# Whangamarino Wetland pilot study: sediment sources

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**March 2009**

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## Max Gibbs

*Prepared for*

## Department of Conservation

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National Institute of Water & Atmospheric Research Ltd
Gate 10, Silverdale Road, Hamilton
P O Box 11115, Hamilton, New Zealand
Phone +64-7-856 7026, Fax +64-7-856 0151
www.niwa.co.nz

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*Reviewed by:* *Approved for release by:*

A. Swales D. Roper

*Formatting checked*

A. Bartley

# Executive Summary

The Whangamarino wetland is receiving fine sediment inputs which appear to be adversely affecting sensitive wetland plant communities in this Ramsar-listed wetland. The Department of Conservation commissioned NIWA to undertake a pilot study to assess the efficacy of methods for determining the sources of sediment deposited in the Whangamarino wetland and to gather preliminary data on sedimentation.

Anecdotal evidence links enhanced sedimentation to engineering structures such as the Pungarehu Canal, that was built in the 1960s to drain Lake Waikare, and a control weir on the Whangamarino River below the confluence with the Maramarua River which was built in 1994 but was washed out in 1995 then reinstated in 2000. However, there is a lack of understanding about how these structures may have influenced wetland sedimentation, and there is no information available on the sediment sources and sinks or the sediment accumulation rates (SAR) in the wetland.

This report presents the findings of a pilot study using stable isotope forensic techniques to determine the likely sources of sediment being deposited in a low lying portion of the wetland (the herb block) adjacent to the Pungarehu Stream and Whangamarino River, near Falls Road. The study used sediment taken from the stream channels of the Whangamarino River and its tributaries upstream of Falls Road, as well as suspended sediments collected from the stream network and Pungarehu Canal during the June to October 2008 flood event.

The results indicate three main sources of sediment: 1) the steep hill country of the Hapuakohe Range at the headwaters of the Whangamarino River catchment; 2) the low grasslands on lowland alluvial plains adjacent to the Waerenga Stream which are periodically used for crops such as maize; and 3) Lake Waikare via the Pungarehu Canal.

Sediment runoff from the lowland alluvial plains is likely to be an intermittent source associated with tillage and bare soil exposure between crops and replanting in grass.

While the steep hill country and low grasslands are continuous sources of sediment to the wetland, the sediment load from Lake Waikare can only enter the wetland when the control gate is open. As there are no flow data for the Whangamarino River / Lake Waikare/ Waikato River flood diversion system, mean annual flood flow data from a NIWA water resources model was used to determine the relative sediment loads in the Whangamarino River at fall Road and from Lake Waikare via the Pungarehu Canal as it discharges into the Whangamarino wetland. On the day of sampling during the June to October 2008 flood event, about 90% of the sediment entering the Whangamarino wetland and water course system came from Lake Waikare.

The estimated mass load of sediment from Lake Waikare of around 730 tonnes per day (t $d^{-1}$) and around 100 t $d^{-1}$ from the Whangamarino River catchment were derived from mean flood flow values from a water resources model as there is no accurate flow data available. Consequently, these estimates have a high degree of uncertainty and should be considered as indications of the relative proportions of sediments contributed from the two main sources, and not absolute values. Furthermore, the hydrographs during the June to October 2008 flood event showed substantial water level fluctuations. This implies changing water velocities that would most likely affect the suspended solids concentrations and, coupled with the uncertainty from modelled flow, it is not possible to extrapolate the sediment loading to an annual estimate.

Bulk stable isotope and compound specific isotopic evaluation of sediment sources relative to the deposited sediment in the herb block of the wetland showed the linkage between the three main sources and provided estimates of the proportional contribution of each sediment source at the surface (0-2 cm layer) and the 10-12 cm layer below the surface of the soil taken from three locations in the wetland. The three locations were sites S1, S2, and S3 at increasing distance from the open waters of the old Pungarehu Stream channel. While there was evidence of sediment attributable to the Lake Waikare source in the surface 0-2 cm layer soil at these three sites, the Lake Waikare source signature was missing from the 10-12 cm depth layer soils at sites S2 and S3. The highest proportion of sediment originating from Lake Waikare was around 14% at site S3, which was furthest from the open water course. The remainder of the sediment in the surface samples came from the steeper parts of the catchment - especially the Waerenga Stream sub-catchment - (means of 22% to 74%) and low grasslands (means of 19% to 70%). Sediment from maize and other crops contributed less than 5% to the surface sediment composition at each site.

At site S3 there was visual evidence of an earlier wetland at around the 10 cm depth below the present surface. This coincided with the sediment having no apparent contribution from Lake Waikare. If this change was related to the commissioning of the Pungarehu Canal, it would be consistent with Lake Waikare sediment only being present in the surface of this site i.e., previously those sediments were only subjected to flood waters from the Whangamarino River. It also implies a SAR of less than 2 mm per year.

At site S1, the Lake Waikare source signature was present in both the surface 0-2 cm and 10-12 cm depth layer samples. This can be interpreted to indicate a higher SAR closer to the open water courses i.e., the pre-canal sediment was at a greater depth than 10-12 cm.

