes no account of the expected lower harvesting costs per cubic metre resulting from the larger mean piece size in the biosolids treated[9]. Please also note that the figures in Table 1 and 2 are time stamped at the date the research trial was published and have not been updated since.

Table 1. Predicted stumpage value ($ ha^{-1}) by log grade and across all grades for each biosolids treatment.

Log grade	Biosolids treatment		
	Control	Standard	High
Large pruned	10,045	14,884	18,458
Small pruned	5,542	5,787	5,533
Large unpruned low velocity	687	5,546	7,546
Large unpruned medium velocity	4,268	7,843	8,696
Large unpruned high velocity	5,376	1,635	1,439
Small unpruned low velocity	1,322	6,552	6,830
Small unpruned medium velocity	8,422	9,502	8,072
Small unpruned high velocity	10,677	1,994	1,345
Pulp	1,471	1,577	1,549
Total	**47,811**	**55,321**	**59,469**
Logging cost	-17,561	-20,808	-22,012
Stumpage	**30,250**	**34,513**	**37,457**

Predicted economic returns in terms of net present value (NPV) and internal rate of return (IRR) are shown for each treatment in Table 2. These use average Radiata Pine Calculator cost inputs, and the predicted volumes and log prices shown above (Table 1). The NPV is calculated for the start of a rotation using a 7% discount rate and does not account for the likely increasing asset value of land. The effect of the treatment is to increase the NPV by about $480 per hectare for the Standard rate, and $840 per hectare for the High rate. The results reported in the current study are based on the growth measured at 18 years old and include the predicted effect of continued increase in growth rate that occurred between ages 11 and 14 years. As the difference in the 300 Index between control and treated trees appears to have stabilised at about age 14 years, the results presented in this report are expected to be close to those achieved at harvest. These are, of course, subject to any changes in log prices[9].

Table 2. Predicted economic returns over a rotation for each biosolids treatment.

Economic result	Biosolids treatment		
	Control	Standard	High
NPV ($ ha^{-1}, 7% discount rate) [a]	1,718	2,202	2,560
IRR (%, excluding land value) [b]	9.41	9.85	10.15
IRR (%, land value = $5000 ha^{-1}) [b]	5.32	5.71	5.96

[a] NPV: net present value ($ ha^{-1}); [b] IRR: internal rate of return (%).

Effects of biosolids application rate on tree nutrition and N uptake

Tree nutrition

Biosolids application significantly increased foliar N, Mg and B concentrations, but reduced foliar Ca and Mn concentrations (Table 3).

Table 3. Cumulative effect of six biosolids applications (i.e. 1997, 2000, 2003, 2006, 2009 and 2012) on foliar nutrient concentrations in March 2015 (research trial)*.

Treat-ment	N		P		K		Ca		Mg		Zn		Cu		B		Fe		Mn	
	%										mg kg^{-1}									
Control	1.40	a	0.14	a	0.60	a	0.20	A	0.14	a	20	a	2.6	a	14	a	35	a	251	a
Standard	1.43	a	0.14	a	0.58	a	0.18	A	0.17	b	19	a	2.5	a	17	b	36	a	147	b
High	1.58	b	0.14	a	0.59	a	0.16	B	0.18	b	22	a	2.6	a	17	b	40	a	165	b

*Values within a column followed by the same letter do not differ significantly (p= 0.05).

Foliar analysis has consistently shown that natural soil N supply in the Moturoa / Rabbit Island radiata pine forest is not enough to meet the growth requirements for optimal productivity, with foliar N concentration of the Control treatment remaining consistently below 1.5% N (Fig 6), a threshold value below which radiata pine may benefit from N fertiliser[25].

Successive applications of biosolids have produced a consistently positive response in foliar N concentration in the subsequent assessment when compared with Control trees (Fig 6). The boost in foliar N generally declined over a period of several years following an application. However, this pattern was not so obvious during the period of last two applications. This could imply that the historical biosolids applications (residual N) might become more influential than the freshly applied biosolids N on foliar N concentration.

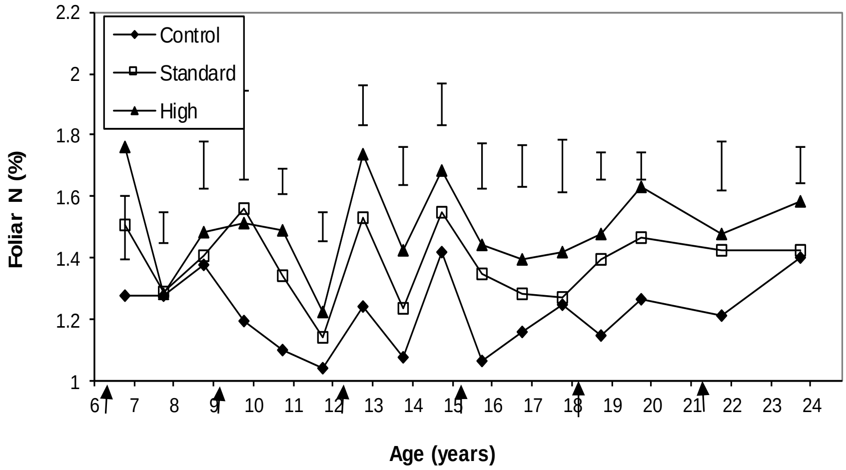

Fig 6. Effect of biosolids application on foliar nitrogen (N) concentration in 1997-2015. Arrows indicate time of biosolids application (i.e. 1997, 2000, 2003, 2006, 2009 and 2012). Error bars show least significant differences (p = 0.05) and can be used to determine the significance of treatment differences.

This indicates that without biosolids application, the radiata pine stand suffers from N deficiency and productivity will increase through N fertilisation via biosolids application. Overall, biosolids application significantly ($P < 0.05$) increased foliar N concentration of the Standard treatment to a marginal level (averaging 1.4% N) and the High treatment to a sufficiency level (averaging 1.5% N) (Fig 6).

Annual and cumulative N uptake by trees

The predicted annual N uptake by live biomass (excluding the forest floor) of pine trees peaked at age 6 and then decreased over the rotation period for all biosolids treatments (Fig 7 and Table 4). For the Control treatment (0 kg N $ha^{-1}$of biosolids), the rate of N uptake increased sharply from 8.0 kg N ha^{-1} yr^{-1} at age 3 to 51.8 kg N ha^{-1} yr^{-1} at age 5; while for the Standard and High biosolids treatments, it increased steeply from 14.0 to 81.2 and from 17.0 to 92.5 kg N ha^{-1} yr^{-1}, respectively (Table 4).

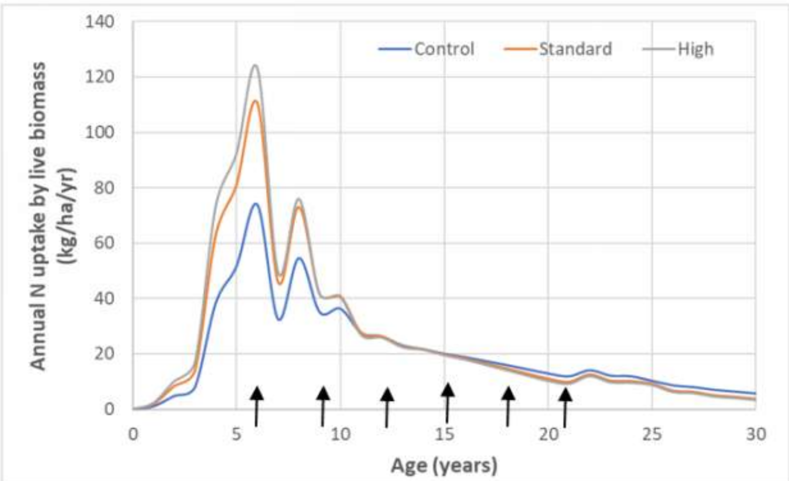

Fig 7. Predicted annual N uptake by live biomass of pine stands (excluding forest floor) for the Control, Standard and High biosolids treatments over the period of a rotation (30 years). Arrows indicate time of biosolids application (i.e. 1997, 2000, 2003, 2006, 2009 and 2012).

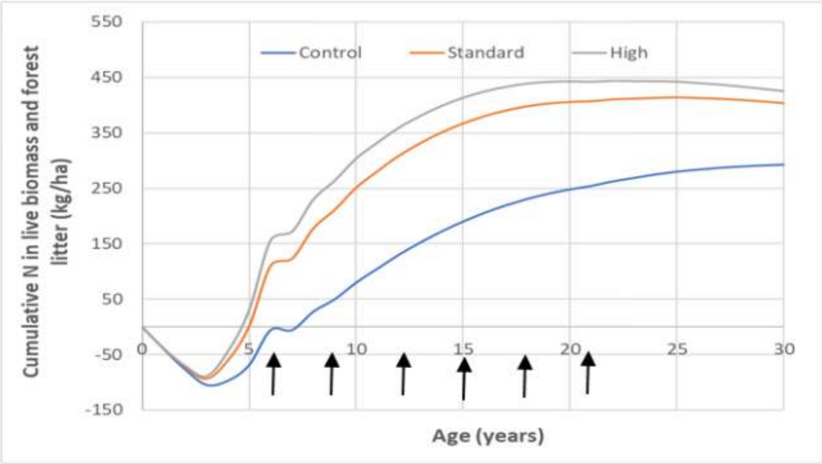

Fig 8. The predicted cumulative N in live biomass and forest floor of pine stands for the Control, Standard and High biosolids treatments over the period of a rotation (30 years). Arrows indicate time of biosolids application (i.e. 1997, 2000, 2003, 2006, 2009 and 2012).

The cumulative amount of N taken up by live biomass and forest floor of pine trees was predicted to increase sharply from age 2 to age 6 and gradually from age 7 to age 15 and then flattened off for all three biosolids treatments, with flattening off being relatively slow in the Control treatment (Fig 8). As shown in Fig 8 (see the trend at ages 0-5), the N supply from the preceding rotation forest residues in the forest floor masks the treatment related N uptake by live biomass, which are therefore presented separately in Table 4. The cumulative amount of N uptake by live biomass (excluding forest floor) for Standard and High biosolids treatments was 751 and 786 kg ha^{-1}, respectively, increasing by 18.9% and 24.5% when compared to the Control (Table 4).

Table 4. Predicted annual N uptake and cumulative N uptake by the live biomass of pine stands over a rotation of 30 years.

Predicted annual N uptake (kg N ha^{-1} year^{-1}) [a]			
Age	Control	Standard	High
3	8.0	14.0	17.0
5	51.8	81.2	92.5
7	32.6	46.0	49.4
9	35.1	41.5	41.6
12	26.3	26.4	25.9
15	20.1	19.8	19.5
18	16.0	14.7	14.1
21	11.9	9.9	9.2
24	11.9	10.1	9.6
27	8.0	6.3	5.8
30	5.7	3.8	3.3
Predicted cumulative N uptake (kg ha^{-1}) over a rotation (30 years) [a]			
	Control	Standard	High
	631.2	750.5	785.6
Increase %		18.9	24.5

Standard: application rate of biosolids at 300 kg N ha^{-1}
High: application rate of biosolids at 600 kg N ha^{-1}
[a] predicted N in live biomass of above- and below-ground

In consideration of the low N supply of the sandy raw soil at Moturoa / Rabbit Island, it is anticipated that the biosolids-derived N would be the main N source for pine tree growth, especially up to age 15. The demand for N from the soil is expected to decrease later in the rotation due to (1) increasing N re-translocation from old biomass to support new growth, and (2) increasing availability of N from the decomposition of forest floor litter created by the trees.

Effects of biosolids application rate on soil properties

Soil chemical properties

In 2013, about one year after the last application of biosolids in 2012, both the Standard and High biosolids treatments showed significantly increased soil total C, N and P, Olsen P and CEC but reduced pH at 0−25 cm (Table 5). The High biosolids treatment significantly increased total C, N and P, Olsen P while both Standard and High treatments reduced soil pH at 25−50cm. Biosolids application had no significant effect on exchangeable cations, base saturation and CEC in this layer (Table 5). At 50–75 cm, High treatment significantly increased total C, N and Olsen P while both Standard and High treatments had no significant effect on pH, exchangeable cations, base saturation and CEC. Both Standard and High treatments significantly increased total N, but had no significant effect on other soil chemical properties at 75–100 cm.

The multiple-year soil results (data not shown) indicate that biosolids application, especially the High treatment, not only resulted in accumulation of total C, N and Olsen-P in the topsoil but was associated with increased concentrations of these nutrients down the soil profile.

Table 5. Cumulative effect of six biosolids applications (i.e. 1997, 2000, 2003, 2006, 2009 and 2012) on soil chemical properties at November 2013 (research trial) [*]

Depth	Treatment	pH		Total C		Total N		Total P		C/N		Olsen P		CEC*	
				%								mg kg^{-1}		cmol$_c$ kg^{-1}	
	Control	5.1	a	0.75	b	0.047	c	0.024	c	16	a	24	c	12.4	b
0-25 cm	Standard	4.7	b	0.86	b	0.060	b	0.029	b	15	b	40	b	16.1	a
	High	4.5	b	1.11	a	0.075	a	0.032	a	14	b	70	a	16.6	a
	Control	5.7	a	0.28	b	0.027	b	0.026	b	10	a	13	b	8.26	a
25-50 cm	Standard	5.5	b	0.32	a	0.031	ab	0.026	b	10	a	17	b	9.99	a
	High	5.0	C	0.35	a	0.034	a	0.030	a	10	a	29	a	10.5	a

[*]For each depth, values within a column followed by different letters differ significantly at *P* = 0.05 (LSD test). The data for the soil layers of 50-75 cm and 75-100 cm are not presented in Table 5 due to no significant differences among the biosolids treatments.
* CEC – cation exchange capacity

Biosolids applications significantly ($P < 0.05$) increased total concentrations of Cr and Pb in the litter (Table 6). This indicates that a proportion of the biosolids-derived metals were retained in the litter layer. High metal retention capacity by forest litter was also reported by McLaren et al[26], who found that concentrations of heavy metals in the litter layer were still elevated even a few years after application of biosolids.

In the soil layer of 0−25 cm, there were no significant differences between biosolids treatments for the heavy metals except for Cr, which had significantly greater concentrations in the High treatment than the Control (Table 6). In the soil layer of 25−50 cm, no significant differences were found between biosolids treatments for the concentrations of other heavy metals except Zn, which was only significantly greater in the High treatment (Table 6). In both layers of 50-75 cm and 75-100 cm, there were no significant differences between biosolids treatments for the concentrations of all measured heavy metals (Table 6).

Table 6. Cumulative effect of six biosolids applications (i.e. 1997, 2000, 2003, 2006, 2009 and 2012) on the concentrations of total heavy metals in litter and soil at November 2013 (research trial) *

Depth	Treatment	As	Cd	Cr	Cu	Pb	Hg	Ni	Zn
		mg kg^{-1}							
	Control	0.48 a	0.12 a	0.27 B	9.9 a	0.62 b	1.8 a	12 a	27 a
Littler	Standard	0.62 a	0.09 a	0.53 A	6.1 a	1.2 ab	1.5 a	13 a	16 a
	High	1.0 a	0.09 a	0.48 A	9.1 a	2.0 a	1.6 a	13 a	21 a
	Control	2.9 a	0.04 a	43 B	2.6 a	3.6 a	0.03 a	23 a	21 a
0-25 cm	Standard	3.3 A	0.03 a	41 B	4.1 a	3.9 a	0.04 a	23 a	23 a
	High	3.5 A	0.03 a	54 A	4.8 a	4.1 a	0.02 a	32 a	25 a
	Control	3.6 A	0.04 a	42 A	2.7 a	3.4 a	0.05 a	36 a	21 b
25-50 cm	Standard	3.7 A	0.03 a	45 A	3.1 a	3.5 a	0.02 a	34 a	22 b
	High	3.3 A	0.03 a	49 A	3.3 a	3.7 a	0.03 a	33 a	25 a
	Control	4.7 A	0.04 a	48 A	3.1 a	3.7 a	0.04 a	48 a	22 a
50-75 cm	Standard	4.2 A	0.03 a	45 A	3.3 a	3.6 a	0.05 a	45 a	22 a
	High	3.8 A	0.03 a	47 A	3.2 a	3.4 a	0.03 a	47 a	22 a
	Control	4.3 A	0.03 a	48 A	3.4 a	3.9 a	0.03 a	46 a	24 a
75-100 cm	Standard	4.0 a	0.04 a	57 A	2.8 a	3.6 a	0.04 a	47 a	21 a
	High	4.0 a	0.03 a	49 A	2.7 a	3.4 a	0.01 a	52 a	23 a
Soil limit or ceiling concentrations by guidelines									
NZ Biosolids [a]		20	1.0	600	100	300	1.0	60	300
DOH1992 [b]		10	3.0	600	140	300	1.0	100	300

* For each depth, values within a column followed by different letters differ significantly at P = 0.05 (LSD test)

[a] The guidelines for the safe application of biosolids to land in New Zealand (NZWWA 2003)

[b] Department of Health 1992 Guidelines for arable land – existing consent limits

As a result of biosolids application, a downward movement of Cr (in top 25 cm) and Zn (in top 50 cm) were observed. Nevertheless, concentrations of heavy metals in soils without and with 6 repeated applications of biosolids were low (Table 6) and well under the soil contaminant limits defined by the guidelines for the safe application of biosolids to land in New Zealand[11] and the Department of Health 1992 Guidelines for arable land[27] (i.e. current consent limits). The results of soil samples collected in 2017 and 2019 (Table S1) further confirmed the slow accumulation of Cu, Pb and As in surface soil (0-25 cm) and Zn in both surface and sub soils (25-50 cm) due to biosolids application. Our findings indicate that six applications of biosolids on this forest site had a slight but statistically significant impact on the accumulation of some heavy metals in the litter and the top 50 cm soil layers.

Soil physical properties

There were no differences found between the biosolids treatments for bulk density, macro porosity, or water holding capacity parameters (Table S2). This indicates that the biosolids application process had not caused any negative effect on soil physical properties.

Soil biological properties

In 2014, the soil microbial community structure in biosolids treatments differed significantly from that of the control treatment in both winter and summer (Fig S1). The differences between the biosolid treatment and control treatment were greater at the High application rate than at the Standard application rate. These changes in community structure were mainly attributable to a significant decrease in the level of arbuscular mycorrhizal fungi and a significant increase in the ratio of Gram-positive bacteria to Gram-negative bacteria (data not shown). Increased soil N and P availability and decrease in soil pH following biosolids application were primarily associated with changes in the soil microbial community structure (Fig S1)[28].

In 2010, the results of soil microbial biomass carbon and total microbial cell counts indicate that more soil microbes were present in soils that received biosolids (Standard or High rates) than in the Control soil (Fig. S2a). This suggests that the slow accumulation of heavy metals or organic contaminants from long-term repeated applications of biosolids had no adverse effect on the growth of soil microorganisms. Our results agree with a previous long-term study on the sewage sludge application effects on soil functioning in an agricultural soil[29].

Ecotoxicological assessment

The collembolan reproduction test with *Folsomia candida* is commonly used as a tool to evaluate the ecotoxicological potential of organic wastes applied to soil. Biosolids treatment and soil layer (litter vs surface mineral soil) had a significant effect ($P<0.05$) on production of *Folsomia candida* neonates, which increased significantly in the High (600 kg N ha^{-1}) treatment (Fig. S2b). Our results indicate that the long-term repeated applications of biosolids did not have any negative ecotoxicological effects on collembolan reproduction.

Triclosan is present in personal care products and is a priority organic contaminant with antimicrobial effect. In 2010, the tolerance of soil microbes to triclosan stress was assessed using the EC_{50} and EC_{10} values as the basis for comparison. The results showed no significant differences among the biosolids treatment[10], indicating that the level of triclosan required to influence the soil microbial community was higher than the levels contained in the biosolids applied to the soil at Moturoa / Rabbit Island.

A recent investigation based on the biosolids research trial at Moturoa / Rabbit Island has found no evidence for long-term repeated applications of biosolids to result in accumulation of perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA) in the surface soil (0-25 cm) sampled in November 2019 [30]. It is important to note that deeper soils and groundwater were not tested in this investigation.

Summary

In summary, six repeated applications of biosolids considerably improved tree nutrition and growth with slight negative impact on wood properties (density and stiffness). Biosolids application also markedly improved soil fertility despite causing slow accumulation of Cu, Zn, Pb, As, Cd and As in the soil and slightly downward movement of N, P and some heavy metals (Cr, Cu, Zn). Importantly, the concentrations of all metals were well below the soil limit guidelines for New Zealand. To date, repeated applications of biosolids showed no significant adverse effect on soil quality and health. However, there are knowledge gaps on the impact of harvesting and reestablishment operations on the fate of nutrients (N and P), heavy metals and emerging contaminants in the receiving environment. Further research is warranted.

Operational areas

Effect of biosolids application on soil chemical properties

Soil pH, organic matter and total N

The current resource consent requires that soil pH be maintained above 5.0. Except for some individual soil samples, the average soil pH values in both top and sub soils were all above 5.0 and gradually increasing over the period of 1999-2019 for four selected pine stands (Fig 9a). The average soil pH was consistently lower in the top soil than the sub soil, which could be attributed to the greater mineralisation and nitrification of biosolids-derived organic N in the top soil than the sub soil.

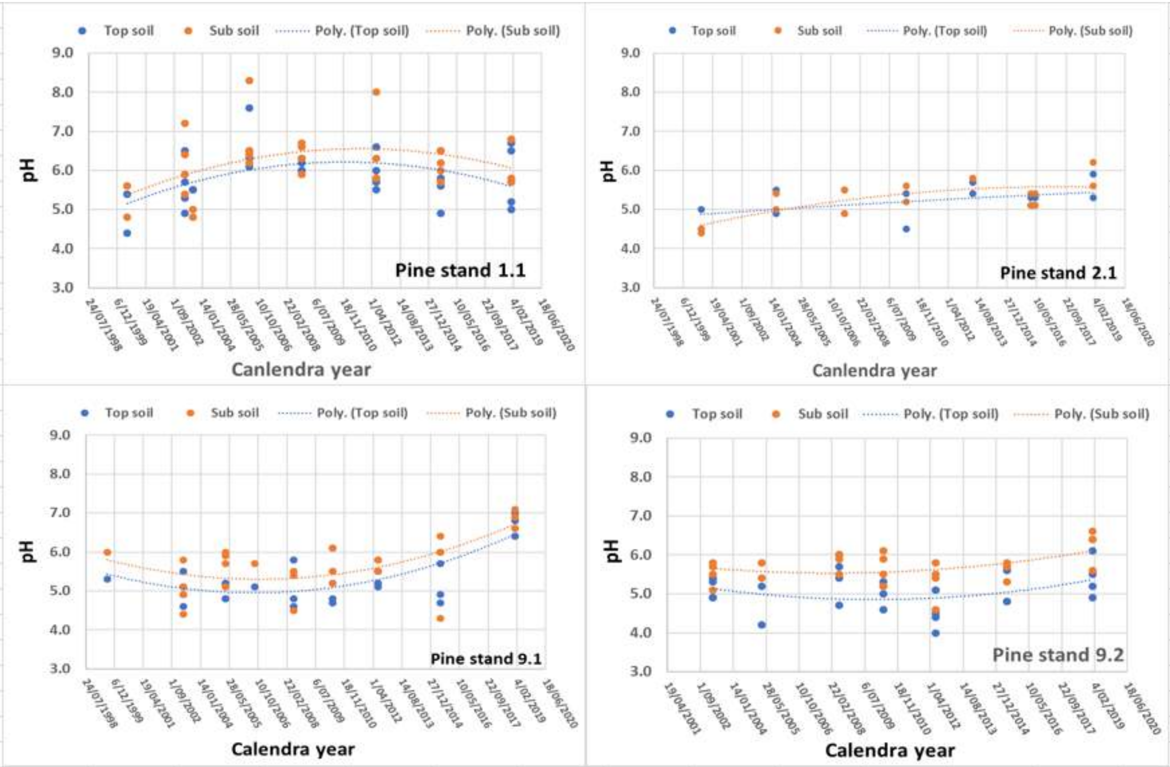

Fig 9a. Changes of the average soil pH in top- and sub-soils of four selected pine stands in the operational areas over the period of 1999-2019. Poly. (Top soil) and Poly. (Sub soil) represent polynomical regression models to be fitted to the data for top and sub soils, respectively.

Soil organic matter contents were steadily rising in both top and sub soils during the first 10 years of biosolids application and slightly decreasing afterwards (Fig 9b). Soil organic matter contents were consistently higher in the top soil than the sub soil (Fig 9b), which could be attributed to the greater accumulation of biosolids-derived organic carbon in top soils.

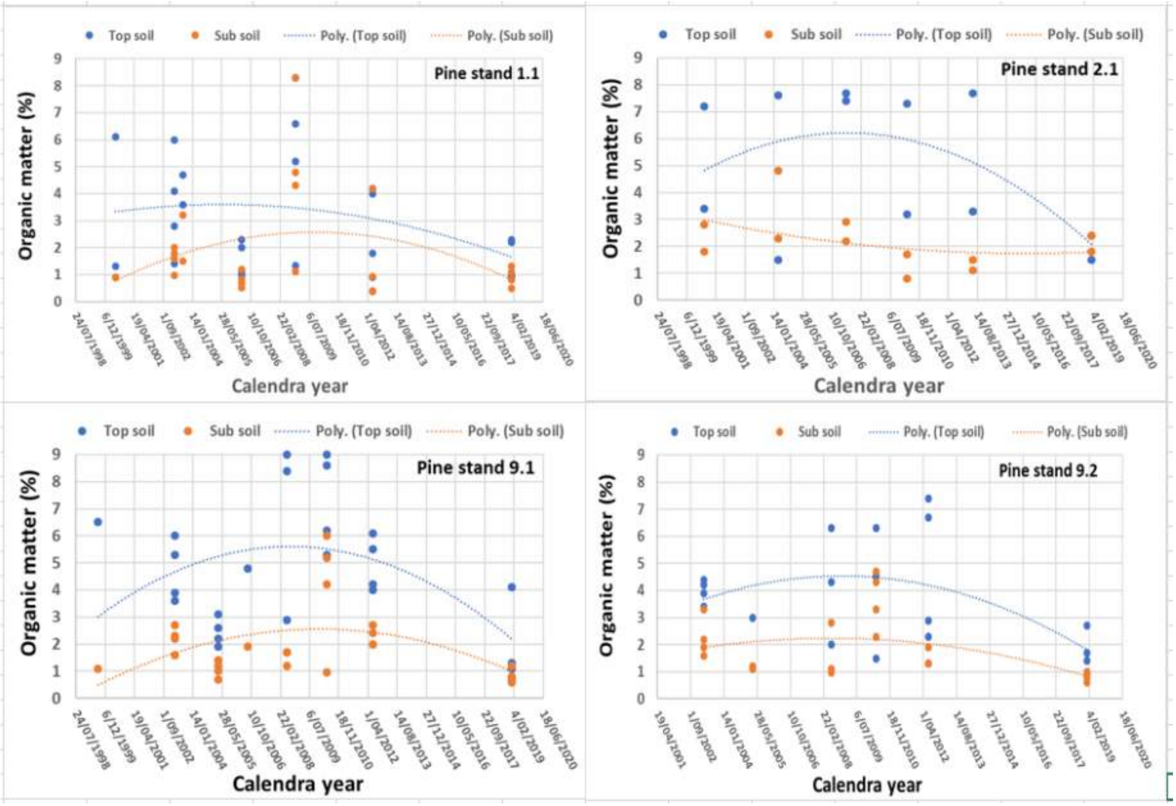

Fig 9b. Changes of the average soil organic matter in top- and sub-soils of four selected pine stands in the operational areas over the period of 1999-2019. Poly. (Top soil) and Poly. (Sub soil) represent polynomical regression models to be fitted to the data for top and sub soils, respectively.

Soil total N contents in both top and sub soils showed a steady increase in pine stand 9.1 but not in other pine stands (Fig 9c). The gradual accumulation of soil organic matter (Fig 9b) and total N in some pine stands indicated the improvement of soil fertility in these pine stand sites by repeated applications of biosolids. However, the Rabbit Island soils are naturally low in N supply and N requirements for pine tree growth should be mainly from the mineralisation of biosolids-derived organic N. This could result in a very slow accumulation of biosolids-derived organic carbon in the soil.

For both soil organic matter and total N contents in a given year, a large spatial variation was found within each of the four selected pine stands. It is not clear if this spatial variation was related to the natural soil variation or the uneven spraying of biosolids within each stand. A consistent soil sampling strategy and plan will enable a robust data set to be obtained to inform future biosolids application.

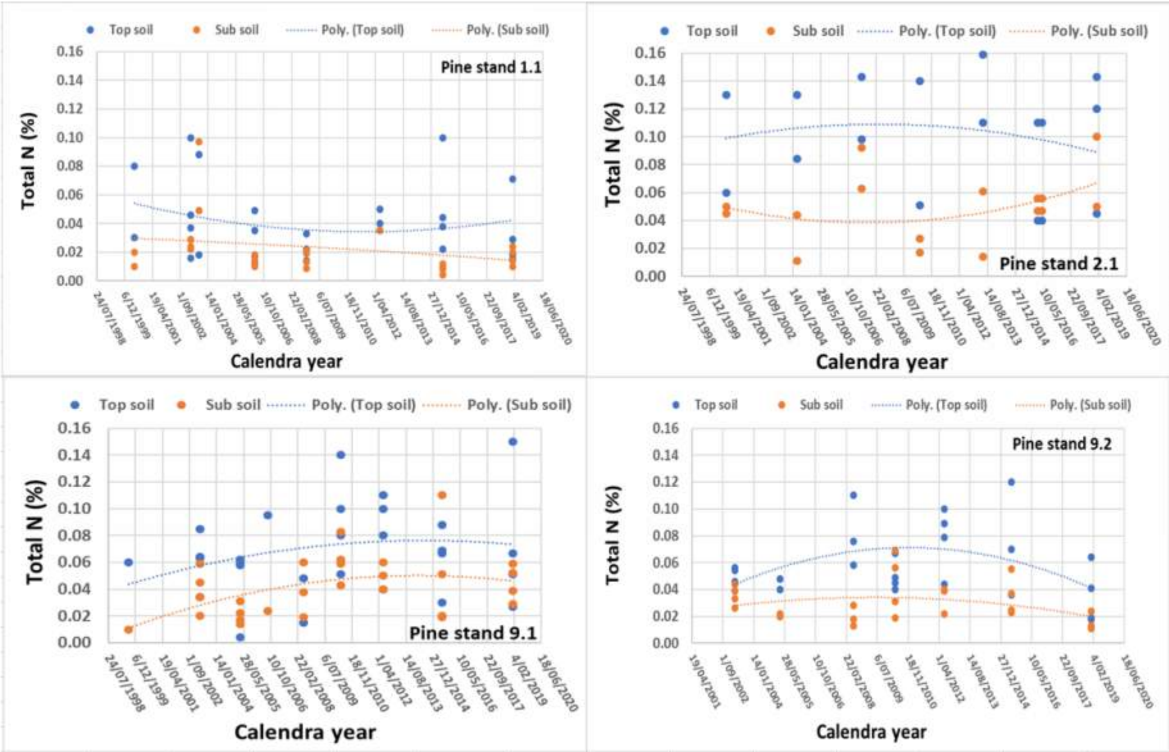

Fig 9c. Changes of the average soil total N in top- and sub-soils of four selected pine stands in the operational areas over the period of 1999-2019. Poly. (Top soil) and Poly. (Sub soil) represent polynomical regression models to be fitted to the data for top and sub soils, respectively.

Soil heavy metal concentrations

The average and maximum concentrations (Table 7) of cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), mercury (Hg) and zinc (Zn) over the period of 1999-2019 were below the soil limits defined the guidelines for the safe application of biosolids to land in New Zealand[11] and the National Environmental Standard for Assessing and Managing Contaminants in Soil to Protect Human Health[31]. This support our findings from the biosolids research trial at Moturoa / Rabbit Island, which are detailed in the previous sections.

The average (1999-2019) concentrations of arsenic (As) and nickel (Ni) were lower than the NZ biosolids guidelines soil limits but the maximum values for As and Ni were greater than those soil limits (Table 7) on occasion. For As, most of the high values were found during earlier testing when the analytical detection limits were higher than in recent times. Since 2005, no soil As values have exceeded the NZ biosolids guidelines soil limit.

The soils at Moturoa / Rabbit Island are naturally high in Ni (geogenic Ni) due to the presence of Ni-rich Dunn Mountain mineral belt within the upper estuary catchment[32]. The soils of Control plots at the biosolids research trial showed comparable Ni concentrations to soils from operational areas (Table 7). In addition, the loading of Ni from the biosolids are well under the limits, indicating a low impact of biosolids application. All those support a ubiquitous geological source influence.

Table 7. Cumulative effect of operational biosolids applications on concentrations of total heavy metals in soil during the period of 1999-2019

	As	Cd	Cr	Cu	Pb	Hg	Ni	Zn
	(mg kg^{-1})							
BRT Control [a] (0-25 cm)	2.9	0.04	43	2.6	3.6	0.03	23	21
BRT Control (25-50 cm)	3.6	0.04	42	2.7	3.4	0.05	36	21
Top soil [b] (0-20 cm)	3.66 (**35**)	0.13 (0.63)	20 (120)	3.82 (41)	3.56 (72)	0.34 (0.53)	42 (**190**)	21 (96)
Sub soil [b] (20-40 cm)	3.56 (**30**)	0.14 (0.52)	19 (100)	4.56 (65)	3.83 (35)	0.38 (0.60)	36 (**210**)	22 (150)
Soil contaminant standards								
NZ Biosolids Guidelines	20	1.0	600	100	300	1.0	60	300
NES [c]	20	3.0	>10,000 (Cr^{3+})	>10,000	210	310	/	/
Resource consent [d]	10	3.0	600	140	300	1.0	100	300

[a] BRT Control – Biosolids research trial control. Data presented here for comparison with the operational sites
[b] Mean (Maximum) values of soil heavy metals presented for the top and sub soils
[c] National Environmental Standard for Assessing and Managing Contaminants in Soil to Protect Human Health - Land-use scenario for Residential 10% Produce – a conservative limit adopted as a precautionary measure
[d] The resource consent limits for both top- and sub-soils, which are based on the Department of Health 1992 Guidelines for arable land

Guidance to biosolids application

Several documents have been developed to guide biosolids application in New Zealand:

- Best Management Practices for Applying Biosolids to Forest Plantations in New Zealand (New Zealand Forest Research Institute Ltd, 2010);
- Guidelines for the Safe Application of Biosolids to Land in New Zealand (NZWWA, 2003);
- New Zealand Environmental Code of Practice for Plantation Forestry (NZFOA, 2007); and
- Background soil concentrations and soil guideline values for the protection of ecological receptors (Eco-SGVs) – Consultation draft (Landcare Research, 2019)

The Best Management Practices for Applying Biosolids to Forest Plantations in New Zealand was developed by Scion in 2010 for backing up the biosolids research trial established in pine forests at Moturoa/ Rabbit Island and this document serves as a guide for applying biosolids to other forest plantations in New Zealand. The purpose of this document is to ensure that the learnings gained from the research trial work are available to the case-study sites nationally so that appropriate best management practice is used in all aspect of the application of biosolids to forest plantations. As Moturoa / Rabbit Island was the original case-study, the best management practices described in this document reflect in the most part the practices that are undertaken at Moturoa / Rabbit Island.

The Guidelines for the Safe Application of Biosolids to Land in New Zealand were produced as a joint initiative of the wastewater industry, central and local government and other key stakeholders in 2003. These guidelines supersede parts of the Department of Health's Public Health Guidelines for the Safe Use of Sewage Effluent and Sewage Sludge on Land (1992). The 1992 guidelines were used to guide the existing resource consent conditions – specifically the imposed maximum heavy metal soil concentrations. The earlier 1992 guidelines have been withdrawn by the Ministry of Health.

This report has adopted the recommended limits of the 2003 Guidelines to assess performance of the biosolids operation at Moturoa / Rabbit Island. The revised heavy metal maximum soil concentration limits recommended in the section below are taken directly from the 2003 Guidelines.

The aim of the New Zealand Environmental Code of Practice for Plantation Forestry is to assist forestry operators to plan, manage, and carry out commercial forest operations in a way that avoids, remedies, or mitigates adverse effects on the environment. While the code is not specifically referenced in this report it is expected that the Tasman District Council Forest Manager (PF Olsen) will operate consistently with the code.

