Sediment source analysis using the CSSI technique - Whangamarino Wetland

Prepared for Department of Conservation

June 2016

Prepared by:
Dr Max Gibbs

For any information regarding this report please contact:

Dr Max Gibbs
Water Quality Scientist
Freshwater Ecology
+64-7-856 1773
max.gibbs@niwa.co.nz

National Institute of Water & Atmospheric Research Ltd
PO Box 11115
Hamilton 3251

Phone +64 7 856 7026

NIWA CLIENT REPORT No:	HAM2016-078
Report date:	June 2016
NIWA Project:	DOC16203

Quality Assurance Statement		
	Reviewed by:	Andrew Swales
	Formatting checked by:	Alison Bartley
	Approved for release by:	Andrew Swales

Cover Photo: Sediment from the winter flood event drying on the side of the Pungarehu Stream near site M1 [Photo by Max Gibbs, 2 December 2015].

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Executive summary

Following the appeal by Integrated Catchment Management, Waikato Regional Council, of the conditions for consent 101727 relating to the discharge of water from Lake Waikare into Whangamarino Wetland, the Department of Conservation requested that NIWA undertake a study to:

- Confirm the % contribution of the Lake Waikare discharge to sediment deposition across a range of sites in the Whangamarino Wetland.
- Evaluate the spatial variation of Lake Waikare sediment deposition, in relation to what is known about the discharge of water under consent 101727.

Within this study, there were two specific tasks:

1. to provide further information about some of the locations in Whangamarino Wetland where Lake Waikare sediment is observed, and
2. to indicate the results are repeatable.

The sampling strategy was to use selected sites, including some of those specified in the proposed monitoring conditions for consent 101727 near Pungarehu Stream and some further downstream adjacent to the Whangamarino River.

Sampling was completed in December 2015 after the winter flood waters had receded.

The results showed that the proportional contributions of Lake Waikare sediment at most of the sites sampled through the Whangamarino Wetland were greater than 20% with the highest proportional contribution of 58 ±2%. This site coincided with a zone several hundred metres downstream of the farm bridge where the Pungarehu Stream channel is particularly shallow and where substantial deposition of fine suspended sediment discharged from Lake Waikare is occurring.

The data indicated that there was likely to be around 20% Lake Waikare sediment in the Whangamarino River water below the confluence with the Pungarehu Stream during flood events.

The triplicate sample results demonstrated that the CSSI method was repeatable with an error term of about ±2% for a 95% confidence level. This means the CSSI method can be used as a compliance monitoring tool.

1 Introduction

1.1 Context

The Department of Conservation administers a substantial area of the Whangamarino Wetland as a Government Purpose Wetland Management Reserve. The wetland is also designated as a wetland of International Importance under the Ramsar Convention.

Whangamarino Wetland receives water from Lake Waikare as part of the Lower Waikato Waipa Flood Protection Scheme, with the discharge of water relating to resource consent 101727. Lake Waikare holds back water from the lake catchment during high flow events in the Waikato River. To extend the capacity of the flood protection scheme to store water, a canal was constructed in 1963 from Lake Waikare into the Whangamarino Wetland linking into the Pungarehu Stream, which flowed naturally into the wetland. This canal is known as the Pungarehu Canal and the flow through it from Lake Waikare to the Whangamarino Wetland is controlled by a bottom opening control gate, known as the Northern Outlet Control Gate (NOCG). The NOCG is located at the Lake Waikare end of the Pungarehu Canal (Figure 1). It has been estimated that on average approximately 20,000 tonnes/yr of sediment is discharged into the Pungarehu Canal from Lake Waikare (Jacobs 2015).