An apparent anomaly of a high proportion of suspended sediment entering the Whangamarino wetland system (90%) from Lake Waikare but only a 14% contribution from that source in the soil sample in the herb block is consistent with the position of the herb block sampling site closer to the Whangamarino River inflow than the Pungarehu Canal inflow.

This pilot study demonstrates that the NIWA stable isotope forensic technique can be used to identify the likely sources of sediment being deposited at different locations in the Whangamarino wetland. It has identified three major sediment sources and shown that the technique is capable of separating the land-use sediment source contributions from sediment derived from Lake Waikare, dispersed laterally across the wetland and vertically over time. The technique determines the proportion of each source at a location as a % of the whole. Quantification requires flow-weighted concentration data or SAR data.

Examination of historical water level records from the Falls Road level recorder showed high minimum water levels in 1965 after the Pungarehu Canal was commissioned. Those records also show the lowering of Lake Waikare after 1965, an extended period of low minimum water levels, and the two attempts to raise the minimum water level in 1994 and 2000, all with the almost annual flood event from the Waikato River superimposed. This complex hydraulic regime is likely to have an equally complex sedimentation regime. To understand that sedimentation regime requires the use of sediment coring at a number of locations across the wetland relative to the two main water inflows to determine the SAR at each location. Application of the stable isotope forensic techniques to sediment from those cores would determine the relative source soil contributions at each location and provide a better understanding of how sediment is moving through the wetland. That understanding is fundamental to the development of management strategies to protect the Whangamarino wetland from further degradation and initiate a recovery.

# 1. Introduction

Department of Conservation (DoC) requested NIWA to undertake a pilot study to assess the efficacy of methods for determining the sources of sediment deposited in the Whangamarino wetland and to gather preliminary data on sedimentation.

The Whangamarino wetland is the second largest bog and swamp complex in the North Island. It is a significant habitat for wetland bird species and is a Ramsar-listed wetland. DoC have identified the ongoing deposition of sediment in the swamp and marsh (riverine influenced) areas of the wetland as one of the long term threats to the Whangamarino wetland. While there is anecdotal evidence of sedimentation in the Whangamarino there is currently no information available on the sediment sources and sinks or the rates of deposition. Engineering structures that have modified the hydrology of the wetland are also likely to affect sediment transport and deposition processes. These include the Pungarehu Canal built in the mid-1960s to drain Lake Waikare and the control weir built on the Whangamarino River below the confluence with the Maramarua River to increase minimum water levels in the wetland. Initially a rock weir was constructed in April 1994 but this was washed out in 1995. The weir was reinstated in 2000. There is a lack of understanding about how these structures may have influenced sedimentation. These key information gaps need to be filled before any options for managing sediment in the Whangamarino can be explored. It is intended that a more comprehensive study will be designed to answer specific questions based on the outcome of this pilot study.

## 1.1 Background

The Whangamarino Wetland is on the eastern side of the Waikato River and extends inland from the confluence of the Whangamarino River, just south of Mercer, to Te Kauwhata in the south. The Whangamarino Wetland has two distinct areas. The northern part around the Maramarua River is separated from the southern part by a low ridge of permanently dry farm land which extends east from the confluence of these two rivers. The southern part of the wetland, which is the focus of this study, is bisected by the Whangamarino River upstream to the confluence of the Whangamarino River with the Pungarehu Stream and drainage canal from Lake Waikare further south (Fig. 1). The headwaters of the Whangamarino River drain part of the Hapuakohe Range which separates the Waikato River valley from the Hauraki Plains further east. The headwater streams come from steep forested or pastoral land with underlying greywacke rock and then flow through almost flat unconsolidated alluvial plains or low rolling hills of volcanic clays before joining the Whangamarino River as it enters the wetland.