The background soil concentrations and soil guideline values for the protection of ecological receptors (Eco-SGVs) by Landcare Research (2019) is a consultation draft only. Eco-SGVs are intended to inform consent limits for application of wastes (e.g. managed fill, clean-fill, organic wastes) and in this respect are 'pollute-up-to' criteria. In setting criteria for waste disposal, protection of human health and groundwater resources should also be considered, thus Eco-SGVs are only one component for consideration. A key difference between developing Eco-SGVs and developing criteria for cleanfills, managed fills, application of biosolids to land, etc. is that for the latter all potential impacts – i.e. to human health, leaching to groundwater, protection of soil biota – should be considered. For some contaminants, human health impacts or leaching to groundwater may pose a greater potential risk than the impact on ecological receptors (e.g. soil biota) and be the defining point for setting relevant criteria. It is recommended that the 2003 Guidelines are the appropriate reference document, particularly when setting heavy metal maximum soil concentration limits.

Resource consent conditions

An application to change conditions for the previous resource consent (NN940379V2) was considered in 2008, and the new resource consent (NN940379V3) was granted on 3 December 2008 and will expire on 8 November 2020.

The following section of this report considers relevant existing consent conditions and any change recommended to these, both in light of the discussion above and to update the biosolids monitoring regime to align with industry best practice.

Application of biosolids

<u>Existing condition 4.6</u>

Based on the above discussion within this report, we consider that maintaining the application rate under the current consent is appropriate, provided ongoing monitoring is undertaken to manage potential future effects on the receiving environment.

Monitoring

<u>Biosolids – existing condition 7.1</u>

In the existing consent conditions, biosolids are primarily monitored for pathogens, chemical properties including dry solids, organic matter, pH, total and ammoniacal nitrogen, phosphorous, potassium and heavy metals (As, Cd, Cr, Cu, Pb Hg, Ni and Zn).

It is important that any new consent conditions provide a pathway for the NRSBU biosolids operation to keep up to date with new monitoring requirements as these become available. An example of this is proposed limits of PFAS in organic waste product at 0.01 mg kg^{-1} dry weight as contained in the Guidelines for Beneficial Use of Organic Materials on Productive Land[32]. This document is still watermarked "Draft for Public Comment" and so the NZ Biosolids Guidelines 2003 have been adopted as the current framework in assessment. However, safe limits of PFAS in biosolids have been proposed by many countries including USA, Europe, Australia and it follows that provision is made in the new consent for any changes to the existing guideline framework to be implemented as these become available.

It is recommended that a Monitoring Technology Review Report be included as a condition of consent to ensure that there is an obligation on the NRSBU to maintain a current monitoring regime and to provide a pathway for the biosolids operation to respond to monitoring results over the life of a new consent.

Soils – existing condition 7.3

Monitoring the build-up of contaminants in the receiving soil is an important risk management measure. The Beca Ltd Biosolids Process Alternatives Assessment confirms that the biosolids applied at Moturoa / Rabbit Island are Grade A biosolids as per the NZ Biosolids Guidelines 2003[11] and the Guidelines for Beneficial Use of Organic Materials on Productive Land[33], and Class A biosolids as defined by the US EPA and required under the existing consent conditions.

After reviewing the existing soil monitoring conditions, we recommend some amendment as follows:

- Soil from sites to which biosolids have been applied should be sampled using an unbiased pattern such as a grid or rectangle to capture the GPS location of the sample collection site;
- The table included at existing condition 7.3 (b) is updated to reflect the NZ Biosolids Guidelines 2003 as per the below:

Heavy metals	**Maximum Soil Concentrations (mg/kg dry weight)**
Arsenic (As)	20
Cadmium (Cd)	1
Chromium (Cr)	600
Copper (Cu)	100
Lead (Pb)	300
Mercury (Hg)	1
Nickel (Ni)	60
Zinc (Zn)	300

It is acknowledged that the existing table 7.3 also contains maximum annual and cumulative loadings however these are only used to guide biosolids application and are not real-time indicators. Accordingly, only the maximum soil concentration limits as recommended by the Biosolids Guidelines are recommended for inclusion in the consent table.

Conclusions

Overall monitoring results from the long-term biosolids research trial indicate that, during the period of 1997-2019, repeated applications of biosolids (six times in 1997, 2000, 2003, 2006, 2009 and 2012) have not resulted in significant adverse effects on soil quality and health but have improved tree nutrition and growth of radiata pine stands. This has transformed the forest site from a relative low productivity to an average or above average productivity site with improved forest profitability.

Our key findings are:

- Repeated applications of biosolids to planted pine forests on a low fertility sandy soil significantly increased soil total C, N and P and plant-available N and P in soil.
- Repeated applications of biosolids enhanced pine growth by improving soil N supply and tree N nutrition. However, annual N uptake by pine trees after age 20 years dropped considerably to less than 10% of the peak annual N uptake at age 6 years.
- Despite small reduction (5-7%) in wood density and stiffness caused by application of biosolids, the considerable increase in tree stem volume more than compensated for the value loss caused by the slightly reduced wood quality.
- Repeated applications of biosolids, especially the High treatment (600 kg N ha^{-1}), caused a reduced soil pH and slow accumulation of Cu, Zn, Pb, As, Cd and As in the litter and soil. Overall concentrations of these heavy metals were well below the soil contaminant limits defined by the NZ Biosolids Guidelines 2003.
- Up to 2010, ecotoxicological assessment showed no significant adverse effects on soil quality and health caused by repeated applications of biosolids.
- No evidence was found for the accumulation of perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA) in the surface soil (0-25 cm) at Moturoa / Rabbit Island as a result of repeated applications of biosolids.
- In consideration of the positive effect on tree growth and the potential risk of N leaching, application of 300 kg N ha-1 per 3 years was justified as an appropriate application rate at Moturoa / Rabbit Island.
- Biosolids-derived heavy metals were strongly retained in the litter layer. The mobility and long-term fate of these heavy metals in the receiving environment warrant further monitoring.
- In consideration of the relatively uniform soils across Moturoa / Rabbit Island and the same forest management practices (by PF Olsen), we believe the research trial reflects the wider scheme of operational areas, and it is therefore justified to extrapolate findings from this research trial to operational sites.

On review of available data collected from the monitoring of soils across the operational areas of Moturoa / Rabbit Island, we conclude:

- Repeated applications of biosolids improved soil fertility, by increasing soil organic matter and available nutrients (e.g. N, P) over time, in both the top and sub soils.
- Overall, soil pH was maintained above 5, although it gradually decreased with repeated applications of biosolids over time and dropped below 5 at some sites on occasion.

- Despite the slow accumulation, the concentrations of Cd, Cr, Cu, Pb, Hg and Zn were below the soil limits defined the NZ Biosolids Guidelines 2003 and the National Environmental Standard for Assessing and Managing Contaminants in Soil to Protect Human Health (MFE 2012).
- The average concentrations of As and Ni were below the NZ biosolids guidelines soil limits but the maximum values for As and Ni were higher than those soil limits on occasion.
- The existing application rates of 300 or 450 kg N ha-1 every 3 years depending on the stand age have been justified as appropriate and should be retained.
- Improved soil monitoring regime is warranted to safeguard the receiving environment (e.g. soil and groundwater).

Acknowledgements

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Supplementary figures and tables

Table S1. Cumulative effect of six biosolids applications on the concentrations of total heavy metals in the soil sampled in November 2017 and 2019* (biosolids applied in 1997, 2000, 2003, 2006, 2009 and 2012)

Depth	Treatment	As	Cd	Cr	Cu	Pb	Hg	Ni	Zn
		mg kg^{-1}							
Year 2017									
	Control	3.5 a	0.03 a	/	5.1 a	7.0 a	0.39 a	22 a	23 a
0-25 cm	Standard	3.5 a	0.05 a	/	7.0 b	7.2 a	0.44 a	21 a	24 a
	High	3.7 a	0.05 a	/	7.9 c	7.6 b	0.47 a	21 a	25 a
	Control	4.1 a	0.02 a	/	5.1 a	3.4 a	0.005 a	38 a	22 a
25-50 cm	Standard	4.1 a	0.02 a	/	5.0 a	3.5 a	0.005 a	37 a	23 ab
	High	4.3 a	0.03 a	/	5.1 a	3.7 a	0.005 a	39 a	25 b
Year 2019									
	Control	2.6 a	0.02 a	17 A	4.6 a	3.4 a	0.005 a	24 a	26 a
0-25 cm	Standard	3.0 b	0.03 b	18 A	5.9 b	3.6 a	0.007 a	26 a	27 ab
	High	2.9 b	0.03 b	17 A	6.6 c	3.8 a	0.005 a	25 a	28 b
	Control	3.3 a	0.03 a	19 A	5.5 a	3.6 a	0.005 a	40 a	27 a
25-50 cm	Standard	3.6 a	0.03 a	19 A	5.2 a	3.3 a	0.045 a	40 a	27 a
	High	3.5 a	0.03 a	22 A	5.2 a	3.4 a	0.005 a	42 a	29 a
Soil limit or ceiling concentrations by guidelines									
NZ Biosolids [a]		20	1.0	600	100	300	1.0	60	300
DOH1992 [b]		10	1.0	600	140	300	1.0	100	350

* For each depth, values within a column followed by different letters differ significantly at *P* = 0.05 (LSD test)

[a] The guidelines for the safe application of biosolids to land in New Zealand (NZWWA 2003)

[b] Department of Health 1992 Guidelines for arable land

Table S2. Cumulative effect of five biosolids applications on soil physical properties under *Pinus radiata* at May 2010 (biosolids applied in 1997, 2000, 2003, 2006 and 2009)

Depth (cm)	Treatment	BD ($g\ cm^{-3}$)	TP (%)	MP (%)	AC (%)	TAWC (%)	RAWC (%)	K_{-40} ($mm\ h^{-1}$)	H rating
0–10	Control	1.01 a	62 a	32 a	44 a	14 a	8 a	103 a	2.3 a
	Standard	1.03 a	61 a	35 a	46 a	11 a	7 a	87 a	2.9 a
	High	1.03 a	61 a	32 a	44 a	13 a	9 a	125 a	2.5 a
10–20	Control	1.24 a	54 a	25 a	40 a	11 a	8 a	113 a	1.3 a
	Standard	1.23 a	54 a	24 a	41 a	10 a	7 a	107 a	2.4 a
	High	1.24 a	54 a	26 a	41 a	10 a	7 a	97 a	2.0 a

BD – Bulk density; TP –Total porosity; MP – macroporosity; AC – air capacity; TAWC – total available water capacity (10–1500 kPa); RAWC – readily available water capacity (10–100 kPa); K_{-40} – Unsaturated hydraulic conductivity (at −40 kPa); H rating –Hydrophobicity average rating (1 – low, 5 – high); Control, Standard and High represent biosolids application at 0, 300 and 600 kg N ha^{-1}, respectively.

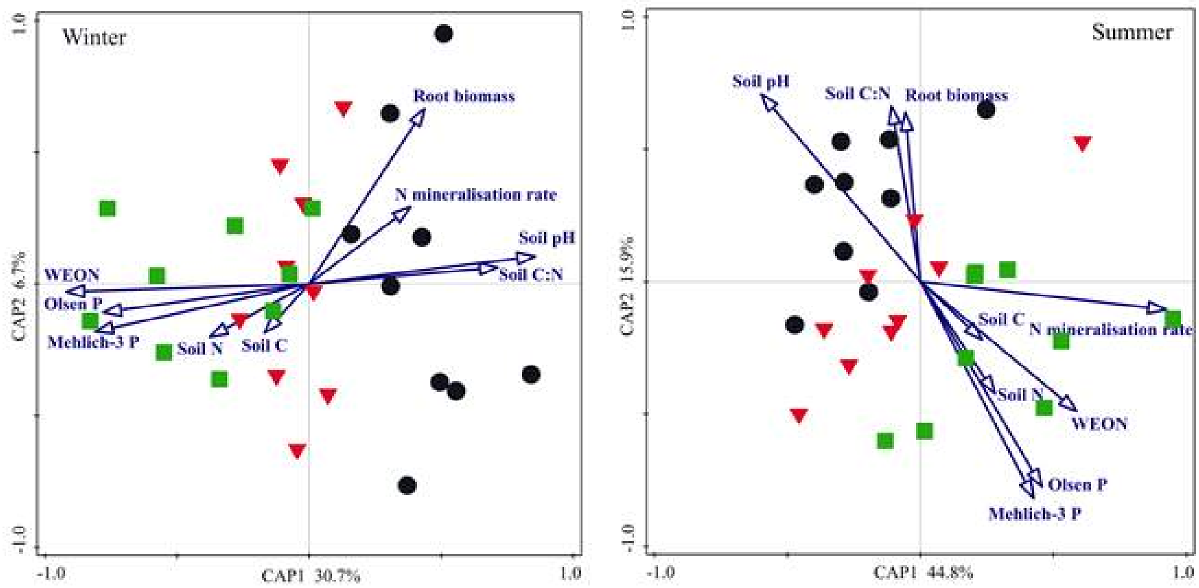

Fig S1. Changes in soil microbial community structure among different biosolids treatments in winter (left panel) and summer (right panel). Black circles, red triangles and green squares represent Control (0 kg N ha^{-1}), Standard (300 kg N ha^{-1}) and High (600 kg N ha^{-1}) biosolids treatments, respectively; Groups are significantly separated.

WEON represents water-extractable organic N; Soil C represents total soil C; Soil N represents total soil N; CAP1 and CAP2 represent the first constrained axis and the second constrained axis in distance-based redundancy analysis, respectively. Soil samples (0-10cm) were collected in winter (July) and summer (November) 2014. Biosolids were applied in 1997, 2000, 2003, 2006, 2009 and 2012.

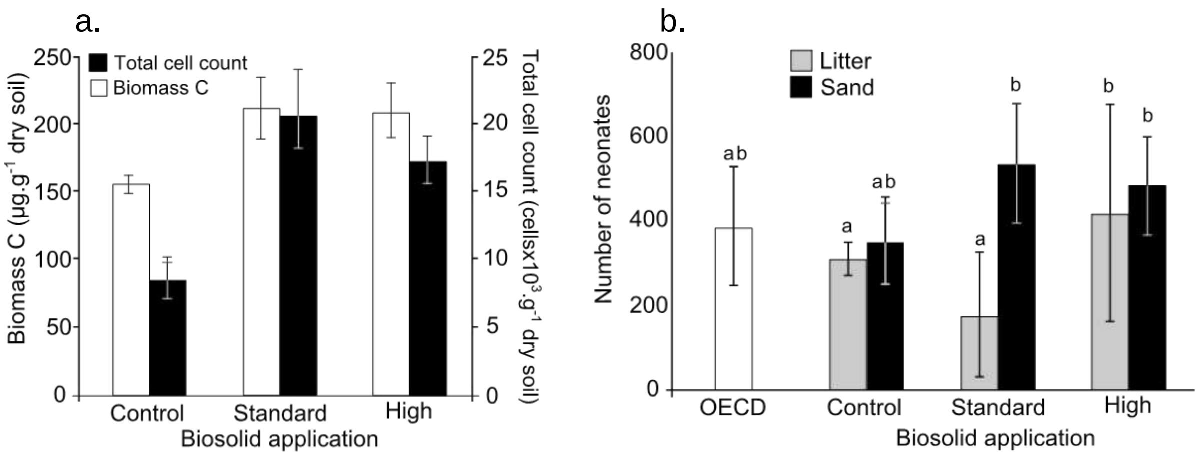

Fig S2. Cumulative effect of five biosolids applications on soil microbial biomass carbon (C) and total microbial cell counts (a.), and on juvenile collembolas (*F. candida*) produced in the litter and soil at the end of 28-day incubation experiment (b.). Soil samples (0-25 cm) were collected in May 2010. Biosolids were applied in 1997, 2000, 2003, 2006 and 2009.

Attachment H

REPORT

Moturoa / Rabbit Island Biosolids Application

Groundwater assessment

Prepared for
Nelson Regional Sewerage Business Unit

Prepared by
Tonkin & Taylor Ltd

Date
August 2020

Job Number
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Table of contents

1 Introduction

Tonkin & Taylor Ltd (T+T) has been engaged by the Nelson Regional Sewerage Business Unit (NRSBU) to prepare a technical assessment of actual and potential effects of the application of biosolids on groundwater at Moturoa / Rabbit Island. This report details the results of our assessment and has been undertaken in accordance with our Professional Services Brief dated 23 March 2020.

This report will be used as part of the Assessment of Environmental Effects (AEE) for resource consent renewal in conjunction with a number of other specialist technical reports prepared by other members of the consenting project team.

1.1 Project background

NRSBU is responsible for managing and operating the Bell Island Wastewater Treatment Plant (WWTP), which is jointly owned by the Nelson City and Tasman District Councils (NCC and TDC). The operation of the WWTP is subject to resource consents that were granted in February 2020.

Sludge from WWTP processes is stabilised in digesters at the WWTP and the resultant biosolids are then pumped to storage tanks at the Biosolids Application Facility (BAF) on Moturoa / Rabbit Island. From there the biosolids are sprayed onto plantation forestry on Moturoa / Rabbit Island.

NRSBU holds an existing resource consent, under the Resource Management Act 1991 (RMA), for the discharge on Moturoa / Rabbit Island (ref: NN940379V3[1]). This consent, issued by TDC, expires on 8 November 2020.

1.2 Scope of work

In order to meet the objectives of this groundwater assessment, we have undertaken the following scope of work:

- Review available information relating to the quality and quantity of biosolids applied and groundwater quality and levels, as well as existing consent conditions and published guidance documents for biosolids application in New Zealand:
  - Best Management Practices for Applying Biosolids to Forestry Plantations in New Zealand[2].
  - Guidelines for the Safe Application of Biosolids to Land in New Zealand[3].
- Develop a hydrogeological conceptual model and identification of relevant contaminant fate and transport parameters and estimates of nutrient uptake from plantation forestry.
- Complete an assessment of the availability and likely quantity of contaminants to enter groundwater, as well as the potential for key contaminants to migrate to the coastal environment. This assessment was restricted to contaminants cited in the published guidance documents[2,3] and for which there was sufficient site-specific information to complete an assessment.
- Undertake analytical fate and transport modelling to estimate likely contaminant loading on the coastal environment.

This technical report details the findings of the work undertaken to support the preparation of an AEE, including comment on the relevant consent conditions and whether they remain fit for purpose.

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[1] Tasman District Council, 3 December 2008. *Decision on application to change consent conditions.* New Resource Consent Number: RMNN940379V3, Consent holder: Nelson Regional Sewerage Business Unit.

[2] Magesan, G. N., Wang, H., & Clinton, P. (Scion), February 2010. *Best Management Practices for Applying Biosolids to Forestry Plantations in New Zealand* (45869). Scion, New Zealand.

[3] New Zealand Water & Wastes Association, 2003. Guidelines for the Safe Application of Biosolids to Land in New Zealand. New Zealand Water & Wastes Association.

2 Development of Conceptual Site Model

2.1 Location, site description and setting

The site is located at Moturoa / Rabbit Island, which is located in Tasman Bay, approximately 3 km northwest of the Nelson airport at its closest point. The island is roughly elliptical in shape, oriented approximately northwest-southeast and is approximately 8.3 km long and 2 km wide. The island is low-lying, with a maximum elevation of around 6 m above sea level. The site is shown in Figure 1.

Moturoa / Rabbit Island is used for forestry as well as land- and water-based recreational activities. Recreational areas are located in the central portion of the northern coast of the island, including toilet facilities as well as cycle and walking tracks in the northwestern part of the island.

There are a number of bores on the island for monitoring consent compliance as well as regional groundwater levels. These bores are shown in Figure 1 and further described in Section 2.3.

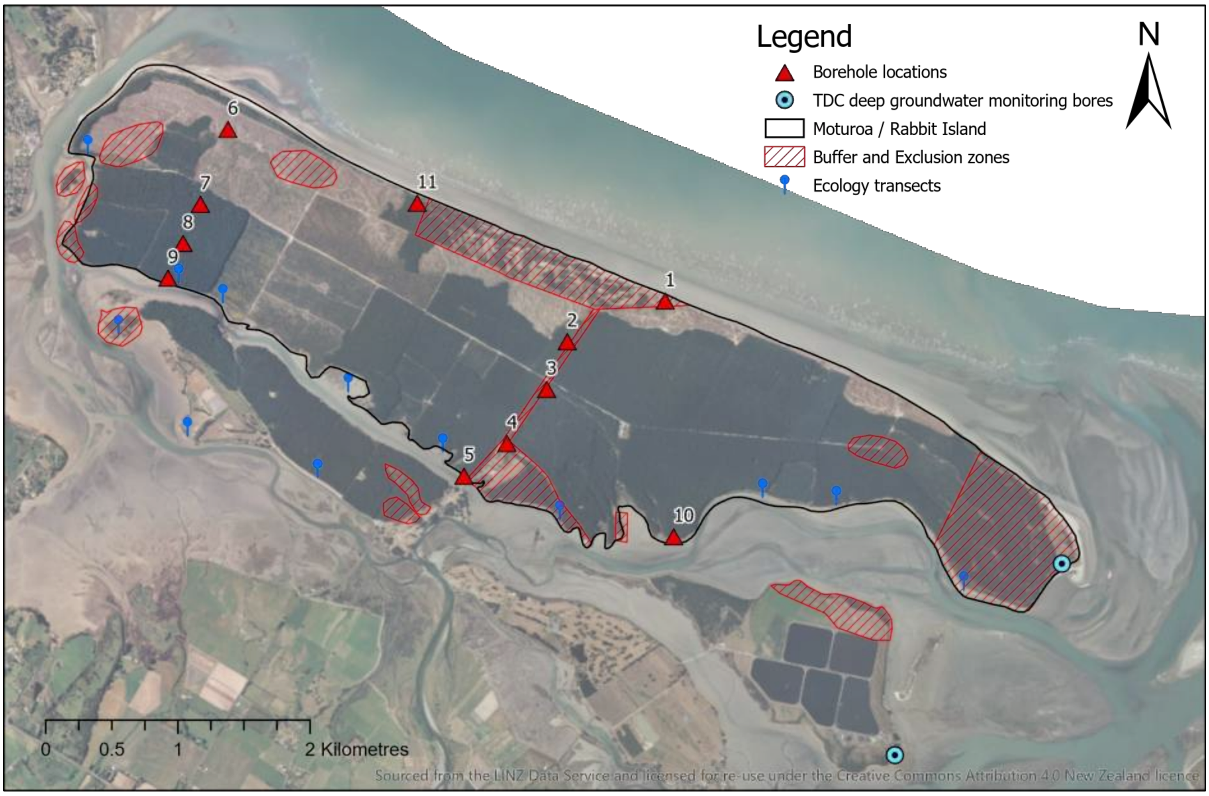

Figure 1: Site and bore location plan. The buffer and exclusion zones depicted are from the existing resource consent and are subject to change.

2.2 Regional geology and hydrogeology

The geology of the area of interest located at the coastal extent of the Waimea Plains has been described previously by Dicker and others[4] and is summarised in the following section. The Waimea Plains form part of the Moutere Depression that has been created through tectonic activity and subsequent infilling with marine and terrestrial sediments. The western boundary of the Waimea Plains is formed by Moutere Gravels eroded from the Spenser Mountains, and the eastern boundary comprises the scarp of the northeast-oriented Waimea Fault.

The Waimea Plains was formed in the late Quaternary period from the infilling of this depression with predominantly terrestrial gravels. The composition of these sedimentary units was influenced

[4] Dicker, M. J. I., Fenemor, A. D., & Johnston, M. R. (1992). *Geology and Groundwater Resources of the Waimea Plains, Nelson* (New Zealand Geological Bulletin No. 106). DSIR Geology and Geophysics, Lower Hutt.

by the source of the sediments as well as climatic changes. Significant stratigraphic units include the Hope Gravels (clay-bound gravels) and the Appleby Gravels.

The hydrogeology of the Waimea Plains is largely determined by the permeability of the stratigraphic units. Major water-bearing features are found within the Hope Gravels in generally discrete aquifer units, known as the Lower Confined Aquifer and the Upper Confined Aquifer. The Appleby Gravels also form an unconfined aquifer from which groundwater is extracted.

The Lower Confined Aquifer extends beneath the Waimea Inlet at least as far as the northeast coastline of Moturoa / Rabbit Island. Groundwater levels at the eastern tips of Rabbit Island[5] and Bell Island[6] are monitored via telemetry by the Tasman District Council. The data from these bores indicate that the Lower Confined Aquifer is artesian and is influenced by tidal cycles.

2.3 Site-specific geology and hydrogeology

Moturoa / Rabbit Island is composed of late Quaternary clastic deposits, comprising the Rabbit Island Gravels overlain by the Tahunanui Sand. The Rabbit Island Gravels comprise rounded gravels and cobbles with varying lithology, predominantly from the Moutere area, as well as the Port Hills area[4]. The gravels have been deposited there via longshore drift, and has been reworked in part from older beach ridges. The Rabbit Island Gravels are up to 20 m thick. The Tahunanui Sand is a fine-grained sand that forms beach ridges and dunes that overlie or laterally grade into the Rabbit Island Gravels. The Tahunanui Sand is estimated to be 16 m thick within the area of interest[7].

The hydrogeology of Moturoa / Rabbit Island comprises an unconfined aquifer within the unconsolidated sediments of the Tahunanui Sands and Rabbit Island gravels. This unconfined aquifer is underlain by the clay-bound Hope Gravels that may act as an aquitard, separating the island aquifer from other water-bearing units. The unconfined aquifer at the island is recharged through rainfall and it is likely that there is a lens of freshwater underlain by saline water intruding from Tasman Bay and the Waimea Inlet. Watercourses on the island are expected to be ephemeral only.

As part of the original resource consent application, two hydrogeological investigations[8,9] were undertaken, including the installation and sampling of two transects of groundwater bores. These bores are arranged in two transects that cross the Moturoa/Rabbit Island from northeast to southwest, with an additional two bores located adjacent the northwest boundary of the central recreational area (bore 11) and at the closest point of the island to Bell Island (bore 10, refer Figure 1). The bores are generally screened in the Tahunanui Sands at depths between 3-7 metres below ground surface. The groundwater surface is between 2-4 metres below ground surface.

Groundwater surfaces and contour maps for selected dates between 2009 and 2019 have been interpolated from groundwater level information from bores 1-10. Note that bore 11 was omitted, as the groundwater levels in this bore appeared anomalous. The interpolation was completed using the SciPy linear radial basis function tool[10] and selected maps are included in Appendix A.

[5] https://www.tasman.govt.nz/my-region/environment/environmental-data/groundwater-levels/waimea-lower-confined-aquifer-at-east-rabbit-island/
[6] https://www.tasman.govt.nz/my-region/environment/environmental-data/groundwater-levels/waimea-lower-confined-aquifer-at-bells-island/
[7] BH_103119, drilled 01/06/1976. Accessed from the *New Zealand Geotechnical Database.*
[8] Thorpe, H. R., 1994. *Interim report on the ground water system at Rabbit Island, Richmond.* Appendix Two of: NZ Forestry Research Institute, September 1994. *Biosolid application on Rabbit Island*. Preliminary report prepared for Beca Steven. Appendix A of Beca Steven, November 1994. *Disposal of biosolids to Rabbit Island*. Report prepared for Nelson Regional Sewerage Authority.
[9] Thorpe, H. R., 1995. *The ground water system at Rabbit Island, Richmond.* Second report, prepared for Beca Steven. Appendix A of: Beca Steven, August 1995. *Biosolids disposal to Rabbit Island and draft resource consent conditions.* Prepared for Nelson Regional Sewerage Authority.
[10] https://docs.scipy.org/doc/scipy-0.14.0/reference/generated/scipy.interpolate.Rbf.html

The interpolated groundwater surfaces indicate a horizontal (on plan) hydraulic gradient i from the northeast to the southwest. There is some spatial variation across the major axis of the island and i has been estimated to vary between 0.0001 and 0.001 $[dh/dx]$. There is some seasonal variation that is likely to be driven by variation in rainfall recharge. Hydrogeological properties for the unconfined aquifer at Moturoa / Rabbit Island have been summarised in Table 2.1.

Table 2.1: Hydrogeological properties

Property		Value	Source
Mean hydraulic conductivity [m/s]		1×10^{-4} m/s (Rabbit Island Sands)	Thorpe[8,9]
Horizontal hydraulic gradient i	5th percentile	0.0001	Derived from groundwater level contours
	50th percentile	0.0003	
	95th percentile	0.001	
Mean porosity [-]		0.44 - 0.5	Thorpe[8,9]
Fraction of organic carbon [-]		0.0025	Veritec[11]

Two additional bores depicted on Figure 1 are maintained by TDC to monitor groundwater levels in the Lower Confined Aquifer. The reported water levels indicate a strong tidal influence and that the Lower Confined Aquifer is artesian (groundwater surface is above ground elevation) at these locations.

Potable water on the island is supplied via the reticulated municipal network. A wastewater rising main traverses the island along Bullivant Road. This wastewater main was replaced in 2011, due to issues with leakage in the old main[12]. Aside from sampling for consent compliance, we are not aware of any other groundwater abstraction from the unconfined aquifer at Moturoa / Rabbit Island.

2.4 Source characterisation

The contaminant source are biosolids originating from the Bell Island WWTP that are applied between forestry stands at Moturoa / Rabbit Island.

2.4.1 Biosolids source

The biosolids are the product of the treatment of municipal sewerage originating from the Nelson region. The biosolids undergo an autoheated thermophilic aerobic digestion (ATAD) process in order to produce a 'Class A' biosolid (according to US EPA standards for the use or disposal of sewage sludge[13] and therefore also the NZ biosolids guidelines[3]). This process reduces contaminant concentrations in the raw sewage sludge. The biosolids are mostly liquid, with an average total solids (by gravimetry) concentration of 15 g/L.

2.4.2 Source application

The biosolids are applied to forestry stands in accordance with best practice[2,3]. The biosolids are pumped to holding tanks at the biosolids application facility at Moturoa / Rabbit Island via a pipeline from Bell Island WWTP. They are then transferred to a travelling irrigator that distributes the biosolids up to 25 m either side of the unit using a spray gun attachment[14]. Forest stands are sprayed

[11] Veritec, 14 June 2017. *Analysis Report, Lab ref: LMS 7305, Task code: J62027.* Issued to Jianming Xue (Scion).
[12] Don Clifford, NRSBU Acting General Manager. Personal communication, 22 April 2020.
[13] US Environmental Protection Agency, 2018. Part 503 – Standards for the use or disposal of sewage sludge. *Code of Federal Regulations 40 – Protection of Environment*.
[14] Wilks, P. & Wang, H., August 2009. The Rabbit Island Biosolids Project. *New Zealand Journal of Forestry 54*(2), 33-36.

approximately every three years, and spraying may occur in a stand for between one to two months, depending on a number of current consent conditions, including:

- Limits on application rates, between 100 to 450 kilograms of nitrogen per hectare per year, depending on the forest status.
- No application within 24 hours of rainfall events or when rainfall is forecast.
- Buffer zones, including:
  - Within 50 m of the coast (mean high water springs).
  - Within 15 m of publicly accessible areas.
- Exclusion zones around areas of cultural or archaeological significance.

  The buffer and exclusion zones above for the current consent are depicted in Figure 1 and are subject to change.
- Regular monitoring of contaminant concentrations in the biosolids, treated soils, groundwater, and the coastal environment, as well as groundwater level monitoring of the bores shown on Figure 1.

2.4.3 Source contaminants

Source contaminants in biosolids can be categorised into the following groups[2,3]: Metals, nutrients, organic contaminants and microbiological contaminants. The source contaminants present in the biosolids are described in further detail in the following subsections. The following data was reviewed in order to characterise the source contaminants:

- Bell Island WWTP biosolids chemistry data for samples collected between February 2013 and May 2018.
- Moturoa / Rabbit Island soil chemistry data for samples collected in May 2019.
- Moturoa / Rabbit Island groundwater chemistry data for samples collected between February 1996 and February 2020.

2.4.3.1 Metals

Metals are contaminants of concern because of their persistence in the environment and the potential for their uptake in plants and crops[3]. Therefore, NRSBU regularly monitors concentrations of metals in biosolids, treated soils and groundwater.

Laboratory analysis data of treated sub soils at Moturoa / Rabbit Island indicate that metals concentrations in the soils are below maximum allowable concentrations for Grade 'a' treated soils under the NZ biosolids guidelines[3] (Table 2.2), except for arsenic and nickel. Elevated arsenic concentrations are likely to be due to higher analytical detection limits during earlier testing; no arsenic concentrations have been reported above the maximum allowable concentrations since 2005[15]. Nickel is known to be naturally elevated in the Nelson and Tasman Districts and elevated concentrations are considered to represent background influences[16].

Groundwater chemistry data indicates that 95th percentile concentrations of some contaminants (chromium, copper, lead, mercury, nickel and zinc) are above ANZG guideline concentrations for slightly to moderately disturbed marine ecosystems[17] (Table 2.3), where any affected groundwater is

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[15] Xue, J. and Coker, G. (Scion), July 2020. *Assessing the impact of land application of biosolids on planted pine forest and soil properties at Moturoa / Rabbit Island.* Scion report 25568248, prepared for NRSBU.
[16] Landcare Research, June 2015. *Background concentrations of trace elements and options for managing soil quality in the Tasman and Nelson Districts*. Report prepared for Tasman District Council.
[17] ANZG, 2018. *Australian and New Zealand Guidelines for Fresh and Marine Water Quality.* Australian and New Zealand Governments and Australian state and territory governments, Canberra ACT, Australia. Available at www.waterquality.gov.au/anz-guidelines.

expected to discharge to. However, the median concentrations for these contaminants are below the ANZG guideline values. Metals concentrations in shallow groundwater at the site sampled prior to the commencement of biosolids application indicates that metals concentrations are occasionally above ANZG guideline concentrations[9], suggesting that background metals concentrations are naturally elevated. This is especially likely for bore 5, for which elevated metals concentrations are often reported.

Metal contaminants applied in the biosolids have been demonstrated to be predominantly retained in the forest litter layer[18]. Heavy metals that were observed in the underlying soils were mostly residual and unlikely to be mobile[18]. This is consistent with partition coefficient values between 29-150 L/kg for the metals with elevated concentrations[19].

Table 2.2: Source contaminants in biosolids and soil – metals

Contaminant	Maximum allowable concentrations in Grade ‘a’ biosolids and treated soils[a] [mg/kg dry weight]	Measured concentrations in biosolids [mg/L]		Measured concentrations in treated sub soil at Moturoa / Rabbit Island [mg/kg][b]	
		Median	95th percentile	Mean	Maximum
Arsenic	20	0.66	5.9	3.56	30
Cadmium	1	0.026	0.045	0.14	0.52
Chromium	600	1.35	4.8	19	100
Copper	100	8.55	13.00	4.56	65
Lead	300	0.65	0.92	3.83	35
Mercury	1	0.023	0.038	0.38	0.60
Nickel	60	0.43	0.59	36	210
Zinc	300	14.5	24	22	150

[a] Maximum concentrations in Grade ‘a’ biosolids are equivalent to maximum allowable concentrations in treated soils.

[b] Adopted from Table 7, (Concentrations of total heavy metals in soil during the period of 1999-2019), Xue, J. and Coker, G, July 2020. *Assessing the impact of land application of biosolids on planted pine forest and soil properties at Moturoa / Rabbit Island.* Scion report 25568248, prepared for NRSBU.

Table 2.3: Source contaminants in groundwater – metals

Contaminant	Measured dissolved concentrations in groundwater [mg/L]		Guideline concentrations in receiving environment waters[a] [mg/L]
	Median	95th percentile	
Arsenic	0.009	0.02	-
Cadmium	0.0005	0.005	0.0007
Chromium	0.0010	0.050	0.0044
Copper	0.0010	0.010	0.0013
Lead	0.0036	0.05	0.0044
Mercury	0.0001	0.0010	0.0001
Nickel	0.0038	0.050	0.007
Zinc	0.0050	0.034	0.015

[a] ANZG/ANZECC guideline values[17] for slightly to moderately disturbed marine ecosystems unless otherwise stated.

[18] Su, J., Wang, H., Kimberley, M. O., Beecroft, K., Magesan, G. N., & Hu, C. (2008). Distribution of heavy metals in a sandy forest soil repeatedly amended with biosolids. *Soil Research*, 46(7), 502.

[19] US EPA, November 2019. *Regional Screening Levels – Generic Tables.* https://www.epa.gov/risk/regional-screening-levels-rsls-generic-tables

2.4.3.2 Nutrients – loading from biosolids

High levels of nutrients in municipal biosolids are beneficial to the growth of pine forests[14], particularly in soils that have low soil fertility, including sandy coastal soils. However, it is important that biosolids application is commensurate with the uptake of nitrogen by the forests in order to avoid leaching of nutrients into groundwater and the associated environmental impacts[3]. Therefore, nutrient concentrations are monitored in the biosolids, soil, groundwater and the coastal marine environment at Moturoa / Rabbit Island, and the nutrient loading of forestry stands is recorded daily during application operations, as prescribed by the existing consent conditions.

