Agenda Memorandum

Date 27 November 2014

Memorandum to
Chairperson and Members
Policy and Planning Committee

Subject: Biological response of earthworms and soil microbes associated with drilling mud wastes in the Taranaki region

Item: 6

Approved by: G K Bedford, Director – Environment Quality

B G Chamberlain, Chief Executive

Document: 1428060

Purpose

The purpose of this memorandum is to introduce a report entitled *Biological response of earthworms and soil microbes associated with drilling mud wastes in the Taranaki region* prepared for the Council by Landcare Research.

The Executive Summary of the report is attached. The full report (which went through Landcare research's internal quality review process) will be made available on the Council's website.

The study reported herein addresses specifically the suitability of the consent conditions imposed by the Council on land application activities. However, the fundamental question raised by critics is that any land application at all should be stopped because of perceived issues around toxicity. The study is therefore being reported today to this Committee, as a matter of policy and practice.

Executive Summary

The Council has implemented and reported annual compliance monitoring programmes at sites being used for the land application of hydrocarbon sector wastes since the first consent was exercised (about 2002). Initially monitoring was based on a regime of inspections and physico-chemical analysis of wastes and soils (pre and post application). Consent conditions for initial loadings and for the surrender criteria were based on established guidelines (both New Zealand and Canadian).

The Council then extended its analytical regime to include ecological-based monitoring at each site, using a number of soil species as indicators of soil health during the rehabilitation phase and to confirm recovery of soil health prior to site release. This work showed that environmental effects were subtle at most, and were in all likelihood due in significant part to mechanical disturbance during site preparation, as much as the nature and manner of the wastes applied. A more rigorous ongoing 3-year study was instigated to further ascertain what effects may be occurring throughout the rehabilitation/re-utilisation process, and to evaluate the suitability or otherwise of the criteria the Council was following in its consenting. After two years of the proposed three year study it became apparent that even such a field-based study was not sensitive enough to provide the detailed information sought by the Council.

Therefore the Council commissioned Landcare Research to conduct a laboratory study into the degree and characteristics of any toxicity that might be associated with drilling muds particularly in relation to the hydrocarbon content. Both water-based (WBM) and synthetic-based (SBM) drilling wastes were tested. That study is reported herein.

The key findings are:-
-high levels of salt and hydrocarbons in conjunction, or high levels of salt would cause toxicity to earthworms;
-initial loading rates of hydrocarbons stimulate microbial action, as shown by increase in biomass and soil respiration rates (the hydrocarbons are utilised as an energy source);
-marked reductions occurred in hydrocarbon concentrations (i.e. natural processes of microbial degradation of hydrocarbons were confirmed);
-at the highest hydrocarbon loading rates there appeared to also be an initial stressing of microbial communities, shown by increased carbon dioxide respiration relative to the microbial biomass; this effect reduced with time which suggests adaptation;
-the highest concentrations of salt in the absence of detectable hydrocarbons (i.e. the water based mud sample) showed an indication of some inhibition of some nitrifying bacteria; the same effect was not seen when high concentrations of hydrocarbons were present, suggesting that hydrocarbons may act to enhance microbial activity and to ameliorate any effects of high salt concentrations.

The key interpretation of the study by the Council is that the current application and surrender conditions are validated as more than adequate to respectively serve to maintain natural soil degradation processes and to allow re-establishment of earthworm population; natural degradation of hydrocarbons is confirmed as occurring at land-based treatment sites, and assurance is provided that consent conditions for site release are consistent with those supporting soil health including re-establishment of earthworm populations following any initial disturbance.

The Council's own field observations and those of Dr Edmeades confirm that re-establishment of earthworms and healthy pasture following site disturbance routinely occurs on land treatment sites in Taranaki. The Landcare Research laboratory studies quantify various aspects of this process.

Recommendations

That the Taranaki Regional Council:

1. receives the report entitled *Biological response of earthworms and soil microbes associated with drilling mud wastes in the Taranaki region* and its findings.
2. notes the findings of the report and their implications for the regulatory control and effective utilisation of land-based treatment of hydrocarbon wastes in the region.

Background

The land treatment of hydrocarbon sector wastes involves the application of such wastes to a site that has been carefully chosen and prepared, the application being under conditions that control the depth of application and the concentration of various key constituents. The purpose is to utilise the natural (microbial) activity of the soil to degrade hydrocarbons while gaining the benefit of the clays and muds present in the wastes to enhance soil structure. Typically a prospective land application site consists of a very sandy, wind-blown, unproductive paddock or two that is vegetated by scrub or weeds.

From the first use of such sites in the region, the Council has utilised guidelines from New Zealand and overseas to ensure that natural processes of degradation at each site are safeguarded so that they remain effective. Monitoring initially focused on ensuring that the conditions were being met, on the assumption that the various guidelines had been developed by authoritative and competent agencies, and were appropriate for the activity. In particular, it was noted that guidelines from Alberta were there applied in an environment of very poor quality soils lacking even the little organic material found in the more sandy soils of Taranaki, and a climate that was extremely dry and for several months of the year frozen. Use of these guidelines in the more temperate climate of Taranaki was considered to provide a comprehensive margin of protection.

The Council makes significant use of ecological indicators in its environmental monitoring, alongside physico-chemical analyses (eg fresh water and marine ecological surveys). This approach was adopted for the land treatment sites, to provide extra assurance alongside the pre-existing physico-chemical based approach to compliance and performance.

Studies were conducted by the Council's terrestrial ecologist in 2007/2008. The first site studied was the earliest landfarm established in Taranaki. It was noted that as such, the degree of control of application depth during its use had not been as stringent and closely considered as was the case subsequently. The site has been converted to dairying following its closure and consent compliance. Soil cores were taken across the site and at control locations adjacent to the site, and analysed for the presence of earthworms. At the part of the site that had received the heaviest loading of hydrocarbon wastes, counts of earthworms were found to be the highest. Statistically, no clear differences between the individual treatment locations and control locations surveyed could be found. All individual soil samples except one contained earthworms; the exception contained an earthworm cocoon. Several earthworm species were found across every sample, with no apparent distinction in distribution between control sites and treatment sites. The conclusion of this study was:

> *The fact that three earthworm species were found in samples collected from treatment areas at the GM Symons land farm indicates a reasonable level of ecosystem health – earthworms identified consisted of both useful top soil mixing and deep burrowing species. The existence of all three species in treatment areas also indicates it is unlikely that the spreading of drilling wastes has resulted in any species becoming locally extinct.*
>
> *No significant differences in earthworm abundances were found among any of the areas sampled and no significant differences in earthworm abundance were found between the treatment and control areas. This could indicate one of two things; a) that the spreading of drilling wastes at this site had no effect on earthworm populations, or b) that the spreading of drilling wastes at this site had negative effects on earthworm populations but these have now subsided and earthworm populations recovered.*
>
> *Results of Taranaki Regional Council investigations of earthworm abundances at other coastal land spreading sites in Taranaki have suggested that application of drilling waste has*

a negative impact on earthworm populations, but that earthworm populations slowly recover over time (> 5 years) (report to be published in 2007/2008 monitoring year).

Despite spreading techniques used at this site being far from what would be considered 'best practice' by today's standards, soil ecology at the Symons land farm seems to have fully recovered to levels equivalent to what would be expected if no drilling wastes had been applied. This indicates that Taranaki land spreading sites operating under the current more comprehensive and conservative suite of consent conditions are likely to provide adequate protection for soil biota in the medium – long term at least. Further research is recommended into the effects of land farming on soil biota, particularly to determine recovery times and mechanisms by which drilling waste application may affect worm population at Taranaki land farm sites.

The second study of this nature (which was the 2007/2008 report referenced in the third paragraph above) extended across three other land treatment sites. Wastes had been applied from four years prior to the study, up to just prior. The results showed that treatment sites which had received the earliest treatments showed the greatest counts of earthworms, which were however still somewhat lower than the control sites; the most recently used site showed no earthworms. No correlation was found between conductivity (a marker of salt concentrations in soil) and earthworm density, but it should be noted in the light of matters covered later in this memo, that conductivities (and hence salt concentrations) were relatively low. The report noted that:

Mixing and tillage of soil could result in fewer earthworms through physical damage to individuals and burrows as well as increased exposure to predators. Other studies in New Zealand and overseas have shown that tillage can have negative effects on earthworm populations (Chan 2001).

In respect of both vegetation and soil, the study noted that *all treatment and control areas attained a moderate to good quality score for both plant performance and soil quality*, other than for one control site.

In 2010/2011 Council officers carried out the first year of a proposed 3-year study involving a large number of soil health and soil community indicators. The study was conducted at two landfarm. Worms were not assessed, but the communities chosen for study included nematodes. It was considered that nematode communities would be less susceptible to mechanical disturbance, and hence a more effective indicator of any possible toxic effects from the application of wastes, than the larger earthworms.

The study found:

Differences in mean nematode abundance between treatment and controls were much greater at the Brown Road landfarm (high chloride and high total petroleum hydrocarbons) than those at the Schrider landfarm (low chloride, low total petroleum hydrocarbons)… Furthermore, all treatment areas at the Brown Road landfarm had lower mean nematode abundances compared with the control area…. However, the large confidence intervals [in the data] *suggest that differences between treatments areas and the control area were not statistically significant.*

The second year of the study, concluding on 30 June 2012, found that again the field-based studies were not sensitive, specific, or definitive enough to identify whether there were any toxic effects. A review of the state of play in May 2012 recommended:

This lack of conclusive results is due to the large number of environmental effects/biases and variation in application methods. In particular, mechanical manipulation and disturbance of soil is a major issue in the landfarming process. During the landfarming process, large amounts of topsoil are stripped and replaced using heavy machinery, and the disturbance and soil compaction this creates may be masking any toxic effects the application of drilling muds may be having on soil biota. Additionally, spatial variability and large differences in soil microclimates even within the same sample plot create large ranges for each of the soil parameters analysed…

The review went on to recommend a change to a laboratory-based study (see next section).

In 2013 the Council commissioned Dr D Edmeades to conduct investigations into the state of soil and pasture at landfarms that had subsequently been brought to use as dairying pasture. The purpose of the study was to determine if the former treatment sites were 'fit for purpose' as pasture. In the course of conducting his studies, Dr Edmeades noted:

Importantly, there were abundant earthworm casts on all sites indicating considerable soil biological activity. The earthworm can be regarded as the 'canary in the mine' with respect to soil biological activity.

The status of the Council's knowledge and experience at this point was that worms (as a sensitive indicator of soil health) showed some impact from the application to land of hydrocarbon wastes; it was unclear whether this was an effect of the mechanical disturbance of the soil or was due to a constituent or constituents within the wastes themselves. Field-based studies were not proving sensitive enough to take this question further. Further, the Council wished to have verification that the limits it imposed on consents, drawing on current criteria from both New Zealand and overseas, were demonstrably relevant to the Taranaki environs.

The Landcare Research study and discussion

Therefore the Council commissioned Landcare Research to conduct a laboratory study into the degree and characteristics of any toxicity that might be associated with drilling muds with differing hydrocarbon concentrations. Both water-based (WBM) and synthetic-based (SBM) drilling wastes were tested. That study is reported herein.

The two types of drilling muds were provided to Landcare Research, along with soil samples from locations used for land application (but to which no drilling muds had been applied). The samples were used in toxicity studies, including with drilling mud/soil mixtures that had been aged for 6 months. The objective of the study was to assess the biological response of earthworms and the indigenous soil microbial population, as key indicators of soil ecological health, to the drilling muds typically used in Taranaki.

The characteristics of the two mud types is shown in the table below, along with current Council consent conditions as applied at time of initial discharge and at time of proposed surrender of consent and relinquishment of the site. By its nature, SBM mud has both a very high hydrocarbon content and high chloride concentration, while WBM are typically very low in hydrocarbons but are still very high in chloride.