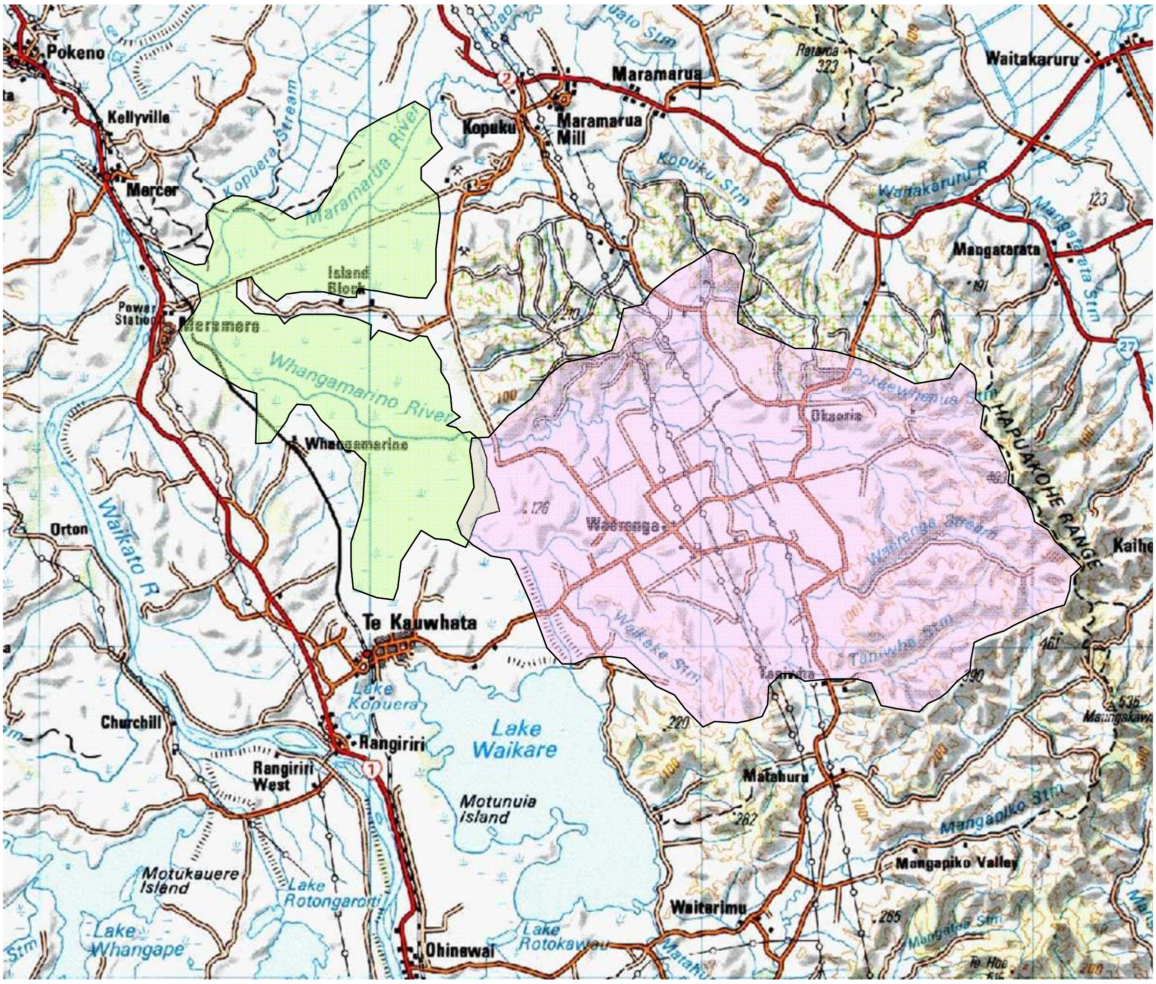



**Figure 1:** Location map showing the position and general shape of the Whangamarino Wetland (pale green overlay) and the Whangamarino River catchment upstream of the wetland (pale red overlay), relative to the major geographic feature of the Waikato River.

Under normal (majority) weather conditions the control gate on the Pungarehu Canal (Fig. 2) is closed and the Whangamarino River catchment provides almost all of the water passing through wetland. Occasional releases through the control gate under non-flood conditions are mostly confined to the canal and river channels. However, under exceptional flood-flow conditions in the Waikato River, the top of the Waikato River flood peak can be diverted into Lake Waikare via a control structure on the Te Onetea Stream at Rangiriri and subsequently into the Whangamarino Wetland system by opening the control gate on the Pungarehu Canal (Fig. 3). During these events, flood water overtops the channel banks and the swamp and marsh areas of the Whangamarino Wetland are inundated by muddy water (Fig.4) to a much greater extent spatially than would occur from local flooding in the Whangamarino River catchment. As the Whangamarino River is also likely to be in flood when the flood water diversion through the Pungarehu Canal occurs, it is uncertain where the sediment causing problems in wetland is coming from.


**Figure 2:** A) The control gate in the closed position on the Pungarehu canal. B) The Pungarehu canal flow with the control gate closed (Photos: M. Gibbs, 14 April 2008).


**Figure 3:** A) The control gate in the open position on the Pungarehu canal. B) The Pungarehu canal flow with the control gate open (Photos: M. Gibbs, 23 June 2008).


**Figure 4:** Panoramic photo time series of the inundation of the Whangamarino wetland during winter 2008, viewed from Falls Road. A) 28 April, canal gate closed; B) 23 June, canal gate open; C) 24 July, canal gate open, Waikato River about 2 m above normal. (Photos M. Gibbs).

### 1.2 Pilot study

Stable isotope based sediment tracking and source identification work by NIWA (Gibbs 2008) has demonstrated that it is possible to determine where sediment is coming from in the catchment and to apportion the contribution of sediment from different sources. This technique has previously been applied to determine the sources of present-day (i.e., surface) sediments deposited in Auckland and Coromandel estuaries and the Waituna River system (Raglan). The source identification technique uses the compound specific isotope (CSI) signature of organic biomarkers (fatty acids) that are bound to the terrigenous soils to link these to specific land-use sources in the catchment. The soil contributions from those land-uses are then apportioned using an isotopic mixing model, IsoSource (Phillips & Gregg 2003).

The sediment source component of this pilot study aims to confirm that the CSI method can identify sources and sinks of surface sediment deposits in the Whangamarino wetland. The focus will be on differentiating between contributions from Lake Waikare via the Pungarehu canal, Waerenga Stream, and other Whangamarino River catchment sources. The pilot study will not extend to the confluence between the Whangamarino and Maramarua Rivers. The Herb Block area where flows from Lake Waikare first enter the wetland will be the sediment sink of most interest during the pilot study, which will include a transect from the river into the wetland in that area (Fig. 5).