Testing information indicates that high levels of nitrogen are present in the municipal biosolids, mainly in organic and ammoniacal forms (Table 2.4). Trace to low levels of nitrite and nitrate are also present.

Table 2.4: Source contaminants – nutrients

Contaminant	Measured concentration in biosolids [mg/L]		Measured concentration in soils [mg/kg]		Measured concentration in groundwater [mg/L]		Guideline concentrations in the receiving environment waters[a] [mg/L]
	Median	95% percentile	Median	95% percentile	Median	95% percentile	
Ammoniacal Nitrogen (as N)	895	1295	-	-	0.01	0.15	2.84
Total Kjeldahl Nitrogen (as N)	1800	2195	-	-	-	-	-
Nitrite (as N)	0.74	2.09	-	-	0.002	0.031	-
Nitrate (as N)	1.28	2.00	-	-	0.082	3.80	-
Total Nitrogen (as N)	1900	2490	0.09	750	-	-	-
Total Phosphorus	310	458	18	84	-	-	-

[a] ANZG/ANZECC guideline values for slightly to moderately disturbed marine ecosystems unless otherwise stated.

A conservative mass-balance approach was used to predict the annual loading of nitrogen into the Waimea Inlet based on mean concentrations of Total Kjeldahl Nitrogen and Ammoniacal nitrogen reported for the biosolids, as well as mean annual biosolids application volumes and rates. The prediction is subject to the following assumptions:

- Approximately 55% of ammoniacal nitrogen is lost to the atmosphere through volatilisation[20].
- Half of the organic nitrogen applied in a soil will be converted to inorganic nitrogen[21].
- The average annual uptake of mineralised nitrogen by pine forest is expected to be 40 kg/ha/year[22]. Uptake of mineralised nitrogen by forestry at Moturoa / Rabbit Island is expected to vary between 5 to 120 kg/ha/year[23], but we have assumed a constant uptake in our predictions.
- All inorganic nitrogen is mineralised to nitrate.

[20] Robinson, M. B., & Röper, H., 2003. Volatilisation of nitrogen from land applied biosolids. *Soil Research*, 41(4), 711.
[21] Wang, H. et al., 2003. Biosolids-Derived Nitrogen Mineralization and Transformation in Forest Soils. *Journal of Environmental Quality 32*(5), 1851–1856.
[22] Beets, P. N., & Pollock, D. S., 1987. Uptake and accumulation of nitrogen in pinus radiata stands as related to age and thinning. *New Zealand Journal of Forestry Science*, 17(2/3), 353–371.
[23] Xue, J. et al, 2020. *Assessing the impact of land application of biosolids on plantation forests and soil properties.* Prepared for Nelson Regional Sewerage Business Unit. Scion Report No. xxx.

- All application rates, volumes and processes are constant and based on average (mean/median) values.
- Denitrification does not occur in the unsaturated zone or groundwater.

The annual loading of nitrogen potentially available to discharge into the surrounding environment is estimated to be approximately 14 tonnes per year. This mass would represent 3% and 0.8% of the reported mean annual cumulative nitrogen loads for the Waimea Inlet and Tasman Bay catchments, respectively[24]. This estimate of annual loading of nitrate is subject to significant uncertainty due to the underlying assumptions listed above.

The derivation of the annual loading estimate is shown in the MathCAD worksheet in Appendix B.

2.4.3.3 Nutrients – review of monitoring data

Concentrations of ammoniacal nitrogen reported in groundwater are generally within expected background ranges. Biosolids ammonia is expected to partially volatilise and be mineralised into forms that can be uptaken by forestry[21]. Ammonia will transform to nitrite and nitrate under aerobic conditions.

Groundwater monitoring indicates low concentrations of nitrite and nitrate, generally within expected background ranges[25]. However, time-series data demonstrate a slug of nitrate-N, in bore 7 from 2006 to 2012, peaking at 60 mg/L during 2008 (Figure 2). No observable nitrate-N breakthrough was apparent at the adjacent monitoring well bore 8, which is expected to be downgradient.

It is not clear whether the observed nitrate in groundwater at bore 7 can be directly attributed to the application of biosolids. This is because it is possible that other sources are responsible, in particular, there is a report of a release of wastewater, which may have been from a breakage of a wastewater rising main near bore 7[26].

Phosphorus concentrations in treated soils are within background ranges reported in New Zealand[27] and we therefore do not consider a risk assessment necessary.

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[24] Morrisey D., Campos C., Gillespie P., 2020. *Assessment of the effects on the coastal environment of biosolids application to land on Moturoa / Rabbit Island*. Prepared for Nelson Regional Sewerage Business Unit. Cawthron Report No. 3500.

[25] World Health Organisation, 2011. *Nitrate and nitrite in drinking-water*. https://www.who.int/water_sanitation_health/dwq/chemicals/nitratenitrite2ndadd.pdf

[26] Don Clifford, NRSBU. Personal communications, 23 April 2020.

[27] Auckland Regional Council, 2001. *Background concentrations of inorganic elements in soils from the Auckland Region,* Technical Publication 153.

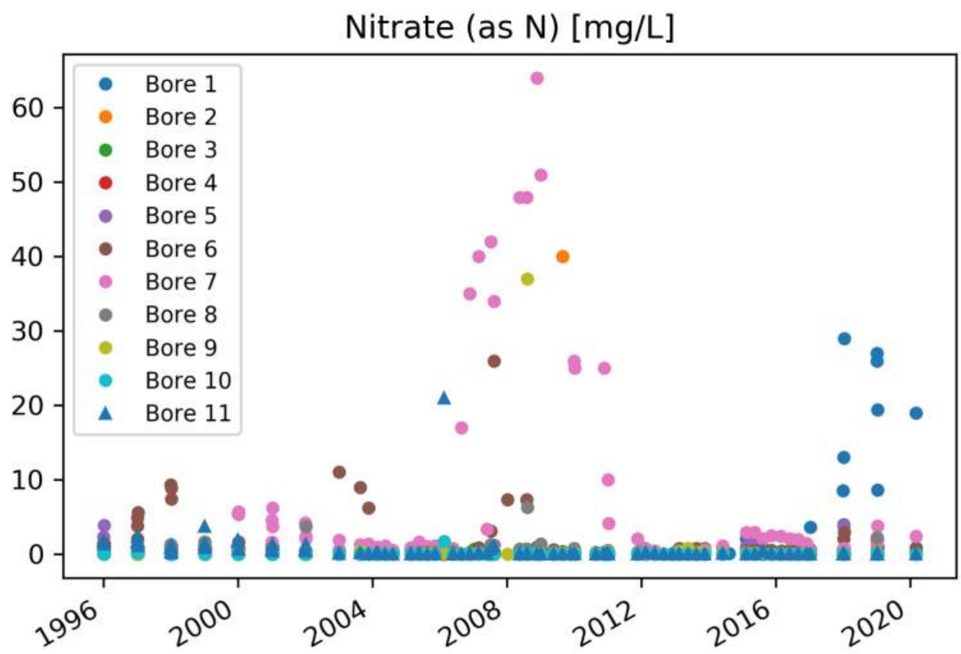

Figure 2: Nitrate-N concentrations in groundwater.

2.4.3.4 Organic contaminants

Concentrations of organochlorine, organonitrogen and organophosphorous pesticides are generally low in biosolids applied in New Zealand[3]. However, to ensure compliance with biosolids guidelines, NRSBU analyses biosolids from the Bell Island WWTP for these contaminants every five years. Concentrations of these pesticides in samples of biosolids analysed in 2013 and 2018 are all below limits of detection. Given this, organic pesticides have not been included in this assessment.

No information regarding other organic contaminant concentrations in the biosolids, treated soil or groundwater was available for review and we have therefore not included other organic contaminants in this assessment.

2.4.3.5 Microbiological contaminants

The ATAD processing method outlined in Section 2.4.1 is understood to result in reduction of microbiological contaminants levels in biosolids to below detection limits. Given this, microbiological contaminants have not been included in this assessment.

2.5 Conceptual site model

The hydrogeological conceptual site model of Moturoa / Rabbit Island consists of a relatively uniform unconfined aquifer in unconsolidated beach/dune sand with underlying sandy gravels (see Figure 3). The unconfined aquifer is shallow (approximately 2-4 m below the ground surface), recharged through rainfall, and is likely to comprise a lens of freshwater that is underlain by seawater.

The predominant groundwater flow direction is to the south west towards the Waimea Inlet and horizontal groundwater flow gradients vary between 0.0001 and 0.001 $[dh/dx]$. These are likely driven by variation in rainfall recharge as well as the coastal geomorphology. Groundwater then discharges into the Waimea Inlet. Aside from consent compliance monitoring, no groundwater is abstracted from the unconfined aquifer at the island.

Biosolids containing metals and nutrients are currently applied to the forestry stands at three-yearly intervals. Metal contaminants from the biosolids are predominantly retained in the forest litter and surficial soils. Organic and ammoniacal nitrogen is expected to be mineralised to nitrite and subsequently nitrate. Elevated nitrate has been observed in groundwater over a six-year period at one of the monitoring wells (bore 7) peaking at 60 mg/L. It is possible that source of the nitrate is from a release from breakage of a wastewater rising main in the vicinity, however its characteristics also match biosolids application. Without further information, and to err on the side of caution, we assume that the observed nitrate in groundwater is due to the biosolids application. Nitrate in groundwater would be expected to migrate to the southwest where it could discharge into the Waimea Inlet and mix with marine water.

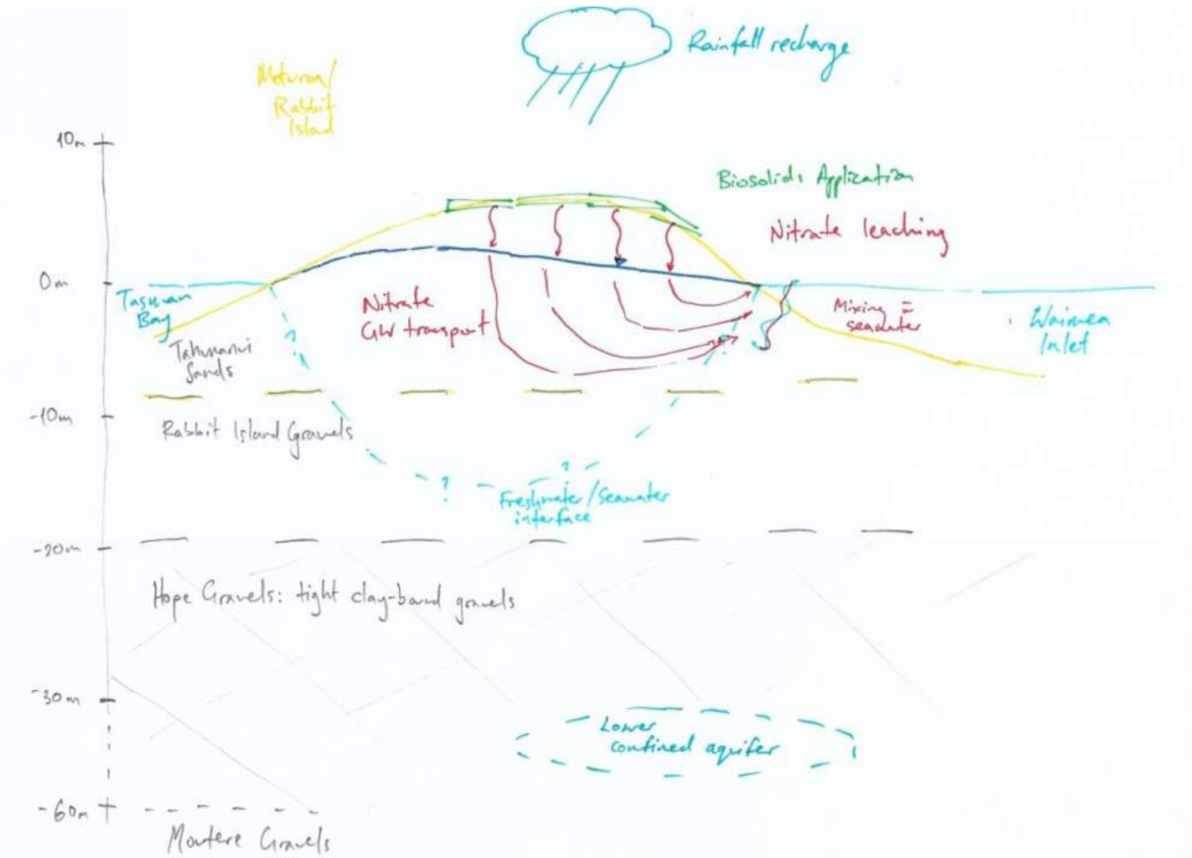

Figure 3: Conceptual site model.

3 Assessment of observed groundwater contamination

3.1 Exposure pathway assessment

We have undertaken an exposure pathway assessment for each group of contaminants described in Section 2.4.3 based on the potential receptors and contaminant concentrations at those receptors. Based on the conceptual site model described in Section 2.5, the only contaminant pathway is through the saturated zone and discharge into the coastal environment. We consider nitrate as the only contaminant with a complete source-pathway-receptor linkage to the coastal environment, as discussed below.

3.1.1 Metals

Groundwater chemistry data indicates that 95th percentile concentrations of some contaminants are above ANZG guideline concentrations, but that median concentrations for these contaminants are below the ANZG guideline values (see Table 2.3). The reported metals concentrations in groundwater are considered indicative of background concentrations for the region. The introduction of additional metals through biosolids application is unlikely to pose a risk to environmental or human health because of the generally low metals concentrations in the biosolids, the immobilisation of metals within the forest litter layer and underlying soils, and the retardation of metals transport in groundwater through partitioning to the aquifer matrix. We have therefore not conducted a detailed fate and transport analysis for metal contaminants.

3.1.2 Nutrients

Potential elevated nitrate-N levels are indicated in the time-series data reviewed in Section 2.4.3.2. Nitrate can move readily through the unconfined aquifer and into the coastal environment where it can contribute to eutrophication of ecosystems (i.e. the Waimea Estuary). We have therefore conducted additional fate and transport modelling to understand potential adverse effects of nitrate.

3.1.3 Pesticides

Concentrations of organochlorine, organonitrogen and organophosphorous pesticides reported in biosolids from the Bell Island WWTP in 2013 and 2018 are all below limits of detection. Given this, and the primary exposure pathway of these contaminants being via grazing animals[3], we consider any potential effects to be negligible.

3.1.4 Microbiological contaminants

Concentrations of microbiological contaminants are generally undetectable or very low due to the ATAD biosolids processing requirements. If microbiological contaminants are present in the biosolids at concentrations below detection, these contaminants are likely to be buffered or filtered in the subsurface[28] such that concentrations at receptors are negligible.

3.2 Contaminant fate and transport

We have undertaken fate and transport modelling in order to estimate potential contaminant loading on the coastal environment. The modelling uses an analytical solution to solve contaminant concentrations over time and is based on the hydrogeological site conceptual model described in Section 2.5.

[28] Pang, L., 2009. Microbial Removal Rates in Subsurface Media Estimated From Published Studies of Field Experiments and Large Intact Soil Cores. *Journal of Environmental Quality*, 38(4), 1531–1559.

3.2.1 Contaminant transport modelling

3.2.1.1 Fate and transport model and parameters

To predict the development of contaminant concentrations in groundwater we have adopted the Domenico analytical solution for a non-continuous contaminant source[29]. We have modelled nitrate-N concentrations in groundwater that discharge to the coastal environment. Although biosolids application occurs across the entire island, we have conservatively modelled application at the minimum distance to the coast of 50 m, based on the buffer zones in the current consent. We have modelled the cumulative effects of multiple pulses of nitrate-N, consistent with the application methods at Moturoa / Rabbit Island.

The source concentration of the nitrate-N has been determined using an iterative process to simulate the observed concentrations in groundwater at BH7. As biosolids application occurs only once every three years at each application location, we have assumed that the source is non-continuous. We have estimated the duration of a source pulse of nitrate to be approximately six months based on the breakthrough of nitrate recorded in bore 7 (see Figure 2). Application records indicate that spraying occurred close to bore 7 around 2006 and that the peak nitrate concentrations were observed approximately two years later, with a maximum concentration just above 60 mg/L. Simulated breakthrough of nitrate-N at bore 7 is shown in the MathCAD worksheet in Appendix B. The source concentrations were determined iteratively and are within the range of nitrogen expected based on the biosolids nitrogen concentrations (see Table 2.4).

The parameters used in the fate and transport modelling include the hydrogeological properties listed in Table 2.1 and additional parameters in Table 3.1 below.

Table 3.1: Fate and transport modelling parameters

Parameter	Value	Source
Source nitrate-N concentration	800 mg/L	Derived using iterative process to simulate observed nitrate levels at bore 7
Distance to receptor	50 m	Based on coastal buffer zones
Water-organic carbon distribution coefficient K_{oc} [L/kg]	10^{-2} L/kg	Texas Commission on Environmental Quality[30]
Dispersion coefficients: Longitudinal Transverse Vertical	 0.1 0.033 0.005	ASTM E1739 - 95(2015) Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites)
Duration of pulse	0.5 years	Based on observed breakthrough at bore 7
Width of nitrate-N plume at the coastal point of discharge	300 m	Based on application area
Intertidal range	1.5 m	Estimated from 0.5 m contours and aerial imagery
Width of inlet mixing zone at high tide	118 m	
Width of inlet mixing zone at low tide	35 m	

[29] Domenico P.A., 1987. An analytical model for multidimensional transport of decaying contaminant species. *Journal of Hydrology 91*, 49-58.
[30] Texas Commission on Environmental Quality (Remediation Division), March 2009. *Toxicity Factors and Chemical/Physical Parameters* RG-366/TTP-19. https://www.tceq.texas.gov/assets/public/comm_exec/pubs/rg/rg-366-trrp-19.pdf

3.2.1.2 Results and discussion

The maximum nitrate-N concentration predicted in groundwater at 50 m from the source is approximately 18 mg/L, with the peak concentration expected to occur between four and five years after the release (Figure 4).

Mixing of affected groundwater with marine water in the Waimea Inlet will reduce the peak nitrate-N concentrations significantly. Conservative estimates of the estuary flow adjacent to Rabbit Island indicate the nitrate-N concentrations would be approximately 0.00035 mg/L in the Waimea Inlet.

Further discussion of the effects of nitrate-N in the environment has been included in the coastal[24] and public health assessments associated with this consent application.

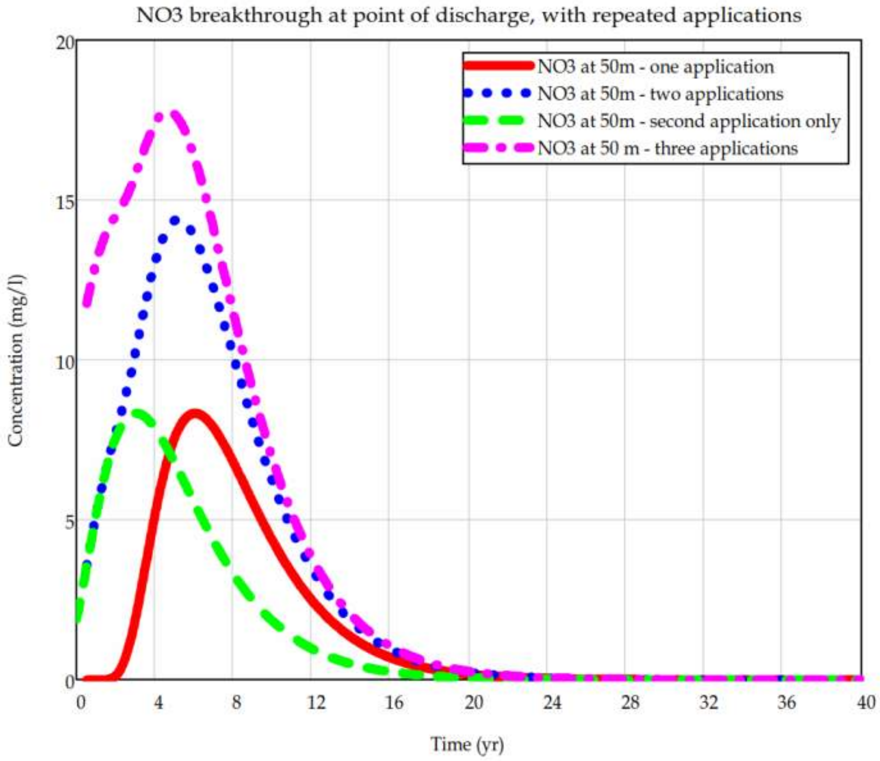

Figure 4: Predicted nitrate-N concentrations in groundwater before discharging to Waimea Inlet.

4 Conclusions and recommendations

T+T has undertaken an assessment of the effects of the application of biosolids at Moturoa / Rabbit Island on groundwater on behalf of NRSBU. The objective of this study was to assess potential for adverse effects to groundwater from the application of municipal biosolids at the island to support a resource consent application.

We have undertaken a review of relevant literature, previous site investigations and laboratory analysis data from regular monitoring of the biosolids, treated soil and groundwater chemistry. Our assessment was restricted to contaminants for which there was available information, namely heavy metals, nutrients and pesticides. Based on our review of available data, nitrogen compounds were assessed as contaminants of concern.

Elevated nitrate has been observed in groundwater over a six-year period at one of the monitoring wells (bore 7), peaking at 60 mg/L. It is possible that the source of the nitrate is an accidental release from a wastewater rising main in the vicinity, however the concentrations suggest that the source is the nitrification of ammonia in the applied biosolids.

Using an iterative process to simulate the observed concentrations, nitrate has been modelled migrating to the coastline and discharging into the Waimea Inlet.

This modelling has indicated that peak concentrations of nitrate-N in groundwater at the point of discharge will be approximately 18 mg/L. However, this short-lived discharge is predicted to be reduced to approximately 0.00035 mg/L at the Waimea Inlet, based on a conservative assessment of mixing in the estuary. Peak concentrations at the point of discharge are likely to be lower where application occurs further from the coastal margin.

Conservative calculations performed using biosolid chemistry, application and volatilisation rates, and pine forest uptake indicate that annual loading of nitrogen into the Waimea inlet is estimated to be around 14 tonnes per year. This would represent 3% and 0.8% of the reported mean annual cumulative nitrogen loads for the Waimea Inlet and Tasman Bay catchments, respectively[24]. The loading estimate is subject to significant uncertainty due to variability in the processes it incorporates. The effect of this discharge is considered in separate coastal and public health assessments.

Based on our groundwater assessment, we consider the risk of contamination to the coastal environment from biosolids application at Moturoa / Rabbit Island to be low. However, to ensure that the risk remains low, we recommend that NRSBU undertake monitoring in biosolids for organic contaminants listed in published guidance documents for biosolids application in New Zealand. Additional monitoring in treated soils and groundwater should be undertaken if concentrations of organic contaminants are found to be above published guidance values for biosolids. The monitoring information may then be reviewed to assess risks from these contaminants to the environment.

5 Applicability

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

We understand and agree that our client will submit this report as part of an application for resource consent and that Tasman District Council as the consenting authority will use this report for the purpose of assessing that application.

We understand and agree that this report will be used by Tasman District Council in undertaking its regulatory functions in connection with Moturoa / Rabbit Island biosolids application facility.

Tonkin & Taylor Ltd

Report prepared by:

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Jeremy Bennett

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Technical review by:

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Senior Contaminated Land Consultant

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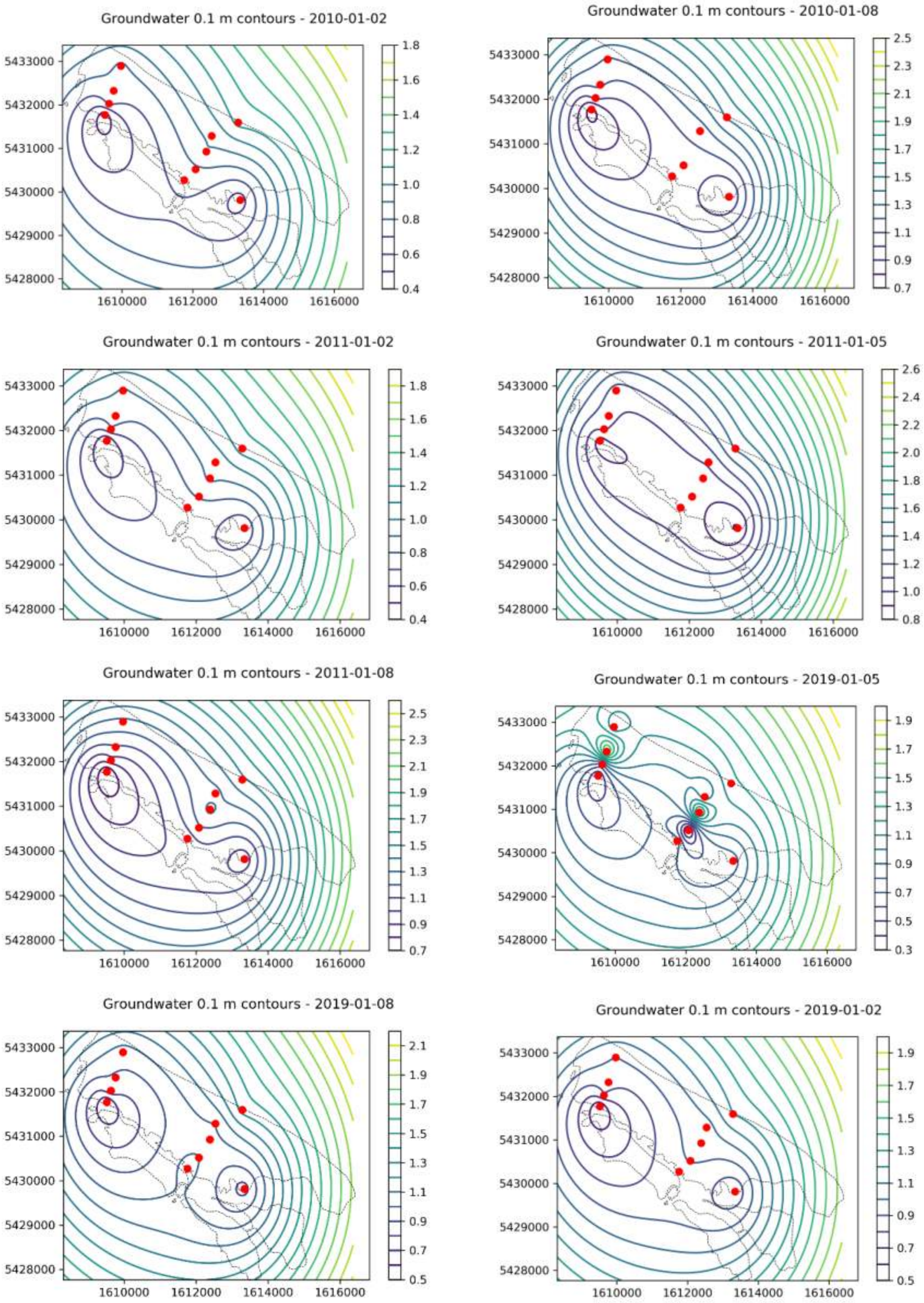
Appendix A: Figures

- **Selected groundwater contour maps**

A1 Selected groundwater contour maps



Contours are the interpolated groundwater surface in metres above sea level. X- and Y-axes are NZTM grid coordinates.

Appendix B: Calculations

- **MathCAD worksheet**

Prediction of nitrogen inputs into the Waimea Inlet from biosolids application at Moturoa / Rabbit Island

This worksheet predicts the loading of nitrogen into the Waimea Inlet from the application of biosolids at Moturoa / Rabbit Island. Full background, including the conceptual site model, is presented in the report to which this worksheet is attached.

Calculation of average annual input of nitrate into the Waimea Inlet

This section calculates the average annual loading of nitrate-N derived from biosolids application at Moturoa / Rabbit Island that is discharged into the Waimea Inlet. The nitrate-N loading is calculated using a mass-balance approach that is subject to the following assumptions:

- The fraction of ammonicacal nitrogen that volatilises is constant.
- The mineralisation factor in soils of biosolids-derived organic nitrogen is constant.
- All inorganic nitrogen is mineralised completely to nitrate.
- The uptake of nitrogen by forestry is composed of inorganic nitrogen only and occurs at a constant rate.
- Total Kjeldahl Nitrogen is composed of organic nitrogen and ammoniacal nitrogen only.
- Median concentrations measured in the biosolids, as well as annual application volumes and areas are constant.
- Parameters adopted from similar settings are valid for Moturoa / Rabbit Island.

Mineralisation factor of organic nitrogen in soils (Table 4, AEM, brown soil, in: Wang, H. et al.. (2003). Biosolids-Derived Nitrogen Mineralization and Transformation in Forest Soils. J. of Env. Qual., 32(5), 1851–1856.). % at which organic nitrogen converted to inorganic/available to leach or for tree uptake.

$f_{Norg} := 0.5$

Remaining fraction of ammoniacal nitrogen during biosolids application following volatilisation (Robinson, M. B., & Röper, H. (2003). Volatilisation of nitrogen from land applied biosolids. Soil Research, 41(4), 711)

$f_{NH4vol} := 0.45$

Median concentration of Total Kjeldahl Nitrogen as N (TKN) in Biosolids

$C_{TKN} := 1800 \cdot mg \cdot l^{-1}$

Median concentration of Ammoniacal nitrogen as N in Biosolids (95th percentile)

$C_{NH4} := 895 \cdot mg \cdot l^{-1}$

Concentration of organic nitrogen in biosolids

$C_{Norg} := C_{TKN} - C_{NH4}$

$C_{Norg} = 905 \cdot mg \cdot l^{-1}$

Concentration of available (inorganic) nitrogen able to be uptaken by forest or leach into groundwater

$C_{Navailable} := C_{Norg} \cdot f_{Norg} \cdots + C_{NH4} \cdot f_{NH4vol}$

$C_{Navailable} = 855 \cdot mg \cdot l^{-1}$

Average uptake of inorganic nitrogen by pine forest (Beets, P. N., & Pollock, D. S. (1987). Uptake and accumulation of nitrogen in pinus radiata stands as related to age and thinning. New Zealand Journal of Forestry Science, 17(2/3), 353–371)

$Q_{pine} := 40 \cdot kg \cdot hectare^{-1} \cdot yr^{-1}$

Application rate of biosolids (mean) - volume

$V_{app} := 22538 \cdot m^3 \cdot yr^{-1}$

Application rate of biosolids (mean) - area per year

$A_{app} := 134 \cdot hectare$

Mass of inorganic nitrogen taken up by pine trees per year

$M_{pine} := Q_{pine} \cdot A_{app}$

$M_{pine} = 5.36 \cdot tonne \cdot yr^{-1}$

Mass of inorganic nitrogen per year

$M_{available} := C_{Navailable} \cdot V_{app}$

$M_{available} = 19.3 \cdot tonne \cdot yr^{-1}$

Amount of inorganic nitrogen assumed to be available for leaching into inlet per year after accounting for mineralisation, volatilisation and uptake from pine forest

$M_{total} := M_{available} - M_{pine}$

$M_{total} = 13.9 \cdot tonne \cdot yr^{-1}$

Prediction of peak nitrate-N concentrations at the point of discharge

This section predicts the maximum concentration of contaminants predicted downgradient of a biosolids application area. Concentrations are predicted using the Domenico analytical solution for advective-dispersive transport.

The Domenico analytical equation assumes:

- A continuous release source.
- Homogeneous aquifer properties.
- One-dimensional groundwater flow.
- No change in groundwater flow direction and velocity.
- First order degradation rate.
- Molecular diffusion based on concentration gradient is neglected.
- A nitrate pulse occurs over a defined time period.

Key Limitations:

- The model should not be applied where vertical flow gradients affect contaminant transport.
- The model should not be applied where hydrogeological conditions change dramatically over the simulation domain.

Reference

Shih T. and Rong Y. (2001) "Preface To Manual For Domenico Non-Steady State Spreadsheet Analytical Model"

Domenico PA (1987). An analytical model for multidimensional transport of decaying contaminant species. Journal of Hydrology 91: 49-58.

United States Environmental Protection Agency (USEPA), (1996). "Soil screening guidance: technical background document E-25pp" EPA/540/R-95/128, PB96-963502.