Analyte	SBM (High-TPH)	WBM (Low-TPH)	Consent conditions-initial	Consent conditions-surrender	Typical at time of surrender
Chloride mg/kg	36,000	22,000	(960)*	700	

C7-C9	1,410	<80		120	<8 - <11
C10-C14	300,000	220		58	<20 - <30
C15-C36	490,000	690		4,000	<40 - 187
TPH	790,000	920	20,000		

TPH = total petroleum hydrocarbons
(960)* = approx, based on comparative conductivity limit
Cm-Cn = various fractions of hydrocarbons; as 'm' and 'n' increase, the hydrocarbons become progressively heavier and thicker.

Various blends of soil and the drilling muds were prepared, and tested for various measures of toxicity. The most concentrated SBM blend comprised 30% SBM muds; this represented a TPH of over 26,000 mg/kg TPH and 12,000 mg/kg chloride. The most concentrated WBM blend comprised 20% WBM: this represented a chloride concentration of about 4,400 mg/kg.

Toxicity to worms was tested on samples after initial preparation and again after 6 months; critically, the samples were not exposed to the natural environment during that period and so chloride concentrations remained unchanged. Under natural conditions there is a rapid and significant reduction in the concentrations of salts after initial application.

Results- earthworms

It was found that significant mortality to earthworms occurred at TPH concentrations of 23,000 mg/kg or chloride concentrations of 4,900 mg/kg. Increased survival was obvious at a chloride concentration of 2,300 mg/kg, and no mortality at 1,800 mg/kg. It can be noted that this represents a concentration more than 3 times higher than the concentration the Council will accept at the time of consent surrender.

The study's authors noted other studies that reported toxic effects on earthworms at concentrations ranging from 2,400 to 8,000 mg/kg.

The study found toxic effects upon earthworms at 23,000 mg/kg TPH when the chloride concentration was 2,700mg/kg; at this chloride concentration, some survival might have been expected and so it was considered that TPH of the concentration reported were having some degree of adverse effect. The author conducted a literature review of other studies and drew the conclusion that 5,000 mg/kg TPH appeared to be a qualitative upper limit for full protection of earthworms, although it may vary if lighter (ie the more toxic) fractions of TPH were predominant.

Results-microbial response

Addition of high-TPH muds with higher concentrations of hydrocarbons led to progressive increase in microbial biomass. That is, the soil microbes were clearly utilising the hydrocarbons as a carbon source for growth (and thereby degrading the hydrocarbons in the process). There was a linear correlation between increasing hydrocarbon addition and increasing biomass growth.

Similarly, there was an increase in basal respiration rates that was clearly related to the amount of hydrocarbons that were added and the increase in biomass in each sample.

However, the most concentrated soil-muds mix for the low-hydrocarbon muds showed a reduction of biomass by comparison with the controls, indicating a degree of inhibition occurred in the absence of higher hydrocarbons. Analysis of the measurements of basal respiration and biomass indicated that there was an element of microbial stress within the most concentrated soil-muds mixtures for the low-hydrocarbon muds. Measurement of nitrate and ammonia present at various stages during the study also indicated that there is a component of the WBM that may inhibit biological nitrification. A literature study identified that chloride can cause such inhibition, and concentrations in the various soil-mud mixtures were well above the reported threshold at which this can occur. The effect remained for some time in the WBM soil-mud mixtures, but disappeared quickly from the SBM-soils mixtures, suggesting that if there was any inhibitory effect in the SBM-soil mixtures it was transitory- either nitrification was quickly re-established, or the ammonia was being assimilated by the increasing biomass.

TPH were found to be quickly degraded during the course of the experiments. In particular, the lighter (and more ecotoxic) fractions were removed more quickly than the heavier, more persistent but less ecotoxic fractions. Two typical results are provided below, for soil-mud mixtures respectively initially within and much more concentrated than allowed by resource consent conditions. Quantitative and percentage reductions are shown.

Carbon fraction	'7.5% SBM' mix -mg/kg -percent reduction		'15% SBM' mix -mg/kg -percent reduction	
	Day 0	Day 56	Day 0	Day 56
C7-C9	10	<9	45	<9 >80%
C10-C14	3,300	250 92%	10,600	2,600 75%
C15-C36	5,000	1,400 72%	16,600	8,200 51%
TPH	8,300	1,650 80%	27,000	10,800 60%

The report includes four recommendations relating to scope for further studies. These focus on exploring what other components of salt might also be contributing to earthworm toxicity (eg besides chloride, could the concentrations of sodium, potassium, and /or calcium be having an effect?); field testing to establish real-world concentrations at differing times after application; refining the no-effects thresholds for salt and TPH at real world concentrations; and further studies of the degree and drivers of inhibition of nitrification.

Officers will review the value of these recommendations for resource management purposes. However, it is noted in the first instance that the primary objectives of the study have been achieved.

Interpretation and conclusions

The study involved exposure of various soil communities, including worms and microbes, to concentrations of hydrocarbons and chloride at various concentrations including those that were well above those currently permitted by the Council through its resource consents.

Effective natural bio-degradation of hydrocarbons was demonstrated.

Up to the highest concentrations of SBM-soil mixtures tested, microbial respiratory activity and biomass increased with increasing TPH, the biomass demonstrably utilising the hydrocarbons as an energy source. At the highest mud concentrations tested (well above consented concentrations for both application and surrender scenarios), some inhibition of some microbial activity was apparent- of very short duration in the case of SBM, and of somewhat longer duration in the case of WBM.

The higher concentrations of chloride may have led to inhibition of nitrification (the natural process of converting ammonium to nitrate). The concentrations in question were higher than those permitted by consent conditions (in both application and surrender scenarios). (In passing, it may be noted that inhibition of nitrification is desirable to reduce loss of nutrients from pasture).

The various inhibitory and ecotoxic effects noted were consistent with those noted in the literature for chloride and for total hydrocarbons at the concentrations in question. That is, there is no evidence for other inhibitory substances; however, given the design of the trial, such a possibility cannot be excluded.

The 'surrender' conditions imposed by the Council are shown to be more than adequate to ensure healthy soil ecology can be established following site restoration to pasture, in terms of the thresholds found in these trials and in literature for inhibitory effects arising from chloride and hydrocarbons.

The Council's own field observations and those of Dr Edmeades confirm that re-establishment of earthworms and healthy pasture following site disturbance routinely occurs on land treatment sites in Taranaki. The Landcare Research laboratory studies quantify various aspects of this process.

Decision-making considerations

Part 6 (Planning, decision-making and accountability) of the Local Government Act 2002 has been considered and documented in the preparation of this agenda item. The recommendations made in this item comply with the decision-making obligations of the Act.

Financial considerations—LTP/Annual Plan

This memorandum and the associated recommendations are consistent with the Council's adopted Long-Term Plan and estimates. Any financial information included in this memorandum has been prepared in accordance with generally accepted accounting practice.

Policy considerations

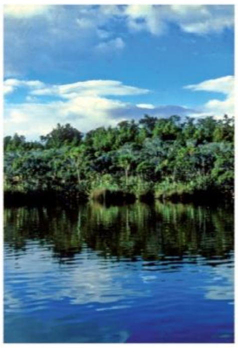
This memorandum and the associated recommendations are consistent with the policy documents and positions adopted by this Council under various legislative frameworks including, but not restricted to, the Local Government Act 2002, the Resource Management Act 1991 and the Biosecurity Act 1993.

Legal considerations

This memorandum and the associated recommendations comply with the appropriate statutory requirements imposed upon the Council.

Attachment

Document: 1428092 Summary from *Biological response of earthworms and soil microbes associated with drilling mud wastes in the Taranaki Region* (Landcare research September 2014

Biological response of earthworms and soil microbes associated with drilling mud wastes in the Taranaki Region





Landcare Research
Manaaki Whenua

Biological response of earthworms and soil microbes associated with drilling mud wastes in the Taranaki Region

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Contents

Summary

Project and Client

Taranaki Regional Council commissioned Landcare Research to conduct laboratory-based research into the potential for ecological effects in soil that might arise from incorporation of drilling wastes into land (‘landfarming’). To provide this assessment, Landcare Research assessed the biological response of earthworms and the soil microbial community to selected drilling muds. Both water-based muds (WBM) and synthetic-based muds (SBM) were tested. The research was conducted from October 2013 to May 2014.

Methods

Two drilling muds were provided by drilling companies for testing. One mud was a synthetic-based drilling mud (SBM) from a deep well (4000 m), and had high concentrations of total petroleum hydrocarbons (TPH) and chloride. The other mud was a water-based mud (WBM) from the first stage of a well-drilling operation (at 40 m depth) and had low hydrocarbon concentrations but high chloride concentrations.

TPH was anticipated to be the primary contaminant of concern and the high- and low-TPH drilling muds were mixed at various ratios. This kept the total drilling mud content of the soil at a nominal 30% dry weight, while allowing the TPH content to be varied. Some testing was also undertaken using the individual muds.

Earthworm testing was conducted following Organisation for Economic Co-operation and Development (OECD) protocols using artificial soil combined with mixtures of low- and high-TPH muds over a range of TPH concentrations. The aging process used (storage in unsealed plastic containers at ambient temperature with moisture content maintained) was not intended to simulate all degradation or loss pathways present in the field.

Microbial testing was undertaken using soils collected from an inland site and a coastal site that were representative of soil types to which drilling muds were being applied. Drilling mud mixtures were added to sieved well-mixed soils and microbial biomass (MBC), basal respiration, and soil ammonium (NH_4^+) and nitrate NO_3^-) concentrations measured at various time points up to 56 days.

Main findings

Earthworm testing resulted in significant mortality to earthworms within 24 h during initial testing, and testing undertaken on 6-month aged soil. Further testing of the individual muds suggests that salts, as indicated by chloride concentration, and hydrocarbons, measured as TPH, appear to be the primary components causing toxicity to earthworms at the mud concentrations tested. TPH appeared to stimulate microbial activity as reflected by an increase in microbial biomass and basal respiration over time with increasing TPH concentration. The most pronounced effects occurred in the coastal soil. Marked decreases in TPH concentrations over 56 days were observed in both the coastal and inland soil treatments.

However, the addition of drilling muds also appeared to initially stress the soil microbial community relative to the control, as indicated by elevated qCO_2 (basal respiration per unit microbial biomass) although this effect tended to reduce over the 56 days, suggesting adaptation of the soil microbial community. The microbial population in the inland soil appeared more able to assimilate the drilling muds with lower qCO_2 over the 56 days.

The addition of low-TPH (WBM) mud only appeared to inhibit nitrification in the coastal and inland soils, with the most pronounced effects observed in the inland soil. A literature review indicated this effect could be due to the chloride concentration, but an additional contribution to inhibition from another contaminant cannot be excluded. The same effect was not observed in treatments to which the high-TPH (SBM) mud was added, suggesting that TPH may ameliorate this effect, likely through enhanced microbial growth associated with TPH degradation.

Recommendations

Based on the findings, the following recommendations are made for further study to clarify the potential effects of drilling muds on earthworms and the soil microbial community:

- Further testing is required to ascertain the concentration of common salt components, other than chloride, that may have contributed to earthworm toxicity (e.g. sodium, potassium, and calcium cations).
- Results of field testing at depth intervals (e.g. above and below the depth of drilling mud application) immediately after application of the drilling muds should be used to establish the typical salt and TPH concentrations present after application, and at time intervals (e.g. 3, 6 and 12 months) after application.
- Further earthworm testing at lower concentrations of drilling mud would be required to determine the salt and TPH concentrations at which effects are not observed, and whether any other components may be contributing to toxicity. This testing should encompass salt and TPH concentrations observed after field application.
- Further testing, including of drilling mud waste that is being applied to land (i.e. mixtures of different drilling muds), should be undertaken to establish if nitrification inhibition is a common response of the microbial population to drilling mud application, and if so whether this relates solely to chloride concentrations or whether other components are contributing to the observed response.