**Figure 5:** Aerial view across the Whangamarino wetland herb block towards the west from above the confluence of the Pungarehu canal with the Whangamarino River. Banding in the wetland indicates different plant communities and appear to coincide with different inundation levels and shows the extent of the riverine influence (i.e., swamp/marsh vs. bog/fen) The broken line approximates to the DoC monitoring line. The yellow markers indicate the approximate relative positions of soil samples collected on 28 April 2008. (Photo: M. Gibbs).

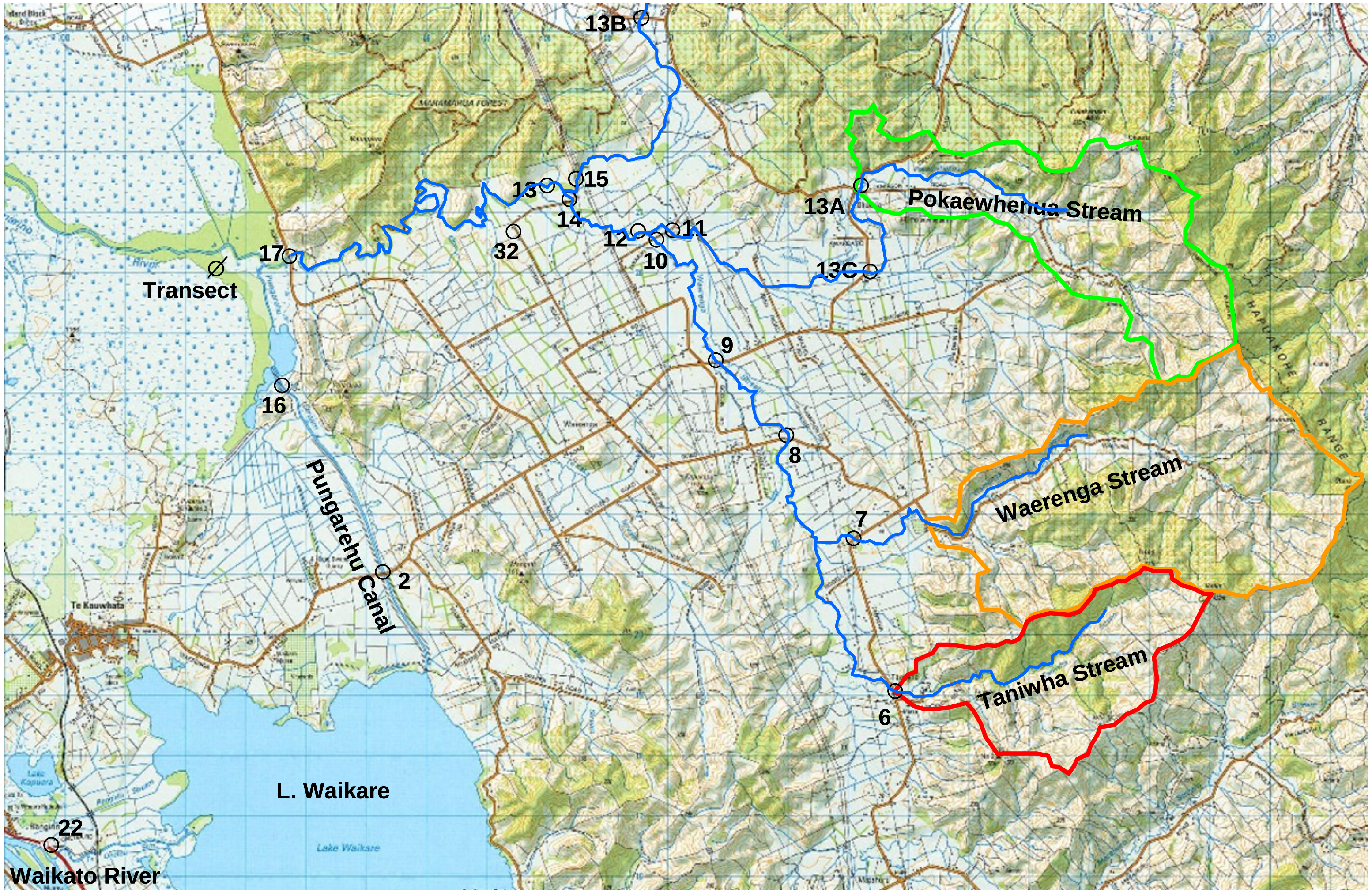



**Figure 6:** Soil, deposited sediment and suspended sediment sample locations (numbers refer to sites in Table 1) for the pilot study of the Whangamarino system. Sites 13B and 22 are just off the map in those areas. Coloured lines enclose sub-catchments referred to in the text. The main stem of the Waerenga Stream and key tributaries are defined in blue.

# 2. Methods

## 2.1 Sample collection

Sediment samples were collected from the tributaries of the Whangamarino River upstream of Falls Road bridge at road bridges (Fig. 6, Table 1), during the low flow period (19 June 2008) the week before the 2008 flood event. Several scoops of surficial material deposited in “sand-bars” in the stream bed or on the bank were combined in a sealable 5-litre plastic (PVC) bucket to produce a single bulk sample of about 2-3 kg wet sediment which was representative of each site. The wet sediment was sieved (1-mm mesh) to remove stones, insects, leaves and woody debris before analysis.