Parameters

Source concentrations (solved iteratively to match observations at BH7)

$Co_{NO3} := 800 mg \cdot L^{-1}$

Hydraulic conductivity

$k_s := 10^{-4} \cdot m \cdot s^{-1}$

Hydraulic gradient	$i_{grad} := 0.001$
Effective porosity	$n_e := 0.45$
Source width	$Y_{source} := 50m$
Source depth	$Z_{source} := 1m$
Degradation half life of contaminant	$t_{half} := 10^{16} day$
Fraction organic carbon	$Foc := 0.0025$
Soil bulk density	$\rho_b := 1800 kg \cdot m^{-3}$

$$Ret(Kd) := 1 + \frac{\rho_b \cdot Kd}{n_e}$$

$$Koc_{nitrate} := 10^{-2} L \cdot kg^{-1}$$

$$Kd_{nitrate} := Koc_{nitrate} \cdot Foc$$

$$Ret(Kd_{nitrate}) = 1.0001$$

Ratio of Transverse and Vertical to Longitudinal dispersion coefficient

ASTM E1739 - 95(2015) Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites

$\alpha_x := 0.1$

$\alpha_y := 0.033$

$\alpha_z := 0.005$

Equations

Average linear velocity	$v_x := \frac{k_s \cdot i_{grad}}{n_e}$	$v_x = 0.019\ m \cdot day^{-1}$
Degradation constant	$\lambda := \frac{0.693}{t_{half}}$	$\lambda = 0 \cdot day^{-1}$

Concentration at distance x from the source at time t (Domenico,1987)

Transient solution for centre line of the plume.
Conditions of continuous source, with finite source dimensions and one dimensional groundwater velocity.

$$Cdom(t, x, y, Ret, C_o) :=$$

$$a_L \leftarrow \alpha_x \cdot x$$

$$a_T \leftarrow \alpha_y \cdot x$$

$$a_Z \leftarrow \alpha_z \cdot x$$

$$aa \leftarrow \frac{C_o}{8} \cdot \mathrm{erfc}\left[\frac{x - \frac{v_x}{Ret} \cdot t \cdot \sqrt{1 + \frac{4 \cdot \lambda \cdot a_L}{\frac{v_x}{Ret}}}}{2\left(a_L \cdot \frac{v_x}{Ret} \cdot t\right)^{0.5}}\right]$$

$$bb \leftarrow \exp\left[\frac{x}{2a_L} \cdot \left(1 - \sqrt{1 + \frac{4 \cdot \lambda \cdot a_L}{\frac{v_x}{Ret}}}\right)\right]$$

$$cc \leftarrow \mathrm{erf}\left(\frac{y + \frac{Y_{source}}{2}}{2 \cdot \sqrt{a_T \cdot x}}\right) - \mathrm{erf}\left(\frac{y - \frac{Y_{source}}{2}}{2 \cdot \sqrt{a_T \cdot x}}\right)$$

$$dd \leftarrow \mathrm{erf}\left(\frac{Z_{source}}{2 \cdot \sqrt{a_Z \cdot x}}\right) - \mathrm{erf}\left(\frac{Z_{source}}{2 \cdot \sqrt{a_Z \cdot x}}\right)$$

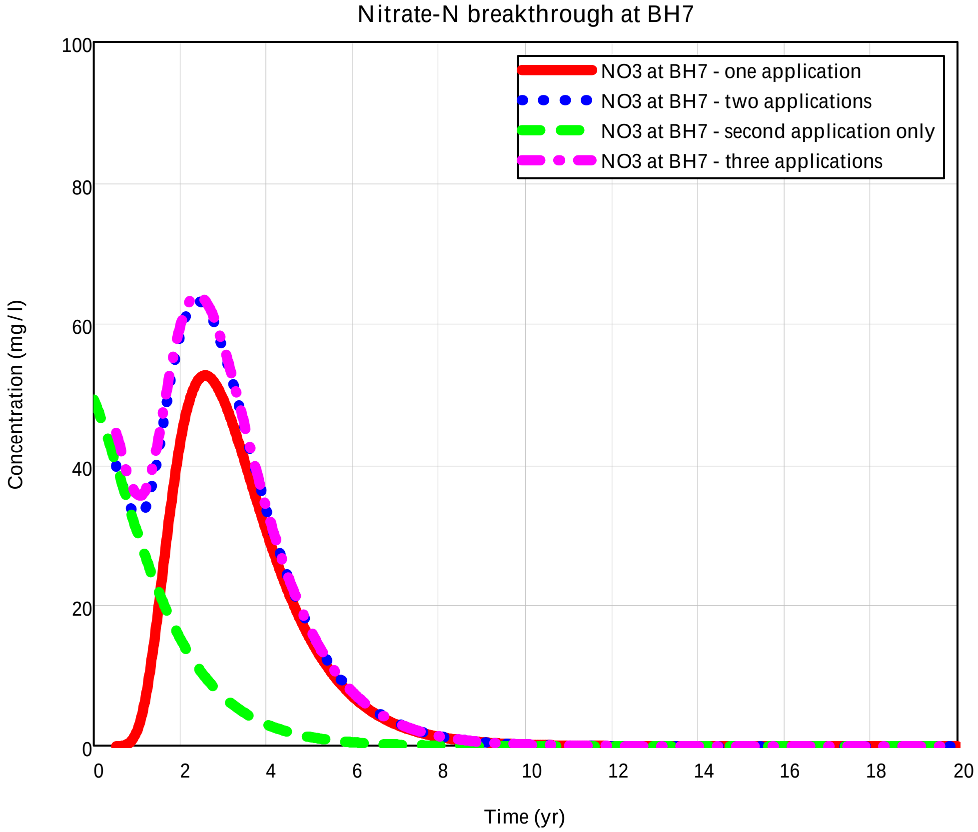
$$ee \leftarrow \exp\left[\lambda \cdot \left(t - \frac{x}{\frac{v_x}{Ret}}\right)\right]$$

$$aa \cdot bb \cdot cc \cdot dd \cdot ee$$

Nitrate-N concentrations at BH7 and point of discharge

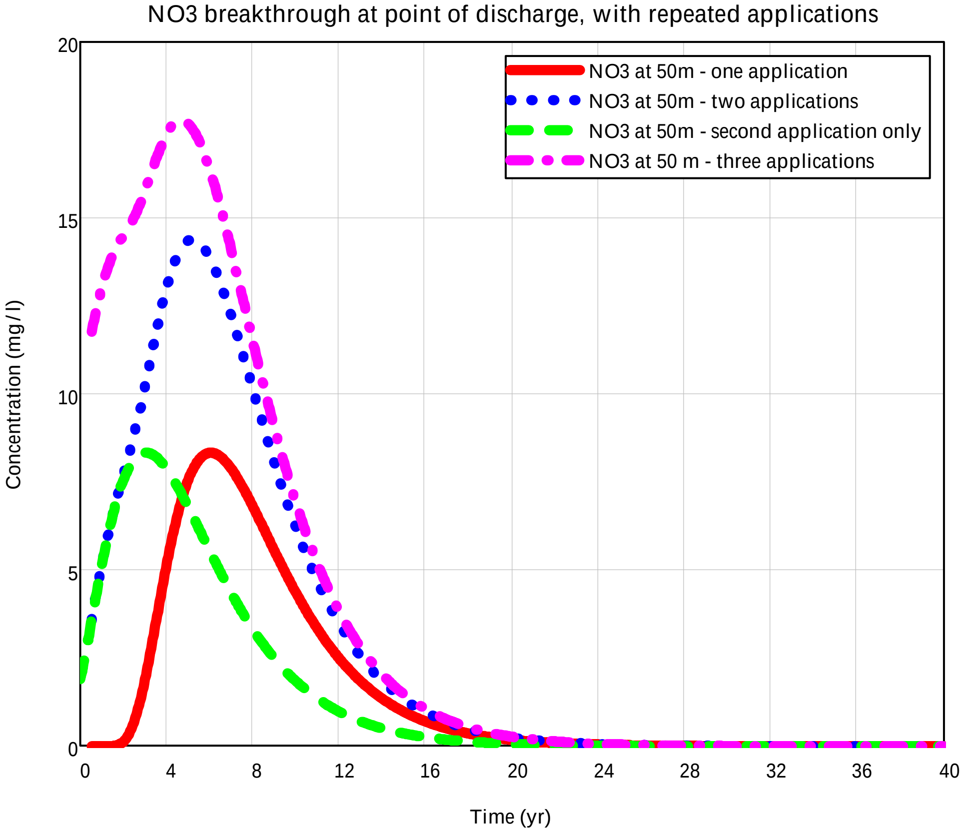
Length of the source application (estimated iteratively) $t_{pulse} := 0.5$

Distance from source to BH7 (assumed) $d_{BH7} := 20 \cdot m$



Distance from source to point of discharge
(Based on minimum 50 m exclusion zone at coastal margin

$d_{receptor} := 50 \times m$



Accounting for mixing with water in the Waimea Inlet

In this section, the mixing of affected groundwater with water in the Waimea Inlet is calculated to predict a peak nitrate-N concentration. This prediction is subject to the following assumptions:

- Mixing occurs only with water within the intertidal zone.
- The intertidal zone is assumed to have a trapezoidal profile.
- The contaminant plume is 300 m wide when it enters the Waimea Inlet.

Groundwater contaminant plume width as it enters the Waimea Inlet. $W_{gwsw} := 300m$

Intertidal range $\Delta z := 1.5 \cdot m$

Width of inlet (MHWS) $w_{MHWS} := 118 \cdot m$

Width of inlet (LHWS) $w_{LHWS} := 35 \cdot m$

Inlet crossectional area $A_{inlet} := \frac{w_{MHWS} + w_{LHWS}}{2} \cdot \Delta z$

Inlet volume $V_{inlet} := A_{inlet} \cdot W_{gwsw}$

Tide time $t_{tide} := \frac{745}{2} \cdot min$

Inlet discharge $Q_{inlet} := \frac{V_{inlet}}{t_{tide}} = 1.54\, m^3 \cdot s^{-1}$

Darcy velocity $V_{gw}(k_s) := k_s \cdot i_{grad}$

Factor by which groundwater contaminants are diluted $DF_{gwsw}(k_s, Q_{sw}) := \left(1 + \frac{Q_{sw}}{V_{gw}(k_s) \cdot Z_{source} \cdot W_{gwsw}}\right)^{-1}$

Surface water concentration $C_{sw}(C_{gw}, k_s, Q_{sw}) := C_{gw} \cdot DF_{gwsw}(k_s, Q_{sw})$

$$DF_{gwsw}(k_s, Q_{inlet}) = 1.948 \times 10^{-5}$$

$$\frac{1}{DF_{gwsw}(k_s, Q_{inlet})} = 5.1 \times 10^{4}$$

Continuous source receptor concentrations

Peak nitrate -N concentration in groundwater at point of discharge $C_{NO3peak} := 18 \cdot mg \cdot L^{-1}$

Peak nitrate-N concentration in inlet water following mixing at point of discharge $C_{NO3peak} \cdot DF_{gwsw}(k_s, Q_{inlet}) = 3.5 \times 10^{-4} \cdot mg \cdot L^{-1}$

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Attachment I

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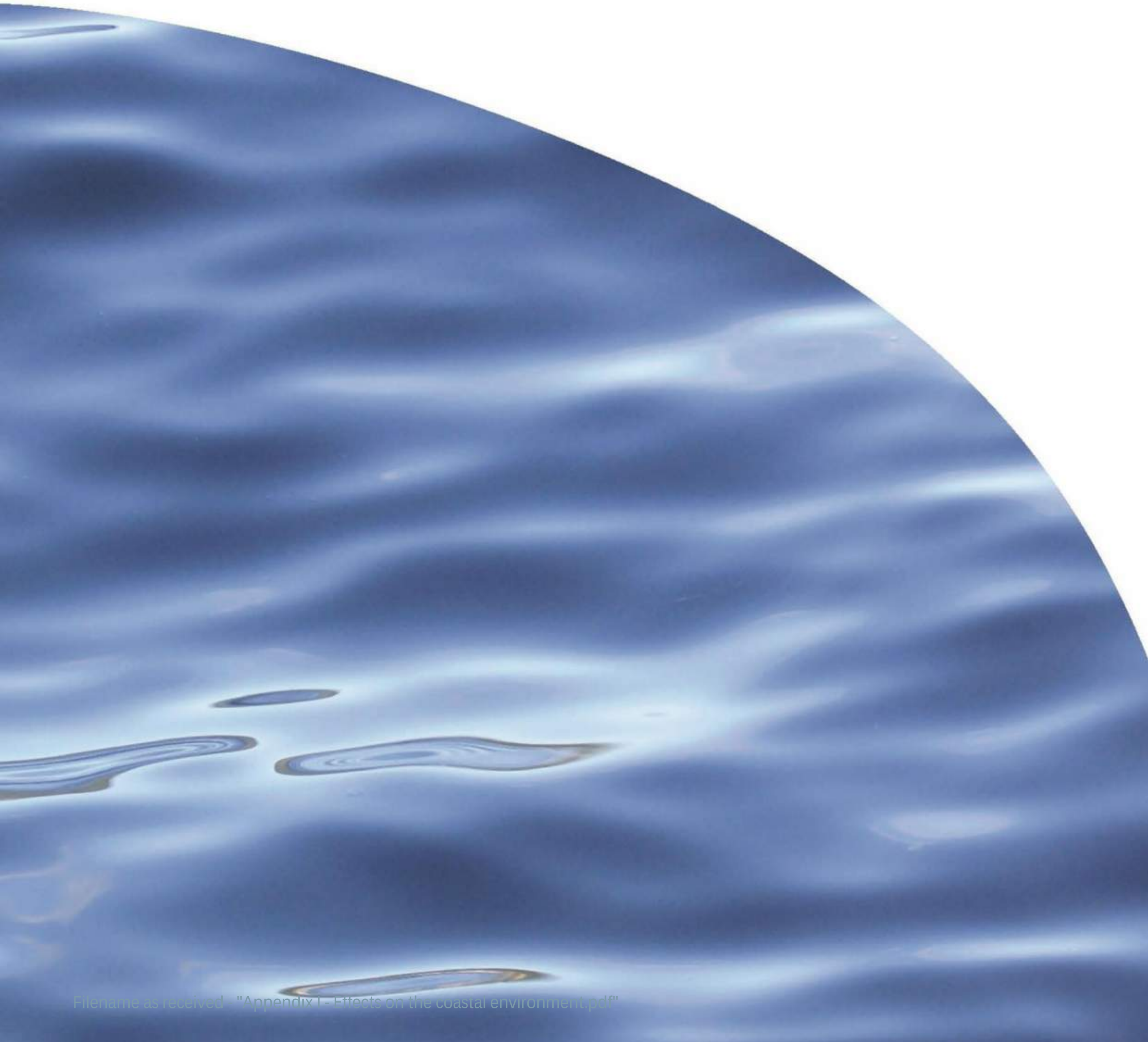
ASSESSMENT OF THE EFFECTS ON THE COASTAL ENVIRONMENT OF BIOSOLIDS APPLICATION TO LAND ON MOTUROA / RABBIT ISLAND



ASSESSMENT OF THE EFFECTS ON THE COASTAL ENVIRONMENT OF BIOSOLIDS APPLICATION TO LAND ON MOTUROA / RABBIT ISLAND

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EXECUTIVE SUMMARY

Biosolids from the Bell Island wastewater treatment plant, operated by Nelson Regional Sewerage Business Unit (NRSBU), are pumped via a pipeline to Moturoa / Rabbit Island and then applied to forestry blocks on the Island by travelling spray irrigators. Application of biosolids to land is currently authorised under resource consent NN940379V3, which expires in November 2020.

NRSBU have engaged the Cawthron Institute (Cawthron) to assess the actual and potential effects of the land application of biosolids on coastal water quality, including the ecology of the intertidal and subtidal receiving environment of Waimea Inlet. Direct measurement of effects on the water quality in Waimea Inlet is very difficult against the background of natural and anthropogenic variation caused by other factors, including other sources of contaminants and tidal mixing of Inlet waters with those of Tasman Bay. However, potential effects from the application of biosolids extend beyond those on water quality to habitats and organisms that are exposed to any change in quality.

The likely mechanism for potential effects of the application of biosolids on the coastal environment is leaching of particulate and soluble components of the biosolids into the ground water and thence, by surface runoff and groundwater flow and seepage, into the coastal zone. The principal components of concern are nutrients (including nitrogen and phosphorus species) that may cause enrichment, leading to excessive growth of micro- and macro-algae, and toxic contaminants such as ammonia and trace metals, that may adversely affect organisms living in the sediment. The class A biosolids produced at the Bell Island Wastewater Treatment Plant are subject to treatment processes that significantly reduce volatile organic matter and eliminate pathogens to the extent that they are not considered to pose a risk to human health or to adversely affect other organisms.

Overall, the results of the monitoring programme indicate that application of biosolids to land on Moturoa / Rabbit Island has less than minor adverse effects on the enrichment or contaminant status of intertidal habitats around Moturoa / Rabbit and Rough islands, nor have any effects on the sediment-living fauna been identified.

Our assessment of effects was based on a review of data from consent monitoring studies undertaken to date[1]. The existing consent specifies monitoring of the coastal environment by intertidal surveys focussed on the southern side of Moturoa / Rabbit Island (groundwater flow is towards the southwest). Sediment samples are analysed for grain-size, nutrients and trace metals. To identify possible ecological effects, the amounts of micro- and macro-algae on the sediment surface are recorded and the composition of the assemblages of animals living in and on the sediment is quantified. Concentrations of trace metals and faecal indicator bacteria are measured in shellfish.

[1] Intertidal surveys were done in 1996 (pre-application baseline), 2003, 2008, 2014 and 2019.

Intertidal monitoring to date has shown no adverse symptoms of organic enrichment (e.g. excessive algal growth, sediment anoxia and presence of hydrogen sulphide) at most sites. Spatial and temporal differences in organic matter and total nitrogen content in sediments among transects reflect differences in sediment texture, and there were no patterns that would suggest an effect of biosolids application. Rather, the increases in mud and organic matter at some transects are likely to reflect the generally increasing muddiness of Waimea Inlet over time, identified from state-of-the-environment monitoring.

To complement our assessment, we updated a previous nitrogen budget for Waimea Inlet to quantify the relative contribution of nitrogen from biosolids application in relation to other sources affecting the Inlet. Our review incorporated estimates of nitrogen concentrations and loads developed by the groundwater component of the application (reported separately). We also reviewed water-quality data for Waimea Inlet collected in other monitoring surveys by Cawthron on behalf of NRSBU. Collection of additional field data was beyond the scope of the present study.

The estimated potential concentration of 18 g/m^3 of nitrate-N in groundwater from Moturoa / Rabbit Island at the point of discharge into the coastal environment suggests a biosolids contribution of approximately 3% to the reported mean annual cumulative nitrogen loads to Waimea Inlet from its catchment. The estimated contribution from biosolids to the nitrogen load to Tasman Bay from its catchment is 0.8%.

The discharge of some organic matter and nitrogenous compounds (through groundwater and surface runoff) to Waimea Inlet from biosolids application is moderately likely. However, the rate and load are likely to be small, both in absolute terms and relative to other inputs to the Inlet, and the magnitude of effect is therefore expected to be low / minor. Consistent with these expectations, there is no evidence of accumulation of organic matter and nitrogen adjacent to application areas, relative to the general increase in muddiness and associated organic matter over time throughout Waimea Inlet. The spatial scale of potential effects is medium (hundreds of metres) in the case of effects on the intertidal area adjacent to application areas, but large (kilometres) in terms of effects on Waimea Inlet. Any enrichment that might occur will be degraded by microbial activity in the sediments and water column after the cessation of biosolids application (at time-scales potentially ranging from individual spraying events to the harvest cycle of the trees, depending on the rate of degradation). Consequently, the risk of adverse effects from cumulative nutrient enrichment of intertidal sediments and the wider Waimea Inlet due to future application of biosolids (in amounts no higher than those applied to date) is likely to be **less than minor**.

Monitoring data suggest that the application of biosolids to land on Moturoa / Rabbit Island has not resulted in the accumulation of arsenic or any of the monitored trace metals in intertidal sediments as a result of the seepage of contaminated groundwater. Consistent with this, infaunal monitoring has found no evidence of any detrimental effect from the biosolids programme on infaunal communities at the study transects. Consequently, the risk of adverse effects from toxic contaminants on the biota of intertidal sediments and the wider

Waimea Inlet due to future application of biosolids (in amounts no higher than those applied to date) is likely to be **less than minor**.

Because adverse effects are predicted to be less than minor, no additional mitigation is recommended; but, the existing buffer zone to protect the coast should be maintained to minimise the risk of runoff entering the coastal waters during high-rainfall events at the time of biosolids application.

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GLOSSARY

Value	Definition
AEE	Assessment of Environmental Effects
AFDW	Ash-free dry weight (measure of organic matter content)
ANZG	Australia and New Zealand Guidelines for freshwater and marine sediment and water quality (supersedes ANZECC 2000)
cfu	Colony forming units
DIN	Dissolved inorganic nitrogen
DOC	Department of Conservation
DGV	Default Guideline Value (concentration in sediment at which biological effects are possible)
DRP	Dissolved reactive phosphorus
FC	Faecal coliform
FIB	Faecal indicator bacteria
g/m^3	Grams per cubic metre (parts per million, equivalent to mg/L)
GV-High	Guideline Value-High (concentration in sediment at which biological effects are likely)
ha	Hectare
km	Kilometre
LoD	Analytical limit of detection
m	Metre or metres
m^3/s	Cubic metres per second (cumec)
MfE	Ministry for the Environment
mg/kg	Milligrams per kilogram (parts per million)
mg/L	Milligrams per litre (parts per million, equivalent to g/m^3)
MPN	Most probable number
N	Nitrogen
NCC	Nelson City Council
NH_3 / NH_4	Ammonia (unionised form) / ammonium (ionised form)
NO_3	Nitrate
NRSBU	Nelson Regional Sewerage Business Unit
psu	Practical salinity unit
Taxon (plural taxa)	Unit of classification of living organisms (e.g. species)
TDC	Tasman District Council
TN	Total nitrogen
TP	Total phosphorus
WWTP	Wastewater treatment plant

1. INTRODUCTION

1.1. Background

Nelson Regional Sewerage Business Unit (NRSBU) manages and operates the Bell Island wastewater treatment plant (WWTP). At the plant, waste activated-sludge is treated in an Autothermal Thermophilic Aerobic Digestion unit that produces class A biosolids. These biosolids are then pumped, via a pipeline across Waimea Inlet, to storage tanks at the Biosolids Application Facility on Moturoa / Rabbit Island. From the storage tanks, the biosolids are transported by trucks and tankers to forestry blocks where they are applied to the ground via travelling spray irrigators.

NRSBU holds a consent (NN940379V3) for the discharge of biosolids on Moturoa / Rabbit Island. This consent, issued by Tasman District Council (TDC), expires on 8 November 2020.

1.2. Project scope

NRSBU needs to prepare and lodge resource consent applications with TDC to renew the existing consent to discharge the biosolids on Moturoa / Rabbit Island, and to obtain any other resource consents necessary to operate the Biosolids Application Facility.

In broad terms, NRSBU proposes to continue the activity authorised by the existing consent. The consent authority previously considered that the adverse effects on the environment as a result of the existing activity are no more than minor (TDC 2008).

NRSBU have engaged the Cawthron Institute (Cawthron) to prepare an assessment of the potential and actual effects of the land-application of biosolids on coastal water quality and the ecology of the intertidal habitat of Moturoa / Rabbit Island and the wider receiving environment of Waimea Inlet.

1.3. Approach and scope of the assessment of ecological effects

The potential adverse effects from the application of biosolids include reduction in water quality in nearby areas of Waimea Inlet and associated impacts on the seabed habitats and organisms that are exposed to any change in quality. Direct measurement of effects on the water quality in Waimea Inlet that may be caused by application of biosolids would be very difficult against the background of natural and anthropogenic variation caused by other factors, including other sources of contaminants and tidal mixing of Inlet waters with those of Tasman Bay. Consequently, assessment of effects is focussed on the intertidal area where groundwater seeps into the Inlet. Seepage may also occur subtidally but such locations are more difficult to identify and effects would be expected to be generally similar to those in the intertidal area.

As discussed in more detail in Section 3.4, our assessment of effects of application of biosolids to land on the coastal receiving environment is based on a review of data from consent monitoring studies undertaken to date. To complement our assessment, we have updated a previous nitrogen budget for Waimea Inlet developed by Stevens and Robertson (2010) to quantify the relative contribution of nitrogen from biosolids application in relation to other sources affecting the Inlet. Our review incorporates estimates of nitrogen concentrations and loads developed by the groundwater component of the application for the new consent reported by Tonkin & Taylor Ltd (2020).

As specified by NRSBU in the Request for Proposal (RFP), this technical report considers and assesses, among other items, the proposed biosolids application rates, exclusion zones and buffer zones as required to appropriately manage coastal water quality effects. Assessment of the effects of these factors on groundwater quality (which, in turn, determines the quality of groundwater seepage to the Inlet) is outside our area of expertise. This effect is considered in a companion report (Tonkin & Taylor Ltd 2020). Furthermore, we note from the Assessment of Environmental Effects (AEE) for the existing consent (Beca Steven 1994) that exclusion and buffer zones were determined to protect human health rather than groundwater quality. Application rates are based on the capacity of the trees to take up the nutrients applied and, therefore, only indirectly on their effects on the receiving environment of Waimea Inlet. Consequently, we have only considered buffer zones in general terms and do not refer to exclusion zones or application rates.

Potential effects on birds and lizards are addressed in separate studies and are not considered in the present report.

As specified in the RFP, our assessment of effects was a desktop exercise with no collection of additional field data. However, we believe that its conclusions are fully supported by the existing evidence base.

2. DESCRIPTION OF THE RECEIVING ENVIRONMENT

2.1. Waimea Inlet

Waimea Inlet is a shallow, bar-built estuary located within Tasman Bay adjacent to the city of Nelson. According to Hume et al. (2016), it is classified as a shallow drowned valley. One of the largest inlets in New Zealand (c. 3,460 ha), it contains approximately 3,307 ha of intertidal area with the remaining c. 150 ha being subtidal, e.g. river and tidal channels (Davidson & Moffat 1990; reassessed by Robertson et al. 2002 and Stevens & Robertson 2014) (Figure 1). Within the Inlet, ten islands, totalling approximately 296 ha, contribute to the considerable habitat heterogeneity (Robertson et al. 2002). There are two tidal openings located at opposite ends of Moturoa / Rabbit Island, which forms a barrier between the Inlet and Tasman Bay.

2.1.1. Freshwater inputs

Freshwater contributions are minor in comparison to the volume of the tidal component; however, reduced salinities have been reported for areas in the vicinity of freshwater discharge channels (Gillespie & Asher 1999). The main freshwater inflow to the Inlet is from the Waimea River and its tributaries (mean annual flow is 27.5 m^3/s[2]). The freshwater discharge from the Waimea River separates into two channels just south of Moturoa / Rabbit Island, with most of the flow travelling along the eastern side of the Island towards the eastern entrance to the Inlet. Several smaller streams also contribute to the total freshwater inflow.

2.1.2. Catchment characteristics

The Waimea Inlet catchment area is 933 km^2 (Hume et al. 2016), with much of the central lower catchment being relatively flat or undulating, particularly the Waimea Plain and adjacent river valleys. However, the catchment extends south to the Gordon Range and east to encompass the steep, eastern slopes of the Richmond and Bryant ranges and Dun Mountain. The Dun Mountain 'mineral belt' region contains ultramafic rock formations particularly high in metals such as chromium, copper and nickel and are a source of these metals to Waimea Inlet and Tasman Bay. The composition of the catchment and its soils reflect the complicated geological structure and history of the region. Most soils are characteristically of low natural fertility, but the fertile, deep, fine soils on the lower flood plain of the Waimea River are a notable exception (Chittenden et al. 1966).

[2] NZ River Maps: https://shiny.niwa.co.nz/nzrivermaps/

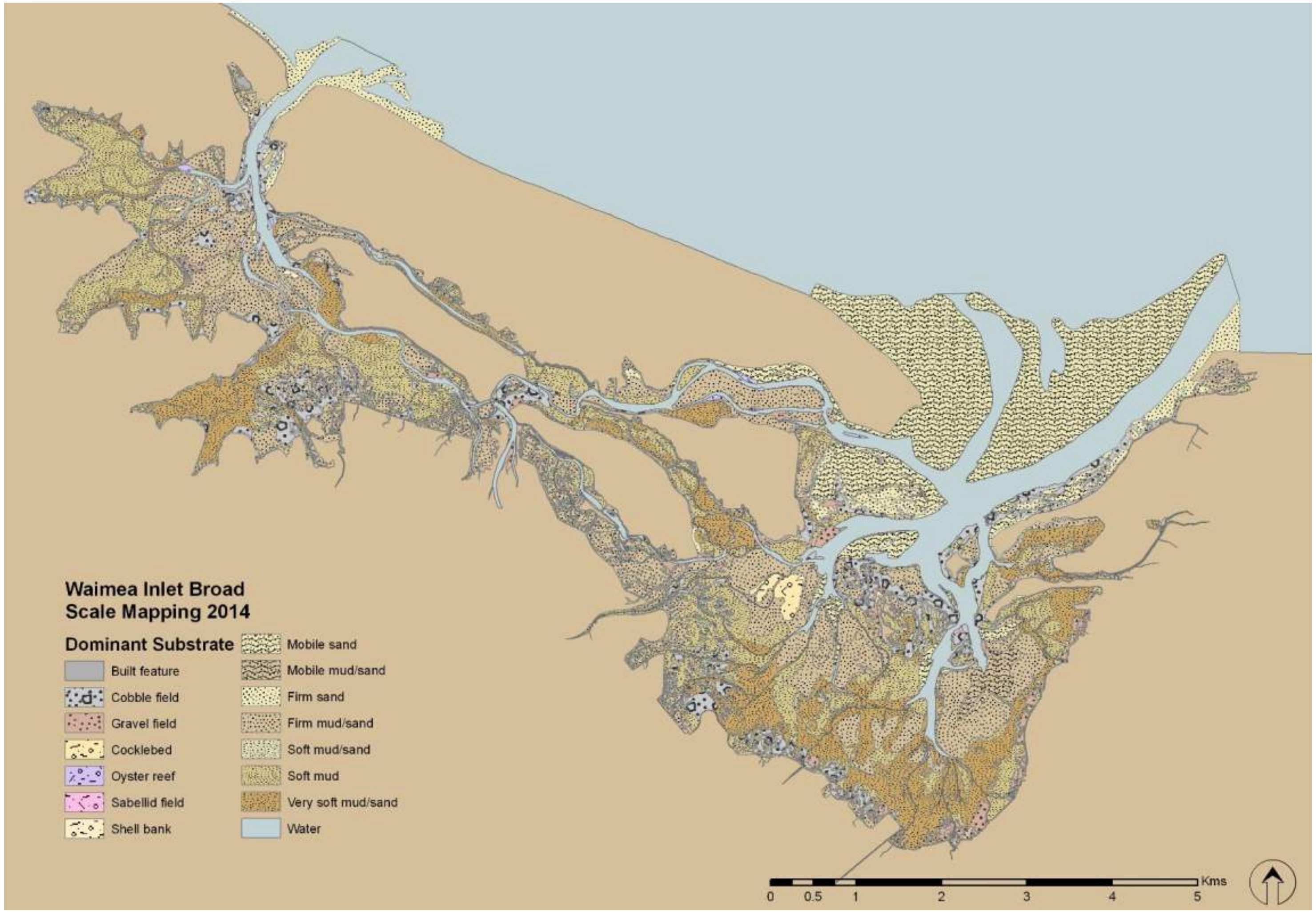

Figure 1. Map of Waimea Inlet, showing the dominant types of substrata in 2014. Figure prepared by Wriggle Coastal Management for Tasman District Council (from Stevens & Robertson 2014).

2.1.3. Hydrodynamics

As noted above, 95% of the area of Waimea Inlet is intertidal. Due to its broad, shallow configuration, and a spring tidal range of 3.7 m (Hume et al. 2016), the tidal compartment is largely drained with each ebbing tide, resulting in a relatively rapid flushing rate (Robertson et al. 2002). The estimated residence time (total volume / spring tidal component plus average runoff) of the waters in the Inlet is 0.6 days (Heath 1976).

A hydrodynamic model of inner Tasman Bay and Waimea Inlet was developed as part of the application process for the Bell Island WWTP discharge (MetOcean 2017). Modelling focussed on the eastern end of Moturoa / Rabbit Island, where the discharge occurs. At the discharge location, currents travel into the Inlet on the flooding tide and out on the ebb, and are aligned with the course of the channel. Maximum velocities are c. 0.9 m/s. Under extreme conditions (i.e. during large flood events), current velocities approach 1.5 m/s at the discharge site.

The MetOcean model was used to estimate dispersal and dilution of the WTTP discharge (which occurs on the first three hours of the ebb tide). It indicated that although it is possible that some of the wastewater leaving the Inlet on the ebb tide returns on the following flood tide, the level of dilution remains high (dilution factor > 400) over the three-day scenario modelled. This suggests that it is unlikely that concentrations of contaminants will increase progressively over time due to incomplete flushing of the WWTP discharge from the Inlet. By extension, other inputs of contaminants are generally likely to be flushed from the Inlet by tidal flow and dispersed and diluted in Tasman Bay. Exceptions may occur in less-well flushed areas of the inner Inlet but this is unlikely to apply to the shores of Moturoa / Rabbit Island, which are close to the main channels and border areas that drain at low tide (Figure 1).

The waterway between Moturoa / Rabbit and Rough islands (The Traverse) was largely closed when two causeways to Moturoa / Rabbit Island were constructed in the 1960s (TDC 2016). Flushing of The Traverse improved after 1998, when the causeway and culvert at the western end was removed (Asher et al. 2008). Much of the high-tide area within The Traverse, apart from the low-tide channel, drains at low tide. The two arms of The Passage are connected by a culvert that continues to drain during low tide, taking water from the western side to the eastern and thence to the main channel leading to Tasman Bay (pers. obs. D. Morrisey).

2.1.4. Ecological and conservation values

Waimea Inlet is listed in Schedule 25D of the Tasman Resource Management Plan (TRMP) as an area (Area 22) with nationally significant ecosystem values. These values include the Inlet's status as the largest barrier-enclosed estuary in the South Island. The Inlet is one of only two sites where the endangered peppercress plant

(*Lepidium banksii*) has been recorded and the endangered grey saltbush (*Atriplex cinerea*) is also present. The Inlet is ‘considered of outstanding importance to waders’, and is used by white heron, royal spoonbill, Australasian bittern and banded rail.

As described in the following sections, the Inlet’s variety of coastal habitats provide biodiversity value in terms of the numbers and range of types of organisms. The Inlet also provides ecosystem services. These services include retaining and processing sediments and other contaminants from the catchment, nutrient cycling, and primary and secondary production, some of which is exported to Tasman Bay. It also serves as a feeding or nursery area for several species of fish and birds.

Waimea Inlet plays a significant role in the integration of terrestrial and coastal marine ecosystems (Robertson et al. 2002). High value is placed on the Inlet’s terrestrial-wetland-coastal aquatic continuum as habitat for wildlife (e.g. waterfowl), fish and invertebrates, and its complex, heterogeneous physical and biological structure (Robertson et al. 2002). Davidson and Moffat (1990) recommended that eleven intertidal, and eight terrestrial areas, including the whole western Inlet, be protected due to their special biological assets. The Inlet has also been assessed by the Department of Conservation (DOC) as meeting the criteria for a wetland of international importance (Cromarty & Scott 1995).

2.1.5. Condition of the Inlet

Based on four State of the Environment monitoring stations in unvegetated tidal flat habitat (two located within West Waimea and two within East Waimea), the Inlet was in a generally healthy ecological state at the time of assessment compared to a number of other New Zealand estuaries (Gillespie et al. 2007). However, it has been considerably impacted by extensive habitat loss / modification and sedimentation (Tuckey & Robertson 2003; Davidson & Moffat 1990; Robertson & Robertson 2014). Localised areas of nutrient enrichment are present, and more widespread faecal bacteriological contamination occurs in regions of freshwater inflows, largely from agricultural sources within the catchment (Figure 2). Stevens and Robertson (2014) reported that 28 ha of the Inlet was degraded by nutrient enrichment, high macroalgal growth and accumulation of fine mud. The areas found to be most affected are locations of high natural deposition, where concentrated catchment inputs of sediments and nutrients provided suitable conditions for the growth of opportunistic algae. None of these areas are around the shoreline of Moturoa / Rabbit Island.

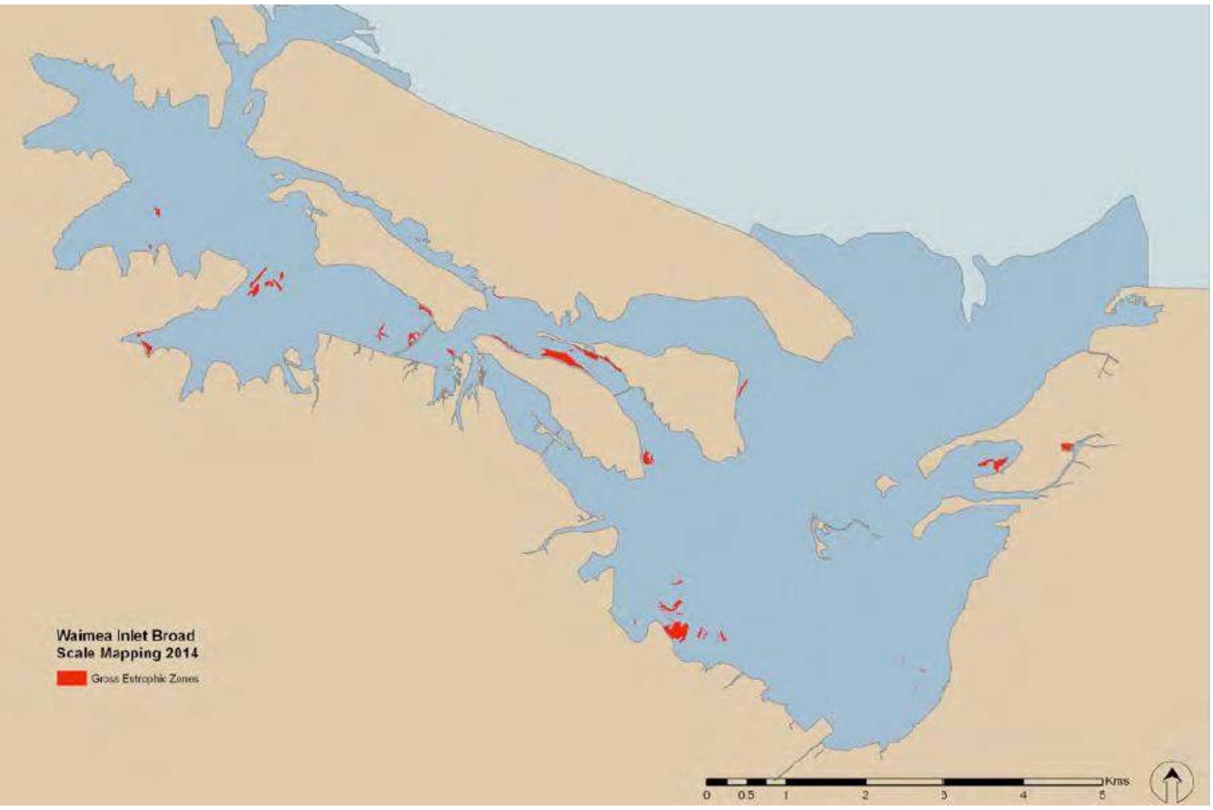

Figure 2. Map of Waimea Inlet, showing areas of eutrophication in 2014 (in red). Figure prepared by Wriggle Coastal Management for Tasman District Council (from Stevens & Robertson 2014).

2.1.6. Unvegetated habitats

Most of the intertidal area in Waimea Inlet is comprised of unvegetated mud / sand flats (Figure 1) (Stevens & Robertson 2014). At the time of Stevens and Robertson's survey in 2014, soft and very soft mud cover was extensive (40%, 1,195 ha) and present mostly in the upper parts of the central basin and sheltered arms. Very soft mud was reported to have increased dramatically since 1999, a likely consequence of fine sediment inputs from natural and human-related catchment land disturbance.

2.1.7. Vegetation

Twenty estuarine vascular plants have been recorded within the Waimea Inlet intertidal zone (Davidson & Moffat 1990). The dominant vegetated habitat is herbfield (primarily glasswort, *Sarcocornia quinqueflora*) and rushland (primarily searush, *Juncus kraussii*) (Figure 3). The high proportion of glasswort is relatively unusual in comparison to many other New Zealand estuaries (Tuckey & Robertson 2003). In 2014, saltmarsh vegetation was present in both West and East Waimea, covering 9% of the area (Figure 3). There was a 14% decline in the area of saltmarsh between 1946 and 2014 (Stevens & Robertson 2014). The Inlet is also home to rare and threatened native plants, such as coastal peppercress (*Lepidium banksii*), occurring within West Waimea (No Mans Island and off Bronte Peninsula), and grey salt bush (*Atriplex cinerea*), occurring within West Waimea (No Mans Island) and East Waimea (Bell Island West saltmarsh) (DOC 2015). Cromarty and Scott (1995) also noted that the Inlet contains the southernmost populations of the estuarine tussock, *Stipa stipoides*, and that the rush *Baumea articulata* has been recorded from the Rough Island wetland, the only locality for this species in the South Island.