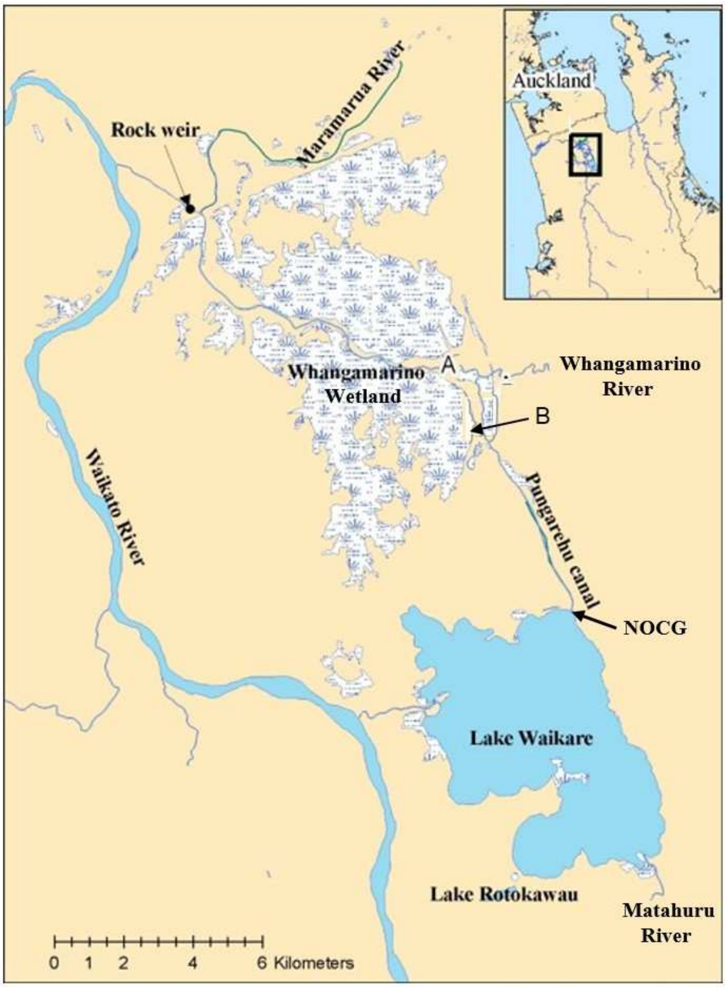

Figure 1: Site map of Lake Waikare and the Whangamarino Wetland with the interconnecting Pungarehu Canal. NOCG = Northern Outlet Control Gates; sampling sites: A = 28 April 2008; B 14 Jan 2010.

Presently at issue is the amount of sediment discharged from Lake Waikare that is depositing in Whangamarino Wetland, especially in the wetland habitat in proximity to Pungarehu Stream (Figure 2), and how to mitigate the adverse effects of that sediment in the wetland. Two previous studies by NIWA have applied the compound specific stable isotope (CSSI) technique to provide information about contemporary and historical sources of sediment accumulating in in Whangamarino Wetland (Gibbs, 2009, Reeve et al. 2010). These studies determined that sediment from Lake Waikare was accumulating in the wetland and was present in substantial amounts in an area of the wetland near the discharge from the Pungarehu Canal and in lesser amounts in an area near the confluence with the Whangamarino River (Figure 1). These data are consistent with sediment monitoring by Waikato Regional Council (WRC) that implied that there is a diminishing proportion of sediment from Lake Waikare downstream of the confluence.

A WRC hearing of an S128 review of Conditions 6 to 11 inclusive of resource consent RC101727 to discharge water from Lake Waikare for lake level control was held at Te Kauwhata on 11th to 15th May 2015. The Hearing Commissioners made a decision, which included a revised set of monitoring conditions. One of those monitoring conditions required the use of the CSSI sediment tracing technique as a compliance monitoring tool. The relevant extract from document 1-346981, Lake Waikare S128 Review Decision Report with Conditions from the Waikato Regional Council Hearing Committee, dated 05/08/2015 states:

Paragraph 47

Within six months of this condition commencing, the consent holder shall carry out the following monitoring:

a) Surveys of the level and rate (mm/yr) of sediment deposition and the proportional (%) contribution of the Waikare discharge to sediment deposition at six transects as indicated in Attachment B of this consent. The methods for monitoring sediment deposition shall be:

ii. The proportional (%) contribution of sediment deposited from the Lake Waikare Discharge shall be assessed at 24 sites (Sites M1 to M12 and Sites F1 to F12) located as shown on the six transects as indicated in Attachment B. Surveys shall be conducted in 2016 and 2017 and then every two years thereafter. The methods utilised shall include the Compound-Specific Stable Isotope (CSSI) technique as detailed in the protocols produced by Dr Gibbs in NIWA Client Report HAM2010-129. The methods of sampling shall be documented and made available the Waikato Regional Council and the Liaison Group established in condition 16 on request.

The attachment B referred to is given in Figure 2

This condition has been appealed by Integrated Catchment Management, Waikato Regional Council.

While the CSSI technique (Gibbs 2008) has been used in more than twenty studies in New Zealand and adopted in about 40 other countries, the paragraph 47 condition of the Lake Waikare S128 Review Decision will be the first time that the CSSI method has been used as a consent compliance monitoring tool. Consequently, although information regarding the sources of sediment depositing in the wetland has previously been provided using the CSSI technique (Gibbs 2009, Reeve et al. 2010), it was considered appropriate by the Hearing Committee that additional sampling from a greater range of sites would reduce uncertainty of the sediment contribution due to operation of consent 101727.

Department of Conservation has asked NIWA to do this work.