Soil samples (Table 1) were collected during a site inspection in preparation for coring along the transect line (Fig. 5) at 3 points moving away from a channel loop through the herb block west into the wetland under dry conditions (28 April 2008). These samples were taken by taking spade depth sods and placing it into a sealable plastic bucket for sectioning in the laboratory. The subsequent coring exercise was thwarted by rising water levels and sediment cores were not taken. Consequently, these three soil samples were used to indicate the sources of recent sediment deposition at that location in the wetland.

Each sample was separated in a top 2-cm layer and a layer from 10 cm to 12 cm below the surface. Plant roots and stones were removed by hand picking.

As this was a pilot study, a full library of catchment soil types was not collected. Soil samples representing the main bare-soil land-uses i.e., maize, re-grassing through maize stubble, and mustard cropping on the flat alluvial soils, were collected (Table 1). These samples were collected as multiple small samples from an area of about 10 $m^2$ and combined to produce a single bulk sample representative of each source.

During the flood event from 23 June to 1 October 2008 (e.g., Fig. 4), the opportunity was taken (24 July 2008) to collect water samples for suspended solids (SS) to enable relative sediment mass transport evaluations at the tributary sampling points and in the Pungarehu Canal (Table 1).

**Table 1:** Sample codes, site descriptions, sample type, and locations (also see Fig. 6). Suspended solid (SS) dry weights are for the water samples. Main stem sample sites start at the headwaters of the Waerenga Stream and progress downstream.

| Sample code | Site Description | Easting | Northing | Soil | Sediment | Water | SS |
|---|---|---|---|---|---|---|---|
| **Main stem Waerenga Stream** | | | | | | | ($g\ m^{-3}$) |
| 7 | Waerenga Stream at 3-culvert Taniwha Rd | 2713105 | 6421595 | | × | × | 26.6 |
| 8 | Waerenga Stream at Taniwha Rd bridge | 2711960 | 6423245 | | × | × | 42.3 |
| 9 | Waerenga Stream at Stannard Rd bridge | 2710780 | 6424480 | | × | × | 50.0 |
| 10 | Waerenga Stream at Awariki Rd bridge | 2709765 | 6426560 | | × | × | 57.9 |
| 12 | Confluence Waerenga & Junction Streams | 2709520 | 6426620 | | × | | |
| 14 | Waerenga Stream (Jefferies Rd) | 2708395 | 6427185 | | × | × | 55.2 |
| 13 | Confluence Waerenga & Kopuku Streams | 2708190 | 6427430 | | × | | |
| 17 | Whangamarino River (Falls Rd bridge) | 2703728 | 6426255 | | | × | 29.3 |
| **Sub-catchment tributaries** | | | | | | | |
| 6 | Taniwha Stream at Taniwha Rd bridge | 2713760 | 6419000 | | × | × | 15.4 |
| 13A | Pokaewhenua Stream at Jamieson Rd bridge | 2713156 | 6427321 | | × | × | 24.0 |
| 13C | Pokaewhenua Stream at Okaeru Rd bridge (Becomes Junction Stream above site 11) | 2712956 | 6425683 | | | × | 22.5 |
| 11 | Junction Stream at Awariki Rd bridge | 2709950 | 6426675 | | × | × | 35.0 |
| 13B | Kopuku Stream at Kopuku Rd culvert (Upstream of site 15) | 2709490 | 6430234 | | | × | 15.9 |
| 15 | Kopuku Stream (Jefferies Rd) | 2708455 | 6427305 | | × | × | 23.5 |
| 32 | Clear flood water (Jefferies Rd) (mustard crop land?) (enters main stem between site 13 and site 17) | 2707596 | 6426512 | | | × | 2.1 |
| **Pungarehu Canal from Lake Waikare** | | | | | | | |
| 2 | At Waerenga Rd bridge | 2705282 | 6421006 | | | × | 163.2 |
| 16 | At Farm bridge as canal enters the wetland | 2703692 | 6424022 | | | × | 128.7 |
| **Major inflows to Lake Waikare** | | | | | | | |
| 22 | Waikato River inflow in Te Onetea Stream (SH1) | 2699885 | 6416349 | | | × | 14.7 |
| 27 | Matahura Stream Southern inflow at Waiterimu Rd bridge | 2708320 | 6410895 | | | × | 61.2 |
| **Reference crop soils** | | | | | | | |
| Gr/Mz | Grass through maize | 2708290 | 6427095 | × | | | |
| Mustard | mustard | 2708045 | 6425725 | × | | | |
| Maize | maize | 2705402 | 6421091 | × | | | |
| **Soil samples from herb block transect line** | | | | | | | |
| S1T | surface (0-2 cm) | 2702612 | 6426189 | × | | | |
| S1B | 10-12 cm deep layer | 2702612 | 6426189 | × | | | |
| S2T | surface (0-2 cm) | 2702469 | 6426126 | × | | | |
| S2B | 10-12 cm deep layer | 2702469 | 6426126 | × | | | |
| S3T | surface (0-2 cm) | 2702406 | 6426094 | × | | | |
| S3B | 10-12 cm deep layer | 2702406 | 6426094 | × | | | |

While water level recorders are installed at key points through the Whangamarino hydraulic system, there appear to be no flow rating curves at most sites and thus the flow volumes are not recorded. Mean flow and mean annual flood-flow between 1993 and 1997 taken from the NIWA WRENZ web model, were used to estimate the mass transport of sediment from Whangamarino River and Lake Waikare via the Pungarehu canal into the wetland. Because these are modelled flow data, there is high uncertainty in the absolute values and the results can only be used to give relative contributions of sediment from these two sources.