1 Introduction

Land farming of onshore drilling wastes is undertaken in the Taranaki Region. Land farming is a practice whereby drilling mud waste is applied to land to facilitate bioremediation of petroleum hydrocarbons contained within the drilling muds. Application involves the initial storage of drilling mud waste in an open pond until sufficient waste is accumulated for application to land. Conventional land application typically occurs in coastal areas and entails the removal of the approximately top 150 mm of soil prior to the application of drilling mud. The drilling mud waste is then spread in a 50–150 mm layer (the depth depending upon the TPH concentration) and cultivated into the substrate prior to the topsoil being replaced and subsequently cultivated. Some application has also occurred on inland volcanic soil where drilling mud waste is typically applied to the surface prior to subsequent cultivation and growing of pasture. While some field studies have been undertaken to assess the potential environmental effects of landfarming operations, including effects upon various measures of soil ecology (Taranaki Regional Council 2011; Edmeades 2013), few studies have specifically investigated the toxicity of drilling mud waste to soil biota in a systematic and controlled manner.

Taranaki Regional Council therefore commissioned Landcare Research to test selected drilling muds for toxicity to selected soil biota to provide further information as a basis upon which to regulate landfarming activities. The research was conducted from October 2013 to May 2014.

2 Objective

- To assess the biological response of earthworms and the indigenous soil microbial population, as key indicators of soil ecosystem health, to selected drilling muds.

3 Methods

3.1 Drilling muds

Two drilling muds provided by drilling companies were used for testing. As TPH was anticipated to be the primary contaminant of concern, one mud was a synthetic-based drilling mud from a deep well (4000 m), and had high concentrations of total petroleum hydrocarbons (TPH) and chloride (Table 1) and is hereafter referred to as the ***high-TPH mud***. The other mud was a water-based mud from the first stage of a well-drilling activity for a shallow well (40 m) and had low hydrocarbon concentrations (Table 1) and is hereafter referred to as the ***low-TPH mud***. This mud also contained a high concentration of chloride.

The high- and low-TPH drilling muds were mixed together to enable samples of varying TPH content to be prepared while keeping the total content of drilling mud in the soil at a nominal 30% dry weight. A relatively high percentage of mud was used to ensure high TPH concentrations and to simulate waste application and mixing. As the same concentrations were used for testing earthworm and microbial response, the drilling muds were initially mixed and then added to the soils for earthworm and microbial testing. Drilling mud mixtures were prepared on a wet-weight basis at ratios of 1:1, 1:3 and 1:7 high-TPH mud to low-TPH mud to subsequently generate the nominal 15%, 7.5% and 3.75% high-TPH treatments respectively for testing earthworm and microbial response (see sections 3.2 and 3.3).

Table 1 Total petroleum hydrocarbon and chloride content of two drilling muds

Analyte	Todd MHWC SBM (high-TPH mud)	TAG Cheal C WBM (low-TPH mud)
Dry matter (mg/100g)	56	18
Chloride (mg/kg wet wt)[1]	36 000	22 000
Total petroleum hydrocarbon (mg/kg dry wt)		
C7–C9	1410	<80
C10–C14	300 000	220
C15–C36	490 000	690
Total hydrocarbons (C7–C36)	790 000	920

[1] Due to difficulties in analysis, chloride was measured using a Titraclor-C kit used for measuring chloride in oil.

3.2 Earthworm testing

3.2.1 Soil preparation

Artificial soil as per OECD (Organisation for Economic Co-operation and Development) guidelines was prepared and mixed with drilling muds. The high- and low-TPH drilling muds were mixed with soil keeping the total content of drilling mud in the soil at a nominal 30% dry weight, while varying the TPH content. A relatively high percentage of mud was used to ensure high TPH concentrations and to simulate waste application and mixing. These treatments are hereafter referred to as the mud mixture treatments. The starting points were the nominal 30% dry weight of the high-TPH (30% HM treatment) and low-TPH (30% LM treatment) muds. As the concentration of the low-TPH mud in the mixtures increased, the dry weight proportion of the mud decreased, due to the higher moisture content of the low-TPH mud (Table 1). Water was added to provide a moisture content of approximately 70% for every sample; pH was measured but not adjusted. The actual amount of soil and muds added, moisture content and pH for the mud mixture tests are provided in Appendix 1. A summary of the TPH content of the mud mixtures is given in Table 2.

Table 2 Summary of treatment name, nominal and actual percent (based on dry weight) of high- and low-TPH added to test soil for chronic earthworm testing of mud mixtures.

Treatment name	Nominal % high-TPH drilling mud	Nominal % low TPH mud	Actual % high-TPH drilling mud[1]	Actual % low TPH drilling mud[1]
30% HM	30	0	30	0
15% HM	15	15	17	4
7.5% HM	7.5	22.5	9.0	5
3.75% HM	3.75	26.25	4.7	8.3
30% LM	0	30	0	20
Control	0	0	0	0

[1]Calculated using 87% dry matter for high-TPH mud, and 22% dry matter for low-TPH mud. HM = high-TPH and LM = low-TPH mud mixtures.

Soils were prepared and half of each treatment used for immediate testing, and half kept for testing again at 6 months. Soils for testing at 6 months were transferred to buckets that were unsealed but with lids placed loosely over the top, and stored outside in the shade at ambient temperature over October to April. The stored soils were regularly checked and water added as required to ensure soils were kept moist. This process will reflect all the loss processes present under field conditions (e.g. leaching, biodegradation by the indigenous soil microbial population), although losses through volatilisation may occur. Enhanced sorption of the polycyclic aromatic hydrocarbons (PAHs) to organic matter may also occur over the storage time, which may reduce toxicity.

Due to the unexpected death of earthworms within 24 h of starting the chronic toxicity test, acute toxicity testing using the individual muds was also undertaken (*single mud* experiment). The individual drilling muds and sufficient water to provide a moisture content of approximately 70% were added to artificial soil. The amount of drilling muds added and the dry weight percent are shown in Table 3, with moisture content and pH shown in Appendix 1.

Table 3 Treatment names, nominal and actual percent (based on dry weight) of individual drilling mud used for acute toxicity testing of the individual muds.

Treatment name	Nominal % high-TPH drilling mud	Nominal % low-TPH drilling mud	Actual % high TPH drilling mud[1]	Actual % low TPH drilling mud[1]
30% H	30	0	30	0
15% H	15	0	18	0
7.5% H	7.5	0	9.6	0
3.75% H	3.75	0	5.1	0
30% L	0	30	0	9.8
15% L	0	15	0	5.1
7.5% L	0	7.5	0	2.7
3.75% L	0	3.75	0	1.3
Control	0	0	0	0

[1]Calculated using 87% dry matter for high-TPH mud (H), and 22% dry matter for low-TPH mud (L).

3.2.2 Toxicity testing

Chronic testing was undertaken according to OECD Guideline 222. Soils were prepared as described in section 3.2.1. Earthworm survival was assessed at days 1 and 28 and growth was assessed after 28 days. Worms were fed weekly with horse manure, and adult worms were removed after 28 days. Soil was returned to the jars and cocoon production and number of juveniles were assessed after 56 days.

Unexpectedly all the worms in all drilling mud treatments died within 24 h. Therefore acute toxicity testing of the individual muds was undertaken. Testing was conducted according to OECD Guideline 207. Soils were prepared as described in section 3.2.1, and earthworm survival monitored at days 7 and 14.

3.3 Microbial response

3.3.1 Soil collection

Soils for testing microbial response were collected from an inland site and a coastal site that were representative of soil types to which drilling muds were being applied. The soils for this testing were collected from locations that had not had drilling muds applied. For the coastal site, soil was collected from two depths, 0–150 mm and 150–300 mm, to reflect landfarming application practices. Soil samples were collected from five locations across the paddock and composited to form a single sample. Assessment of the microbial population through analysis of basal respiration and substrate-induced respiration (SIR) was undertaken on samples from both soil depths to determine which soil to use for testing. The higher SIR in the topsoil indicated a greater microbial biomass, so the topsoil was used for subsequent testing.

For the inland site, where soils are typically surface applied, soils were collected from 0–100 mm depth at five locations across a paddock on two occasions to yield sufficient sample.

Collected soils were sieved through a sieve of 4-mm mesh size to remove large stones and debris and to provide a well-mixed sample for testing.

3.3.2 Preparation of soils for microbial testing

The aim for microbial testing was to have an approximate maximum concentration of 30% mud based on dry weight, while also ensuring that the soils were not too moist, which could also give rise to negative effects on the microbial population. The nominal amount of mud to be added to achieve the nominal 30% drilling muds was calculated, and then the mud mixtures added gradually with additions stopping before mixtures became too wet. This resulted in a much lesser amount of mud being added and actual percentages of the muds were lower than anticipated (Table 4). The calculated and actual amounts of muds and soil added are shown in Appendix 1.

Table 4 Treatment names, nominal and actual percent of the low-TPH (LM) and high-TPH mud mixtures (HM) added to the coastal and inland soils to assess microbial response.

Soil	Treatment name	Nominal % high-TPH mud (dry wt)	Nominal % low-TPH mud (dry wt)	Actual % high-TPH mud[1] (dry wt)	Actual % low-TPH mud[1] (dry wt)
Coastal	30% HM	30	0	16	-
	15% HM	15	15	6.2	1.6
	7.5% HM	7.5	22.5	2.9	2.0
	30% LM	0	30	-	2.7
	Control	0	0	0	0
Inland	30% HM	30	0	10.4	-
	15% HM	15	15	6.8	1.7
	7.5% HM	7.5	22.5	2.7	2.1
	30% LM	0	30	-	3.3
	Control	0	0	0	0

[1]Calculated from known composition of mud mixture added, and using 87% dry matter for high-TPH mud, and 22% dry matter for low-TPH mud and actual moisture content of the individual soils (65% dry matter for inland soils and 80% for coastal soils)

3.3.3 Testing

Respiration (as an indication of carbon cycling) and nitrification are two important processes of the soil microbial community. This study investigated respiration, nitrification and microbial biomass to ascertain the general effect of drilling muds on the soil microbial population. Testing of basal respiration of soil incubated for 7, 28 and 56 days was undertaken at Landcare Research facilities in Hamilton using standard methodologies (Anderson & Domsche 1978; Sparling & Zhu 1993). Basal respiration was calculated as the increase in CO_2 content of sealed jars over an 18-h period at 20°C with soils at ~60% water holding capacity. One gram dry weight of soil was used for each replicate. Results are expressed as µg CO_2–C per g soil per hour.

Analysis of microbial biomass, ammonium-N and nitrate-N of soils at day 0 and 7, 28 and 56 days' incubation was undertaken at Landcare Research's Environmental Chemistry Laboratory at Palmerston North (see http://www.landcareresearch.co.nz/resources/laboratories/ environmental-chemistry-laboratory/services/soil-testing/ for specific details). In brief, ammonium and nitrate-N were measured colorimetrically from a 2 M KCl extract (1:10 ratio of soil to extract). Microbial biomass carbon was calculated as the increase in carbon after fumigation from a 0.5M K_2SO_4 extractant and multiplied by a factor of 0.41 to convert the amount of carbon in the extractant to microbial biomass C.

3.4 Chemical analyses

Drilling muds and soil samples were sent to Hills Laboratories for analysis of total petroleum hydrocarbon (TPH), chloride, soluble salts and conductivity.

3.5 Statistical analyses

Microbial data was transformed when necessary to more closely meet assumptions of normality and homogeneity of variance. Treatment effects were tested by analysis of variance to give an indication of differences between treatments. Levels of drilling mud addition within each time period were compared using a Bonferrroni multiple comparison test (α = 0.05). Treatment effects over time were compared by least significant difference (LSD) from a repeated measures analysis of variance when the time term was significant (Fisher's protected LSD). Regression analysis of overall treatment means against the percentage of high-TPH drilling mud was also performed.

4 Results

4.1 Earthworms

Earthworms placed in all the mud mixture treatments initially exhibited avoidance behaviours and were observed climbing the walls of the glass jars, and remaining on the surface of the soils (Figure 1). Unexpectedly, after 24 h all earthworms in the mud mixture treatments appeared to have died, with mortality confirmed at day 7. No mortality of earthworms was observed in the control treatments, where earthworms were healthy for the duration of the test (56 days).

After aging of the soils for 6 months the test was rerun to establish if there was any reduction in toxicity; however, the same results were observed with earthworms exhibiting initial avoidance behaviours and appearing to have died after 24 h with mortality confirmed at day 7.