Seagrass / eelgrass (*Zostera muelleri*), an ecologically valuable habitat, is present within Waimea Inlet. Davidson and Moffat (1990) mapped 58 ha of intertidal seagrass habitat, largely within East Waimea but with two beds present within West Waimea. Intertidal seagrass beds (where seagrass was the dominant habitat category) were estimated to cover 28 ha (revised to 35 ha by Stevens & Robertson 2014) in 1999/2001 and 21 ha in 2006/2007 (Robertson et al. 2002; Clark et al. 2008). In 2014, 34 ha of dense seagrass habitat (where cover was > 50%) and 110 ha of seagrass habitat overall, was recorded within the Inlet, with no seagrass mapped within West Waimea (Figure 4) (Stevens & Robertson 2014). It therefore appears that between 2000 and 2014, the overall area of dense seagrass remained relatively stable, with some variation either due to differing mapping procedures or actual contraction / expansion of seagrass beds. However, Stevens and Robertson (2014) noted specific areas of decline, including loss of approximately 4 ha of seagrass fringing an area south/southwest of Saxton Island, and the loss of a small area (< 0.1 ha) of seagrass due to the Monaco-Bell Island pipeline upgrade in 2012 (both areas in East Waimea). Comparisons with data from 1990 are not appropriate because the percentage cover of seagrass recorded in the 1990 study was unspecified, and mapping methodologies were less stringent.

Eight macroalgal taxa have been recorded from the Waimea Inlet intertidal zone (Davidson & Moffat 1990). Opportunistic macroalgal growth, a possible indication of nutrient enrichment, was found to be low overall in 2014, although dense beds of both agar weed (*Agarophyton* (*Gracilaria*) sp.) and sea lettuce (*Ulva* sp.) were present in localised areas within West and East Waimea (Stevens & Robertson 2014).

The amount of vegetation (e.g. scrub and forest) immediately surrounding the Inlet was relatively low in 2014 and was comprised largely of plantation forestry on Moturoa / Rabbit and Rough islands (Stevens & Robertson 2014). Ongoing restoration efforts, including native revegetation, within the estuary and its margins are being made by various groups, including those associated with the Waimea Inlet Forum. The Forum was created as a result of the Waimea Inlet Management Strategy and includes groups that have an interest in, and a commitment to, the Waimea Inlet (DOC 2015). Government funding for planting of trees around Waimea Inlet was provided to the Tasman Environmental Trust in July 2019 under the One Billion Trees programme[3].

[3] See https://www.stuff.co.nz/national/113953302/government-announces-70000-trees-to-be-planted-to-protect-tasmans-waimea-inlet, accessed May 2020.

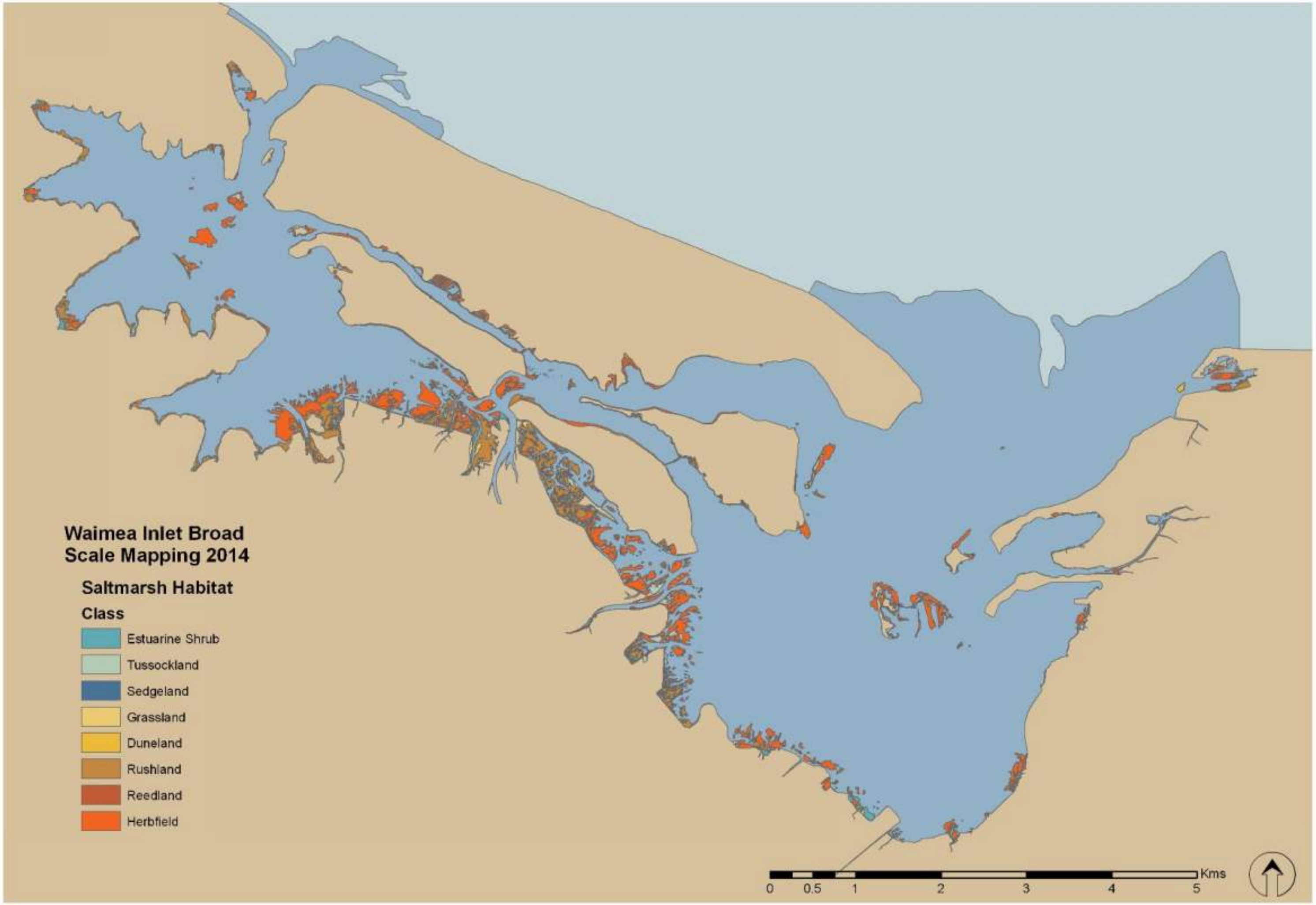

Figure 3. Map showing the extent of saltmarsh vegetation within Waimea Inlet in 2014. Figure prepared by Wriggle Coastal Management for Tasman District Council (from Stevens & Robertson 2014).

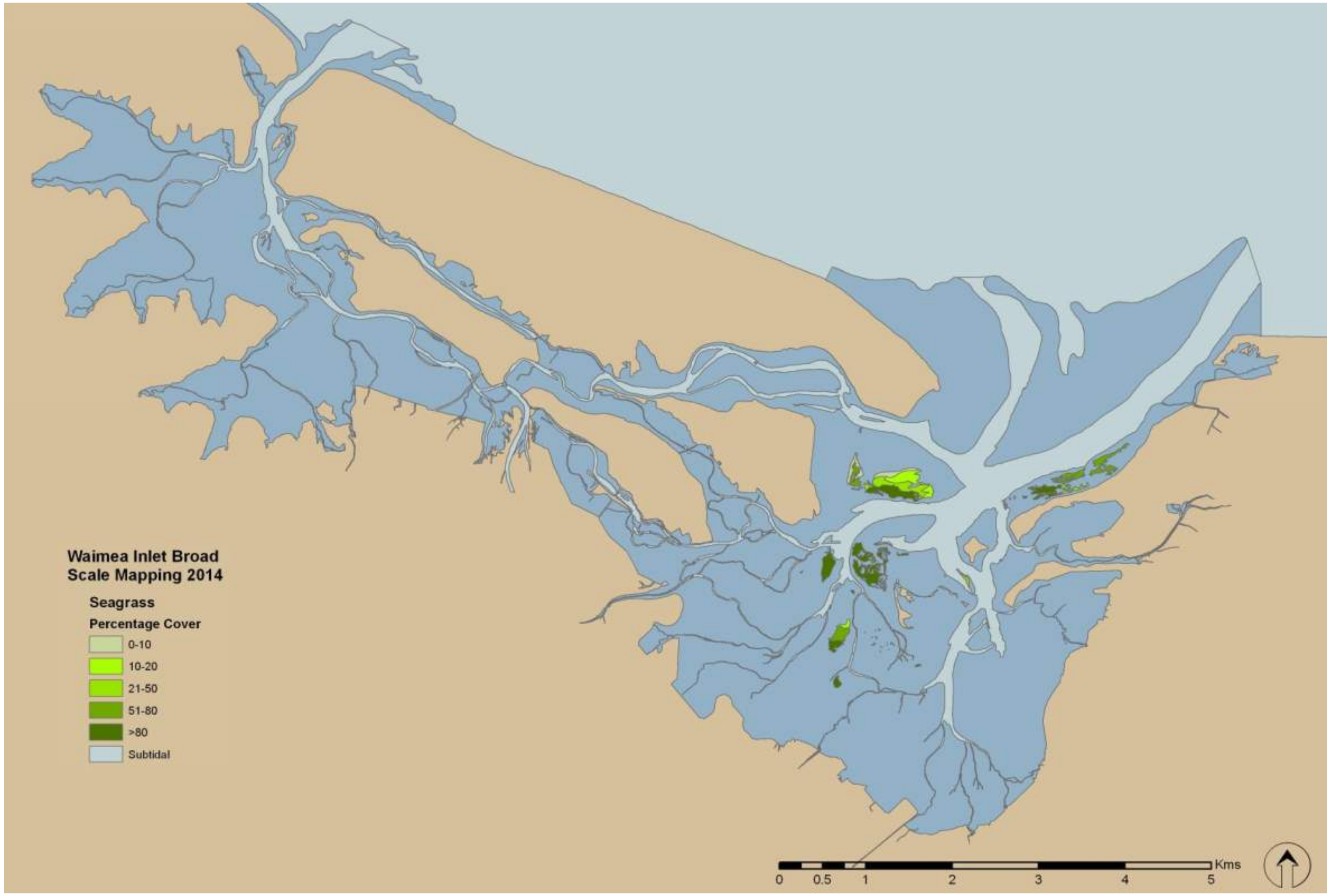

Figure 4. Map showing the extent of intertidal seagrass cover within Waimea Inlet in 2014. Figure prepared by Wriggle Coastal Management for Tasman District Council (from Stevens & Robertson 2014).

2.1.8. Sponge gardens

Sponge gardens (i.e. biologically diverse sponge-associated communities) are present at two locations within the Waimea Inlet (Asher et al. 2008). The Traverse (West Waimea) and Saxton-Monaco channel (East Waimea) sponge gardens covered 1.2 ha and 4.8 ha, respectively, in 2008 and were dominated by the sponge *Mycale* (*Carmia*) *tasmani*, which is often present in harbour and port environments around the South Island. Amphipods, gastropods, encrusting bryozoans and sea lettuce were also abundant.

2.1.9. Benthic invertebrates

Waimea Inlet is home to a range of benthic invertebrates and 112 species have been recorded (Davidson & Moffat 1990). Benthic invertebrate composition within the Inlet was consistent with a range of other New Zealand estuaries, with species richness at representative locations indicating relatively diverse and healthy sandflat habitats containing a broad range of feeding types (Gillespie et al. 2007). However, slight to moderate organic enrichment was indicated at one location (within West Waimea) by the density of polychaete worms belonging to the family Capitellidae. Losses of some mud-sensitive organisms (e.g. pipi) were apparent between 2001 and 2014, although no broad trends of change in macroinvertebrate communities were evident (Robertson & Robertson 2014). The analysis of historical sediment cores also indicated that large increases in mud coincided, at times, with decreases in shellfish populations (Stevens & Robertson 2010).

Shellfish beds are scattered around eastern Waimea Inlet (Figure 5), including oyster reefs, cockle and pipi beds. The pipi beds along the northern side of Moturoa / Rabbit Island and off Tahunanui are harvested recreationally for seafood[4].

[4] Information provided at a meeting for local stakeholders as part of the consent application process for the Bell Island WWTP discharge, 15 June 2017.

Figure 5. Shellfish beds (circled in red) in eastern Waimea Inlet. Note that cockle beds are defined as areas dominated by both live and dead cockle shells, some of which may represent accumulations of dead shells. Figure prepared by MWH / Stantec from data collected by Wriggle Coastal Management for Tasman District Council (adapted from Stevens & Robertson 2014).

2.1.10. Fish

Thirty-one marine and eleven freshwater fish species occur in the estuary and tidal reaches of tributary streams of the Inlet, including the giant kokopu *Galaxias argenteus* (Davidson & Moffat 1990; Cromarty & Scott 1995). Several areas associated with the Waimea Inlet have also been highlighted as inanga spawning grounds (DOC 2015). Most marine fish enter the Inlet from the sea (e.g. kahawai, gurnard and snapper), while others spend their juvenile or adult life in the Inlet (e.g. grey mullet, sand flounder and sole). Many New Zealand freshwater fish species migrate between fresh and salt water at some stage of their life history, with estuaries such as Waimea Inlet providing an essential link in their life cycle. These include whitebait species, and whitebaiting is popular in the lower Waimea River (pers. obs. D. Morrisey).

2.1.11. Exotic intertidal organisms

The exotic saltmarsh cordgrass *Spartina anglica* was introduced into Waimea Inlet during the 1930s through a series of intentional plantings (Gillespie et al. 1990; Robertson et al. 2002). After a period of some 50 years it had become well established, covering > 30 ha and including several dense, monospecific stands. In view of its impact on the natural character of the Inlet, a successful programme of spraying with herbicide was carried out (Gillespie et al. 1990) and *Spartina* has been largely eradicated from the Inlet.

A more recent invasion by an exotic bivalve, the Pacific oyster (*Crassostrea gigas*), occurred in the Nelson region during the early 1980s (Bull 1981) and subsequently spread to Waimea Inlet within a few years. It has now become well established in several intertidal locations within the Inlet. The resulting oyster beds and shell banks result in localised pockets of sediment build-up (i.e. mounding) and enrichment, representing a significant departure from the natural character.

2.1.12. Exotic terrestrial organisms

Vegetation within and immediately surrounding Waimea Inlet contains exotic terrestrial plant species (DOC 2015). During habitat mapping in 2014, gorse and introduced grasses and other weeds were observed within the saltmarsh in the upper-intertidal reaches. The 200-m wide terrestrial margin was dominated by grassland (28%), grass-dominated parks and amenity areas (10%) and exotic forest (20%, located on Moturoa / Rabbit and Rough islands) (Stevens & Robertson 2014). Waimea Inlet is also under threat from invasion by animal pest species (DOC 2015), such as rats, rabbits, mustelids and feral cats.

2.2. Moturoa / Rabbit Island

Moturoa / Rabbit Island, and the adjacent Rough Island, are low-lying sand islands that form the seaward barrier of Waimea Inlet. Maximum elevation over most of the islands is 10 m above mean sea level (Carnus 1994). As noted in Schedule 25D of the Tasman Resource Management Plan (TRMP), Moturoa / Rabbit Island is one of the largest barrier islands in New Zealand. A ridge of sand dunes (> 10 m high in places) runs parallel to, and just inland of, the Tasman Bay shore of Moturoa / Rabbit Island. The sands that make up Moturoa / Rabbit Island overlie greywacke gravels (Carnus 1994). Consequently, the soils have low water-holding capacity and are well drained. Carnus (1994) described the soils of Moturoa / Rabbit Island as part of the assessment of effects of biosolids application:

> Both islands are mapped as Tahunanui sand and gravelly sand (yellow brown sands from greywacke gravels). Site variability is important due to varying depths of sand and to areas of

> gravel…The sand is essentially derived from sediments of very mixed origin carried by rivers to the sea and finally deposited…In some low areas, a fluctuating and high water table is present…Presence of gravels may correspond to the lowest areas of the islands and may indicate shallow groundwater levels…

Prior to human intervention, the dunes of Moturoa / Rabbit Island were vegetated with spinifex (*Spinifex sericeus*) and pingao (*Desmoschoenus spiralis*), with lowland tōtara (*Podocarpus totara*) forest in the more stable southern part of the island (TDC 2016). Most natural vegetation has been lost, with only a few fragments remaining (see below). Pine plantations occupy much of the island, with an understory of grass, broom and pampas grass, though with some regrowth of native species. The present dune vegetation consists mostly of the introduced marram grass (*Ammophila arenaria*). Moturoa / Rabbit Island has been planted with large areas of pine trees since the 1920s (Carnus 1994). The planted area varies with cycles of harvesting and replanting and in 2014, planted forestry blocks covered 975 ha.

A TDC programme to survey natural areas on public and private land (outside public conservation lands) identified six 'Significant Native Habitats' on Moturoa / Rabbit and Rough islands (TDC 2016). These sites are listed below (detailed ecological descriptions are available on TDC's website: www.tasman.govt.nz/link/moturoa).

1. Tōtara-kānuka forest remnant (0.77 ha) at the western end of Rough Island. The only remaining example of original forest cover of the barrier islands of Waimea Inlet, dominated by young lowland totara and kānuka (*Kunzea ericoides*).
2. Rough Island wetland (2.85 ha) at the southeastern end of the island, containing mānuka (*Leptospermum scoparium*) / cabbage tree (*Cordyline australis*) scrub / forest and areas of open, weed-dominated wetland vegetation (reeds, sedges and grasses). The wetland contains the only known South Island populations of two species of sedge.
3. Intact coastal vegetation sequence from saltmarsh herbfield to tall mānuka scrub, including a band of saltmarsh ribbonwood (*Plagianthus divaricus*), areas of estuarine tussock (*Austrostipa stipoides*) and mixed vegetation of rushes and grasses. Occupies a 2-ha area of low-lying sandy soil just above mean high-water in the middle of the landward shore of Moturoa / Rabbit Island.
4. Shorebird breeding and roosting habitat at the eastern and western ends of Moturoa / Rabbit Island. This is one of eight coastal areas of international significance for resident and / or migratory shorebirds in the Tasman District. Breeding sites for variable oystercatchers (*Haematopus unicolor*: Threatened status[5]) and roosting sites for blackback gulls (*Larus dominicanus*), bar-tailed godwit (*Limosa lapponica*), South Island pied oystercatchers (*Haematopus*

[5] New Zealand Threat Classification System: https://www.doc.govt.nz/about-us/science-publications/conservation-publications/nz-threat-classification-system/

finschi), red knot (*Calidris canutus*), ruddy turnstone (*Arenaria interpres*), wrybill (*Anarhynchus frontalis*) and royal spoonbill (*Platalea regia*).

5. Breeding shag colony in a stand of mature pines on the southeastern margin of Rough Island. Used by pied shags (*Phalacrocorax varius*: Threatened, Nationally Vulnerable status) and little shags (*Phalacrocorax melanoleucos*: At Risk, Naturally Uncommon status).

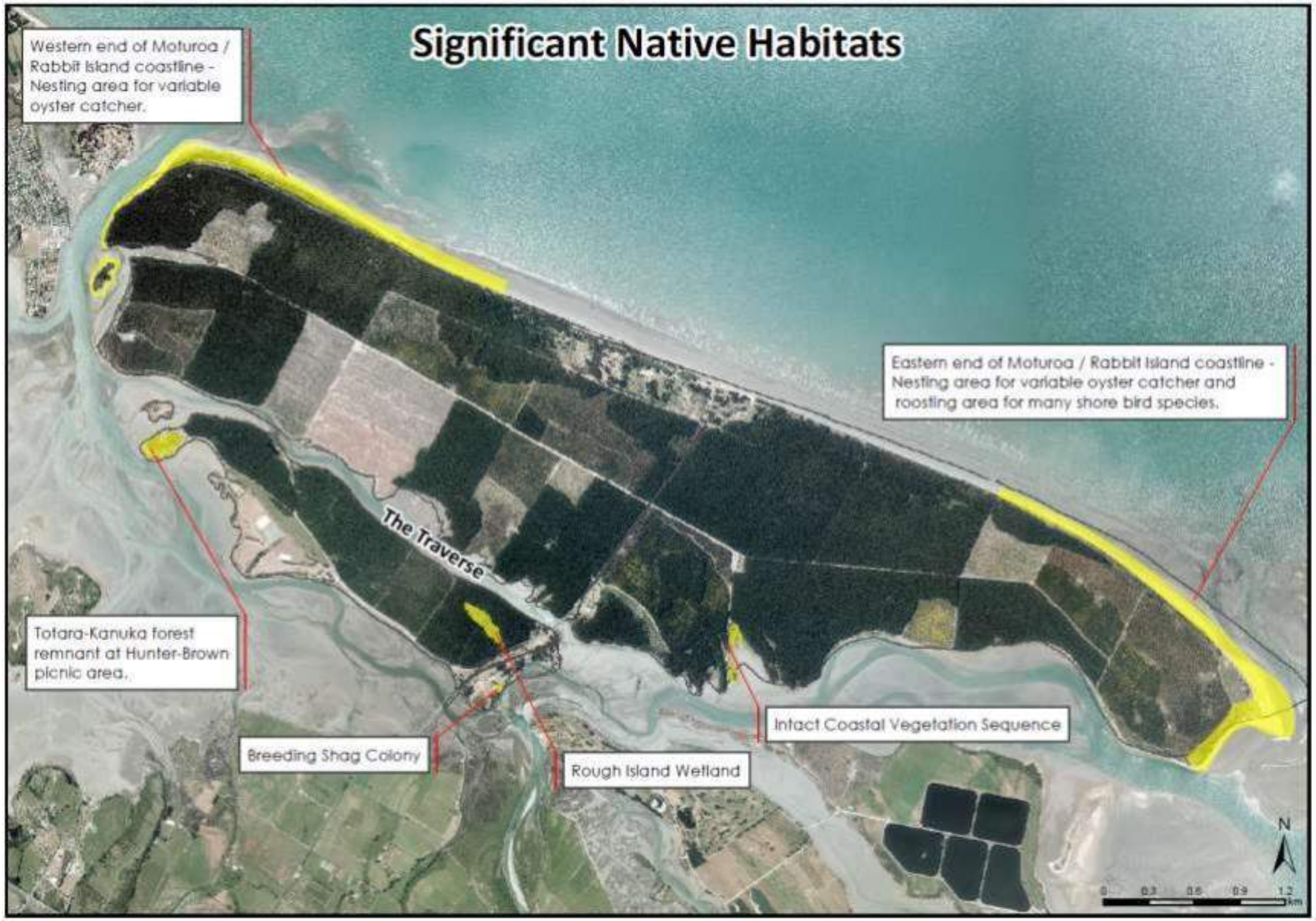

Figure 6. Significant Native Habitat on Moturoa / Rabbit and Rough islands. Source: TDC (2016).

3. POTENTIAL EFFECTS OF THE APPLICATION OF BIOSOLIDS ON THE COASTAL RECEIVING ENVIRONMENT

3.1. Background

Application of treated sewage sludge (biosolids) to forestland can greatly improve and maintain the productivity of soils and thereby stimulate plant growth. Biosolids amend the soil by providing nutrients that are frequently limited in forest soils, especially nitrogen and phosphorus (USEPA 1995). In the short term, the addition of biosolids can improve soil productivity because it supplies nutrients needed for plant growth in an available form. The fine particles and organics in sewage sludge can improve the moisture and nutrient-holding characteristics of the soils. In the long-term, biosolids provide a continual and slow release of nutrients to the soils as the organics decompose.

Forest soils usually have high rates of infiltration, which reduce runoff and ponding, and accumulation of large amounts of organic material. They also have perennial root systems, which makes them well suited to year-round biosolids application in mild climates. Although forest soils are frequently quite acidic, research has found no issues with leaching of heavy metals following application (USEPA 1995; Toribio & Romanyà 2006).

3.2. Potential adverse effects

Despite their beneficial uses, biosolids can contain substances harmful to the environment and human health. These include inorganic contaminants (e.g. metals and other trace elements); organic contaminants (e.g. polychlorinated biphenyls, dioxins, pharmaceuticals and surfactants); microplastics; endocrine disrupting chemicals; emerging contaminants of concern, such as pharmaceuticals and personal-care products; and pathogens (e.g. bacteria, viruses and eggs of parasitic worms). However, the simple occurrence of contaminants in biosolids does not necessarily mean that they pose a risk to public health and the environment. The chemical and biological composition of biosolids depend on the composition of the wastewater entering the wastewater treatment plant and the treatment processes employed. Risks can be reduced or eliminated by placing appropriate controls on the way(s) biosolids are processed and applied and the levels to which contaminants are permitted to enrich in soils.

A schematic diagram of the processes involved in the potential intrusion of biosolids leachate into coastal habitats is shown in Figure 7. As indicated by the model, contaminants originating from the application of biosolids to adjacent coastal lands can percolate through the shallow soil layer, resulting in elevated concentrations in the groundwater. Carnus (1994) noted that percolation is unlikely to affect the quality of groundwater in the deeper confined gravel aquifer below Moturoa / Rabbit Island because the positive pressure in that aquifer would prevent ingress of contaminants from above. Biosolid application will affect the quality of groundwater in the shallow unconfined aquifer but Carnus (1994) predicted that the rate of movement and arrival of leachate into Waimea Inlet would be 'very low'. Groundwater flow and potential effects of application of biosolids on groundwater quality on Moturoa / Rabbit Island are discussed by Tonkin & Taylor (2020).

Where horizontal groundwater flows impinge on the intertidal environment, there is a potential for adverse effects to occur through the transfer of nutrients or toxic contaminants to the coastal environment. There is also the possibility that direct surface runoff could expose intertidal habitats to contaminant effects during periods of heavy rainfall. This risk can be managed by not applying biosolids on steeply sloping land and/or by including appropriate buffer zones to the coast. To maximise the uptake of available nutrients and mitigate potential effects on surface and ground waters, biosolids should be applied when tree crops grow rapidly and have high demand for nutrients (e.g. spring and summer) and not during periods of high rainfall when soils are saturated (Magesan et al. 2010).

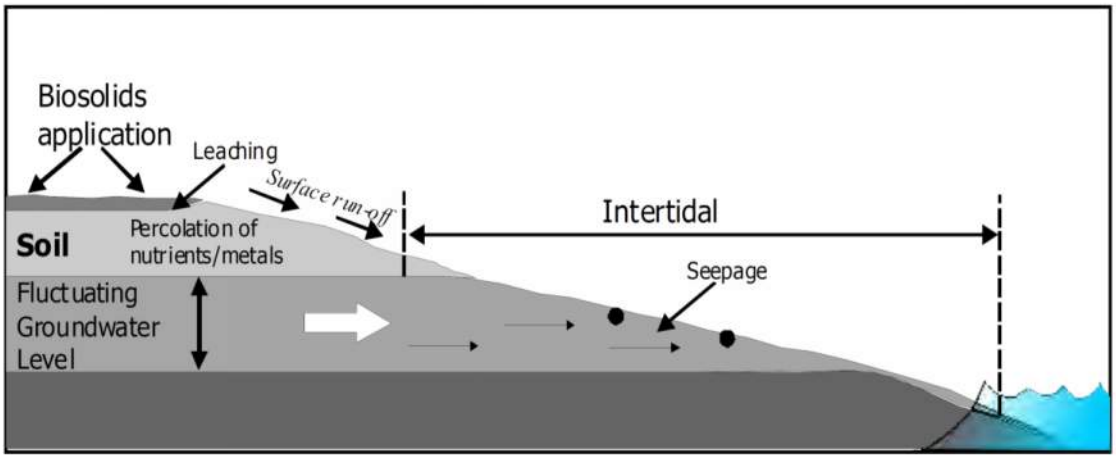

Figure 7. Environmental influences on the fate and transport of contaminants following land application of biosolids. Source: Gillespie & Asher 2004.

Once transported to the coastal environment via groundwater seepage, most contaminants are likely to remain associated with the sediment rather than the water column. Most trace metals and many organic contaminants tend to bind preferentially to sediment particles rather than enter solution, particularly in fine-grained, organic-rich sediments. Toxic contaminants may be acutely toxic at the point where they enter the coastal environment if their concentrations are high enough, or they may accumulate over time until they reach acutely or chronically toxic concentrations.

Nutrients may accumulate in sediments but will also be taken up and used by bacteria, microalgae and macroalgae growing in or on the sediment, enhancing their growth. This enhanced growth can give rise to visible bacterial mats and blooms of micro- and macroalgae. These blooms can smother intertidal and shallow-subtidal habitats, depriving the organisms beneath (such as infauna and seagrass) of oxygen. Reduced availability of oxygen is exacerbated when blooms die and decay and frequently give rise to anoxic conditions[6].

If contaminant loads exceed the capacity of sediments to bind and assimilate[7] them, they may enter the water column either in solution or in suspension attached to sediment particles. Because of the high rate of tidal exchange around Moturoa / Rabbit Island, contaminants entering the water column are unlikely to accumulate. Instead, they will be diluted and dispersed throughout Waimea Inlet and out into Tasman Bay. Consequently, if adverse ecological effects are caused by metals, nutrients and other contaminants derived from biosolids, they will be most obvious at the point where the groundwater enters the receiving environment. Beyond this, dilution and dispersion will make their contribution very difficult to detect. Nevertheless, they will provide nutrient and contaminant loads to the wider Waimea Inlet, in addition to those from rivers, land runoff and anthropogenic sources.

From a human health perspective, the main trace metals of concern are cadmium, lead and mercury. Metal concentrations in sewage sludge depend on the type and amount of industrial waste discharged into the wastewater treatment system. Pathogens subject to regulation in New Zealand are *Salmonella*, enteric viruses, helminth ova, and oocysts of protozoa (MfE & NZWWA 2003). Enteric viruses that normally occur in sewage sludge include hepatitis A virus, norovirus and adenovirus (USEPA 1995; MfE & NZWWA 2003). The abundance of these viruses in sewage sludge depend on many factors, including the level of viral illness present in the community. Faecal indicator bacteria (e.g. faecal coliforms, enterococci, *Escherichia coli*) can be used to indicate the microbiological quality of sewage sludges. Human health effects associated with bacterial and viral contaminants are considered in a separate report (Hudson 2020) and therefore we do not consider them here.

3.3. Concentrations and limits of nutrients and metals in biosolids

Concentrations of nutrients and trace metals in biosolids vary widely, depending on the characteristics of the wastewater influent entering the treatment plant and the

[6] The total absence of oxygen in sediments and overlying water, usually accompanied by the presence of toxic hydrogen sulphide and black iron sulphides.

[7] For example, in the case of nutrients, through uptake by organisms in the sediment.

treatment processes utilised. Generally, biosolids with higher concentrations of trace metals are those produced in more industrialised communities. Advanced wastewater treatment processes and sludge treatment processes, such as the digestion / stabilisation operated at Bell Island WWTP, further reduce contaminant concentrations prior to land application. Table 1 summarises typical concentrations found in biosolids applied to pine forests in New Zealand (including Moturoa / Rabbit Island). To achieve class A, the concentration of trace metals within the biosolids must be at or below the level indicated in the table. The chemical composition of biosolids also varies markedly over time at an individual treatment plant and therefore, for the purposes of this assessment, these concentrations are considered as a ‘benchmark’.

Table 1. Concentrations of nutrients and trace metals in biosolids applied to pine forests in New Zealand.

	Concentration (mg/kg) Average (min-max)	Study site	Reference	Limit in soil (mg/kg dry weight) in class A biosolids[1]
Nutrients				
Total nitrogen	5–35	Multiple sites (NZ)	Magesan & Wang (2003)	-
Total phosphorus	2–6	Multiple sites (NZ)	Magesan & Wang (2003)	-
Metals				
Arsenic				20
Cadmium	2.4–4	Moturoa / Rabbit Island	Wang et al. (2004); Su et al. (2008)	1
Chromium	46–108	Moturoa / Rabbit Island	Wang et al. (2004); Su et al. (2008)	600
Copper	218–487	Moturoa / Rabbit Island	Wang et al. (2004); Su et al. (2008)	100
Lead	32–56	Moturoa / Rabbit Island	Wang et al. (2004); Su et al. (2008)	300
Mercury				1
Nickel	20–41	Moturoa / Rabbit Island	Wang et al. (2004); Su et al. (2008)	60
Zinc	478–1,051	Moturoa / Rabbit Island	Wang et al. (2004); Su et al. (2008)	300

[1] Metal concentrations for class A biosolids have been set at the soil limits. Applicable after 31 December 2012. Before this date, higher limits were allowed to enable wastewater treatment operators to develop and implement treatment facilities. Source: Magesan et al. (2010).

3.4. Approach to assessment and monitoring of effects on the receiving environment of Waimea Inlet

As described in the previous section, effects of the application of biosolids on pine forests on Moturoa / Rabbit Island on the coastal environment will potentially be mediated by leaching of particulate and soluble components of the biosolids into the ground water. These components may then enter the coastal zone by surface runoff and groundwater flow and seepage. The principal components of concern are nutrients (including nitrogen and phosphorus species) that may cause excessive growth of micro- and macroalgae, and toxic contaminants such as trace metals, that may adversely affect organisms living in the sediment. Pathogens are effectively eliminated from biosolids treated at the Bell Island Wastewater Treatment to the extent that they are considered to pose no risk to human health or to adversely affect other organisms. Faecal indicator bacteria are used as surrogates to assess the risk of exposure to sewage-derived pathogens.

Nitrates, rather than phosphates, are the main nutrient limiting plant growth in coastal environments. The AEE for the existing consent predicted that biosolids application would increase concentrations of nitrates in the shallow, unconfined aquifer beneath Moturoa / Rabbit Island (Beca Steven 1994). At some stage, these nitrates would likely enter the estuary, but the rate of arrival was considered likely to be slow. The application rate for biosolids was based on guidelines for application to forests and on values for the net uptake of nitrogen by radiata pine plantations. It was designed to minimise nitrate and metal migration in the groundwater (Carnus 1994). Based on the predicted slow rate of groundwater movement, combined with tidal flushing, the AEE predicted little effect on water quality in the Waimea Inlet. Although it is beyond the scope of the present report, we note that changes in growth rates of trees in response to climate change may affect future rates of nitrogen uptake.

The existing consent (NN940379V3) specifies monitoring of groundwater quality at 11 locations for a suite of variables including nitrogen species and trace metals. Consent monitoring of the coastal environment consists of intertidal surveys along the southern side of Moturoa / Rabbit and Rough islands. The monitoring is focussed on the southern side because groundwater flow is towards the southwest (according to the application for the existing consent, cited by Gillespie & Asher (1997), and see Tonkin & Taylor (2020)). Sediment samples are collected 6-yearly at each of 12 locations and analysed for grain-size, nutrients and trace metals, and the salinity of seepage water is measured. To identify possible ecological effects, the amount of micro- and macroalgae on the sediment surface is recorded *in situ* and the composition of the assemblages of animals living in and on the sediment is quantified. Concentrations of trace metals and faecal indicator bacteria are measured in shellfish. The baseline survey was done in 1996 (Gillespie & Asher 1997) and subsequent surveys in 2003, 2008, 2014 and 2019 (Gillespie & Asher 2004; Gillespie et al. 2008; Gillespie et al. 2014; Campos et al. 2020).

The quality of estuarine receiving waters is not monitored directly under the existing consent. This assumes that ecologically important contaminants derived from the biosolids (i.e. nutrients, trace metals, and also faecal indicator bacteria) are likely to be strongly associated with, and retained within, soils and sediments. Furthermore, given the high flushing and mixing rates of waters in the Waimea Inlet (of which 95% is intertidal), it is not likely that groundwater seepage from Moturoa / Rabbit Island would be identifiable as a source of these contaminants against the background of other, larger sources such as the Waimea River, other waterways and the Bell Island wastewater treatment plant discharge.

The present AEE has adopted the assumption that any adverse ecological effects will be most detectable at the point where groundwater enters the coastal environment. To identify any such effects, we review and assess consent monitoring data collected to date.

We also assess the relative contribution of biosolids application, via groundwater seepage, to the nitrogen budget of Waimea Inlet. The estimated nitrogen load from groundwater seepage is derived from measured concentrations from the groundwater monitoring programme and estimated rates of groundwater flow. The latter is described in the groundwater report prepared for this consent application (Tonkin & Taylor 2020).