## 2.2 Analytical

Wet sediment sample aliquots were placed in pre-weighed aluminium baking trays, weighed and then dried at 60°C in an air oven for 24 hour before being re-weighed to determine moisture content. The dried samples were ground in a stainless steel coffee grinder and sieved to < 100 μm before storage in sealed PET wide-mouth jars pending analysis of stable isotopes and compound-specific stable isotopes (CSI) of fatty acids.

The total suspended solid material from each 1-L water sample was extracted by cold settling, and centrifuging in pre-weighed polyethylene screw-top centrifuge tubes. The centrifuge tubes, and their contents were dried at 60°C in an air oven for 24 hour before being re-weighed to determine the dry weight of suspended solids. The dried samples were ground with a mortar and pestle to a fine powder and stored sealed in the same centrifuge tube pending analysis of stable isotopes. There was insufficient material in the 1-litre samples for CSI analyses.

Stable isotope analyses of bulk carbon and nitrogen, and CSI analyses of fatty acids used the NIWA methods (Gibbs 2008). Dried samples for $^{13}C$ and $^{15}N$ stable isotopes were weighed into tin capsules and analysed at the NIWA stable isotope facility in Wellington by continuous flow, isotope ratio mass spectrometry (IRMS). Results were reported in delta notation (δ) with units of per mil (‰) calculated using the equation:

$$\delta X = (R_{sample}/R_{standard} - 1) \times 10^3$$

where X is $^{13}C$ or $^{15}N$ and R=$^{13}C/^{12}C$ or $^{15}N/^{14}N$, respectively. Analytical precision was <0.1 for $\delta^{13}C$ and <0.2 for $\delta^{15}N$. The IRMS data also give %C and %N content of the samples.

Dried samples for CSI analyses were prepared at Hamilton by extracting about 10 g of sediment with hot (100°C) dichloromethane (DCM) under high pressure (2000 psi) in an Automatic Solvent Extractor (ASE 2000; Dionex). The DCM extract was reduced to dryness in a screw-cap 10-mL glass vial (Kimble) for methylation. A solution of 5% $BF_3$ in methanol was added to each vial (1 mL) before sealing and reacting at 70°C for 20 minutes. After cooling, the fatty acid methyl esters (FAMEs) were extracted from the methylation mixture with hexane and finally reduced to dryness in 2-mL screw-cap vials. A set of 6 fatty acid standards were methylated at the same time using the same reagents. The vials plus a sample of the methanol, were sent to Otago University for CSI analyses. Samples were analysed in triplicate and the mean result was used for sediment source determination. Analytical precision was <0.1‰ for the $\delta^{13}C$ in each fatty acid.

## 2.3 Sediment source determination

The stable isotopic composition data of the suspended solids were used to indicate likely sources and mass transport of fine sediment during the winter 2008 flood event.

Sediment sources were identified and apportioned from the CSI data using the isotopic mixing model, IsoSource (Philips & Gregg 2005) as described by Gibbs (2008). As this was a pilot study, a full library of catchment soil types was not collected for apportionment, and the sediment from above and below each tributary confluence was assessed for proportional contribution from the whole catchment upstream from Fall Road, and from Lake Waikare via the Pungarehu Canal, to the soils in the wetland.

The IsoSource mixing model apportions the sources as feasible by making a table using all possible combinations of the isotopic values from the potential sources, and then selecting only those combinations that match the isotopic values of the wetland soil sample within a selected tolerance (‰). This means that if a match is not found, it is not possible to obtain an isotopic balance with that specific combination of sources. Conversely, the matches found are feasible combinations (solutions). The number of times each feasible solution occurs is summed to give a distribution histogram (see appendix Figs. A1 to A3). Any value within that distribution may be valid but the more times that value occurs the higher the probability that that is the correct proportion. To simplify the data presentation, the mean feasible solution value can be used provided it is treated as the best estimate with a defined level of uncertainty rather than an absolute value. In this method the level of uncertainty is defined by the standard deviation (SD) about the mean expressed as a percentage of the whole.

Each feasible solution is expressed as the isotopic proportional contribution (%) of that source soil to the wetland soil required to produce an isotopic balance. Isotopic proportions that extend from 0% to a finite value are less definitive than those with a full distribution curve as it is possible that those sources may not be present while the full distribution curve are present within the range of the distribution curve. In explanation, a potential source with an isotopic proportion estimate of say 48.2% with a standard deviation of ± 2.4% indicates that that source is present and contributes between 45.8% and 50.6% of the sediment in that sample. Conversely, a potential source with an isotopic proportion estimate of say 1.4% with a standard deviation of ± 1.9% indicates that that source may be present at up to 3.3% but it is just as likely that it is not present in that sample. Such high levels of uncertainty typically occur at the less than 5% contribution and such sources are considered to be minor.