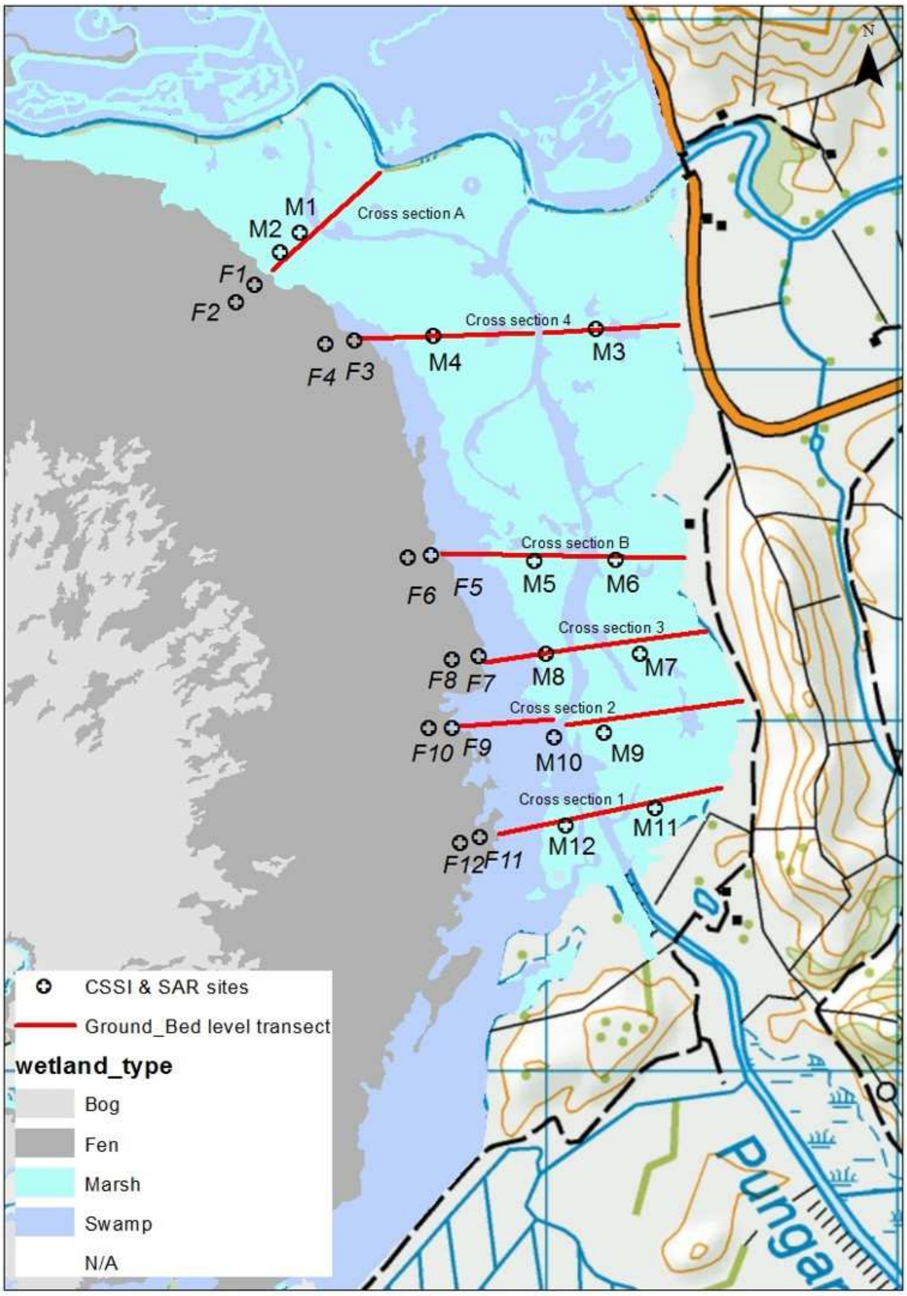

Figure 2: Attachment B schematic diagram of the wetland area near Pungarehu Stream showing the 24 specified sampling sites for monitoring under proposed condition 47(a) ii.

1.2 Objectives

On the basis of the Lake Waikare S128 Review Decision Report, the Department of Conservation have commissioned NIWA to:

- Confirm the % contribution of the Lake Waikare discharge to sediment deposition across a range of sites in the Whangamarino Wetland.
- Evaluate the spatial variation of Lake Waikare sediment deposition, in relation to what is known about the discharge of water under consent 101727.

The specific tasks were:

1. to provide further information about some of the locations in Whangamarino Wetland where Lake Waikare sediment is observed, and
2. to indicate the results are repeatable.

2 Methodology

With the exception of the lake sediment sample, which was collected on 14 December 2015, all samples were collected on 2 December 2015.

2.1 Sampling

To achieve the above objectives, sediment was collected from the Whangamarino River upstream of the Falls Road Bridge and from the Pungarehu Canal near the farm bridge just before the Lake Waikare water discharges into the Whangamarino wetland, as the **source samples**.

The spatial sediment samples were collected from different deposition locations across the wetland and downstream towards the weir, as the **mixture samples**. The sampling locations are shown in Figure 3 and listed in Table 1.