Acute toxicity testing using different concentrations of the individual muds was undertaken after the initial mud mixture testing to provide a better perspective on the toxicity of the individual drilling muds (Figure 2). The same avoidance behaviour was noted in the top two doses for both muds and the nominal 7.5% dose for the high-TPH mud only when the earthworms were originally placed into the treatments. For the other treatments, earthworms remained on the soil surface and after 24 h earthworms in the lower two doses for both muds were in the soil. After 7 days, 100% mortality was observed in the top two doses of both muds and the nominal 7.5% dose for the high-TPH mud only. Some survival was noted in the nominal 3.75% dose of the high-TPH mud, with around 40% survival at 7 days, dropping to approximately 20% survival at 14 days. In contrast, approximately 80% and 100% of earthworms survived after 14 days in the nominal 7.5% and 3.75% doses for the low-TPH mud. This suggests that TPH in addition to other components are toxic to the earthworms.

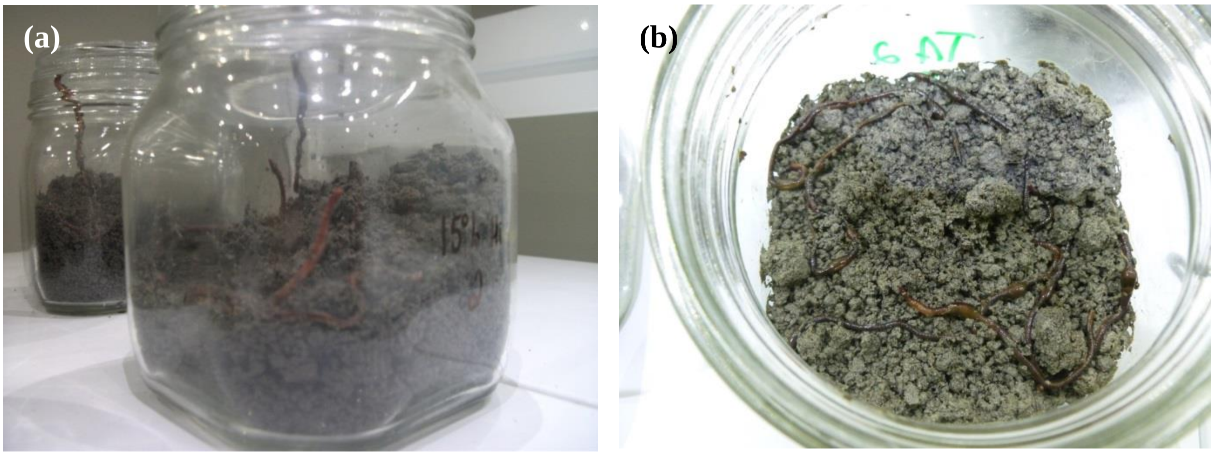

Figure 1 (a) Earthworms displaying avoidance behaviour; (b) earthworms with dehydrated appearance present on the soil surface. Photographs were taken from the single mud experiment, but were representative of mud mixture testing also.

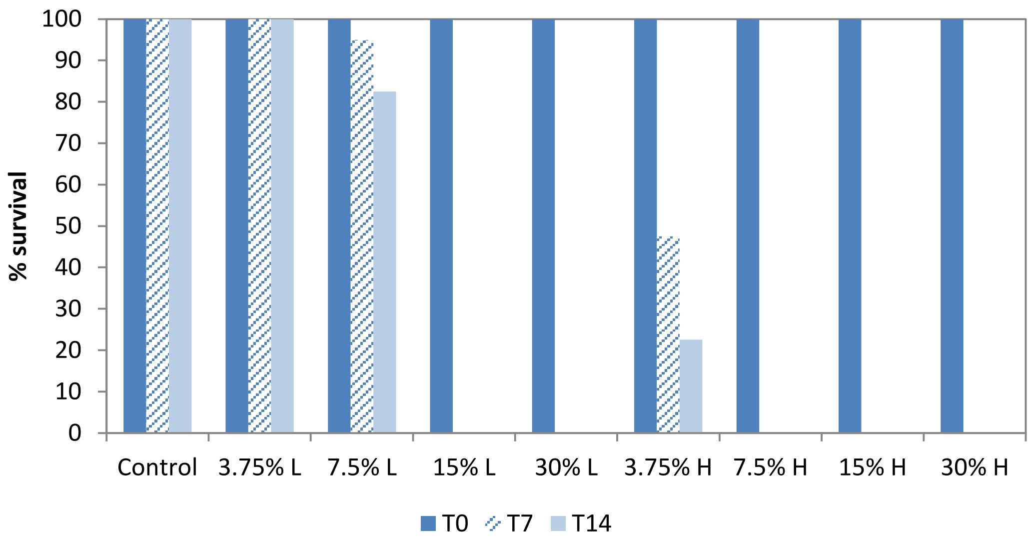

Figure 2 Survival (%) of earthworms over a 14-day acute toxicity test for the low-TPH (L) and high-TPH (H) muds.

Given the observation that mortality occurred in the low-TPH mud treatments as well, only samples from the 3.75% high-TPH mud treatment collected at the start and end of the test were initially sent for chemical analysis (Table 5). These results indicate that significant mortality can occur in earthworms at TPH concentrations of 23 000 mg/kg.

Table 5 Chemical analysis of the 3.75% high-TPH mud treatment at the start and end of the single mud experiment

Analyte	3.75% H	
	T0	T14
Dry matter (% wet wt)	80	79
Soluble salts % dry wt (g/100 g dry wt)	0.64	0.68
Electrical conductivity (EC) (mS/cm)	1.8	1.9
Chloride (mg/kg dry wt)	2700	2700
C7–C9 (mg/kg dry wt)	22	<9
C10–C14 (mg/kg dry wt)	8800	4800
C15–C36 (mg/kg dry wt)	14 600	8600
Total hydrocarbons (C7–C36) (mg/kg dry wt)	23 000	13 400

Salt was not considered as a potential toxicant until chemistry analysis of the 6-month aged mud mixture treatments soils was undertaken and revealed high chloride concentrations (Table 6). Subsequently, additional chemical analysis of the single mud treatments was undertaken, which showed that significant mortality occurred in low-TPH mud treatments with chloride concentrations of 4900 mg/kg, while increased survival was observed at chloride concentrations of 2300 mg/kg and no mortality was observed in treatments with 1800 mg/kg chloride (Table 7).

Table 6 Soluble salts, electrical conductivity, and chloride concentrations in mud mixture treatments aged for 6 months

	Control	30% LM	3.75% HM	7.5% HM	15% HM	30% HM
Dry matter (% wet wt)	-	-	68	67	71	74
Soluble salts (% dry wt)	0.16	2.3	2.5	2.3	2.4	2.4
Electrical conductivity (EC) (mS/cm)	0.4	6.5	7.1	6.6	6.8	6.9
Chloride (mg/kg dry wt)	380	8200	11 500	NT	11 600	NT

NT – not tested due to insufficient sample. High-TPH = HM and low-TPH = LM mud mixtures.

Table 7 Chemical analysis of selected additional treatments of the high-TPH (H) and low-TPH muds (L) used in the *single mud* experiment

Analyte	7.5% H T0	3.75% L T0	7.5% L T0	15% L T0
Dry matter (% wet wt)	79	-	-	-
Soluble salts % dry wt (g/100 g dry wt)	0.96	0.44	0.68	1.23
Electrical conductivity (EC) (mS/cm)	2.7	1.2	1.9	3.5
Chloride (mg/kg dry wt)	4200	1840	2300	4900
C7–C9 (mg/kg dry wt)	42	-	-	-
C10–C14 (mg/kg dry wt)	17 200	-	-	-
C15–C36 (mg/kg dry wt)	29 000	-	-	-
Total hydrocarbons (C7–C36) (mg/kg dry wt)	46 000	-	-	-

Few papers were found that examined the potential toxicity of salts to earthworms. One of these (McGosh & Getliff 2003) examined toxicity of salts used in drilling muds and found that calcium chloride at concentrations of 0.75–1% resulted in 100% mortality to *Eisenia fetida*. Assuming measurements are based on dry weight, 0.75% $CaCl_2$ is equivalent to chloride at 4790 mg/kg, which is similar to the chloride concentration of the 15% low treatment and 7.5% high treatments (Table 7) in which 100% mortality was observed. Lower chloride concentrations were present in the 3.75% H treatment (Table 5), which showed significant mortality suggesting the TPH concentration also contributes to the observed toxicity. Higher chloride concentrations were found in the mud mixture treatments used for the intended chronic testing, suggesting that salt, using chloride concentrations as an indicator, is the primary toxicant. Further, the observed behaviour of earthworms during testing – attempting to avoid contact with the treatment soil, remaining on the soil surface and a dehydrated appearance after death – is consistent with salt toxicity. The electrical conductivity measurements for the mud mixture treatments classify these treatments as ‘poor’ according to guidelines for assessing salt contamination in Alberta, Canada (Table 8).

Table 8 Soil quality guidelines for unrestricted land use specified in Albert Environment (2001)

EC dS/m[1]	Rating categories			
	Good	Fair	Poor	Unsuitable
Topsoil	<2	2 to 4	4 to 8	>8
Subsoil	<3	3 to 5	5 to 10	>10

[1] dS/m is equivalent to mS/cm

Other studies have report toxicity effects on earthworms over chloride concentrations ranging from 2400 to 8000 mg/kg. For example, Owojori et al. (2008a) observed no mortality but significantly reduced weight gain in *Eisenia fetida* at 4000 mg NaCl/kg (2400 mg Cl/kg) over

28 days. Owojori et al. (2008b) had similar observations and also noted 100% mortality at 8000 mg/kg NaCl/kg (4900 mg Cl/kg). Guzyte et al. (2011) found 100% mortality of *E. fetida* after 7 days at NaCl concentrations of 6000 and 8000 mg/kg (~3700 and 4900 mg Cl/kg). However, in studies using NaCl it is unclear to what extent toxicity is mediated by sodium and what is mediated by chloride – Hughes et al. (2009) found that NaCl was more toxic than sodium sulphate (Na_2SO_4) although the difference was minimal, suggesting sodium is the primary toxicant. These authors found that concentrations of 217.5 mmol NaCl (7600 mg Cl/kg) resulted in 100% mortality of *E. fetida* after 14 days while only slight mortality was observed at 108 mmol (3780 mg Cl/kg). Based on material safety data sheets (MSDS) provided by companies involved in landfarming operations in Taranaki for a range of compounds used in drilling operations, potassium chloride and calcium chloride appear to be the primary salts used in drilling operations in this region. Analytical results from a broader range of pre-disposal samples provided by the council indicates that sodium, presumably from sodium chloride, may also be present in the muds.

On the basis of results from the current testing, chloride concentrations of around 2000 mg/kg appear to be an upper limit to ensure no mortality of earthworms in laboratory conditions, assuming that salts are the primary toxicant in non-TPH-containing or low-TPH drilling muds.

As shown in Table 5, TPH appears to contribute to observed toxicity with significant mortality observed in the 3.75% HM treatment which had chloride concentrations that would be expected to result in only a slight decrease in mortality. The concentration in this treatment (23 000 mg/kg TPH) was markedly higher than the initial 3.75% HM treatment (6300 mg/kg, Table 9). The reason for this discrepancy is unclear. A marked decrease in TPH concentration was observed for the 3.75% HM treatment over the 6 months, while there appeared to be an increase in TPH concentrations in the 7.5% treatment. The reasons for the observed increase are unclear but may be due to sample heterogeneity; regardless no significant loss of TPH was observed. The TPH concentration in all mud mixture treatments at 6 months is shown in Figure 3.

Table 9 Total petroleum hydrocarbon concentration in selected high-TPH mud mixture (HM) treatments at time 0 and after 6 months of aging.