The total number of feasible solutions (n) found by IsoSource provides a level of confidence in the solutions. The confidence level increases as n decreases towards 1, which is a unique solution.

The output from IsoSource is based on isotopic values and not soil proportions. As these isotopic biomarkers are part of the total organic carbon in the soil and the total organic carbon may be less than 10% of the whole soil, the **isotopic proportions** must be converted to **soil proportions** i.e., if the source soils were mixed together in the corrected soil proportions, the resultant mixture would have the same isotopic signatures as found in the wetland soil. This is done using a linear correction equation based on the carbon content of each source soil (Gibbs 2008):

$$\%source_n = \frac{I_n / \%C_n}{\sum_n^1 (I_n / \%C_n)} x100$$

where $I_n$ is the mean feasible proportion of source $n$ in the mixture as estimated from isotopic value by IsoSource, and $\%C_n$ is the % carbon in the source $n$ soil. Because this calculation only uses the %C of the source soils for scaling, the proportional contribution of each source soil is independent of any loss of total carbon or fatty acids in the wetland soil through biodegradation. The level of uncertainty defined by the SD remains the same.

Note that only single samples are used from each location as the identification and apportionment method is looking for the major differences that distinguish sources rather than the small variability that may be found within each source. Much of the source variability is accounted for by taking multiple small samples over a large area and combining these into a single bulk sample, which is more representative of that source than replicate single samples. Note also, biomarkers from plants growing on the soil at the wetland sites will be isotopically different from other sources and will be separated by the mixing model. No attempt was made to quantify that influence.

# 3. Results

## 3.1 Carbon and nitrogen

The carbon and nitrogen content of the soil, sediment, and suspended solids was highly variable ranging from <1 % to almost 20 % for carbon and 0.1 % to 1.8 % for nitrogen (Fig. 7). The C:N ratio was more consistent ranging from 9 to 13.3. The C and N content of the deposited sediment was generally lower than the suspended solids and crop soils. The C and N content of the suspended sediment from Lake Waikare was significantly higher than all other sediment samples except for the Jefferies Road site (site 32) and the soil core at site S3 in the wetland. Water at the Jefferies Road site was taken from the flooded crop land on volcanic soil previously planted in mustard. The water was clear (Fig. 8A) with very low sediment load (Table 1) indicating that the high %C and %N were most likely fine plant matter (C:N ratio 11.0). Flooded replanted grasslands on the alluvial plains had much higher sediment content (Fig. 8B) indicating the easy mobility of this soil type. There was a marked difference in %C and %N content in the soil cores taken along the transect with the soil taken closest to the old Pungarehu Stream channel (S1) being more similar to the Whangamarino River catchment sites than the soil taken further inland sites S2 and S3. The S3 sample was similar to the values from Lake Waikare collected from bridges over the Pungarehu Canal (sites 2 & 16).

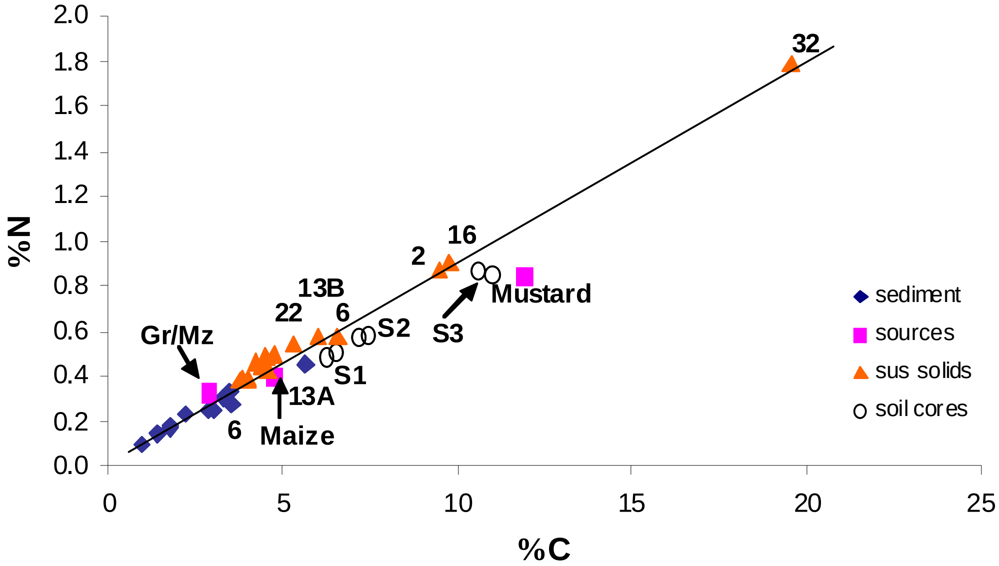



**Figure 7:** Carbon and nitrogen content (%) of all samples: deposited sediment (blue diamonds), suspended solids (orange triangles), crop soils (pink squares), wetland soils (open circles). Labels are the sample codes for selected samples as listed in Table 1. Line represents a C:N ratio of 11:1.


**Figure 8:** **A)** Floodwater from flat crop land previously planted in mustard (Jefferies Road), showing the low sediment content which indicates low erosion; and **B)** surface runoff water from flat grassland on the alluvial plains which indicates the easy mobility of this soil.