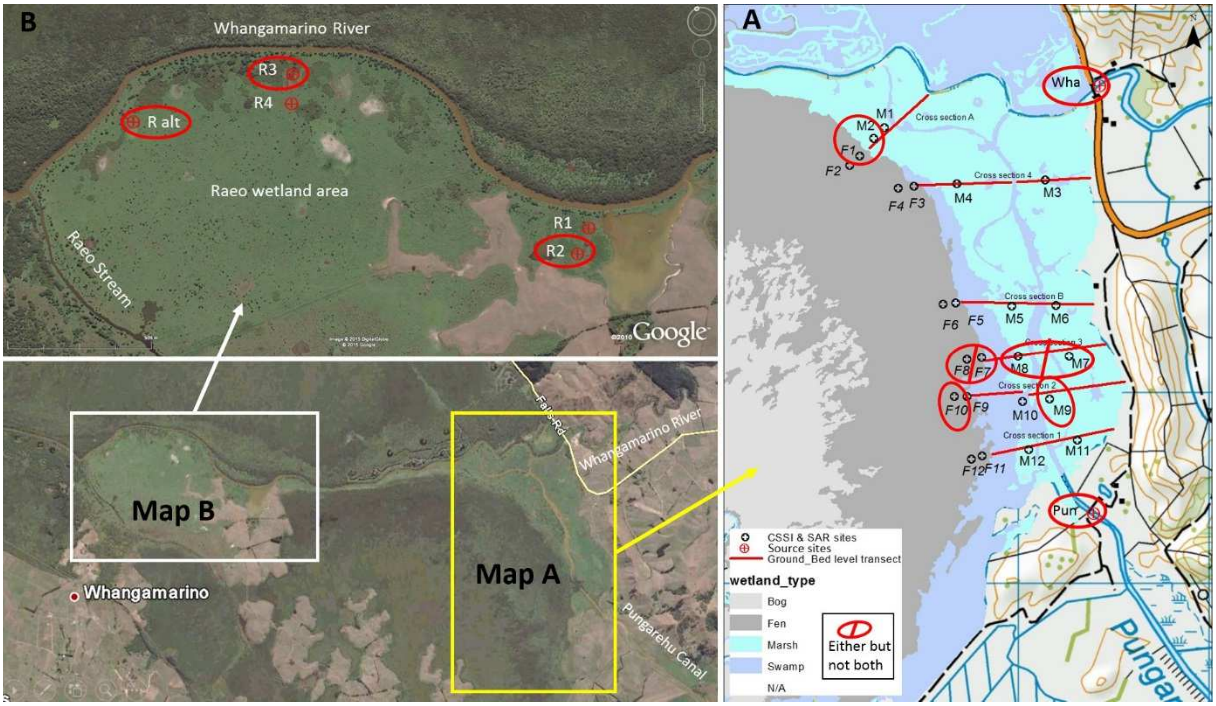

Figure 3: Sampling locations as per the sampling strategy in Table 1. The base map lower left shows the relative positions of the more detailed maps A and B in the Whangamarino Wetland. Red ellipses in parts A and B are the sites to be sampled. Red ellipses with a slash between two site numbers allowed either one of those sites to be sampled but not both.

Table 1: Sampling site schedule showing the actual sample collected with GPS coordinates in NZMT2000 format. Site numbers are as per those shown in Figure 3.

Transect/site	Site ID	Easting	Northing	No. samples	Basis
Task 1					
Raeo	R2	1787938.2	5865053.9	1	Sites slightly further away from river
Raeo	R3	1788823.8	5865872.1	1	Sites slightly further away from river
Raeo	R alt	1788312.4	5865992.8	1	Additional site to provide spatial coverage in similar position to R2 and R3
Cross Section A	M2	1787828.7	5864455.1	1	Marsh site - west of Pungarehu - in zone previously with ~ 10% Waikare contribution
Cross Section A	F1	1787792.1	5864405.9	1	Fen site
Cross Section 2	M9	1788683.3	5864946.6	1	Marsh site - east side of Pungarehu
Cross Section 2	F10	1788528.2	5864948.2	1	Fen site west of Pungarehu - similar location to F8 and F1
Cross Section 3	M8	1788629.2	5865169.8	1	Marsh site- west side of Pungarehu
Cross Section 3	F8	1788565.3	5865152.7	1	Fen site west of Pungarehu - similar location to F10 and F1
Whangamarino R.	Wha Source	1787594.2	5864800.8	1	Upstream of Falls Road bridge - sediment source sample
Pungarehu /L. Waikare	Pun Source	1788796.3	5864653.5	1	Lake Waikare sediment sample in area near NOCG
		Sub-total (sites)		**11**	
Task 2					
Additional samples				6	3 sites selected to do in triplicate to indicate results consistent (Pungarehu source site, and two wetland sites). Sites chosen = F8 and M9
		TOTAL		**17**	

A 4.2 m aluminium pontoon boat was used to access the sampling sites. The main stem of the Whangamarino River was easily navigable, as was the lower end of the Pungarehu Stream between site M6 and the confluence. The water depth in the stream section between M6 and M12 was, however, no more than ~0.5 m causing frequent groundings. These observations would suggest that the stream section and adjacent wetland between M6 and M12 may be a key deposition zone for fine suspended sediment discharged from Lake Waikare and passing through the Pungarehu Canal.

2.1.1 Wetland sampling

Sediment samples were collected in the wetland using a 100 mm ID hand corer (Figure 4). This device was twisted into the ground allowing the teeth to cut through roots and plant stems to take a sediment divot. Although the corer blade was 40 mm deep, only the top 20 mm of each divot was retained and the remainder was cut off and discarded before ejecting the sample to be retained from the corer body. Where it was not possible to use the hand corer due to a hard substrate, the sediment was scraped off using a nylon trowel. At each site, 10 such divots were combined in a bucket, mixed and about a 400 g aliquot was placed in a zip-lock type plastic bag. This bag was placed inside a second zip-lock type plastic bag with a label inside the outer bag, facing out. The double bagged sample was placed in a chilli bin in the dark for transport to the laboratory.