Analyte	Initial		Aged 6 months	
	3.75% HM	7.5% HM	3.75% HM	7.5% HM
C7–C9	<10	<10	<10	<10
C10–C14	1550	4800	670	5900
C15–C36	4700	12 800	2100	14 700
Total hydrocarbons (C7–C36)	6300	17 600	2800	21 000

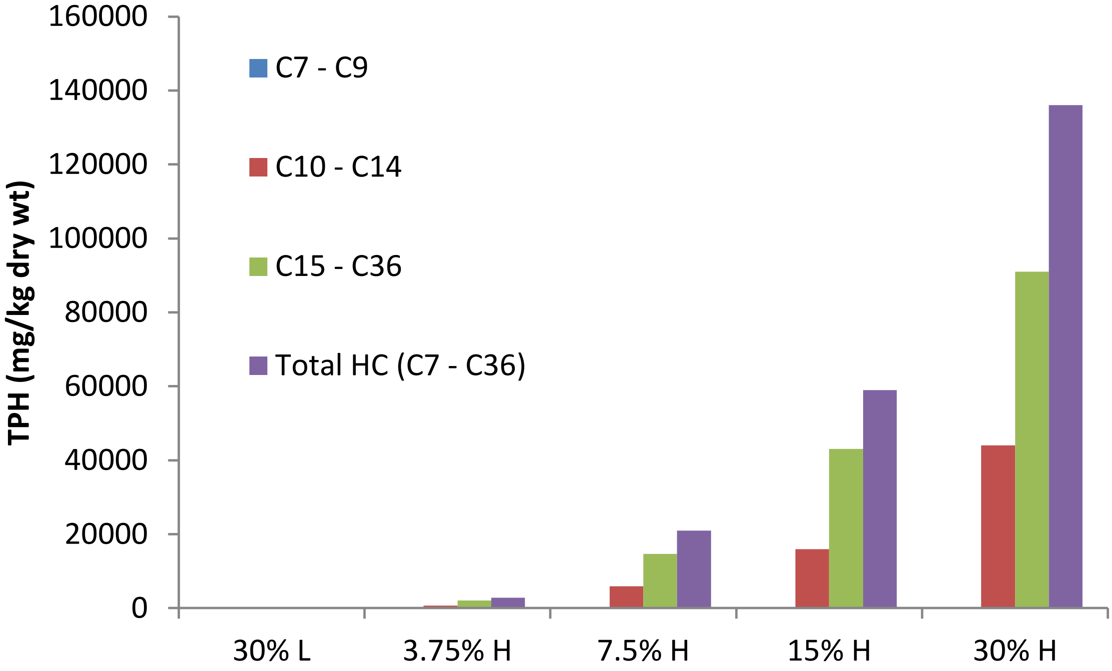

Figure 3 TPH concentrations in the mud mixture treatments aged for 6 months.

The Canadian document *Canada-Wide Standard for Petroleum Hydrocarbons (PHC) in Soil: Scientific Rationale* (CCME 2008) provides one of the most recent comprehensive evaluations of the toxicity of petroleum hydrocarbons in the soil environment, and includes ecotoxicological data for different hydrocarbon fractions. These data show that earthworms are one of the most sensitive organisms and that the lighter fractions are more toxic. A slightly different fractionation regime to that used in New Zealand is used and the following four fractions defined: C6–C10, >C10–C16, >C16–C34 and >C34. This document also developed updated soil quality standards based on soil contact for ecological receptors that form the basis for Tier 1 remediation guidelines for fine soils in Alberta (Alberta Environment 2010). Different guidelines were developed for coarse soils in Alberta Environment (2010).

The Energy Resources Conservation Board (ERCB) produces directives for the management of drill wastes that includes hydrocarbon concentrations in soil that are used as concentrations that cannot be exceeded after the application of drilling muds (hydrocarbon endpoints) (ERCB 2012). These concentrations are shown in Table 10 and are originally sourced from Alberta Environment (2010). As can be seen these concentrations are much lower than the concentrations in the various earthworm treatments in this study.

ECRB (2012) also specifies hydrocarbon concentrations for drill mud waste, based on the specific gravity of the drilling mud, and allowing for a soil-to-waste mixing ratio of 3:1(Table 11). If concentrations in the drilling mud waste are greater than that then the companies applying the waste will be required to sample the receiving soil/waste mix within 60 days of the disposal and analyse it to verify that the endpoints have not been exceeded. This may require different soil-to-waste ratios to be achieved. As can be seen these concentrations are much lower than that in the high-TPH mud sample used in the current study.

Table 10 Hydrocarbon endpoints for drilling mud application specified in ECRB (2012)

Hydrocarbon fraction	Agricultural land	
	Fine soil[1] (mg/kg)	Coarse soil[2] (mg/kg)
F1 (C6–C10, excluding BTEX[3])	210	24
F2 (>C10–C16)	150	130
F3 (>C16–C34)	1300	300
F4 (>C34)	5600	2800

[1] Fine soils have a median grain size <75 um.

[2]Coarse soils have a median grain size >75 um.

[3] BTEX – benzene, toluene, ethylene and xylenes, endpoints have been set but are not included here.

Table 11 Hydrocarbon content in drilling waste adapted from ECRB (2012)*

Hydrocarbon fraction	Concentration in drilling mud waste (wet weight mg/kg)			
	F1	F2	F3	F4
1.1	104	565	1304	12 169
1.5	87	470	1085	10 123
2.0	75	405	934	8716
2.5	67	366	843	7873

*Concentrations are also provided for BTEX but are not included here.

From a different perspective, Schaefer and Juliane (2007) found that during studies to investigate the influence of earthworms on biodegradation of hydrocarbons, TPH concentrations of 5000–9500 mg/kg were increasingly lethal after an incubation of 28 days. Similarly, no mortality was observed in vermicomposting trials of drilling mud wastes with starting concentrations of 4600 mg/kg for the C10–C14 hydrocarbon fraction, i.e. one of the more toxic fractions (Norman et al. 2002), and TPH concentrations decreased to 140 mg/kg in 10 days. In other vermicomposting trials, starting TPH concentrations ranged up to 30 000 mg/kg with no observed mortality (Getliff et al. 2002). However, the authors noted considerable heterogeneity in the vermicompost pile, with TPH concentrations of 33 000 mg/kg found in samples that were not touched by worms, potentially suggesting some avoidance of high TPH concentrations by the earthworms. Thus based on the literature TPH concentrations of 5000 mg/kg dry weight appear to provide a qualitative upper limit. Further testing would be required to validate this as it will likely vary depending on the composition of TPH, with higher concentrations in the lighter fractions anticipated to result in greater toxicity.

While the current laboratory studies indicate a high mortality of earthworms in the drilling mud treatments at mud/soil concentrations that may potentially be observed in the immediate vicinity of drilling mud application in Taranaki, it is unlikely that significant mortality would be observed in the field as earthworms would likely move away from soil with high salt or hydrocarbon contents. However, the implications of this behaviour is that drilling mud application is potentially creating a chemical barrier for the earthworms, and may reduce the biodegradation of hydrocarbons – as the presence of earthworms has been shown to enhance biodegradation of hydrocarbons (Schaefer & Juliane 2007).

4.2 Microbial response

The addition of high-TPH drilling muds resulted in increased microbial biomass in the coastal soils, particularly at the 30% HM treatment (Figure 4). Addition of the high-TPH mud increased the microbial biomass because the hydrocarbons were utilised a carbon source for the microbes. Though the pattern over time for each treatment was somewhat irregular (the maximum biomass was not always reached at the final time point), within a given time (for T7–T56), there was a linear increase in microbial biomass with increasing TPH addition ($P < 0.005$), though the relationship was different for the two soils. The 30-LM treatment for both soils was generally significantly less than the control (Figure 4, Table A2.1 in Appendix 2), suggesting that the low-TPH drilling mud had a negative impact on microbial biomass.

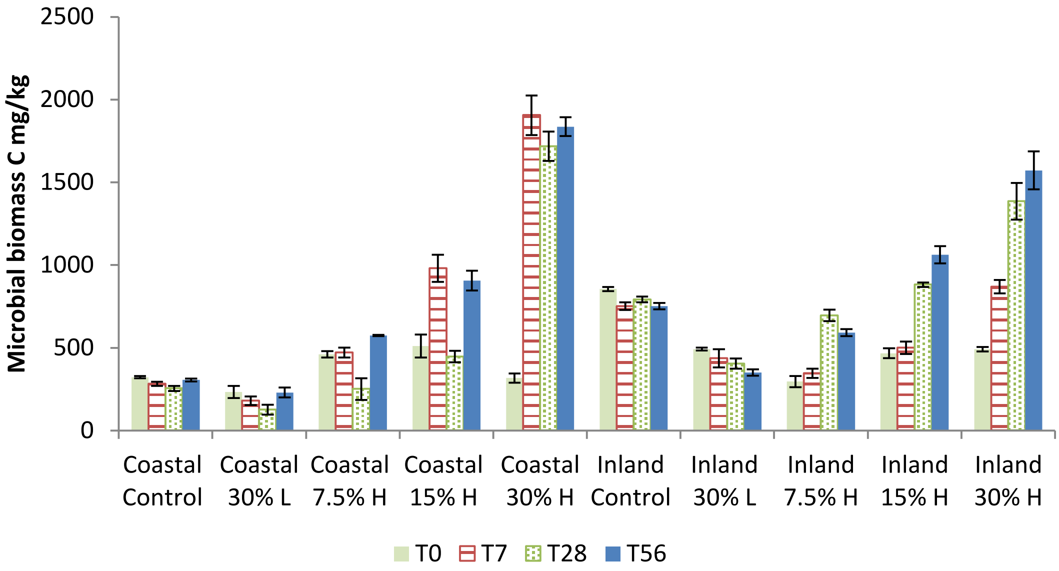

Figure 4 Changes in microbial biomass (mg C/kg soil) over time in the coastal and inland soil treatments.

Changes also occurred in the basal respiration rates, with increases in respiration most marked in the coastal soils (Figure 5). The greatest increase in respiration generally occurred at day 7 for the coastal soils and day 28 for the inland soils with decreases in respiration generally occurring by day 56. Similar to microbial biomass, within each time point there was a significant relationship between the amount of TPH mud added and the respiration rate ($P < 0.05$). There was also a significant relationship between microbial biomass and basal respiration ($P < 0.001$) indicating growth does contribute to the increase in respiration although it does not explain all the variation in respiration. There also was an increase in respiration rate for the controls over time, particularly in the coastal soil, but the increase was small in comparison to the increase due the TPH mud.

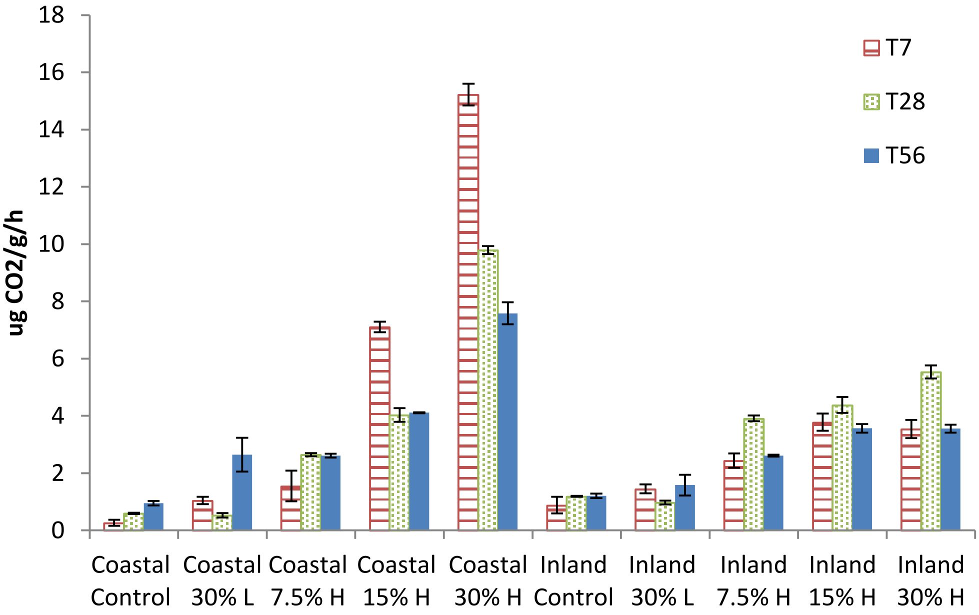

Figure 5 Changes in basal respiration over time in the coastal and inland soil treatments.