Cawthron collects water-quality data in the Waimea Inlet on behalf of NRSBU as part of the assessment of effects and monitoring for the consents for aberrational discharges from the reticulation system supplying Bell Island treatment plant and the treatment plant discharge. The compliance of these data with TDC water-quality standards is assessed to provide a general assessment of water quality in the Inlet, to which groundwater from Moturoa / Rabbit Island contributes.

For the purposes of assessment, we assume that application rates, exclusion zones and buffer zones will remain as per the existing consent.

4. RESULTS OF CONSENT MONITORING 1996–2019: ASSESSMENT OF INTERTIDAL EFFECTS

As discussed in Section 3.4, we review the results of intertidal consent monitoring to date to assess whether they provide evidence of adverse effects of contamination from biosolids application at the points where groundwater enters the receiving environment of Waimea Inlet. First, we summarise the results of the most recent (2019) survey, then we consider the results of all surveys, starting with the baseline survey in 1996. Sampling methods have been consistent across all surveys and are described in Section 4.1.

4.1. Consent monitoring requirements and methods

Under existing resource consent number NN940379V3, the consent holder is required to undertake a coastal monitoring programme to identify any adverse environmental effects of the application of biosolids to land on the adjacent intertidal habitats of Moturoa / Rabbit and Rough islands. The programme consists of:

- a survey of benthic micro- and macro-algal cover prior to biosolids application, repeated every six years[8]
- transect surveys along the foreshore adjacent to the coast, particularly along the Waimea Inlet coastline, prior to biosolids application. These surveys include sediment profile descriptions, sediment grain-size, organic matter and nutrient assessment and quantitative description of the sediment fauna (beginning with the 2008 survey), to be repeated every six years
- visual observations along Moturoa / Rabbit Island foreshore within Waimea Inlet at six-monthly intervals for the first three years of operation of the consent, extended to three-yearly intervals for the duration of the consent.

The following surveys have been undertaken to date:

- a pre-application baseline survey of 12 intertidal monitoring transects (Figure 8) carried out in February 1996[9]
- follow-up visual inspections of all transects carried out at approximately six-monthly intervals after commencement of biosolids applications (February 1996–August 2001)
- a detailed monitoring survey carried out in April 2003
- a visual inspection carried out in May 2006

[8] The consent does not specifically state where these surveys should be undertaken. We understand that this refers to the Waimea Inlet estuarine perimeter of Moturoa / Rabbit and Rough islands.
[9] All transect locations used in the 1996 survey were maintained in subsequent surveys.

- a second detailed monitoring survey carried out in February 2008 including, for the first time, sediment fauna
- a third detailed monitoring survey carried out in February 2014
- a fourth detailed monitoring survey carried out in November 2019.

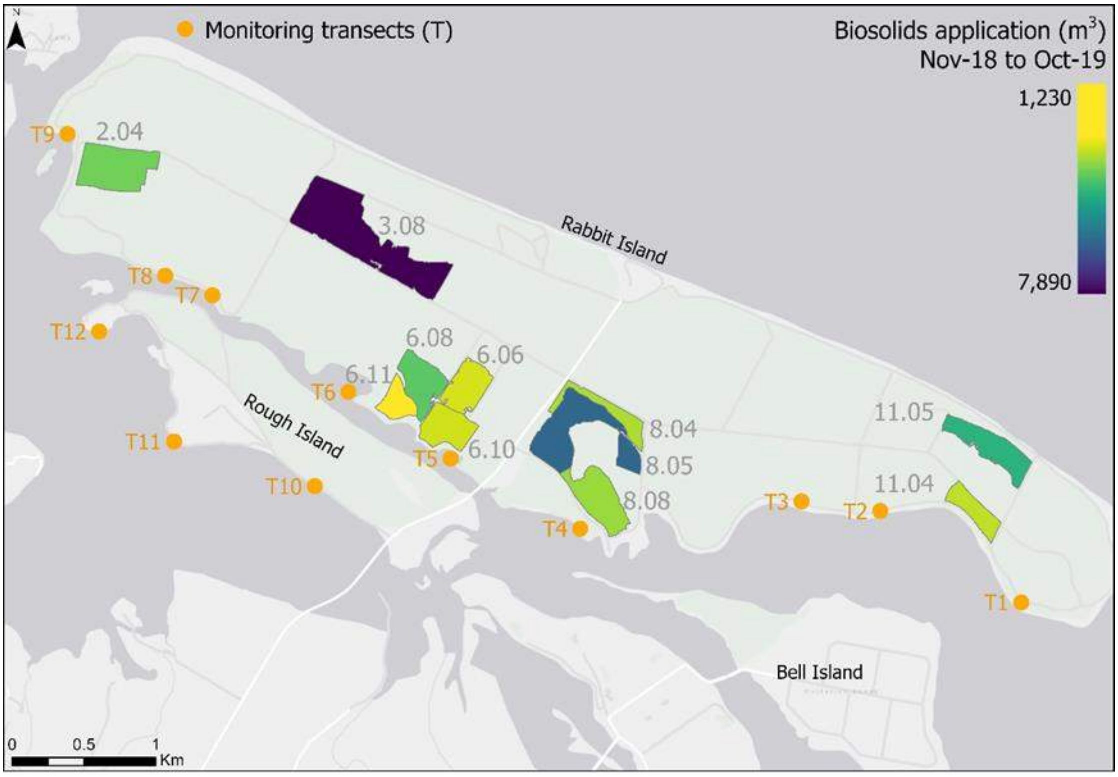

Figure 8. Locations of sampling transects on Moturoa / Rabbit and Rough islands, and the volume of biosolids applied during the period November 2018 to October 2019. Transects 1, 10, 11 and 12 are 'reference' transects. Data source: NMWaste.

Transects were initially selected after consideration of:

- the proposed biosolids application areas
- the predicted direction of groundwater flow towards the inner (southwestern) side of the island (Gillespie & Asher 1997)
- the apparent relative efficiency of tidal flushing.

The twelve transects are therefore situated on the southwestern side of Moturoa / Rabbit / Rough islands extending perpendicular to the shore from approximately spring high water to mean low water. Transects 2–9 are situated adjacent to designated biosolids application areas while transects 1, 10, 11, and 12 are adjacent to non-application areas, thus serving as 'reference' sites less likely to be affected by biosolids applications. The landward end of each transect is permanently marked with a wooden peg.

Sampling methods are summarised here, and a more detailed description is provided by Campos et al. (2020). A measuring tape extending from the transect marker (upper end) through the lower intertidal levels was used to relate shore characteristics to positions on the transect line. Two monitoring sites, designated A (mid transect) and B (lower transect) were chosen at points where groundwater seepage was most apparent. Only one site was sampled on transect T10 (Rough Island) because of the short length of this transect. It is important to note that, due to the uncertainty of determining the direction of groundwater flow at fine spatial scales and the long monitoring interval, it is possible that the reference sites were sometimes compromised by sub-surface contaminant flows. This is relatively unlikely for transect T1, at the eastern end of Moturoa / Rabbit Island because the southwesterly flow of groundwater will carry contaminants away from the transect. It is uncertain whether sub-surface movement of contaminants from Moturoa / Rabbit Island could reach the reference sites on Rough Island across the potential barrier of The Passage (the unconfined aquifer below the islands extends 2–4 m below the ground surface: Tonkin & Taylor (2020)).[10]

4.1.1. *Field observations*

Changes in substrate type, shore topography and major biological habitats along each transect were described in general terms and more detailed quantitative descriptions were made at individual study sites. Photographs were collected for direct comparison with previous surveys. Site characteristics recorded were:

- general characteristics (including location, tidal elevation (relative height) and topography)
- sediment type (mud, sand, shell, etc.)
- abundances of crab holes, shellfish and other surface macroinvertebrate species
- macrophyte species and percent cover. Where a significant macroalgal cover at either Site A or Site B existed, the percent coverage of the sediment habitat was estimated
- sediment profiles (62-mm diameter cores extruded, photographed and described according to stratification of colour and texture and any corresponding indications of sediment anoxia)
- samples of seepage water, when present in sufficient quantities, for measurement of salinity

[10] It should also be noted that the reference transects are much further from sources of contaminants (application areas). Concentrations will reduce with distance from source because of dilution and dispersion, and possibly through biological (microbial uptake) and physico-chemical (adsorption to particulates) action. Consequently, it is unlikely that effects at reference locations, if they occur, would be as marked as at sites near application areas.

- other obvious signs of nutrient enrichment (e.g. hydrogen sulphide odours, bacterial or microalgal mat development, etc.).

4.1.2. Sampling

Sediments

Composite sediment samples were collected at each site (A and B) on each transect and used to determine sediment grain size distribution, total organic matter content as ash-free dry weight (AFDW), concentrations of nutrients (total nitrogen, nitrate-N, nitrite-N and ammonia-N) and concentrations of trace metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel and zinc). Triplicate samples of animals living within the sediment (the 'infauna') were collected at the lower transect (B) sites using a 130-mm diameter, 200-mm deep corer.

Shellfish

Shellfish (cockles, *Austrovenus stutchburyi*, or Pacific oysters, *Crassostrea gigas*) were collected from the vicinity of each transect and analysed for concentrations of faecal indicator bacteria, trace metals and arsenic content. Concentrations of faecal indicator bacteria are discussed in the human health risk assessment (Hudson 2020) and are not considered in the present report.

4.2. Summary of the results of the 2019 survey[11]

4.2.1. Field observations

Most monitoring sites did not show signs of nutrient enrichment, with sediment cores relatively well oxygenated and with little or no macroalgal cover present on the sediment surface. However, there were indications of enrichment at some sites (including those considered reference), as evidenced by relatively high macroalgal cover and/or potentially reduced oxygenation (i.e. anoxia) in sediment profiles.

Habitat characteristics

Visual inspections revealed ongoing changes in habitat characteristics at several transects, particularly in relation to erosion of the high shore.

Salinity

Salinity measurements of sediment interstitial waters at most sites (33.1–37.7 psu) were similar to seawater. However, lower salinity values at seven sites indicated a certain amount of freshwater contribution, possibly through groundwater seepage and / or other freshwater contributions (17.1–29.0 PSU, sites 3A, 4B, 7A, 7B, 8B, 10A and 10B). Salinity at site 1A (43.5 psu) was higher than in Tasman Bay, indicating loss of water through evaporation.

[11] Detailed results are provided by Campos et al. (2020).

Algae and cyanobacteria

Opportunistic taxa such as *Ulva* and *Agarophyton* (*Gracilaria*) *chilense* can reach problem densities in estuaries under enriched conditions. Macroalgal cover was highest at nine of the 23 sites, representing seven of the twelve transects (5, 6, 7, 9, 10, 11 and 12) and including all of those considered to be reference locations (see Figure 9 for examples). Average macroalgal cover per quadrat at these sites ranged from 25% to 87%. The dominant taxon at all sites except one was the genus *Ulva*. The red macroalga *Agarophyton* (*Gracilaria*) *chilense* was dominant at Site 5B. The presence of relatively high macroalgal cover at reference sites does not suggest that nutrient enrichment as a result of the application of biosolids is likely to be the cause.

Visible dark-green mats comprised largely of the cyanobacterium *Microcoleus* (*Phormium*) sp. were noted at Transect 8 along the shoreline at 16–18 m below the high-water mark. *Microcoleus* commonly produces toxins that pose a human health risk through skin contact and ingestion (Wood et al. 2017). Subdominant taxa within the mats were *Oscillatoria* sp. (another cyanobacterium) and diatoms. *Microcoleus* sp. is more commonly found in New Zealand's rivers than estuaries, and in these habitats the presence of blooms is influenced by many factors (e.g. water flow, nutrients) (Wood et al. 2017). No visually obvious microalgal or cyanobacteria mats were recorded at any other site.

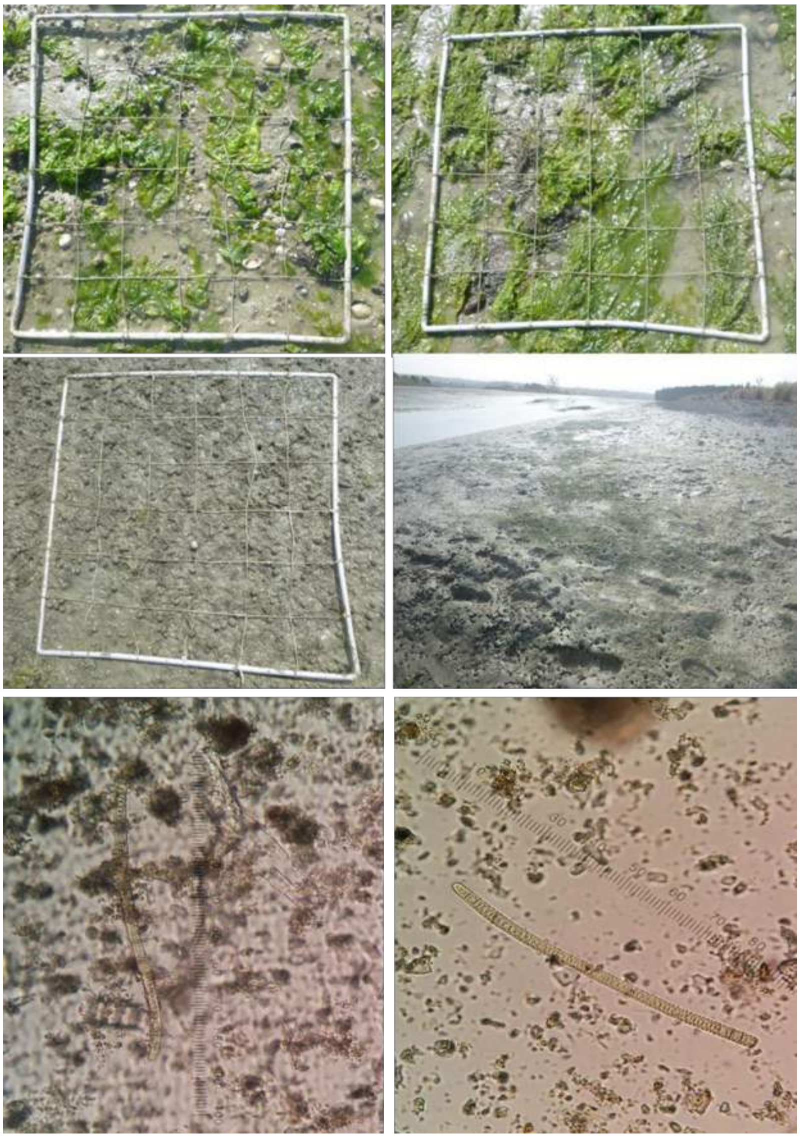

Figure 9. Examples of macroalgal quadrats (top left [Site 12A], top right [7B], bottom left [5B]) and cyanobacteria mats (middle right [Transect 8]) and *Microcoleus* sp. from within the cyanobacteria mats at microscopic (400 x) level (bottom left and right) from the 2019 monitoring survey.

Sediment profiles

Sediment profiles at most sites were light to medium grey-brown mud and/or sand throughout the core, indicating that the sediment was relatively well oxygenated. However, sediment was dark grey starting from between 1 cm to 8 cm deep at nine of the 23 sites (2A, 4A, 4B, 5B, 6B, 7A, 8A and 11A [reference] and 12B [reference]) indicating poorer sediment oxygenation. Sediment was black/blackish starting from between 5 cm to 10 cm deep at three of these sites (2A, 6B and 11A [reference]) indicating the potential existence of an anoxic layer. None of the cores were recorded as having a hydrogen sulphide odour. Examples of the sediment profiles are shown in Figure 10.

Figure 10. Examples of sediment profiles from the 2019 monitoring survey. Cores from Transect 6, Sites A (top) and B (bottom). The cores are oriented so that the sediment surface is on the left.

4.2.2. Sediment physical and chemical characteristics

Grain size

Sediment grain-size distributions at the study sites ranged from silt / clay-dominated to sand-dominated (Figure 11). Sediment at 13 sites comprised > 50% silt / clay, with a very high amount of silt / clay (> 90%) present at five of these sites. Three of the reference sites contained silt / clay-dominated (66–69%) sediments. Sediments were coarser and dominated by sand (sometimes including gravel) at nine sites. Site 2A was approximately half silt / clay and half sand. Fine-grained sediments generally contain different infaunal communities and are also more likely to contain elevated nutrient and / or contaminant concentrations.

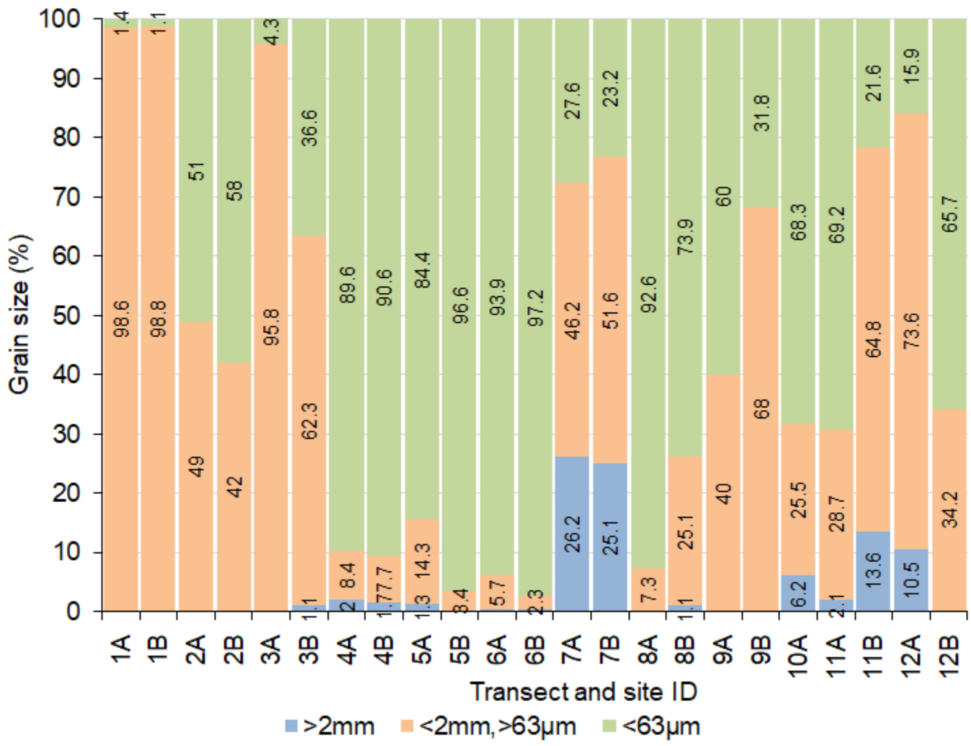

Figure 11. Sediment grain size distribution at Moturoa / Rabbit and Rough islands sites during monitoring in 2019. Numbers are percent composition.

Nutrients

Concentrations of total nitrogen (TN) at sites 1A, 1B and 3A were at or below the limit of detection (LoD) of the method. At all the other sites, samples had concentrations ranging from 400 mg/kg to 1,700 mg/kg of dry weight. Higher concentrations tended to occur at muddier sites, which is consistent with the generally higher organic content of fine, muddy sediments.

Ammonium-N concentrations in sediments were elevated at 9 of 23 sites compared to what would normally be expected for similar intertidal environments in the Nelson region (< 10 mg/kg, Gillespie & Mackenzie 1990; Gillespie & Asher 1997). This suggests slight to moderately enriched conditions at these sites, including some that were not adjacent to biosolids application zones (i.e. sites 11 and 12). The highest ammonium concentration (32 mg/kg) was recorded at site 4A. In contrast, samples from nine sites had ammonium concentrations below the LoD. Concentrations of nitrite and nitrate in were mostly below the LoD. The highest concentrations of nitrite and nitrate were 2.3 mg/kg (site 4B) and 6.7 mg/kg (site 5B). As with TN, higher concentrations of other nitrogen species tended to reflect sediment texture rather than location in relation to biosolids application.

Total organic content

Concentrations of organic matter (% AFDW) were low to moderate, ranging from 4.4% to 6.5% at the mud-dominated sites. The values at most other sites were < 4.2%. The exception was site 10A with a relatively high percentage of mud (68%: Figure 11) but only 3.7% AFDW. Comparisons of values for application and reference transects does not suggest that biosolids application is resulting in accumulation of organic matter in the sediments.

Arsenic and trace metals

With the exceptions of chromium and nickel, all of the metals/metalloids tested were below their respective default guideline values at which adverse ecological effects may occur (ANZG [2018] DGV) (Table 2). Chromium concentrations exceeded the DGV threshold at T4, 10 and 11. Nickel concentrations were also elevated for all transects. These exceeded the ANZG (2018) GV-High threshold at ten transects, indicating that toxicity-related effects are likely at these locations, and exceeded the DGV threshold at the other two transects.

The distribution of contaminant concentrations among application and reference transects, with some of the highest values at reference transects, does not suggest any effect of biosolids application.

Table 2. Sediment metal/metalloid concentrations (mg/kg dry weight) at Moturoa / Rabbit and Rough islands transects (November 2019) and recommended guideline values (ANZG 2018). Shading indicates values above ANZG DGV (grey) or GV-High (black). '*' reference site.

Transect	Arsenic	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Zinc
1*	3.4	<0.010	18	3.9	3.0	<0.02	35	23
2	6.2	0.017	52	12.9	8.3	0.03	**91**	52
3	4.2	0.014	32	7.8	4.9	<0.02	**66**	34
4	6.2	0.034	104	25.0	11.1	0.06	**166**	77
5	7.5	0.023	70	18.9	11.2	0.05	**102**	71
6	7.0	0.024	67	16.8	10.1	0.04	**103**	65
7	5.1	0.020	44	9.7	6.5	0.02	**70**	40
8	7.8	0.023	68	17.9	10.6	0.03	**111**	66
9	4.1	0.012	28	6.0	4.5	0.04	43	24
10*	4.5	0.031	115	21.0	7.6	0.05	**195**	63
11*	5.3	0.030	96	21.0	7.8	0.05	**164**	66
12*	4.3	0.015	35	8.3	5.5	0.02	**61**	32
DGV	20	1.5	80	65	50	0.15	21	200
GV-high	70	10	370	270	220	1	52	410

4.2.3. *Infaunal communities*

Overall, the types and abundances of key taxa were similar between the impact and reference sites. However, pipis (*Paphies australis*) were the most abundant taxon at two of the reference transects (T1 and T11), but none of the 'impact' sites. Davidson and Moffat (1990) found that this bivalve has limited tolerance of dilute seawater and fine sediments and Robertson et al. (2015) also found *P. australis* to be relatively intolerant to mud. Therefore, this result could be due to sediment texture at these sites as they had the lowest proportion of mud of any of the lower (B) sites (see Figure 11).

Under more stressful conditions, the number of taxa generally decreases and the infauna is often dominated by a small suite of tolerant taxa. There was some variation in the number of individuals and taxa among transects (Figure 12), although the variation within transects was also relatively high at some sites (i.e. differences among replicate cores, as indicated by the standard deviations in Figure 12). However, indices of evenness and diversity (Pielou's and Shannon-Wiener's indices, respectively, in Figure 12) were broadly similar among transects and outlying values of diversity occurred at both a reference site (T10) and sites near application areas (T2 and T9).

Transect 9 had both the highest average abundance and number of taxa. At this transect, two taxa indicative of 'moderately enriched' conditions (Keeley et al. 2012) made an important contribution to infaunal community composition. These were the polychaetes *Prionospio aucklandica* and *Aonides trifida*, with abundances of 41.3 and 34.3 individuals per core, respectively. The numbers of individuals and taxa were also relatively high at reference transect T12, and *P. aucklandica* was also present in similar abundances to those at T9.

Taxa known to be indicative of 'moderately enriched' or 'enriched' conditions were important contributors to the structure of the infaunal community at nine out of the twelve transects, including at two of the four reference locations (T10 and T12). Taxa indicative of enriched conditions made an important contribution at transects T2 (*Heteromastus filiformis*, abundance 5.7 individuals per core) and reference transect T10 (Oligochaeta, abundance 24.7 individuals per core), although these were not the most abundant taxa at these transects.

Transects with the lowest number of both taxa and individuals were T5 and T6, followed by T11 and T4. Three of these transects (T4–6) are adjacent to biosolids application areas and T11 is a reference (see Section 4). Consequently, there is no reason to believe that these values are associated with biosolids application. Infaunal communities at T5 and T6 were characterised by the pulmonated gastropod *Amphibola crenata,* which lives on the sediment surface rather than within the sediments.

The range of infaunal abundances were generally similar, and taxa richness was higher in some cases, at the 2019 biomonitoring sites in comparison to those at Waimea Inlet sites monitored for SoE purposes, well away from Moturoa / Rabbit Island (Robertson & Robertson 2014). These differences may reflect the fact that the Moturoa / Rabbit Island sites are nearshore and encompass a larger diversity of benthic habitats than SoE sites which are situated in homogeneous mudflats/sandflats in central areas of the Waimea Inlet.

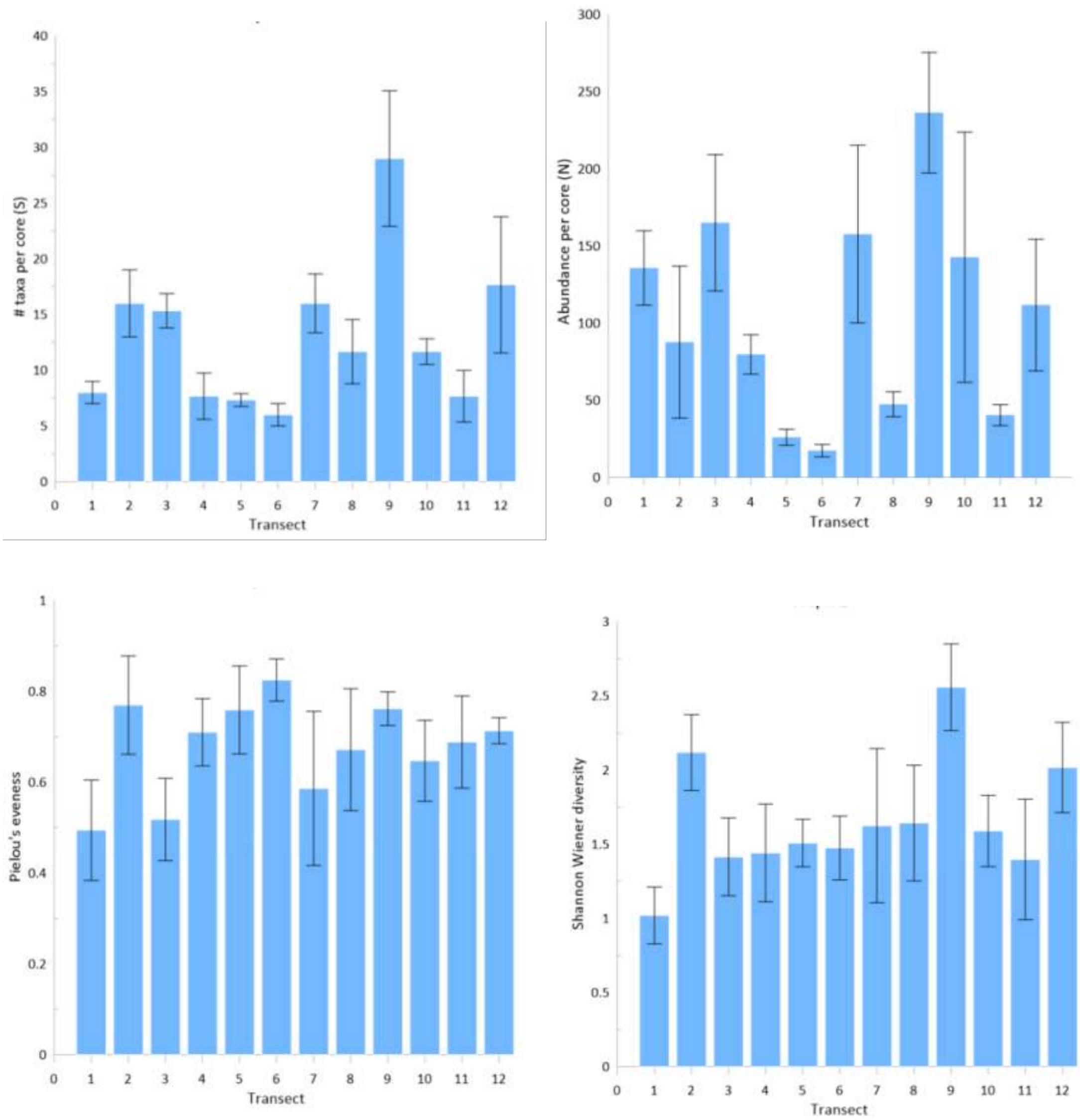

Figure 12. General indicators of benthic invertebrate community structure at Moturoa / Rabbit and Rough islands transects (1–12, taken from site B in each case). Data are mean values ± 1 standard deviation (n = 3).

4.2.4. Arsenic and trace metals in shellfish

Concentrations of arsenic in cockle flesh (1.07–2.8 mg/kg (Table 3) exceeded the Food Standards Australia New Zealand (FSANZ) maximum level for human consumption of 1 mg/kg[12] and also exceeded the Mean International Standards (MIS) guideline for safe human consumption (1.4 mg/kg: Russman 2000) at all sites where samples were collected. However, the data do not suggest that these elevated concentrations were related to biosolids applications because similarly elevated concentrations occurred at both application and reference transects.

Nickel concentrations in shellfish flesh exceeded MIS guideline levels at the four reference sites and at four potentially impacted locations. The samples consisted of composites of whole shellfish tissues, including intestinal tracts. Consequently, ingested inorganic particulate materials may have been the main source of elevated nickel concentrations. Nickel and arsenic concentrations in shellfish throughout Waimea Inlet are affected to varying degrees by the mineralogy of the catchment.

Concentrations of cadmium, chromium, copper, lead, mercury and zinc were below the corresponding MIS guidelines for safe human consumption (Table 3).

[12] Available at: https://www.legislation.gov.au/Details/F2017C00333.

Table 3. Concentrations of trace metals (mg/kg wet weight) and dry matter (g/100 g) at Moturoa / Rabbit and Rough islands transects (November 2019). Oysters were tested in samples from T10 and cockles from all other transects. '*' reference site. '-' no sample collected. Grey-shaded values exceed either or both the Median International Standards (MIS) or Food Standards Australia New Zealand (FSANZ) guidelines for safe human consumption.

Transect	As	Cd	Cr	Cu	Pb	Hg	Ni	Zn	Dry matter
1*	1.58	0.014	0.36	0.63	0.041	<0.010	2.6	6.8	10
2	1.59	0.016	0.86	0.75	0.108	0.012	2.8	8.0	10.5
3	1.87	0.014	0.84	0.67	0.094	0.016	3.0	7.6	9.2
4	1.87	0.017	0.93	0.65	0.079	0.017	3.6	7.2	7.7
5	-	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-
7	2.8	0.025	0.5	0.73	0.066	0.014	1.7	7.2	10.3
8	-	-	-	-	-	-	-	-	-
9	1.74	0.020	0.53	0.74	0.063	0.010	2.3	7.4	10.9
10*	1.5	0.015	0.68	0.59	0.06	<0.02	2.7	7.0	-[5]
11*	1.07	0.014	0.91	0.73	0.116	0.013	2.2	7.0	10.5
12*	1.86	0.014	0.53	0.61	0.076	<0.010	2.3	6.8	10
MIS[1]	1.4	1	1	20	2	0.5	2[3]	70	-
FSANZ[2]	1[4]	2			2	0.5			

[1] MIS: Median International Standards for Trace Elements in shellfish (Russman 2000).
[2] FSANZ: Food Standards Australia New Zealand, maximum level (ML) of contaminants in molluscs.
[3] Developed for Australia.
[4] Refers to inorganic forms only whereas arsenic species in seafoods are predominantly in organic forms that are generally considered to be of low toxicity.
[5] Insufficient sample volume to perform test.

4.3. Comparison of surveys over time

4.3.1. Grain size and organic content

The percentage of mud at most sites was fairly stable among the surveys from 2008, 2014 and 2019, although 2014 values were lower than either of the others at several transects (Figure 13: grain size was not measured in 1996 or 2003). There are few consistent patterns over time, but the percentage has successively decreased at sites 7A and 12A and increased at 4A and 12B (a relatively large change from 16 to 66%). Although the causes of these changes are unknown, the fact that they occur at both application and reference sites suggests that they are not related to biosolids application.

Organic content of the sediments was also relatively stable across time at most sites (Figure 13). There were fairly consistent increases at 4A, 4B, 5A and 8A, and decreases at 6A and 12A. These changes often reflected changes in mud content, which is expected because muddy sediments generally have a higher organic content.

Again, there was no pattern of change that would suggest an effect of biosolids application. Rather, the increases in mud at some sites is likely to reflect the generally increasing muddiness of Waimea Inlet over time, summarised by Stevens and Robertson (2010).

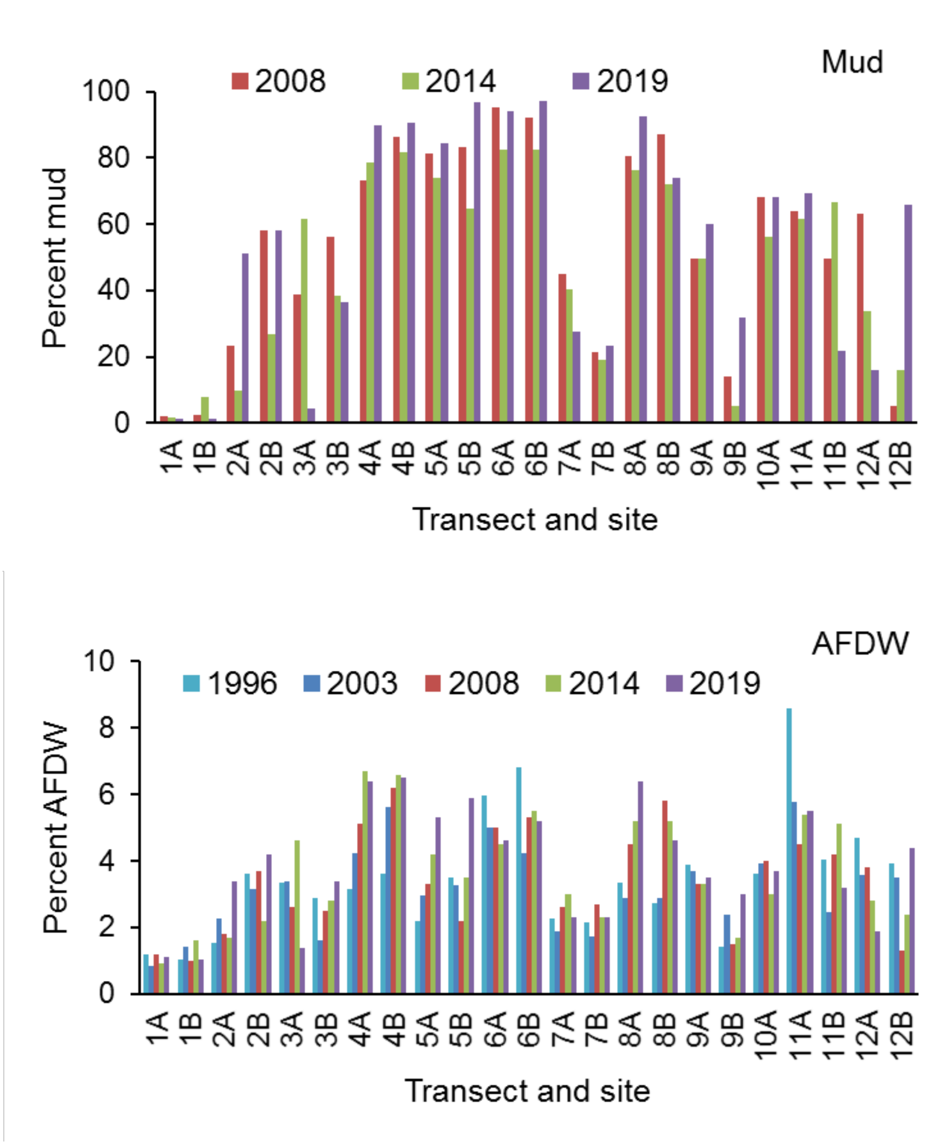

Figure 13. Percentages of mud (upper plot) and organic content (as AFDW) at Moturoa / Rabbit and Rough islands transects 1–12 over surveys from 1996 to 2019. Values are by dry weight. Percentage of mud was not measured in 1996 or 2003.