Figure 4: Hand operated corer (right-yellow) has an internal plunger to eject the soil plug from the corer. The soil plug taken (left) may include plant roots, which will be removed before analysis.

2.1.2 Canal/Lake sampling

The sampling attempt in the Pungarehu Canal at the farm bridge failed because there was no collectable sediment on the canal bed and no deposition sites on the sides of the canal which weren't compromised by bank erosion due to stock movement or back flushing from the wetland adjacent to the canal. The canal bed appeared to consist of hard clay with small (<10 mm) sharp gravel. The source of this gravel is uncertain but may have originated from the western bank of the canal, which appeared to have been amended with gravel and stones at some time (Figure 5). This material was not present on the eastern bank and is therefore mostly likely to have been introduced, possibly as a base course for a farm road or access road during the construction of the canal.

Figure 5: Western side of the Pungarehu Canal between the farm bridge and the Whangamarino wetland has a thick layer of gravel and stones. This material was not present on the Eastern side of the canal.

Because there was no collectable sediment on the bed of the Pungarehu Canal, the sediment source mixture sample was taken in Lake Waikare about 100 m from and in line with the NOCG. This sampling site had a 20 to 50 mm layer of fine, easily suspended soft mud on the surface (Figure 6), which was considered to be representative of the fine sediment being transported through the Pungarehu Canal.

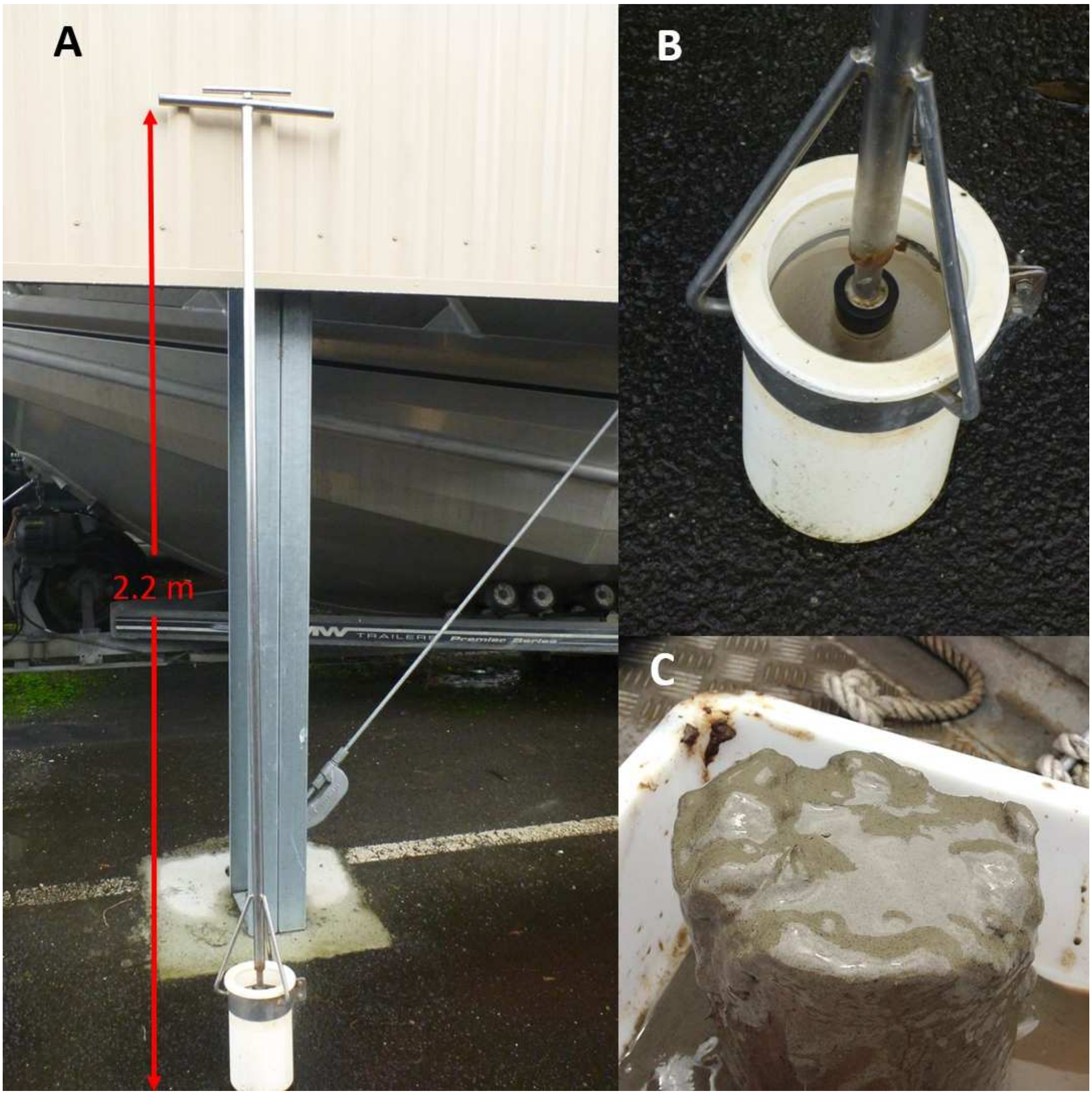

Figure 6: A) Long handled (2.2 m) sediment sampler with a 150 mm diameter ID corer and a central plug actuator. (B) the core barrel plug assembly and (C) is a sediment core showing the soft mud on the core surface.