Increases in basal respiration can occur either as a result of increased growth or microbial stress. The qCO_2 (respiration per unit microbial biomass) provides a useful indicator to differentiate between respiration due to increased growth and stress in the microbial population (a greater value indicates more stress as the microbes are expending energy to regulate their internal functions instead of increasing their biomass). Patterns over time were irregular and varied between the soils (Figure 6, Appendix 2). For treatments containing the high-TPH mud, the qCO_2 generally decreased over the course of the experiment, potentially indicating adaption of the microbial community. The increases in qCO_2 in the treatments containing high-TPH muds in relation to the control may indicate the transient accumulation of acidic degradation products. The inland soil overall showed less increase in qCO_2 than the coastal soils and thus appeared better able to accommodate the addition of drilling muds. In contrast, the qCO_2 tended to increase in the 30% L treatments with the maximum at day 56 for both soils. This suggests that components other than TPH present in the low TPH mud are giving rise to microbial stress for both the coastal and inland soil.

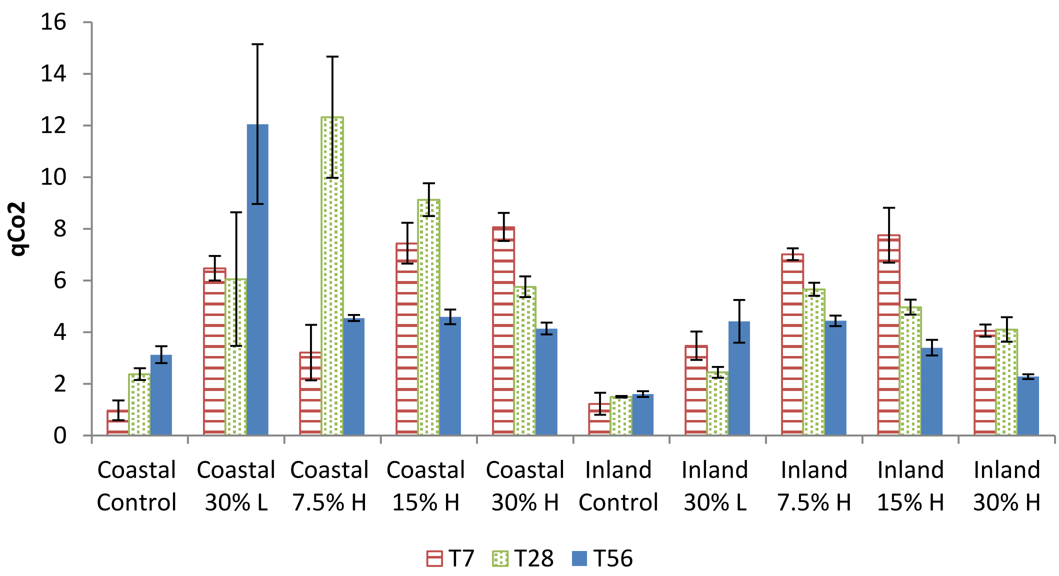

Figure 6 qCO_2 (respiration/microbial biomass) of different treatments at days 7, 28 and 56.

In pasture systems when conditions are aerobic, there is generally little accumulation of ammonium ($NH4^+$) as nitrification (conversion of $NH4^+$ to $NO3^-$) is generally rapid enough to consume $NH4^+$ as quickly as it produced. However, when nitrifying bacteria are stressed, $NH4^+$ can accumulate. There were some differences in $NH4^+$ levels over time for the control (Figure 7, Appendix 2), but levels remained low over the course of the study. Ammonium concentrations for the drilling mud treatments of both soils at day 0 were greater than the controls indicating that there was probably some $NH4^+$ in the drilling muds. There was a significant ($P < 0.05$) negative relationship between amount of TPH mud and $NH4^+$ levels at day 0, which would further suggest that it was the low-TPH mud that contained the ammonium. Ammonium levels for some TPH treatments did increase at day 7 but for both soils they decreased to levels similar (or lower) to the control between days 28 and 56, and likely reflects assimilation during microbial growth in response to TPH degradation. In contrast, there was a general increase in ammonium for both 30%LM treatments through 28 days. At day 56, the ammonium levels for the coastal 30%LM treatment had decreased to about what they were at day 7, whereas for inland 30%LM treatment they remained near their highest levels. These data suggest that there is a component of the low-TPH drilling mud that is inhibiting nitrification. A recent study found that chloride may inhibit nitrification at concentrations as low as 130 mg/kg (Megda et al. 2014). Chloride concentrations were significantly higher in the current study, including in the treatments receiving the high-TPH mud that did not accumulate $NH4^+$ after the first 7 days. This may indicate that TPH ameliorates the negative impact of chloride on nitrification – or that there is another component of the low-TPH mud that is inhibiting nitrification. If the latter is true then there may be some inhibitory component in the high-TPH mud as that also gave rise to accumulation of NH4+ in the first 7 days. Ammonium levels did decline in the high-TPH muds after day 7, but it is difficult to ascertain whether this was because nitrification had recovered, or whether the NH4+ was assimilated by the increased microbial biomass.

For nitrate, there were (relatively small) sequential increases in nitrate levels in the control soils over time as organic N was mineralised to ammonium then nitrate (Figure 8, Appendix 2). There was also a significant ($P < 0.001$) increase in nitrate at day 0 with increasing TPH addition, suggesting that the TPH mud contains high levels of nitrates. The nitrates also decreased rapidly over time (after day 7 in the coastal soil and day 28 in the inland soil) and this likely indicates assimilation during microbial growth associated with TPH degradation.

The results of chemical analysis show an increase in TPH concentrations with an increasing amount of high-TPH mud added to the soils (Figure 9, Table 12). No TPH was detected in the controls or the low-TPH mud only treatments. TPH concentrations decreased over the course of the experiment, with greater proportional loss of the C10–C14 hydrocarbon fraction compared with the C15–C36 fraction (Table 12). As expected, chloride concentrations did not decrease over time. Concentrations were elevated in all mud treatments as expected, with the greatest concentrations occurring in the top two high-TPH mud treatments.

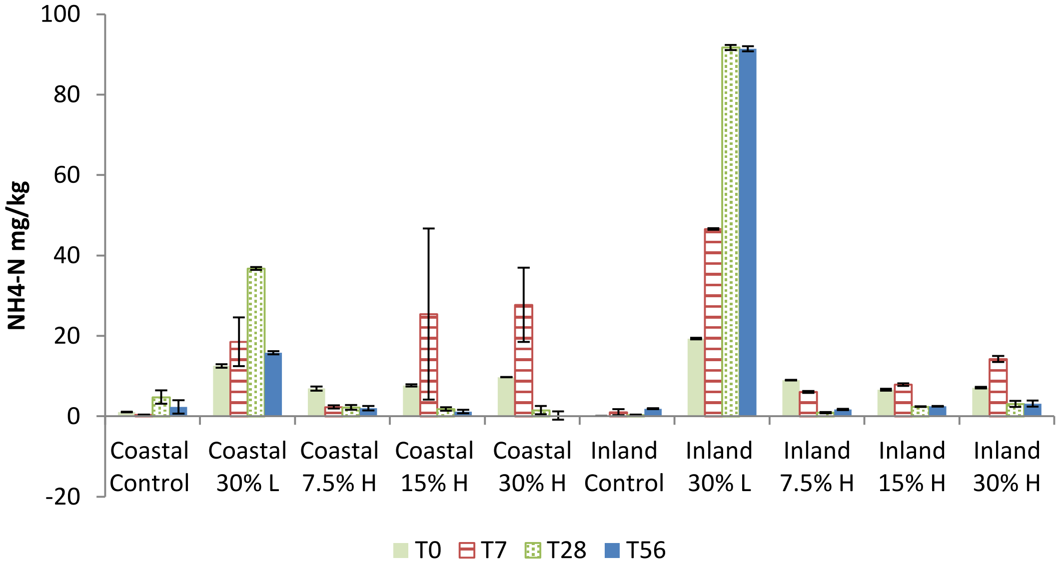

Figure 7 Soil ammonium concentrations (mg/kg dry wt) in different treatments at days 7, 28 and 56.

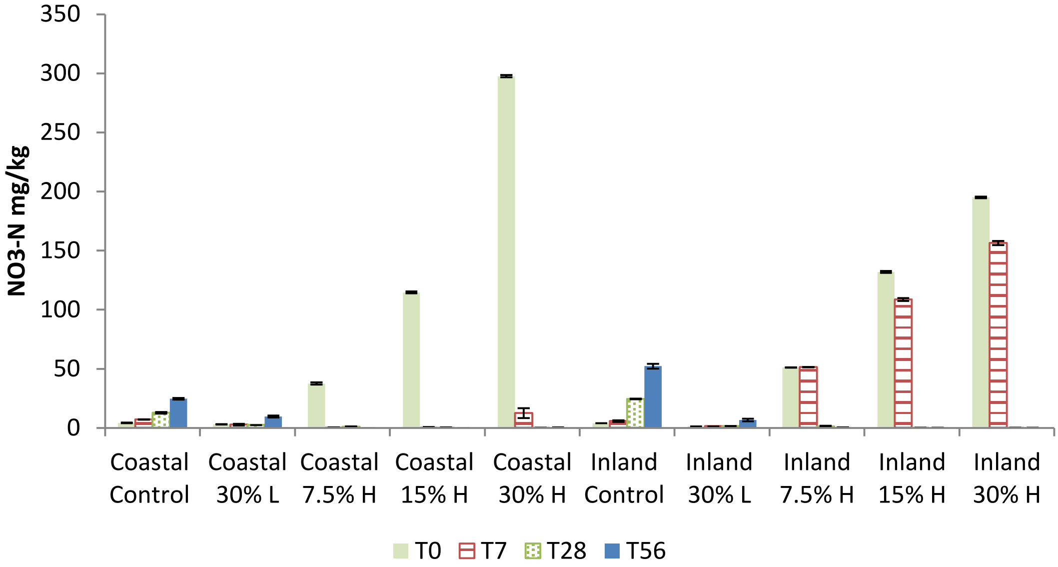

Figure 8 Soil nitrate concentrations (mg/kg dry wt) in different treatments at days 7, 28 and 56.