A comparison of grain size distributions at the monitoring transect locations among the three most recent survey years shows the spatial distribution of changes (Appendix 1). No substantial changes in grain-size distributions are apparent at six transects (T1, 2, 3, 7, 8, 10). The increase in mud at site 4A, and AFDW at 4A, 4B, 5A and 8A, between 2014 and 2018 were near biosolids application areas (Figure 8). However, decreases in mud and AFDW also occurred near application areas (sites 7A and 6A) and increases occurred at reference site 12B. This suggests that there are no cumulative effects of biosolids application on sediment texture or organic content.

The increases in AFDW at T4, T5 and T8 corresponded with increases in TN concentrations in sediments (see Section 4.3.2) and provide some evidence of cumulative nutrient enrichment occurring at these sites. These results are also consistent with the increasing trends in total organic content found at all SoE sites in the Waimea Inlet (Robertson & Robertson 2014).

4.3.2. Total nitrogen in sediments

The results indicate increasing TN concentrations at T4, T5 and T8 over successive surveys (Figure 14 and Appendix 2). These sites are potentially impacted by nutrient inputs from biosolids application. However, at T6 (also potentially impacted), TN concentrations in the baseline (1996) survey were higher than in later surveys. Several application and reference sites showed no consistent pattern of change over time. There were also large differences between sites (A and B) on the same transect in individual surveys, such as T2, T11 and T12 in 2014. Samples from T1 (reference) had the lowest TN concentrations over the years, consistent with its coarser sediment. These results suggest that while there are cumulative increases in sediment TN concentrations over time at some transects, such increases are not consistent among application transects and it is unclear whether there is an effect of biosolids application.

The increases in AFDW at T4, T5 and T8 corresponded with increases in TN concentrations in sediments (see Section 4.3.1) and provide some evidence of cumulative nutrient enrichment occurring at these sites. These results are also consistent with the increasing trends in total organic content found at all SoE sites in the Waimea Inlet (Robertson & Robertson 2014). Nitrogen values were slightly higher at the Moturoa / Rabbit Island transects than at other locations in the Inlet monitored under the consent for the Bell Island discharge (a range among site means of 127–420 mg/kg in 2011 and 200–667 mg/kg in 2016).

Robertson et al. (2016)[13] developed a suite of indicators for the condition of estuaries in New Zealand, including indicators for TN. The indicators place estuarine sediments into bands associated with different levels of stress on sensitive sediment infauna. The TN concentrations measured in the 2019 Moturoa / Rabbit Island survey were generally within bands indicating minor (250–1000 mg TN/kg) or moderate (1000–2000 mg TN/kg) stress.

[13] Note that the Estuary Trophic Index guidelines proposed by Robertson et al. (2016) are interim and have not been through a full peer-review process.

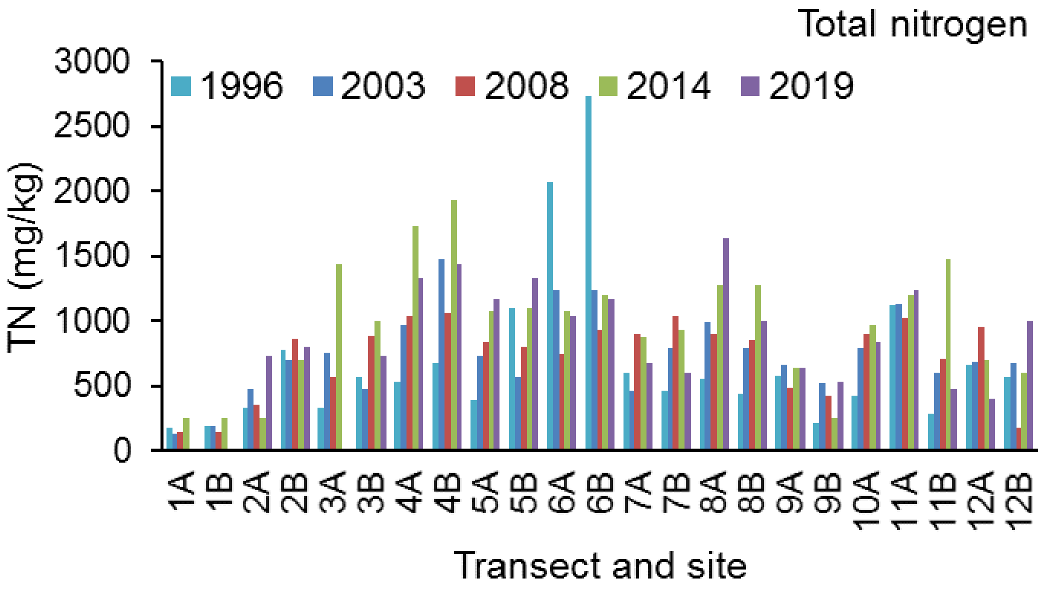

Figure 14. Concentrations of total nitrogen in sediment samples collected in five surveys at Moturoa / Rabbit and Rough islands transects 1–12. Missing data represent values less than the analytical limits of detection (200 mg/kg).

Overall, the results do not show consistent differences in the TN contaminant profile between impacted and reference sites over the years. Gillespie et al. (2014) reported progressive increases in sediment TN concentrations at sites adjacent to areas that had not received biosolids in the year prior to the survey. We note that TN concentrations at some of the Moturoa / Rabbit and Rough islands sites have historically exceeded 1,000 mg/kg (moderate stress) limit used in the State of the Environment (SoE) monitoring programme. In comparison, SoE sites did not exceed this value in 2001–2014 (Robertson & Robertson 2014). The monitoring database is still insufficient to assess temporal trends and determine if there is a deterioration in the nutrient status of the study area.

4.3.3. Arsenic and trace metals

Concentrations of arsenic showed a decrease over time at all transects (Figure 15). In contrast, concentrations of copper, nickel and zinc show increases at some or all transects (Figure 15). However, for all three metals this pattern was evident at reference transects T10, T11 and T12 in addition to transects adjacent to application areas. In fact, concentrations at the reference transects were higher than at several of the others—compare, for example, nickel concentrations at T10 and T11 with those at T5–T9. This suggests that the cause of increase is unlikely to be related to the application of biosolids and derives from a source or sources acting at a broader spatial scale. Copper and zinc are ubiquitous contaminants around sites of human activity, entering the aquatic environment via stormwater runoff and frequently accumulating in sediments over time (Williamson & Morrisey 2000). Nickel (and chromium) concentrations are generally high in coastal sediments around Nelson relative to other parts of New Zealand, because of the composition of the source material in the mineral-belt catchment (Robertson 2002).

Differences in concentrations of chromium, lead and mercury are inconsistent over time (Figure 15). They do not show any trends or spatial patterns (differences among application and reference transects) that might suggest that application of biosolids was causing an accumulation of these metals in coastal sediments over time.

The concentrations of arsenic and trace metals at T1 were consistently low relative to other transects. This is very likely to be due to the relatively coarse sediment at this transect, because these contaminants preferentially bind to organic-rich, fine-grained sediments.

Interpretation of changes in concentrations of cadmium is problematic because values in 2003 were consistently higher than in subsequent surveys (Figure 15). Furthermore, relatively large decreases occurred between 2008 and 2014. Values in 2014 and 2019 were consistently much lower and more consistent with other surveys of concentrations in sediments in Waimea Inlet. Cadmium concentrations in sediments at sites around and downstream of the Bell Island WWTP discharge in the eastern part of Waimea Inlet, sampled in 2016, were in the range < 0.01–0.03 mg/kg (Morrisey & Webb 2016), similar to those measured at the Moturoa / Rabbit Island transects in 2014 and 2019. This suggests that the 2003 and 2008 results may not be reliable[14]. The 2014 and 2019 results suggest that concentrations around Moturoa / Rabbit Island are similar to those in other parts of Waimea Inlet and that there is no evidence for an effect of application of biosolids to land.

Comparison with guideline values for the protection of aquatic life (ANZG 2018) shows that the concentrations of arsenic and most of the trace metals included in the surveys (Figure 15) were well below those that may have adverse ecological effects (Default Guideline Values [DGV]: Table 4). The exceptions were chromium and nickel, both of which exceeded their DGV values and, in the case of nickel, also exceeded the guideline at which adverse ecological effects would be expected (Guideline Value–High [GV-High]). Chromium is another metal derived from the Nelson mineral belt soils and concentrations measured in the eastern part of Waimea Inlet in 2016 (Morrisey & Webb 2016) were in the range 25–72 mg/kg. This range is lower than that recorded at Transects T4, T10 and T11 and concentrations of nickel at these sites were also higher than in the eastern Inlet in 2016 (41–82 mg/kg). These three transects lie closest to the outflow of the Waimea River (Figure 8) and may receive the highest inputs of sediment and associated metals from the catchment.

[14] The reasons for this are not known. They are likely to be analytical, given that there is no reason that contamination of samples would have occurred to this degree after collection.

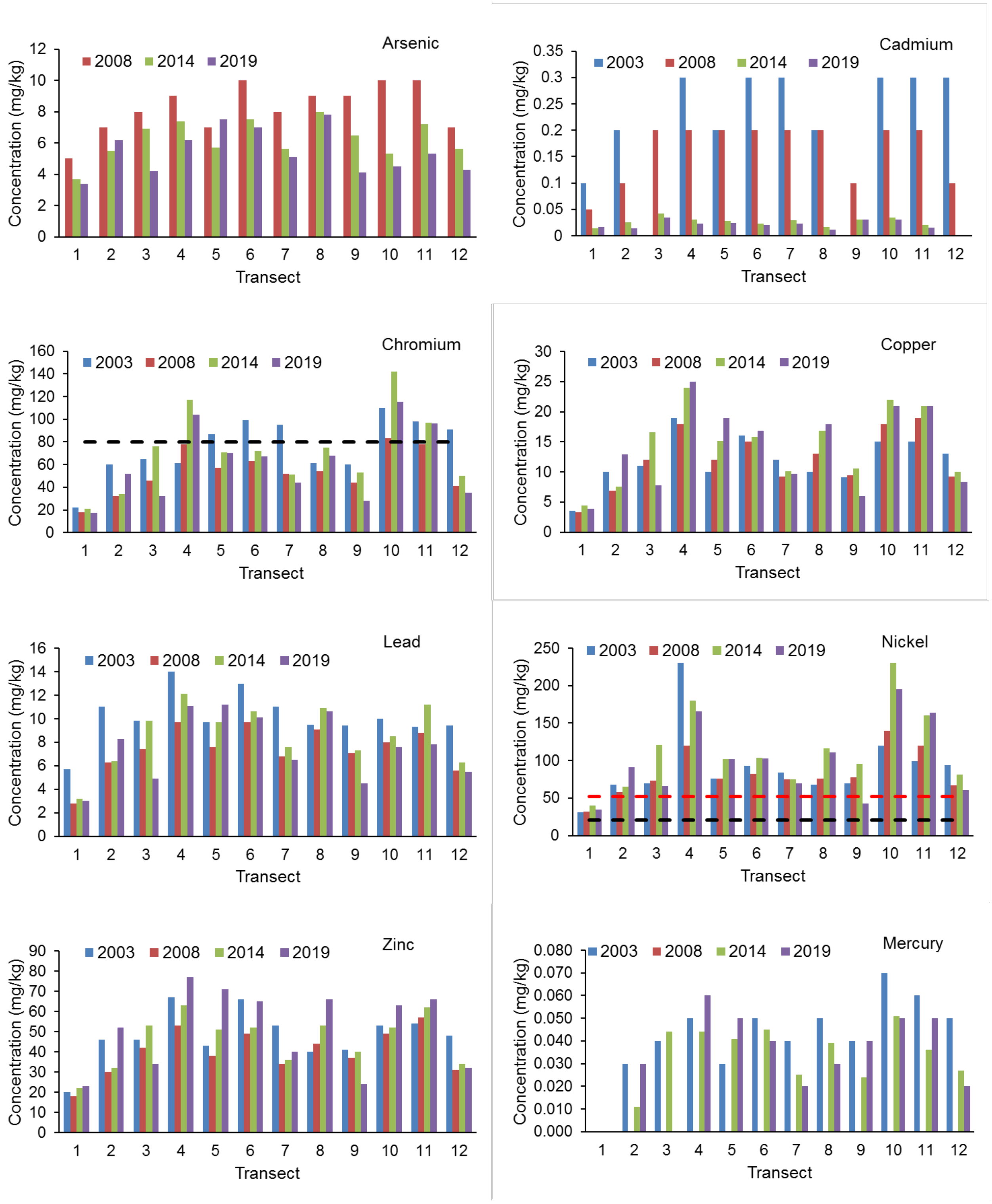

Figure 15. Concentration of arsenic and trace metals in sediment samples collected at Moturoa / Rabbit Island transects 1–12 over surveys from 2003-2008. Dashed lines show ANZG (2018) DGV (black) and GV-High (red) guideline values for cadmium and nickel. Values are for individual, composite samples. Missing data represent values less than the analytical limits of detection (LoD). Values for arsenic in 2003 and mercury in 2008 were all less than LoD (10 and 0.05 mg/kg, respectively). No data were collected in 1996.

Table 4. ANZG (2018) guideline concentrations values (mg/kg) for arsenic and trace metals in sediment. 'DGG' Default Guideline Value (concentration at which ecological effects *may* become apparent). 'GV-High' Guideline Value – High (concentration at which ecological effects are *likely*).

	Arsenic	Cadmium	Chromium	Copper	Lead	Nickel	Zinc	Mercury
DGV	20	1.5	80	65	50	21	200	0.15
GV-High	70	10	370	270	220	52	410	1.0

4.3.4. Infaunal communities

Infaunal surveys to date (2008, 2014 and 2019) have found no evidence of any detrimental effect of the biosolids programme on infaunal communities at the study transects. Opportunistic polychaete worms indicative of moderately enriched sediments, such as *Heteromastus filiformis* and *Prionospio* sp., have been consistently recorded at several monitoring transects in all three surveys. However, their presence at both application and reference transects (and at SoE monitoring sites elsewhere in Waimea Inlet), and the general similarity of communities at both types of transect, are not consistent with an effect of application of biosolids to land on Moturoa / Rabbit Island.

4.4. Summary

The intertidal monitoring to date has shown no symptoms of organic enrichment (e.g. sediment anoxia and presence of hydrogen sulphide) at most sites. Macro- and micro-algae were present on seven transects including reference transects. Evidence of enrichment has been recorded at some sites near biosolids application areas, but this has not been consistent among surveys. Furthermore, extensive algal mats were reported in the channel between Moturoa / Rabbit Island and Rough Island during the baseline survey, before application of biosolids began, and blooms have been found in other, localised areas of Waimea Inlet unrelated to application (Stevens & Robertson 2014). This spatial and temporal variability suggests that periodic, local evidence of enrichment is likely to represent background[15] seasonal and interannual patterns of algal growth.

Consistent changes in sediment texture have occurred over successive surveys at some transects but comparisons of application and reference transects suggest that they are not related to biosolids application. Changes in organic matter and TN tend to reflect changes in sediment texture over time, and there was no pattern of change that would suggest an effect of biosolids application. Rather, the increases in mud and

[15] The term 'background', rather than 'natural' is used here because these patterns may be influenced by anthropogenic inputs of nutrients to Waimea Inlet from activities in the catchment.

organic matter at some sites is likely to reflect the generally increasing muddiness of Waimea Inlet over time, identified from state-of-the-environment monitoring.

Increases or decreases in the concentrations of arsenic and some trace metals over time at some transects do not show patterns that might suggest that application of biosolids was causing an accumulation of these metals. For example, concentrations of copper, nickel and zinc have increased at reference transects in addition to some application transects. Concentrations of most metals are lower than guideline values for the protection of aquatic life, the notable exceptions being chromium and nickel. These latter metals occur naturally at relatively high concentrations in coastal sediments in the Nelson region and derive from mineral-belt soils in the catchment. Observed variations in their concentrations among monitoring transects is likely to reflect proximity to the mouth of the Waimea River, the main source of sediment.

Sampling of the sediment fauna has consistently found that communities at transects near application areas are similar to those at some of the reference transects. There is no evidence of any detrimental effects of biosolids application on infaunal communities.

Concentrations of arsenic and nickel have been consistently elevated in cockles during the monitoring programme, and often exceed guidelines for human consumption. The fact that this is observed at both reference and application transects (and at other locations in Waimea Inlet) suggests that natural background contamination is the cause, rather than an effect of biosolids application.

Overall, the results of the monitoring programme indicated that application of biosolids to land on Moturoa / Rabbit Island has had less than minor adverse effects on the enrichment or contaminant status of intertidal habitats around Moturoa / Rabbit and Rough islands.

5. NUTRIENT LOADS AND CONCENTRATIONS IN WAIMEA INLET AND INNER TASMAN BAY

5.1. Nutrient loads from catchment sources

The mean annual cumulative (instream) nutrient loads generated from the Waimea Inlet and Tasman Bay catchments have previously been estimated using the Catchment Land Use for Environmental Sustainability (CLUES) model (Gillespie & Berthelsen 2017). CLUES is a steady-state, spatially distributed and integrated modelling system within ArcGIS and predicts mean annual loads and concentrations of TN and total phosphorus (TP) with a spatial resolution of 0.5 km^2. CLUES couples modified versions of OVERSEER, SPARROW and SPASMO water quality models and its spatial unit is the River Environments Classification (REC) reach and surrounding sub-catchment. Spatial data are lumped within each REC sub-catchment. Catchment characteristics such as soil and slope are aggregated by the average value for each sub-catchment. The CLUES model represents land use in each REC sub-catchment by the percentage of the sub-catchment area covered by each of 19 land-use classes. The model considers both surface and groundwater transport. The latter is modelled through SPARROW, which has a groundwater network structure that mimics the surface stream network and a set of model parameters that quantify the transfer of water and solute between the two. Further details on the modelling framework can be found in Elliott et al. (2016).

The resulting TN loads were reported as 461 and 1803 tonnes per year (t/y), respectively, for the two catchment areas. Total phosphorus loads, estimated similarly, were 57 and 257 t/y. Here we focus on nitrogen, rather than phosphorus, because nitrogen is considered to be relatively more limiting for photosynthetic (plant) production in temperate coastal environments generally (Redfield et al. 1963; Plew et al. 2020) and in Tasman Bay (MacKenzie 2004). It should be noted that these modelled nutrient loadings are only approximate and can vary considerably between years, in part as a result of changes in rainfall patterns associated with climate change and intensification of land uses, and therefore the vulnerability of the estuary to eutrophication over the duration of the new consent (Stevens & Robertson 2010). The CLUES model does not account for climate change effects. Nevertheless, we consider that the model outputs provide a means of comparing the relative magnitude of individual nutrient sources to these coastal environments.

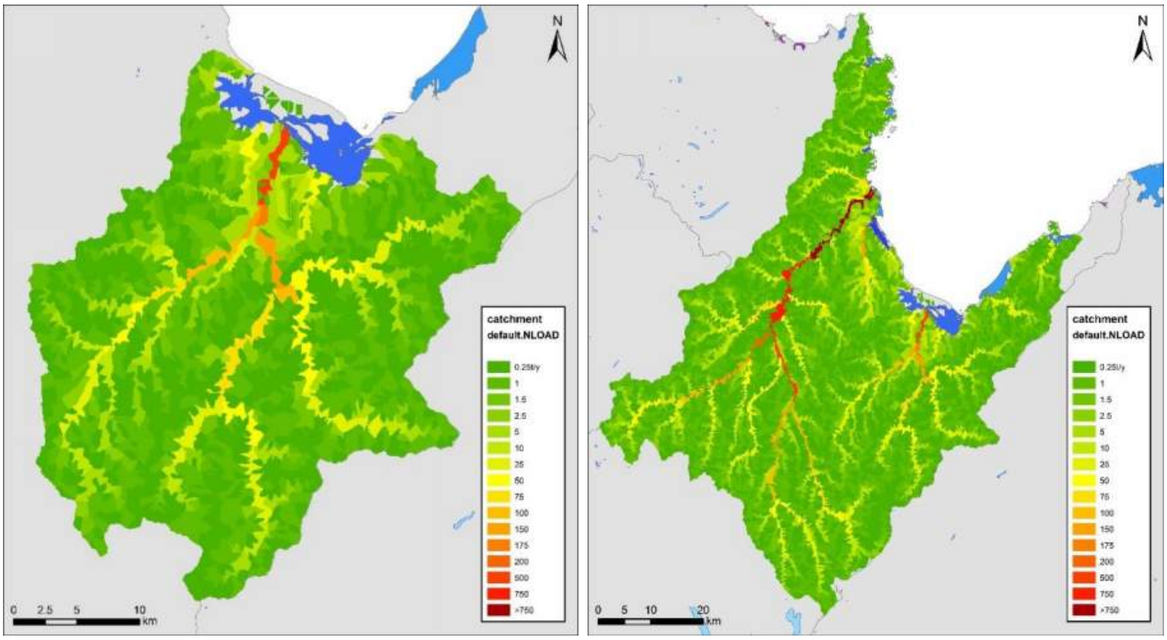

Figure 16. CLUES model outputs for TN and TP in Waimea Inlet (left) and Tasman Bay (right) under a default catchment land use scenario.

Stevens and Robertson (2010) estimated the total nitrogen contribution to Waimea Estuary from biosolids through surface runoff to be a maximum of 80 t/y assuming there is no post-application uptake (i.e. an unlikely scenario). They considered a more relevant estimate would be around 16 t/y assuming only around 20% discharge to the estuary (i.e. 80% uptake prior to discharge). This would amount to an approximately 3% contribution from the biosolids to the total TN input to the Inlet.

Tonkin & Taylor Ltd (2020), in their groundwater assessment report provided a prediction of the biosolids contribution to groundwater nitrogen based on bore water data. They predicted the annual TN contribution from biosolids to Waimea Estuary to be approximately 14 t/y. They further evaluated the fate and transport of biosolids-generated nitrate via groundwater using a hydrogeological site conceptual model. The model outcome suggested a potential concentration of 18 g/m^3 of nitrate-N in groundwater at the point of discharge into the coastal environment. This value represents an approximate mass balance based on assumptions described in the groundwater assessment report. The estimate indicates a biosolids contribution of approximately 3% and 0.8%, respectively, to the reported mean annual cumulative nitrogen loads of Waimea Inlet and Tasman Bay from their catchments.

Gillespie et al. (2011) reported that the average amount of nitrogen discharged into Tasman Bay annually would constitute only about 40% of the amount potentially lost through denitrification (the microbial conversion of nitrate-N to N_2 gas). This suggests that the modelled prediction of an additional 14 t/y of biosolids-generated nitrogen discharged into Tasman Bay would not have a measurable effect on the enrichment status of the greater Bay area. Considering the strong mixing characteristics within Tasman Bay (Tuckey et al 2006), we consider that this assumption is also appropriate for the inner Tasman Bay region.

5.2. Estimated contribution of nitrogen from biosolids to receiving-water concentrations

Accounting for the mixing the of groundwater with estuary water, Tonkin & Taylor's (2020) groundwater assessment predicted a nitrate concentration of 3.5×10^{-4} g/m^3 (or 0.35 mg/m^3) [16] in the inner Moturoa / Rabbit Island part of the Waimea Inlet receiving environment. This was achieved through implementation of a hydrogeological conceptual model and identification of relevant contaminant fate and transport parameters, including estimates of nutrient uptake from plantation forestry.

The modelled nitrate concentration in groundwater represents a very small proportion of a previously measured average dissolved inorganic nitrogen (DIN) concentration of 216 mg/m^3 at reference sites in Waimea Inlet (see Table 21 in Gillespie and Berthelsen 2017). The modelled concentration is equivalent to a relative contribution of < 0.2% from Moturoa / Rabbit Island groundwater to the existing Waimea Inlet DIN concentration. In addition, the intertidal monitoring, to date (Campos et al. 2020), has shown no consistent effects of the application of biosolids on land on the concentrations of nitrogen species in adjacent intertidal sediments. Nor has it shown symptoms consistent with organic enrichment (e.g. excessive algal growth, sediment anoxia and presence of hydrogen sulphide) at most sampling sites.

We conclude, based on the lack of evidence of biosolids effects on either the intertidal seabed or water column environment of the inner Moturoa/Rabbit Island region or Tasman Bay, that biosolids-related enrichment effects are less than minor.

5.3. Measurements of nutrients in seawater

The effects of the Bell Island WWTP discharge on the Waimea Inlet / inner Tasman Bay area are regularly assessed by collecting samples of water and shellfish at sites within the identified discharge mixing zone and sites in the wider Inlet and inner Bay and testing these samples for nutrients and faecal indicator bacteria. Water column profiles of physical and chemical parameters are also taken at these sites. To inform the present assessment, we selected nutrient data at 15 of these sites from surveys in 2006, 2011 and 2016. Sites T12, 8 and 11 are situated in the Waimea Inlet and the others are in inner Tasman Bay (Figure 17).

[16] Note that g/m^3 is equivalent to mg/L.

Figure 17. Sample collection sites in the inner Tasman Bay and Waimea Inlet.

The six nutrient species reported here (nitrate-nitrogen, ammonium-nitrogen, DIN, dissolved reactive phosphorus (DRP), TN and TP) influence aquatic primary production, i.e. they control the growth of benthic microalgae, phytoplankton, macroalgae, and aquatic vascular plants in the marine environment. This is because nitrogen and phosphorus are commonly in shortest supply relative to demand by aquatic primary producers during spring and summer in these environments (Dudley & Milne 2019). However, as stated above, of these two nutrients, nitrogen is more limiting in the Waimea Inlet.

Nitrate-nitrogen is one of the most common contaminants of rivers, coastal waters and groundwater in rural and urban areas. Sources of nitrate include excessive application of inorganic fertiliser and animal and human waste (LAWA 2019). Generally, this nitrogen species is the most water-soluble and therefore of concern for groundwater contamination because of its high mobility in most soil types (USEPA 1995). In the Bell Island WWTP surveys, nitrate-nitrogen concentrations were extremely low and below 0.1 g/m^3 at all sites, except at Site T12 near the discharge of the Waimea River where concentrations of 0.18 g/m^3 and 0.19 g/m^3 were detected in 2011 and 2016, respectively (Figure 18). These concentrations are not thought to represent toxicity to marine organisms (CCME 2003).

Inorganic nitrogen in the form of ammonium (NH_4) can readily volatilise as ammonia (NH_3) when sewage sludge is applied to soils rather than incorporated or injected, and thus may not be available to plants (USEPA 1995). This form of nitrogen enters rivers and estuaries primarily through sewage discharges or dairy shed effluents and is toxic to marine organisms at high concentrations (LAWA 2019). ANZG (2018) sets out a trigger limit for toxicity in marine waters (based on a pH of 8 and protection of 95% of taxa) of 0.91 g/m^3 (ANZG 2018[17]). Concentrations of ammonium-nitrogen in Waimea Inlet have been well below this limit with the maximum concentration of 0.042 g/m^3 detected at Site 15 in the 2016 survey (Figure 18).

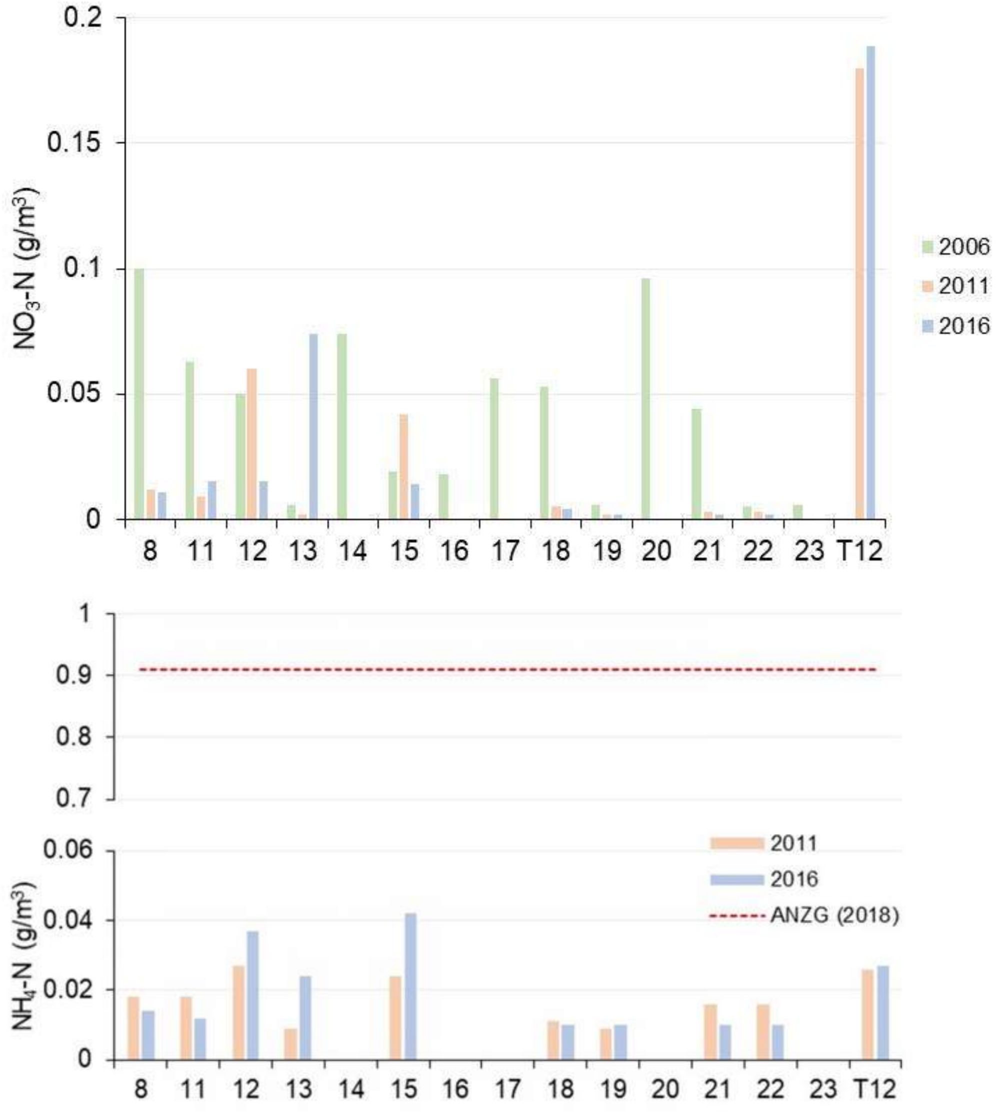

Figure 18. Concentrations of nitrate-nitrogen (NO_3-N) and ammonium-nitrogen (NH_4-N) in water samples collected at 15 sites in the Waimea Inlet and inner Tasman Bay. The ANZEEC (2000) guideline for ammonia (now superseded by ANZG 2018, but the value has not changed) is shown as a horizontal dotted line.

[17] Note that this value is lower than that shown in Table 5 because the latter was for a lower pH (7.3). The ratio of unionized ammonia (the more toxic form) to ionized ammonium increases with increasing pH.

Concentrations of DIN (the sum of inorganic nitrogen species) and DRP varied markedly among sites and among surveys and generally increase towards the shore. These are general features of the area as reported by Gillespie and Berthelsen (2017). Another characteristic of the area is the low molar ratios of nitrogen to phosphorus[18] evidenced by the data and previously reported by Gillespie and Berthelsen (2017). The highest DIN concentrations (0.2 g/m^3) were detected at Site T12 which is representative of nutrient inputs from the Waimea River (Figure 19). Concentrations of DRP were generally lower than 0.015 g/m^3, except those detected at Sites 8 and 17 in the 2006 survey (Figure 19). These are lower than concentrations detected at a site near the Bell Island WWTP discharge in the same surveys (0.08–0.11 g/m^3).

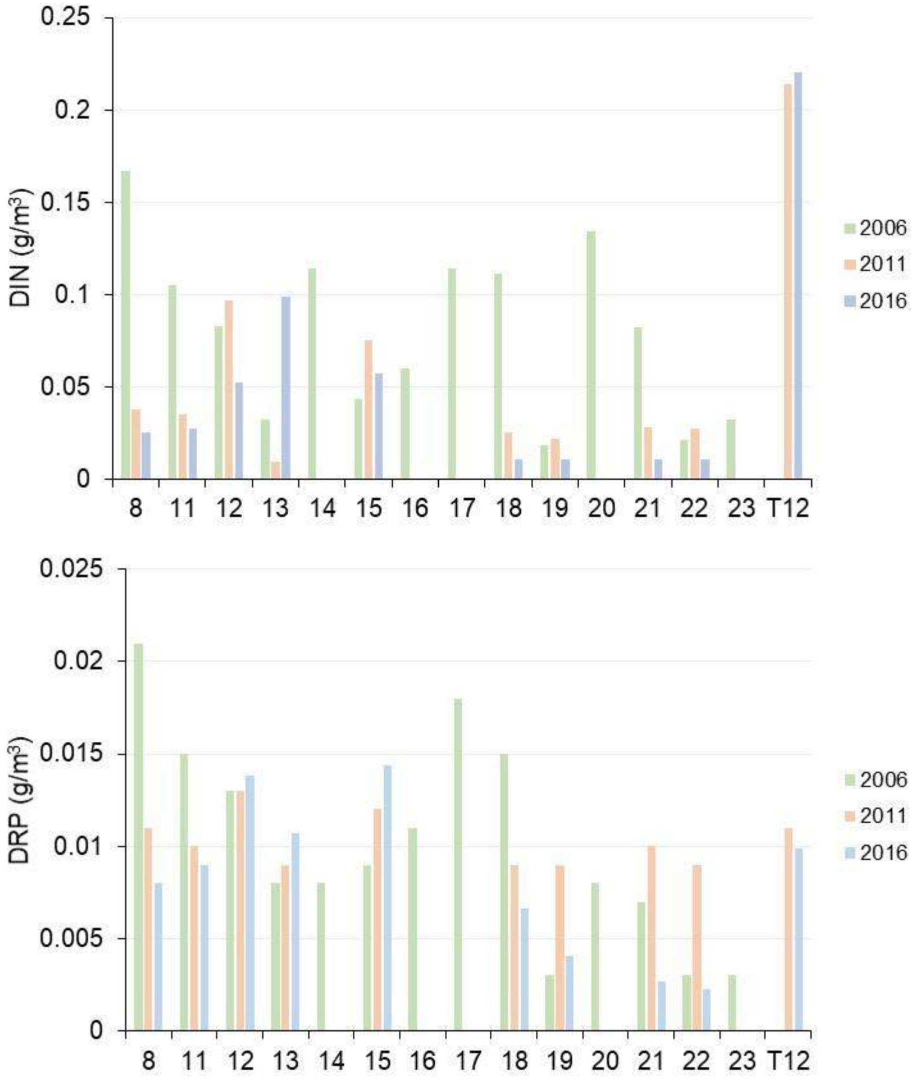

Figure 19. Concentrations of dissolved inorganic nitrogen (DIN) and dissolved reactive nitrogen (DRP) in water samples collected at 15 sites in the Waimea Inlet and inner Tasman Bay.

[18] Nitrogen is relatively more limiting for plant growth.

Concentrations of total nitrogen (organic and inorganic species) were higher in the 2006 survey than in the 2011 and 2016 surveys at most sites and did not exceed 0.41 g/m^3 (Figure 20). In contrast, concentrations of total phosphorus were higher in the 2011 survey than in the other two surveys. The maximum concentration of total phosphorus was 0.06 g/m^3 (Figure 20). Concentrations of these nutrient species were again in the lower range of those detected at Bell Island WWTP discharge (TN: 0.73–0.18 g/m^3; TP: 0.11–0.016 g/m^3) and much lower than typical concentrations found in soils receiving biosolids applications (TN: 5–35 g/m^3; TP: 2–6 g/m^3: Table 1).