In use, the central plug actuator was raised to allow water to escape as the core barrel was pushed into the mud, and then held closed to allow the sediment sample to be pulled out of the lake bed by the suction inside the core barrel. The surface layer from four cores were combined in a bucket and about a 400 g aliquot was double bagged, as described above, and placed in a chilli-bin in the dark for transport to the laboratory.

2.2 Analysis

The analytical methodology used was essentially the same as described in Gibbs (2009) and Reeve et al. (2010). Large plant fragments including roots, sticks and leaves were hand-picked and removed, along with stones and insects. Samples were freeze dried and sieved to remove any large particles. The sieving also has the effect of completely mixing the dried sample.

2.2.1 Bulk carbon for $\delta^{13}C$

An aliquot of each sample was acidified, with 1 N hydrochloric acid (HCl) to remove inorganic carbonates. Acid was added as a step-wise procedure until the addition of acid did not produce any further effervescence. The sample was rinsed with distilled water to remove any residual HCl, before drying at 50 °C in an air fan oven and grinding into a fine powder in a mortar and pestle. The acidified samples were sent to the NIWA Stable isotope facility at Greta Point, Wellington for analysis of carbon content as %C and bulk carbon isotopic signature as $\delta^{13}C$ on a continuous flow, isotope ratio mass spectrometer (CF-IRMS).

2.2.2 Compound Specific Stable Isotopes

An aliquot of non-acidified sediment from each sample was extracted in a Dionex Accelerated Sample Extractor (ASE200) using dichloromethane (DCM) at 100°C and 2000 psi, two cycles per sample, to extract the fatty acid biomarkers from the sediment samples. The fatty acid extracts were dried at 35°C and then converted into non-polar fatty acid methyl esters (FAMEs) using 5% Boron trifluoride catalyst in analytical grade methanol. The FAMEs were extracted from the derivatisation mixture, dried under a stream of pure nitrogen gas before being sent the University of California at Davis Stable Isotope Facility (UC Davis SIF) to be analysed for the suite FAMEs representing the fatty acids from carbon chain length 14 to 24 i.e., C14:0 to C24:0. The methanol used for the derivatisation step was analysed for bulk $\delta^{13}C$ to allow the isotopic value of each FAME to be converted back to its fatty acid value.

2.2.3 Modelling and interpretation

The $\delta^{13}C$ isotopic signatures of the bulk soil and the fatty acids extracted from the soil were collated with the %C values into a table, and the proportional contribution of each source to each mixture sample was determined using a two-endmember linear mixing model. This model assumes that the $\delta^{13}C$ isotopic values of the downstream site sediment mixture is the sum of the $\delta^{13}C$ isotopic values of inputs from each upstream source, A and B, where A can be the tributary and B can be the main stem of the river.

$$\delta^{13}C\text{mixture} = fA\delta^{13}CA + fB\delta^{13}CB \qquad 1$$

Where fA and fB are the fractions or proportions of each source. This equation can also be rewritten

$$1 = fA + fB \qquad 2$$

To solve for fA, the equation is rewritten as:

$$fA = (\delta^{13}C\text{mixture} - \delta^{13}CB)/(\delta^{13}CA - \delta^{13}CB) \qquad 3$$

and for fB, the equation is rewritten as:

$$fB = (\delta^{13}C\text{mixture} - \delta^{13}CA)/(\delta^{13}CB - \delta^{13}CA) \qquad 4$$

The caveat for the two-endmember mixing model is that the $\delta^{13}C$ value of the mixture must be between the $\delta^{13}C$ values of the sources A and B. Theoretically, this will always be the case. However, because we are dealing with a wetland ecosystem where the sediments are being deposited from two rivers at different flows under flood conditions onto an existing plant community, there can be variability in the isotopic signatures in the deposition zone mixtures. When the isotopic signatures of the tracers are similar, the two-endmember mixing model will allow some combinations of fatty acids to fall outside this criterion and result in non-valid values for f.

To assess the source contribution at each location, the two-endmember mixing model was applied to each tracer in turn and then the full suite of results were averaged to provide the best estimate with an estimate of uncertainty provided by the standard deviation about the mean.

3 Results

3.1 Task 1

Provide further information about some of the locations in Whangamarino Wetland where Lake Waikare sediment is observed

The results of the spatial modelling of the CSSI and bulk $\delta^{13}C$ isotopic data (Table 2) show that there is a high contribution of sediment from Lake Waikare at sites near the discharge of the Pungarehu Canal into the Whangamarino Wetland. They also show a reducing contribution of Lake Waikare sediment at downstream sites along the Whangamarino River, and that sediment was spreading into the fen habitat.

Table 2: Proportional contribution of Lake Waikare and Whangamarino River sediment at the selected sampling site in the Whangamarino Wetland. (n = the number of isotopes that produced valid results).