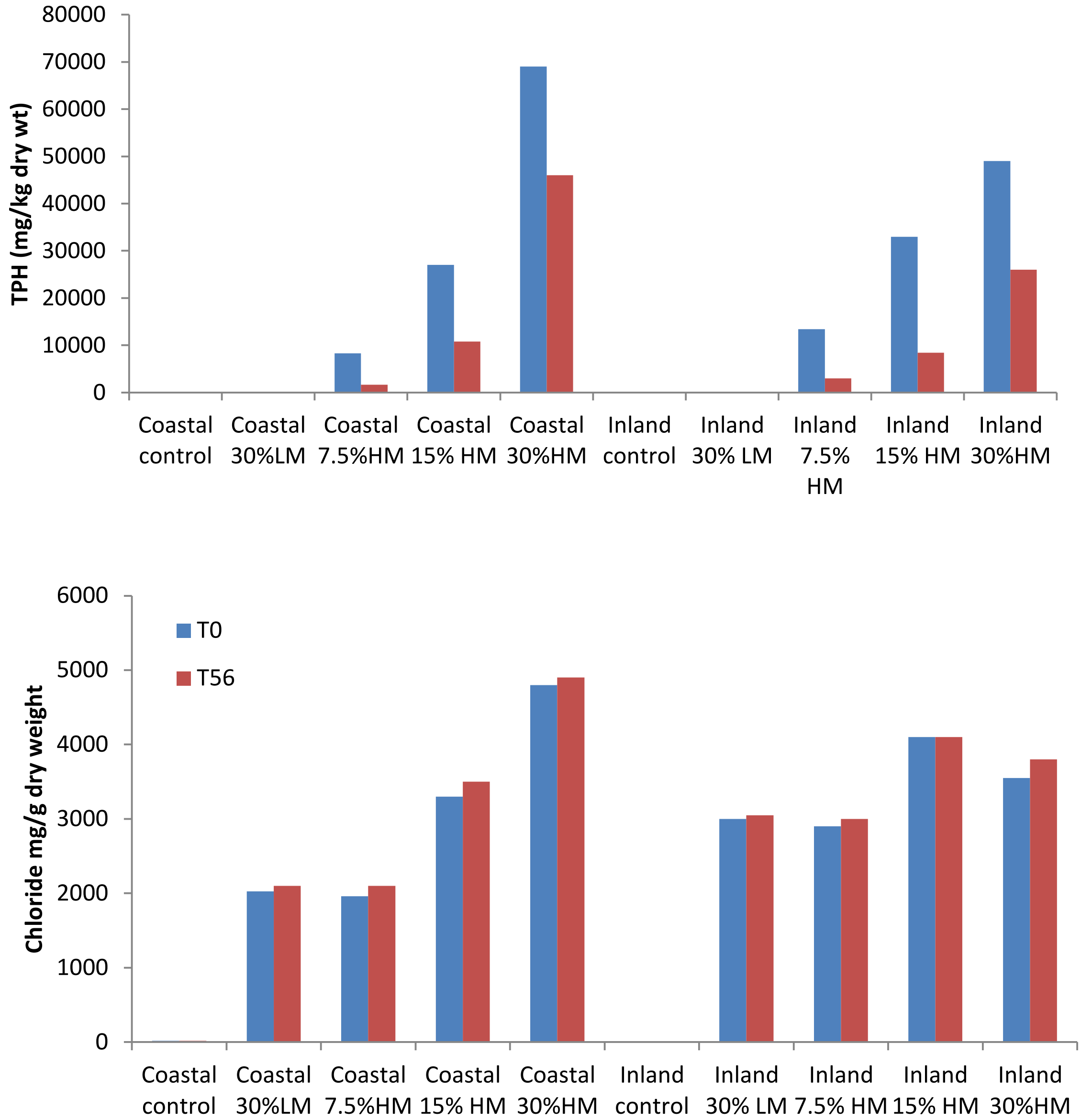

Figure 9 Concentrations (mg/kg dry wt) of total TPH and chloride present in the different mud mixture treatments (HM = high-TPH; LM = low-TPH) used for assessing microbial activity.

Table 12 Chloride and TPH concentrations (mg/kg dry wt) at day 0 and 56 days in mud mixture treatments (HM = high-TPH; LM = low-TPH) used for microbial testing

Treatment	Day 0					Day 56				
	Chloride (mg/kg dw)	C7–C9 (mg/kg dw)	C10–C14 (mg/kg dw)	C15–C36 (mg/kg dw)	Total hydrocarbons (C7–C36) (mg/kg dw)	Chloride (mg/kg dw)	C7–C9 (mg/kg dw)	C10–14 (mg/kg dw)	C15–C36 (mg/kg dw)	Total hydrocarbons (C7–C36) (mg/kg dw)
Coastal control	17	<8	<20	<40	<70	17	<8	<20	<40	<70
Coastal 30% LM	2025	<8	<20	<40	<70	2100	<8	<20	<40	<70
Coastal 7.5% HM	1960	10	3300	5000	8300	2100	<9	250	1400	1650
Coastal 15% HM	3300	45	10600	16 600	27 000	3500	<9	2600	8200	10 800
Coastal 30% HM	4800	132	26000	43 000	69 000	4900	85	12 600	33 500	46 000
Inland control	7	<8	<20	<40	<70	10	<8	<20	<40	<70
Inland 30% LM	3000	<8	<20	<40	<70	3050	<8	<20	<40	<70
Inland 7.5% HM	2900	17	5200	8100	13 400	3000	<12	660	2300	3000
Inland 15% HM	4100	58	12 700	20 000	33 000	4100	<12	2200	6200	8400
Inland 30% HM	3550	91.5	18 900	30 000	49 000	3800	<11	7100	18 600	26 000

5 Conclusions

Earthworms

The drilling muds are highly toxic to earthworms and cause some stress to indigenous microbial populations at the concentrations tested. The mortality of earthworms in both muds indicates that there are substances other than TPH in the drilling muds that are causing toxicity to the earthworms. Salts, as indicated by chloride concentrations, appear likely to be the primary cause of toxicity at higher proportions of drilling mud waste. Based on current testing a chloride concentration of approximately 2000 mg/kg appears to be an upper limit not giving rise to earthworm mortality under laboratory conditions. However, TPH does appear to contribute to the observed toxicity, with concentrations of 23 000 mg/kg resulting in significant mortality after 14 days with chloride concentrations that would be expected to have a minimal influence on toxicity (2700 mg/kg). The presence of high salt or high TPH in drilling mud waste applied to land may present a chemical barrier for earthworms, and would reduce the influence of earthworms on the biodedgradation of the hydrocarbons.

Microbial community

The highest levels of microbial stress (as measured by qCO_2) were observed in coastal soils treatment with only the low-TPH mud added, while inhibition of nitrification, as observed by an increase in $NH4^+$, was most pronounced in the inland soil treatment with only the low-TPH mud added. The microbial population in the inland soils seemed more resilient to the addition of the high-TPH mud, with lower levels of stress (as measured by qCO_2) observed in those treatments with the high-TPH mud added. TPH may ameliorate the effect of other components causing stress, with the 30% high-TPH treatment in soils having a higher microbial biomass and lower qCO_2 than treatments with lower concentrations of the TPH mud and decreasing over time. There may have been some initial inhibition of nitrification in the high-TPH treatments, ammonium levels did decline after 7 days, but it is difficult to ascertain whether this was because nitrification had recovered, or whether the $NH4^+$ was assimilated by the increased microbial biomass

6 Recommendations

- Further testing is required to ascertain the concentration of common salt components, other than chloride, that may have contributed to earthworm toxicity (e.g. sodium, potassium, and calcium cations).
- Results of field testing at depth intervals (e.g. above and below the depth of drilling mud application) immediately after application of the drilling muds should be used to establish the typical salt and TPH concentrations present after application, and at time intervals (e.g. 3, 6 and 12 months) after application.
- Further earthworm testing at lower concentrations of drilling mud would be required to determine the salt and TPH concentrations at which effects are not observed, and whether any other components may be contributing to toxicity. This testing should encompass salt and TPH concentrations observed after field application.

- Further testing, including of drilling mud waste that is being applied to land (i.e. mixtures of different drilling muds), should be undertaken to establish if nitrification inhibition is a common response of the microbial population to drilling mud application, and if so whether this relates solely to chloride concentrations or whether other components are contributing to the observed response.

7 Acknowledgements

Thanks go to Keith Brodie and David Olson (Taranaki Regional Council) for collecting the soil samples for microbial testing; Todd Energy and TAG Oil for providing drilling mud samples; and Ruka Te Moana (MI Swaco), Randy Toone (TAG Oil) and Carl Jenssen (NewPark, Australia) for providing MSDSs for components used in drilling operations in Taranaki. Jackie Aislabie (Landcare Research), Gary Bedford and Victoria Mckay (Taranaki Regional Council) provided useful comments on the draft report and Christine Bezar provided editorial assistance.

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Appendix 1 – Details of soil treatments

Table A1 Amounts of drilling mud added to artificial soil for chronic earthworm testing of mud mixtures

Treatment name	High-TPH mud[1] (dry wt, g)	Low-TPH mud[1] (dry wt, g)	Artificial soil (g)	Actual % high-TPH drilling mud (dry wt)	Actual % drilling mud waste (mix of high and low)
30% HM	840	0	1960	30	30
15% HM	420	106	1960	17	21
7.5% HM	210	159	1960	9.0	16
3.75% HM	105	186	1960	4.7	13
30% LM	0	212	1960	0	20
Control	0	0	1960	0	0

[1]Calculated using 87% dry matter for high-TPH mud (HM treatments), and 22% dry matter for low-TPH mud (LM).

Table A1.2. Moisture content and pH of mud mixtures (HM = high-TPH; HL = low-TPH) used for chronic toxicity test

	Time 0			6 months		
	Moisture (g/100g)	Dry matter (g/100g)	pH	Moisture (g/100g)	Dry matter (g/100g)	pH
30% LM	28.4	71.6	7.21	32.3	67.7	6.44
3.75% HM	27.1	72.9	7.31	33.1	66.9	6.42
7.5% HM	25.6	74.4	7.44	34.3	65.7	6.47
15% HM	26.2	73.8	7.52	30	70.0	6.67
30% HM	27.3	72.7	7.58	23.4	76.6	6.78

Table A1.3 Amount of drilling muds and soil, and actual percent drilling mud, used for acute toxicity testing of the individual muds.

Treatment name	Wet wt mud added	Artificial soil (dry wt)	High-TPH mud[1] (dry wt, g)	Low-TPH mud (dry wt, g)	Actual % drilling mud waste[1]
30% H	419	850	364.53	0	30
15% H	241	980	209.67	0	18
7.5% H	135	1100	117.45	0	9.6
3.75% H	71	1150	61.77	0	5.1
30% L	510	1035	0	112.2	9.8
15% L	270	1096	0	59.4	5.1
7.5% L	136	1100	0	29.92	2.7
3.75% L	71	1150	0	15.62	1.3
Control	0	1000	0	0	0

[1]Calculated using 87% dry matter for high-TPH mud (H), and 22% dry matter for low-TPH mud (L).

Table A1.4. Moisture content and pH in treatments for acute toxicity testing of the individual muds

Treatment	Moisture (g/100g)	Dry matter (g/100g)	pH
3.75% L	25.65	74.35	7.27
7.5% L	22.15	77.85	7.18
15% L	21.8	78.2	7.07
30% L	24.65	75.35	6.87
3.75% H	19.2	80.8	7.48
7.5% H	19.4	80.6	7.42
15% H	19.2	80.8	7.44
30% H	7.2	92.8	7.57

High-TPH mud (H); low-TPH mud (L).

Table A1.13 Calculated and actual amount of individual muds (wet wt) added to coastal and inland soil to assess microbial activity. (Actual moisture contents of treatments was ~60% dry matter for inland soils and 80% for coastal soils)

Soil	Treatment name	Calculated high-TPH mud[1] (g wet wt)	Calculated low-TPH mud[1] (g wet wt)	Actual mud mixture added (g wet wt)	Actual high-TPH mud (g wet wt)	Actual low-TPH mud (g wet wt)	Actual % high-TPH mud[3] (dry wt)	Actual % low-TPH mud[3] (dry wt)
Coastal	30% H	689		365.8	365.8	-	16	-
	15% H	345	345	286.9	143[2]	143[2]	6.2	1.6
	7.5% H	173	520	244.3	61[2]	183[2]	2.9	2.0
	30% lL		689	246.9	-	246.9	-	2.7
	Control	0	0	0	0	0	0	0
Inland	30% H	560		193.9	193.9		10.4	-
	15% H	280	280	256.9	128	128	6.8	1.7
	7.5% H	140	420	204.2	51	153	2.7	2.1
	30% L		560	245.9	-	245.9	-	3.3
	Control	0	0	0	0	0	0	0

[1]For 2500 g wet-wt soil (based on dry matter content for coastal soil of 80% and inland soil of 65%).

[2]Calculated from known composition of mud mixture added.

[3]Calculated using 87% dry matter for high-TPH mud (H), and 22% dry matter for low-TPH mud (L).