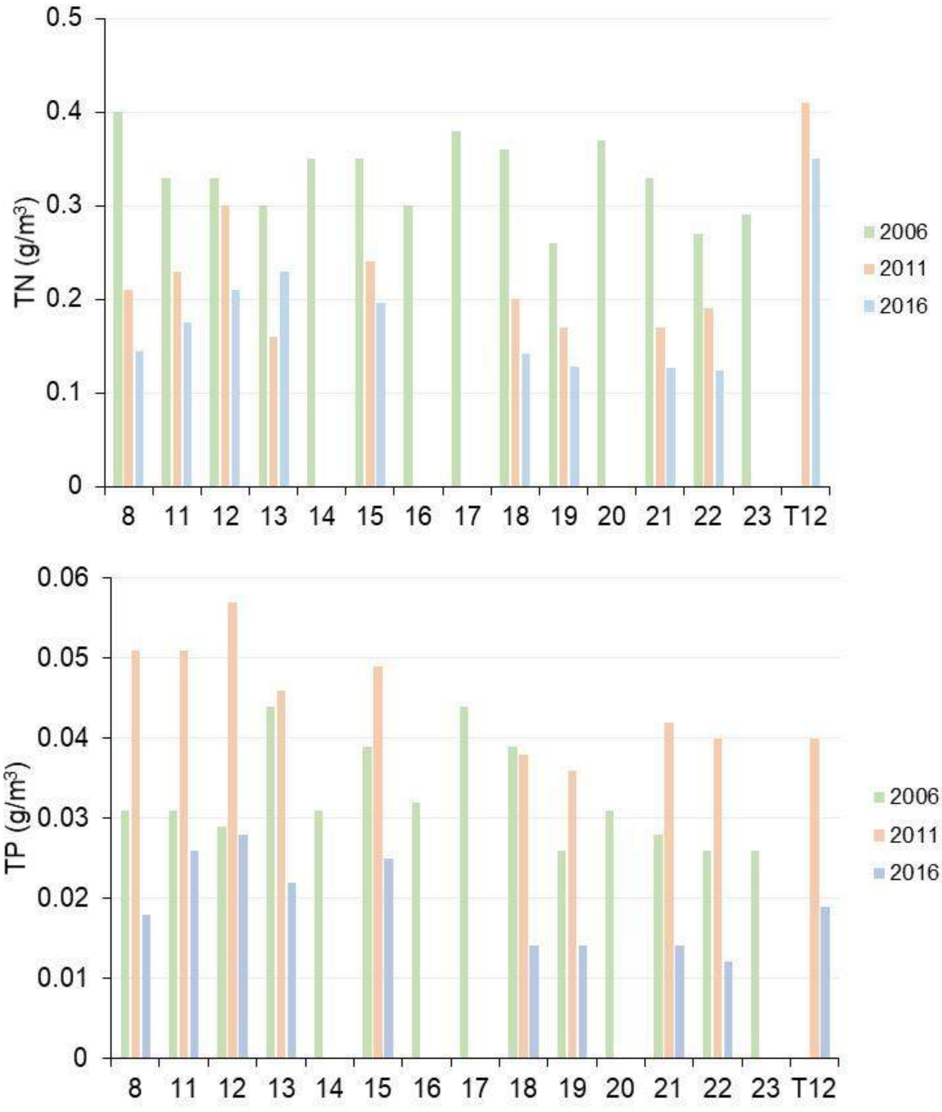

Figure 20. Concentrations of total nitrogen (TN) and total phosphorus (TP) in water samples collected at 15 sites in the Waimea Inlet and inner Tasman Bay.

In summary, these nutrient concentrations do not suggest an effect of biosolids application and are below those that would be expected to occur in estuaries with high frequency of phytoplankton blooms or persistent, very high percentage of benthic macroalgal growths (Plew et al. 2020). Most parts of the Waimea Inlet experience strong tidal flushing and short water retention times, which mitigate the risk of nutrient enrichment. Gillespie and Berthelsen (2017) reported that these concentrations are characteristic of waters in the low-mesotrophic status, although with a moderate-to-high vulnerability for enrichment effects to occur. Stevens and Robertson (2010) concluded that areal nitrogen loading to the Inlet (30 $mg/m^2/day$) is consistent with an unenriched state and is 'below the range where nuisance macroalgal conditions in NZ tidally dominated estuaries generally begin to appear'.

6. ASSESSMENT OF ECOLOGICAL EFFECTS ON WAIMEA INLET

6.1. Values of affected species and habitats

The receptors most likely to be affected (by contaminants transported from biosolids application areas via groundwater and surface runoff) are the adjacent intertidal areas and the communities of organisms living in them. These do not contain any organisms of special ecological or conservation value, but they do provide food for fish and birds, some of which are listed as Threatened or At Risk. The area potentially affected (c. 37 ha[19]) is small relative to the total intertidal area available to fish and birds in Waimea Inlet (3,307 ha). Melville and Schuckard (2013) identified breeding and roosting sites of international importance to species of oystercatchers, gulls and terns off the western and eastern ends of Moturoa / Rabbit Island. None of these are on or adjacent to the southern shore of the island. One site is at the northeastern tip of the island (i.e. upstream of the direction of groundwater flow), and all the others are separated from the island by the main low-tide channels of the Inlet. Based on these factors, the value of the potentially affected area is considered **moderate**.

Waimea Inlet as a whole is considered to be of **high** value for the features described in Section 2.1, notably the diversity of habitats including those that support Threatened and At Risk species.

6.2. Effects of organic material and nutrients derived from biosolids

The intertidal monitoring to date has shown no symptoms of organic enrichment (e.g. sediment anoxia and presence of hydrogen sulphide) at most transects. Macro- and microalgae were present on seven transects including reference transects, which suggests that their presence is not a response to enrichment from biosolids application. Spatial and temporal differences in organic matter and TN content in sediments among transects reflect differences in sediment texture, and there have been no patterns that would suggest an effect of biosolids application. Rather, the increases in mud and organic matter at some transects is likely to reflect the generally increasing muddiness of Waimea Inlet over time, identified from state-of-the-environment monitoring.

The contribution of nutrients from biosolids carried by surface runoff during heavy rain events is expected to be small given the sandy nature of the soil, the generally flat topography and the consent condition that proscribes spraying of biosolids beyond

[19] Based on the median transect length of 40 m, representing the width of the intertidal zone, and the length of shore from Transect 1 to Transect 12 (9.2 km).

15 m in (i.e. landward) from the edge of the forest or 50 m landward of mean high water of spring tides, whichever is the greater.

Based on groundwater monitoring and modelling, the estimated potential concentration of 18 g/m^3 of nitrate-N in groundwater at the point of discharge into the coastal environment suggests a biosolids contribution of approximately 3% and 0.8%, respectively, to the reported mean annual cumulative nitrogen loads to Waimea Inlet and Tasman Bay from their catchments (see Section 5.1). Modelled nitrate concentrations in groundwater suggest that this source contributes < 0.2% to measured concentrations of DIN at reference sites in Waimea Inlet (see Section 5.2). As concluded in Section 5.3, nutrient concentrations in the waters of Waimea Inlet do not exhibit an effect of biosolids application and are below levels that would be expected to occur in estuaries with high frequency of phytoplankton blooms or problematic benthic algal growths. Most parts of Waimea Inlet experience strong tidal flushing and short water retention times, which mitigate the risk of nutrient enrichment.

Although the discharge of some organic matter and nitrogenous compounds to Waimea Inlet from biosolids application is of moderate likelihood, the rate and load are likely to be small, both in absolute terms and relative to other inputs to the Inlet and the magnitude of effect is therefore expected to be low / minor. Consistent with these expectations, there is no evidence of accumulation of organic matter and nitrogen adjacent to application areas, relative to the general increase in muddiness and associated organic matter over time throughout Waimea Inlet. The spatial scale of potential effects is medium (hundreds of metres) in the case of effects on the intertidal area adjacent to application areas but large (kilometres) in terms of effects on Waimea Inlet. Any enrichment that might occur will persist for the duration of the application programme to particular areas but will then be degraded by microbial activity in the sediments and water column. Consequently, the risk of adverse effects from cumulative nutrient enrichment of intertidal sediments and the wider Waimea Inlet due to future application of biosolids (at amounts not higher than historic rates) is likely to be **less than minor** (Section 6.5).

6.3. Effects of toxic contaminants derived from biosolids

As discussed in Section 4.3.3, concentrations of arsenic decreased over time at all monitoring transects. In contrast, concentrations of copper, nickel and zinc increased at some or all transects. However, for all three metals this pattern was evident at reference transects T10, T11 and T12 in addition to transects adjacent to application areas. In fact, concentrations at the reference transects were higher than at several of the others. Differences in concentrations of chromium, lead and mercury have been inconsistent over time. This suggests that the application of biosolids to land on Moturoa / Rabbit Island has not resulted in the accumulation of arsenic or any of the monitored trace metals in intertidal sediments as a result of the seepage of contaminated groundwater.

Infaunal monitoring surveys to date (2008, 2014 and 2019) have found no evidence of any detrimental effect of the biosolids programme on infaunal communities at the study transects (Section 4.3.4). This is consistent with the lack of evidence of the accumulation of arsenic and trace metals in sediments around intertidal seepages of groundwater. As noted in Section 4.3.3, concentrations of arsenic and trace metals, with the exception of chromium and nickel, have been below guidelines for the protection of aquatic life. Concentrations of chromium and nickel are naturally high in Waimea Inlet, and the composition of infaunal communities throughout the Inlet presumably reflects this.

Although there is no evidence of accumulation of arsenic or metals in sediments, or of any difference in the infauna from before to after the start of biosolids application, or between application and reference areas, it is possible that dissolved contaminants could be acutely toxic at groundwater seeps. Acute toxicity is more relevant in the present situation where organisms may occasionally be exposed to high concentrations of contaminants in groundwater seepage in the short period before the groundwater is greatly diluted by mixing with overlying water.

The absence of differences in the fauna between application and reference sites suggests that acute toxicity is not having adverse effects, but as an additional assessment of this risk we have compared concentrations of dissolved toxicants in groundwater with ANZG (2018) water-quality guidelines (Table 5). Concentration 95%ile values for several of the trace metals exceeded the guideline, by factors ranging from 2.3 (zinc) to 11 (chromium and lead)[20]. This suggests that groundwater could potentially exhibit periodic toxicity. However, it is important to note that this assessment is very conservative because the ANZG and US EPA guidelines protect against chronic toxicity rather than acute (for which the guidelines would be higher). Furthermore, no allowance has been made for reduction in concentrations as groundwater travels from bore hole to the intertidal area as a result, for example, of adsorption to soil particles and suspended particulate matter. The fact that none of the median values exceeded the guidelines reassures that any toxic effects are likely to be infrequent if they occur at all. Furthermore, concentrations in groundwater measured in 1995 (Thorpe 1995, shown in Table 5), prior to the start of biosolids application, were similar to the median values after application began, indicating that additional inputs from biosolids are relatively small.

As noted in Section 5.3, ammonia / ammonium acts as a nutrient at low concentrations but is toxic at high concentrations (the degree of toxicity is dependent

[20] Where values were less than the analytical limit of detection (LoD) they were substituted by the value of the LoD to allow calculation of percentiles. This will tend to inflate the percentile values, making comparison with water-quality guidelines more conservative. Cadmium was omitted because the data were unreliable.

on salinity and pH). Concentrations of ammonia / ammonium in groundwater were well below the guideline for protection of aquatic life (Table 5).

Table 5. Summary statistics (5, 50 and 95 percentiles) for concentrations of dissolved toxicants (arsenic, trace metals and ammonia) in water samples taken from Moturoa / Rabbit Island bore holes between 1996 and 2020. ANZG (2018) guideline concentrations for the protection of aquatic life in 'slightly to moderately disturbed systems' are shown for trace metals and ammonia (at the median pH of bore water samples, 7.33). The US EPA's *National Recommended Water Quality Criteria – Aquatic Life Criteria*[21] chronic toxicity guideline is shown for arsenic because the ANZG (2018) guideline is a low-reliability, interim value. Grey cells indicate exceedance of the guideline. The final column shows the range of concentrations measured in groundwater prior to the start of biosolids application. All values are g/m^3. Data provided by NRSBU and from Thorpe (1995).

	5%ile	Median	95%ile	ANZG 95%	Pre-application
Arsenic	0.0003	0.002	0.013	0.036	< 0.002
Chromium	0.0001	0.001	0.05	0.0044	< 0.0005
Copper	0.0003	0.001	0.01	0.0013	< 0.0005–0.0031
Lead	0.0001	0.0032	0.05	0.0044	0.0004–0.005
Mercury	0.00005	0.0001	0.001	0.0001	Not measured
Nickel	0.0005	0.0038	0.05	0.007	0.009–0.01
Zinc	0.0011	0.005	0.034	0.015	0.027–0.068
Ammonia	0.005	0.01	0.146	2.84	Not measured

The contribution of surface runoff during heavy rain events to inputs of toxicants to the receiving environment is expected to be small given the sandy nature of the soil, the flat topography of Moturoa / Rabbit Island and the consent condition that prescribes spraying of biosolids beyond 15 m in (i.e. landward) from the edge of the forest or 50 m landward of mean high water of spring tides, whichever is the greater.

Based on the considerations above, we consider that although the likelihood of some input of toxic contaminants derived from biosolids to the Inlet is moderate, the magnitude of adverse effects on intertidal fauna living in the sediments from future application of biosolids is likely to be low / minor for both chronic and acute effects. The spatial scale is medium (hundreds of metres) in the case of effects on the intertidal area adjacent to application areas but large in terms of effects on Waimea Inlet. Arsenic and trace metals will persist on the receiving environment beyond the duration of the application programme but once activities cease ammonia will be

[21] US EPA (https://www.epa.gov/wqc/national-recommended-water-quality-criteria-aquatic-life-criteria-table#table), accessed 13 April 2020.

degraded by microbial action. Consequently, the risk of adverse effects from toxic contaminants on the biota of intertidal sediments and the wider Waimea Inlet due to future application of biosolids (at amounts not higher than historic rates) is likely to be **less than minor** (Section 6.5).

6.4. Effects on shellfish quality

Over the monitoring programme, concentrations of arsenic and nickel in shellfish have consistently (and copper and zinc occasionally) exceeded guidelines for safe human consumption. There is, however, no evidence that these relatively high concentrations are related to the application of biosolids because they occur at both application and reference transects. Arsenic and nickel concentrations appear to be naturally elevated in shellfish in Waimea Inlet (see, for example Morrisey & Webb 2017).

6.5. Risk assessment summary

The approach to risk assessment was based on modifications of those proposed by EIANZ (2015) and Burgman (2005). The levels of risk were derived from the sequential consideration of the following factors (the categories of each factor are shown in Table 7):

- the ecological value of the organisms or habitats affected
- the spatial scale and duration of the effect
- the magnitude, or consequences, of the effect occurring
- the likelihood of the effect occurring.

The level of ecological risk is derived from a combination of the value of the ecological feature and the magnitude of the effect (Table 6).

Table 6. Level of risk of an adverse effect.

		Ecological Value			
		Very high	**High**	**Moderate**	**Low**
Magnitude	High / severe	Significant	Significant	More than minor	Minor
	Moderate / medium	Significant	More than minor	Less than minor	Negligible
	Low / minor	Minor	Less than minor	Less than minor	Negligible
	Negligible	Less than minor	Negligible	Negligible	Negligible

Because potential adverse effects are predicted to be less than minor, no additional mitigation is recommended. Nevertheless, the existing buffer zone to protect the coast should be maintained to minimise the risk of runoff entering the coastal waters during high-rainfall events at the time of biosolids application. The width and position of buffer zones should be reviewed periodically to take account of erosion of the shoreline and increased frequency and intensity of rainfall due to climate change.

For the purposes of this assessment, we have assumed that biosolids application rates, exclusion zones and buffer zones shall remain as at present. From the perspective of ecological effects on the receiving environment of Waimea Inlet, based on monitoring to date we see no reason to change these.

Table 7. Summary of potential ecological effects on the coastal receiving environment of the application of biosolids. Levels of ecological risk are shown before and after mitigation where relevant ('NA' – mitigation not considered necessary). The assessment assumes that application levels of biosolids are consistent with those applied to date.

Potential environmental effect	Ecological feature	Value	Spatial scale of effect	Duration of effect	Magnitude of effect	Likelihood of effect	Level of risk	Mitigation options	Residual risk
Inputs of nutrients and organic matter via groundwater seepage	Biota of intertidal sediments adjacent to application areas	Moderate	Medium	Persistent (duration of activity)	Low / minor (based on monitoring)	Moderate	Less than minor	NA	
	Habitats and biota of wider Waimea Inlet	Very high	Large	Persistent (duration of activity)	Negligible (based on relative load)	Moderate	Less than minor	NA	
Inputs of trace metals and other toxicants via groundwater seepage	Biota of intertidal sediments adjacent to application areas	Moderate	Medium	Persistent (beyond duration of activity)	Low / minor (based on monitoring)	Moderate	Less than minor	NA	
	Habitats and biota of wider Waimea Inlet	Very high	Large	Persistent (beyond duration of activity)	Negligible (based on relative load)	Moderate	Less than minor	NA	
Inputs of nutrients and organic matter via surface runoff	Biota of intertidal sediments adjacent to application areas	Moderate	Medium	Persistent (duration of activity)	Low / minor (based on monitoring)	Moderate	Less than minor	Existing buffer zones	Negligible
	Habitats and biota of wider Waimea Inlet	Very high	Large	Persistent (duration of activity)	Negligible (based on relative load)	Moderate	Less than minor	Existing buffer zones	Negligible
Inputs of trace metals and other toxicants via surface runoff	Biota of intertidal sediments adjacent to application areas	Moderate	Medium	Persistent (beyond duration of activity)	Low / minor (based on monitoring)	Moderate	Less than minor	Existing buffer zones	Negligible
	Habitats and biota of wider Waimea Inlet	Very high	Large	Persistent (beyond duration of activity)	Negligible (based on relative load)	Moderate	Less than minor	Existing buffer zones	Negligible

Definition of terms used in table:

Spatial scale of effect:	Small (tens of metres), Medium (hundreds of metres), Large (> 1 km)
Duration of effect:	Short (days to weeks), Moderate (weeks to months), Persistent (years or more)
Magnitude of effect:	Negligible (no or very slight change from existing conditions), Low / Minor (minor change from existing conditions, minor effect on population or range of the feature), Moderate / Medium (loss or alteration to key element(s) of existing conditions, moderate effect on population or range of the feature) , High / Severe (major or total loss of key element(s) of existing conditions, large effect on population or range of the feature)
Likelihood of effect:	Low (< 25%), Moderate (25–75%), High (> 75%)
Level of risk:	Negligible (effect too small to be discernible or of concern), Less than Minor (discernible effect but too small to affect others), Minor (noticeable but will not cause any significant adverse effects), More than Minor (noticeable that may cause adverse impact but could be mitigated), Significant (noticeable and will have serious adverse impact but could be mitigated)

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8. APPENDICES

Appendix 1. Sediment grain size distributions and organic-matter content at Moturoa / Rabbit Island transects in 2008, 2014 and 2019. Imagery sourced from LINZ Data Service (Campos et al. 2020).

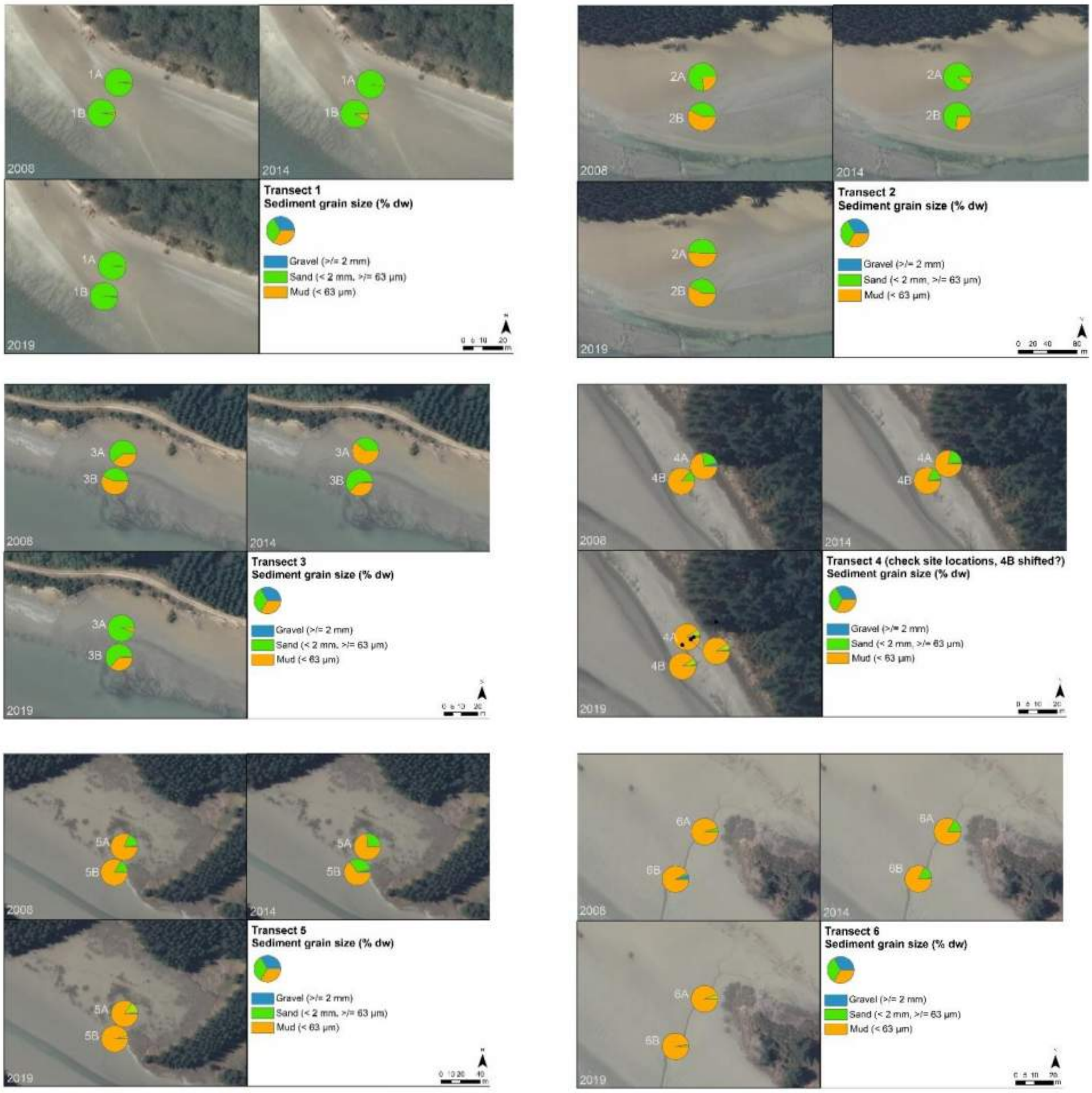

Figure A1.1. Sediment grain size distributions at transects 1–6 in 2008, 2014 and 2019. Imagery sourced from LINZ Data Service.

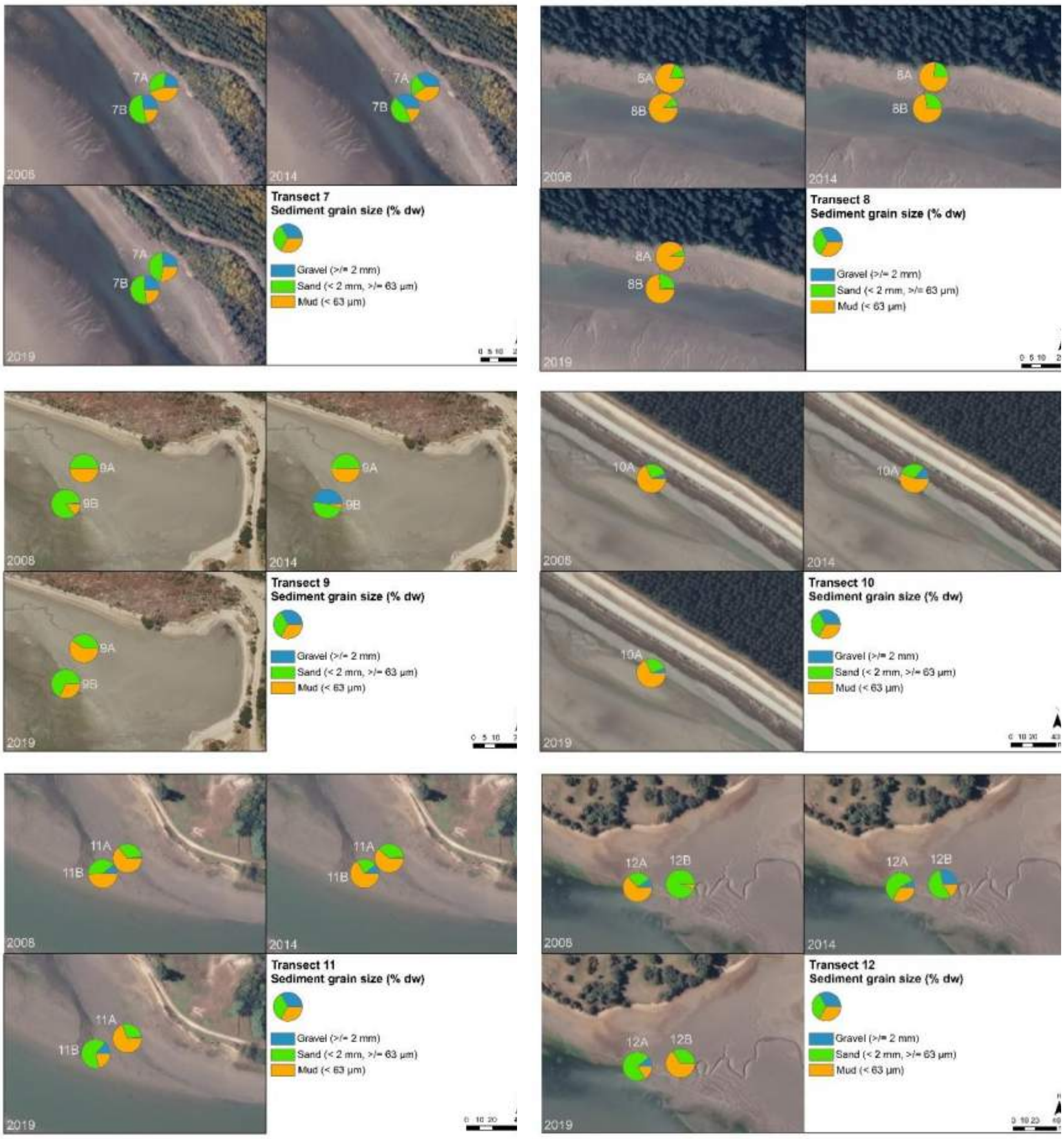

Figure A1.2. Sediment grain size distributions at transects 7–12 in 2008, 2014 and 2019. Imagery sourced from LINZ Data Service.

Figure A1.3. Concentration of organic matter (as ash free dry weight) at transects 1–4. Imagery sourced from LINZ Data Service. Site IDs and results of the 2019 survey are shown next to the bar charts.

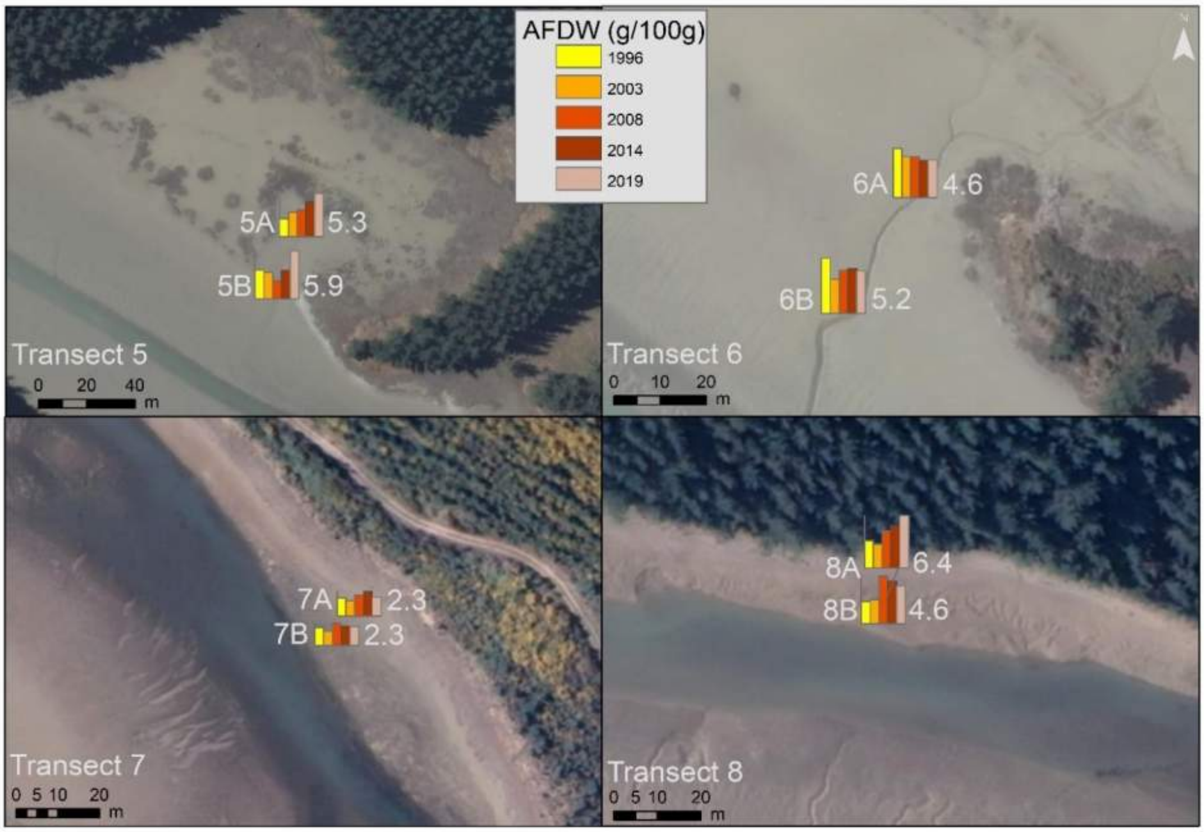

Figure A1.4. Concentration of organic matter (as ash free dry weight) at transects 5–8. Imagery sourced from LINZ Data Service. Site IDs and results of the 2019 survey are shown next to the bar charts.

Figure A1.5. Concentration of organic matter (as ash free dry weight) at transects 9–12. Imagery sourced from LINZ Data Service. Site IDs and results of the 2019 survey are shown next to the bar charts.

Appendix 2. Sediment total-nitrogen content at Moturoa / Rabbit Island transects in 2008, 2014 and 2019. TN represents all forms of nitrogen present while total Kjeldahl nitrogen (TKN) also approximates total nitrogen but is methodologically defined (and largely superseded by TN). Imagery sourced from LINZ Data Service (Campos et al. 2020).

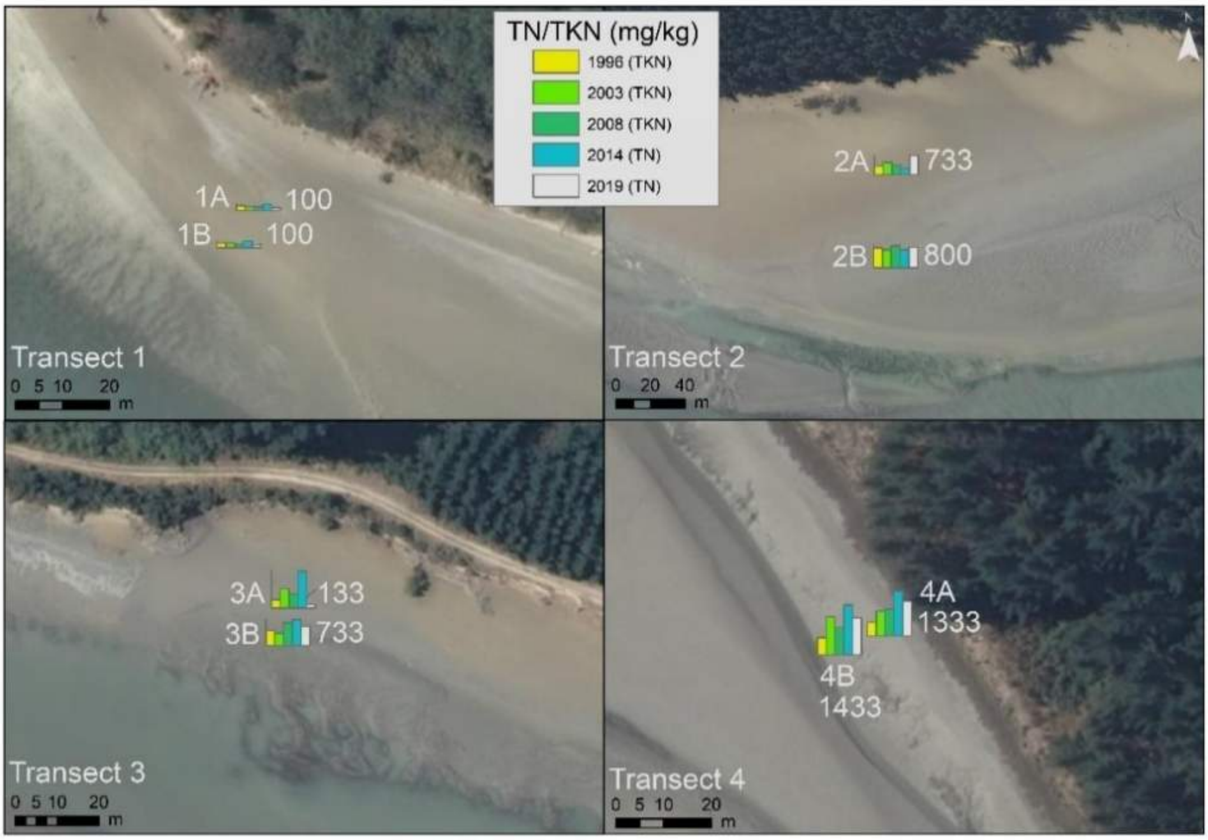

Figure A2.1. Concentrations of total nitrogen in sediment samples collected in five surveys at transects 1–4. Imagery sourced from LINZ Data Service. Site IDs and results of the 2019 survey are shown next to the bar charts.

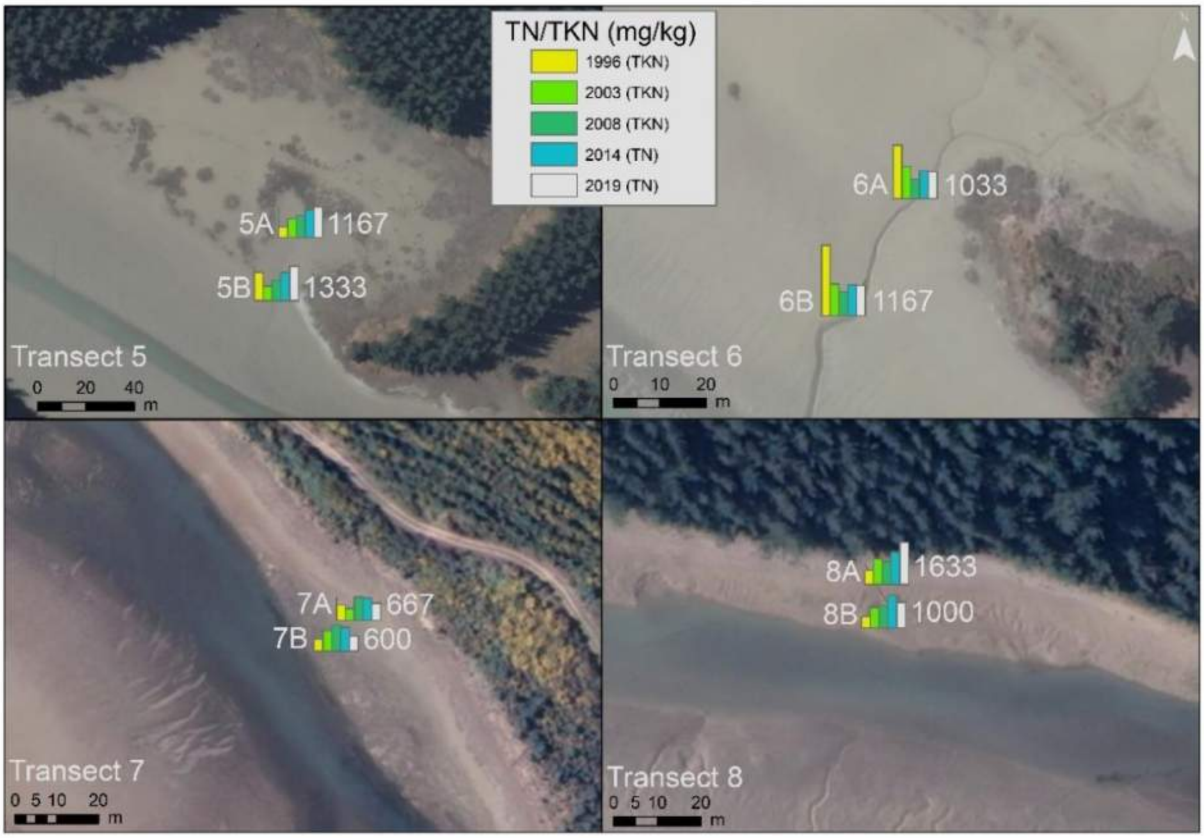

Figure A2.2. Concentrations of total nitrogen in sediment samples collected in five surveys at transects 5–8. Imagery sourced from LINZ Data Service. Site IDs and results of the 2019 survey are shown next to the bar charts.

Figure A2.3. Concentrations of total nitrogen in sediment samples collected in five surveys at transects 9–12. Imagery sourced from LINZ Data Service. Site IDs and results of the 2019 survey are shown next to the bar charts.