Site	% Waikare	%Whangamarino	SD (%)	n
R Alt	7.3	92.7	-	1
R3	13.3	86.7	11.2	6
R2	38.3	61.7	8.2	5
M2	19.7	80.3	14.7	5
F1	4.9	95.1	3.5	7
M8	22.1	77.9	10.3	6
F8 Rep A	24.3	75.7	9.9	8
F8 Rep B	26.2	73.8	5.1	6
F8 Rep C	25.5	74.5	9.1	8
M9 Rep A	59.0	41.0	11.2	5
M9 Rep B	57.4	42.6	13.2	7
M9 Rep C	57.5	42.5	12.6	9
F10	23.1	76.9	10.3	9

The proportional contribution of Lake Waikare sediment at site M9 averaged 58%, which is comparable with the 62% estimated in the surface sediment of a core taken at the equivalent of site M10 (Figure 2) in January 2010 (Reeve et al. 2010).

For most mixture sites, the two-endmember mixing model produced at least 5 valid results that could be averaged and a standard deviation determined. The exception was site 'R Alt' where only one valid result was produced. The reason for this is unknown but may be due to that site receiving a high proportion of sediment from local farm runoff rather than from the Whangamarino River.

More information on the proportional distribution of Lake Waikare sediment through the wetland is obtained when the results (Table 2) are plotted in their relative positions on a schematic of the wetland and river system (Figure 7). There is an apparent spatial distribution pattern of elevated Lake Waikare sediment contributions of greater than 20% from the Pungarehu Canal down the Pungarehu Stream and down the Whangamarino River below its confluence with the Pungarehu Stream. Once the water from Lake Waikare has fully mixed with the Whangamarino River water, the proportional contribution of sediment from each source should be relatively constant from that point on downstream. This implies that for the time period assessed (i.e., top 2cm wetland soil) the Whangamarino River transported on average about 20% Lake Waikare sediment during high flow events with the NOCG open.

The higher proportion of Lake Waikare sediment at site R2 than R3 may reflect the proportional contributions from earlier flood events, i.e., the hand corer may have sampled too deep and was not of an equivalent 20mm sample (and therefore may reflect sediments from previous flood events). While this result can be considered an outlier, it is consistent with expectation that sediment from Lake Waikare is moving down the Whangamarino River and spilling into the wetland during high flow events, and therefore does not affect monitoring interpretation when examined in conjunction with other sample sites.

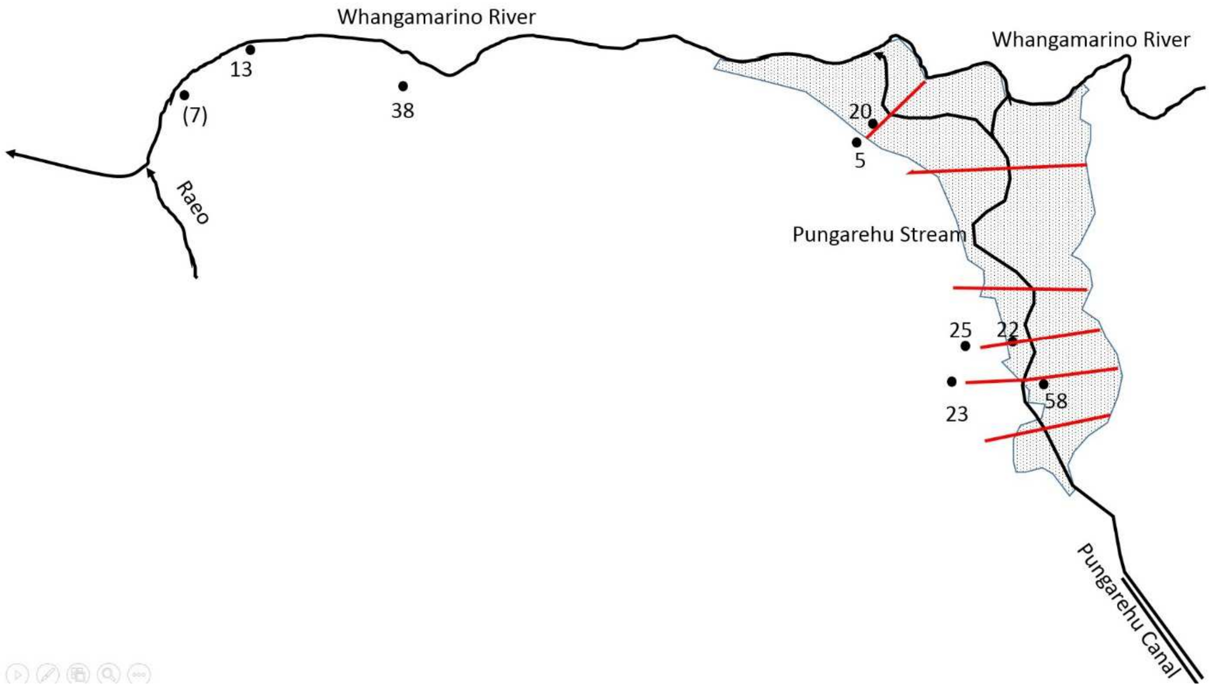

Figure 7: Schematic diagram of the Whangamarino wetland showing the proportional contribution of Lake Waikare sediment (%) at the sampling locations. The shaded area is the marsh area from Figure 2 and the red lines are the transect lines from that figure. Black dots are the sample positions for this study. The value in parentheses has high uncertainty as the two-endmember mixing model produced only one valid result for this site

Because these elevated proportional contributions are outside of the stream channel, they are likely to be sediment deposited during the 2015 winter flood event which overtopped the river banks. This is supported by observations of high water levels marked by silt lines on the sides of duck shooter Maimai structures (Figure 8).