Appendix 2 – Coastal and inland treatment differences over time

Table A2.1 Mean values of individual muds (H = high-TPH; L = low-TPH muds) by treatment and date. The differing letters before the comma denote differences by treatment for each date. Differing letters after the comma denote differences for drilling mud addition over time

Test	Treatment	Coastal				Inland			
		Time (days)							
		0	7	28	56	0	7	28	56
Microbial biomass									
	Control	322ab,a	283b,a	254ab,a	306b,a	856c,a	751c,a	792b,a	752c,a
	30% L	233a.c	179a,b	125a,a	230a,c	492b,b	437ab,ab	404a,ab	350a,a
	7.5% H	461b,b	471c,b	251ab,a	575c,b	296a,a	346a,b	696b,c	592b,c
	15% H	510b,a	980d,b	447b,a	906d,b	467b,a	500b,a	881b,b	1063d,b
	30% H	317ab,a	1905e,b	1718c,b	1837e,b	492b,a	869c,b	1386c,c	1572e,c
Nitrate									
	Control	4a,a	7.16b,ab	12.75c,b	24.74c,c	4a,a	6a,b	24.45c,c	52.3c,d
	30% L	3a,a	2.71ab,a	2.4b,a	9.71b,b	1a,a	1a,a	1.51b,a	6.66b,b
	7.5% H	38b,c	0.39a,ab	0.87a,b	0.07a,a	51b,b	51b,b	1.16ab,a	0.44a,a
	15% H	114c,b	0.71a,a	0.34a,a	0.05a,a	132c,c	109c,b	0.34a,a	0.26a,a
	30% H	298d,c	12.59b,b	0.31a,a	0.19a,a	195c,c	156e,b	0.26a,a	0.25a,a
Ammonia									
	Control	1.07a,a	0.36a,ab	4.77a,b	2.34b,b	0.08a,a	1.04a,b	0.27a,ab	1.87a,c
	30% L	12.54d,a	18.55a,ab	36.76b,b	15.81c,a	19.31d,a	46.57d,b	91.73c,c	91.41c,c
	7.5% H	6.90b,b	2.31a,ab	2.21a,ab	1.99b,a	8.98c,d	6.07b,c	0.92a,a	1.69a,b
	15% H	7.66b,ab	25.42a,b	1.81a,a	1.18b,a	6.64b,b	7.89bc,b	2.39b,a	2.47ab,a

Test	Treatment	Coastal				Inland			
		Time (days)							
		0	7	28	56	0	7	28	56
	30% H	9.74c,ab	27.71a,b	1.52a,a	0.21a,a	7.12b,b	14.24c,c	3.06b,a	3.15ab,a
Basal respiration									
	Control		0.27a,a	0.59a,b	0.95a,c		0.88a,a	1.19a,b	1.20a,b
	30% L		1.05b,b	0.53a,a	2.65b,c		1.45ab,ab	0.97a,a	1.58a,b
	7.5% H		1.55b,a	2.64b,b	2.61bc,b		2.44bc,a	3.91b,b	2.61b,a
	15% H		7.11c,b	4.03c,a	4.11c,a		3.78c,a	4.38b,a	3.56b,a
	30% H		15.22c,b	9.80d,ab	7.58d,a		3.54c,a	5.54c,b	3.55b,a
Substrate-induced respiration									
	Control		4.27a,a	7.55b,b	5.99b,ab		6.53b,a	6.83a,a	7.09bc,a
	30% L		5.60ab,a	6.50ab,a	6.13b,a		3.03a,a	6.44a,b	5.59a,b
	7.5% H		5.00ab,a	5.80a,a	4.81ab,a		5.21b,a	10.09b,b	5.83ab,a
	15% H		6.68b,ab	7.92b,b	4.58a,a		5.27b,a	10.44b,b	7.97c,b
	30% H		6.73b,a	19.03c,b	11.09c,a		5.43b,a	12.84b,b	8.54c,b
qCO_2									
	Control		0.97a,a	2.37a,b	3.12a,b		1.22a,a	1.50a,a	1.60a,a
	30% L		6.47b,ab	6.06ab,a	12.05b,b		3.48.b,ab	2.44b,a	4.41c,b
	7.5% H		3.21ab,a	12.32b,b	4.55a,a		7.01b,b	5.66d,ab	4.44c,a
	15% H		7.44cb,ab	9.12b,b	4.59a,a		7.75b,b	4.97cd,b	3.40bc,a
	30% H		8.00bc,a	5.75ab,a	4.14a,a		4.06b,b	4.10c,b	2.28ab,a

qCO_2 = basal respiration per unit microbial biomass

Appendix 3 – Curriculum vitae of authors

Dr Jo Cavanagh
Senior Researcher
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Jo is involved in the integration of science into policy, particularly in the management of contaminants in the environment and providing for the protection of human health and the environment. Jo has extensive experience in various aspects of environmental contamination in soil and air, including chemical and toxicological effects, and mitigation techniques and processes.

- **Expertise / Skills**
  - Toxicology
  - Soil and air contaminants
  - Risk assessment

- **Experience / Work History**
- 2001 – Current : Landcare Research
  Researcher
  Jo's current research includes understanding the effects of soil contaminants to improve the management of soil quality, for example cadmium accumulation arising from fertiliser application, biological responses associated with biosolids. Current and previous research involves the application of scientific information in a regulatory context to enhance environmental management, such as toxicological review of selected priority soil contaminants underpins the development of soil guideline values used in the "National Environmental Standard for assessing and managing contaminants in soil". Jo also undertakes air quality research, investigating the toxicity of ambient particulates and associated contaminants.
  Jo was seconded as an advisor to the Hazardous substances group, Environmental Risk Management Authority in 2006 where she undertook assessment of the risks of new substances to human health and the environment, and to the Contaminated Land Management Group Ministry for the Environment in 2004.
- 2000: Australian Institute of Marine Science.
  Research Assistant
- 1994 – 1996: Barwon Water, Geelong, Australia.
  Biological Scientific Officer
- **1993 – 1994: University of Tasmania / CSIRO Marine Laboratories, Hobart, Australia.**
  Research Assistant

- **Qualifications**
- 2001: PhD, Environmental chemistry and toxicology, and risk assessment James Cook University of North Queensland/Australian Institute of Marine Science,
- 1999. 1st Class honours "Environmental Law and Policy"
- 1993: BSc Honours, Chemistry and Microbiology, University of Tasmania/ CSIRO Marine Laboratories.
- 1992: BSc, Chemistry and Marine Science, University of Melbourne

Number of peer- reviewed publications and patents	Journal articles	Books, book chapters, books edited	Conference proceedings	Patents
	20	2	7	0

Dr Lynn Booth
Toxicology Laboratory Manager
boothl@landcareresearch.co.nz

Lynn has conducted research into the bioavailability of contaminants in soils to soil invertebrates and development of ecological soil screening levels; and determination of the toxicity and fate of vertebrate pesticides and their metabolites in soil, baits, and water. Lynn is currently involved in vertebrate pesticide research and manages the Toxicology Laboratory at Lincoln, which provides residue analysis of vertebrate pesticides in various matrices as a service to a wide range of clients including local councils and government organisations.

- **Expertise / Skills**
  - Toxicology
  - Vertebrate pesticide degradation pathways
  - Bioavailability of contaminants

- **Experience / Work History**
- 2006 – Current : Landcare Research
  Toxicologist.
  Lynn's current role is manager of the Toxicology Laboratory which carries out analytical services to support major research projects, and contract analyses. Lynn is involved in development of new methods for pesticide residue analysis, writing reports, completing analytical/scientific tasks to schedule, liaising with clients and acquiring analytical contracts. Lynn also works on research projects, in particular undertaking toxicity testing using soil invertebrates.
- 2003-2005: Environmental Toxicologist, Landcare Research
  Environmental Toxicologist
  Working on pesticides, soil contaminants and invertebrates, bioavailability of contaminants in soils and remediation of contaminated sites.
- 2001-2002: Oklahoma State University and Ohio State University, United States
  Postdoctoral Fellow
  Bioavailability of contaminants in soils to soil invertebrates and development of ecological soil screening levels (EcoSSLs)
- 1996-2001: Landcare Research
  Research Scientist

- **Qualifications**
- 2002: PhD, Environmental toxicology, Lincoln University,
- 1994. MSc (Hons) Biochemistry, University of Canterbury
- 1991: BSc, Biochemistry, University of Canterbury

Number of peer- reviewed publications and patents	Journal articles	Books, book chapters, books edited	Conference proceedings	Patents
	29	5	8	0

Dr Bryan Stevenson
Researcher
stevensonb@landcareresearch.co.nz

Bryan's expertise centres on soil biogeochemistry (particularly carbon, nitrogen and phosphorus cycling) and microbial interactions in defining soil quality in New Zealand's managed and native ecosystems.

- **Expertise / Skills**
  - Biogeochemistry
  - Soil C and N cycling
  - Microbial ecology
  - Soil quality
  - Pedology

- **Experience / Work History**
- 2005 – Current : Landcare Research

Researcher
Bryan 's research area focuses around soil biogeochemical processes how soil microbes, carbon and nutrients interact. Primary research involves C and N cycling and microbial interactions in New Zealand pastoral and native ecosystems. Projects include measuring denitrification rates in agronomic systems, using stable isotopes (^{15}N) as an indicator of fractionating N loss from ecosystems, quantifying labile C and N fractions, and investigating microbial functioning on a landscape scale. He is also involved in measuring soil quality (and defining soil quality indicators) at regional and national scales for environmental reporting.

- 2003-2005: Postdoctoral Research Associate Desert Research Institute. Reno, Nevada USA
- 2001 – 2003: Postdoctoral Research Associate, Landcare Research Hamilton.
- 1999 – 2001: Environmental Soil Scientist. Sugnet and Associates. Denver Colorado.

- **Qualifications**
- 1997: PhD, Soil Science. Colorado State University. Fort Collins Colorado, USA
- 1993: MS Rangeland Ecosystem Science, Colorado State University. Fort Collins Colorado, USA
- 1986: BA Zoology and Environmental Science. University of California, Santa Barbara, Santa Barbara California, USA.

Number of peer- reviewed publications and patents	Journal articles	Books, book chapters, books edited	Conference proceedings	Patents
	27	2	25	0

Matthew Campion
Laboratory technician
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Expertise / Skills

- Experience with a range of lab instrumentation and techniques:
  - Chromatography: GC, GC/MS, HPLC, Ion exchange, Gel Permeation.
  - Spectroscopy: AAS, UV/VIS, IR, NMR.
  - Wet chemistry and organic synthetic techniques.
- Extensive knowledge of laboratory standards, safe work practices and the implementation of quality systems:
  - Hazardous Substances and New organisms Act 1996.
  - ISO/IEC 17025: General requirements for the competence of testing and calibration laboratories.
  - Good Laboratory Practice.
- Excellent experimental and report writing skills.
- Tidy and meticulous, with a focus on attention to detail and the delivery of timely results.

Qualifications

- 2009-2011: Graduate Diploma in Toxicology, Royal Melbourne Institute of Technology.
- 2005: Graduate Diploma in Laboratory Technology, Christchurch Polytechnic Institute of Technology:
- 2001-2003: Bachelor of Science (Biochemistry major), University of Canterbury:
- Additional onsite and offsite training has also been received in Gas Handling (BOC), Laboratory Accreditation (IANZ) and GC/MS instrument operation and maintenance (Agilent).

Experience / Work History

- June 2006 – present: Landcare Research

Toxicology Laboratory Technician

  - Operation and maintenance of various types of chromatographic equipment and data capture systems/software. These include GC, GC/MS, HPLC, Ion Exchange and Gel Permeation.
  - Undertaking and managing analyses of pesticides following standard methods and instructions. Extraction of toxins from a range of biological materials and matrices.
  - Method development and validation.
  - Meeting GLP and quality assurance requirements in accordance with laboratory accreditation.
  - General upkeep of the laboratory including specification and purchasing of lab consumables.
  - Research and contribution to Landcare Research publications.

Alex McGill
Laboratory technician
mcgilla@landcareresearch.co.nz

Alex's role includes the collection of soil in the field, sample preparation and analysis. Much of the work involves studying C and N dynamics under different conditions, the movement of dairy shed effluent through various soil types and microbial studies.

- **Expertise / Skills**
  - C and N interactions
  - Bypass flow of DSE
  - Soil quality

- **Experience / Work History**
- 1997 – Current : Landcare Research

  Technician

  In Alex's time at Landcare Research a large body of work has focused on studying chemical and biological changes in dairy farming soils. Some of the research has focused on greenhouse gas emissions, in particular nitrous oxide production, N cycling and leaching.
  A large ongoing project has involved the study of microbial transport through soils irrigated with dairy shed effluent. This has led to a spatial soils database with shows the potential, high to low, for a soil to leach microbes.

- **Qualifications**
- 1996: BSc, Hydrology and Ecology, University of Waikato

Number of peer- reviewed publications and patents	Journal articles	Books, book chapters, books edited	Conference proceedings	Patents
	13	0	3	0