Observations of channel siltation in the Pungarehu Stream between sites M6 and M12 may indicate that this is likely to be one of several key drop out zones for sediment from the Pungarehu Canal, and is consistent with the higher proportional contributions of Lake Waikare sediment at site M9.

Figure 8: High water marks are clearly visible on the side of this Maimai near site 6 in the Pungarehu Stream. To form a silt line, the water level had to be steady at that level for several days.

3.2 Task 2

Indicate the results are repeatable.

The analytical results for the triplicate analyses of samples from three sites (i.e., F8, M9, Lake) show good agreement with low standard deviations between most of the isotopic tracers in the samples, but also show that some isotopic tracers were more variable than others (Table 3). Because the larger standard deviations are for different isotope tracers (except C14:0), the cause is unknown. However, when the full data sets of isotopic tracers were used in the two-endmember mixing model, the results for site F8 are 25.3 ± 0.9 % and for site M9 are 58.0 ± 0.9 of sediment from Lake Waikare. This suggests that the proportional contribution estimated using the two-endmember mixing model are within ±1 for a 68% confidence level (one standard deviation) and within ±2 for a 95% confidence level (two standard deviations).

These results indicate that the results are repeatable within those limits.

Table 3: Triplicate sample analyses with means and standard deviations about the mean for bulk δ^{13}C and key fatty acid biomarkers. Yellow highlighted cells indicate standard deviations that could cause increased uncertainty.

Site	%C	δ^{13}C	C12:0	C14:0	C16:0	C18:0	C18:1	C18:2	C20:0	C22:0	C24:0
F8 Rep A	20.85	-28.54	-28.33	-32.61	-32.90	-30.26	-31.91	-30.82	-31.95	-31.03	-31.05
F8 Rep B	20.76	-28.78	-27.03	-31.59	-31.93	-29.67	-31.27	-30.72	-31.65	-30.81	-30.67
F8 Rep C	20.49	-28.58	-28.72	-32.74	-32.91	-30.06	-30.94	-30.84	-31.64	-30.77	-30.78
Mean	20.70	-28.63	-28.03	-32.32	-32.58	-30.00	-31.37	-30.80	-31.75	-30.87	-30.83
SD	0.19	0.13	0.88	0.63	0.57	0.30	0.49	0.07	0.18	0.14	0.20
M9 Rep A	6.93	-25.49	-26.83	-28.54	-26.37	-29.22	-27.78	-29.26	-32.16	-31.11	-29.32
M9 Rep B	6.99	-25.49	-26.92	-28.58	-27.01	-26.87	-27.41	-26.57	-31.60	-31.04	-29.12
M9 Rep C	6.91	-25.51	-26.77	-28.29	-25.96	-28.32	-27.18	-26.17	-30.40	-30.15	-28.80
Mean	6.95	-25.50	-26.84	-28.47	-26.45	-28.13	-27.46	-27.33	-31.39	-30.77	-29.08
SD	0.04	0.01	0.07	0.16	0.53	1.19	0.30	1.68	0.90	0.53	0.26
Lake Rep A	5.16	-26.07	-23.33	-23.55	-21.54	-24.56	-25.42	-22.09	-28.62	-27.31	-24.37
Lake Rep B	4.90	-26.24	-23.52	-24.99	-24.08	-24.91	-26.76	-22.78	-28.18	-26.29	-23.86
Lake Rep C	5.08	-26.07	-23.32	-24.53	-22.77	-23.90	-26.90	-22.93	-28.24	-27.08	-23.79
Mean Lake	5.05	-26.13	-23.39	-24.36	-22.79	-24.46	-26.36	-22.60	-28.35	-26.89	-24.01
SD lake	0.13	0.10	0.11	0.74	1.27	0.51	0.82	0.45	0.24	0.53	0.32

4 Conclusions

The investigation of the spatial distribution of Lake Waikare sediment in the Whangamarino Wetland confirms that sediment from Lake Waikare is entering the wetland. It also determined that fine suspended sediment from Lake Waikare is being deposited in the wetland at considerable distance from the main river and stream channels during flood events. The extent of dispersion is at least as far down the Whangamarino River as the Raeo Stream confluence and probably further.

Triplicate analysis of selected samples showed that the measurements at a location were repeatable with an expectation of an error term of ±2% for a 95% confidence limit.

5 Acknowledgements

The design of this study was developed with Dr Hugh Robertson, Department of Conservation. David Bremner and Greg Olsen (NIWA) assisted with the field work. Greg Olsen also processed the samples ready for analysis.

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