## 3.2 Suspended Solids

The suspended solid load in the water samples was lowest in the headwater streams and increased downstream to Jefferies Road bridge (sample 14) and then decreased again towards the Whangamarino wetland at Falls Road bridge (Table 1). The difference between the catchment stream sediment loads and those from Lake Waikare were visually striking (Fig. 9). The Lake Waikare samples contain sediment from the lake bed resuspended by wind-induced mixing.

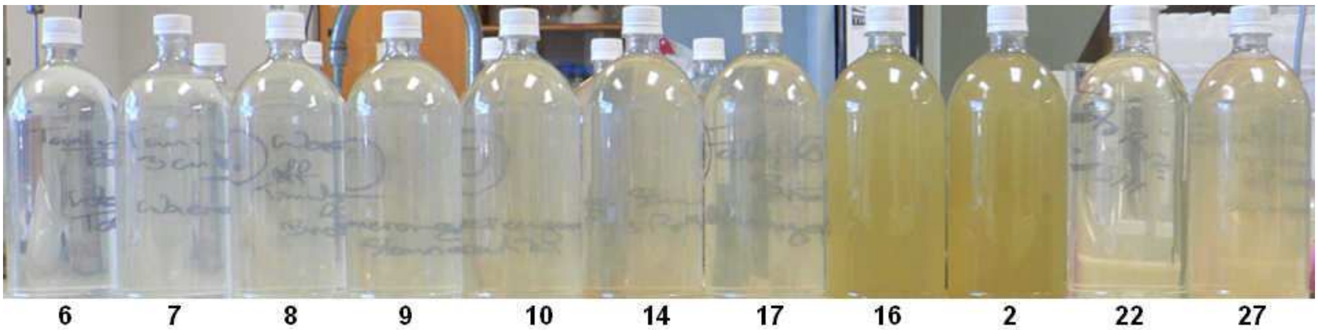



**Figure 9:** Photo of water samples (site numbers below) showing the low levels of suspended solids in the headwater streams (6, 7) increasing to site 14 then decreasing again to site 17. Samples 2 and 16 are from the Pungarehu Canal (i.e., Lake Waikare), sample 22 is the Waikato River inflow and sample 27 is the Matahura Stream which flows into the south end of Lake Waikare.

In the absence of real flow data, to obtain the relative proportional contribution of fine sediment to the Whangamarino wetland from the Whangamarino River catchment and Lake Waikare via the Pungarehu Canal, mean annual flood flow estimates were taken from Water Resources Explorer (http://wrenz.niwa.co.nz/webmodel/) based on flow estimates from 1993 to 1997. These estimates coupled with actual suspended solids loads in the Whangamarino River at Falls Road (site 17) and the Pungarehu Canal as it enters the wetland (sample 16) indicate that about 7 times more sediment enters the wetland from Lake Waikare than from the Whangamarino River upper catchment (Table 2). This proportionality appears consistent with visual evidence (Fig. 9), but the actual proportions will vary with flow volumes on a daily basis and the degree of wind-induced sediment resuspension in Lake Waikare. Flow volumes can change rapidly as indicated by the changes in water levels during the winter 2008 flood event (Fig. 10). The proportion of these sediment load being retained in the wetland is unknown. Note that the estimates in Table 2 are based on modelled flow estimates and have a high degree of uncertainty. They should be considered as indications of the relative proportions of sediments contributed from the two main sources, and not absolute values.

**Table 2:** Estimated relative sediment contributions to the Whangamarino wetland from the Whangamarino River catchment and Lake Waikare via the Pungarehu Canal under mean annual flood flow conditions. The canal flow is assumed to be the sum of the water from the Waikato River and the flow from the Matahura River, which allows an estimate of the relative sediment load inputs to Lake Waikare. The proportion of these input loads being retained in the wetland is unknown.

| **Water source** | **Catchment Area** ($km^2$) | **Flow Estimate** ($m^3 s^{-1}$) | **Suspended sediment** ($mg m^{-3}$) | **Sediment load** ($kg d^{-1}$) | **Relative Contibution** (%) |
|---|---|---|---|---|---|
| **Into Whangamarino wetland** | | | | | |
| Whangamarino River | 135 | 41 | 29 | 103 | 10 |
| L. Waikare via Pungarehu Canal | 210 | 52 | 163 | 732 | 90 |
| **Into Lake Waikare** | | | | | |
| Matahura River | 105 | 31 | 61 | 163 | 86 |
| Waikato River via Te Onetea Stream | - | 21 | 15 | 27 | 14 |

The water level data (Fig. 10) show the rapid changes that occurred between 1 June and 1 October 2008. There was a lack of synchronicity between the flood water level peaks in the Waikato River, the Matahura River inflow to Lake Waikare and the Whangamarino River, although the highest water levels in each river coincided at the beginning of July and again at the beginning of August. There is a strong visual correlation between water level changes in Lake Waikare and the Whangamarino River at Falls road (i.e., the confluence with the Pungarehu Canal with the Whangamarino River). The sharp hydrographs in the Matahura River are not present in the Whangamarino River water level record, even though both catchments are of similar size (Table 2) and drain similar landscapes adjacent to each other.

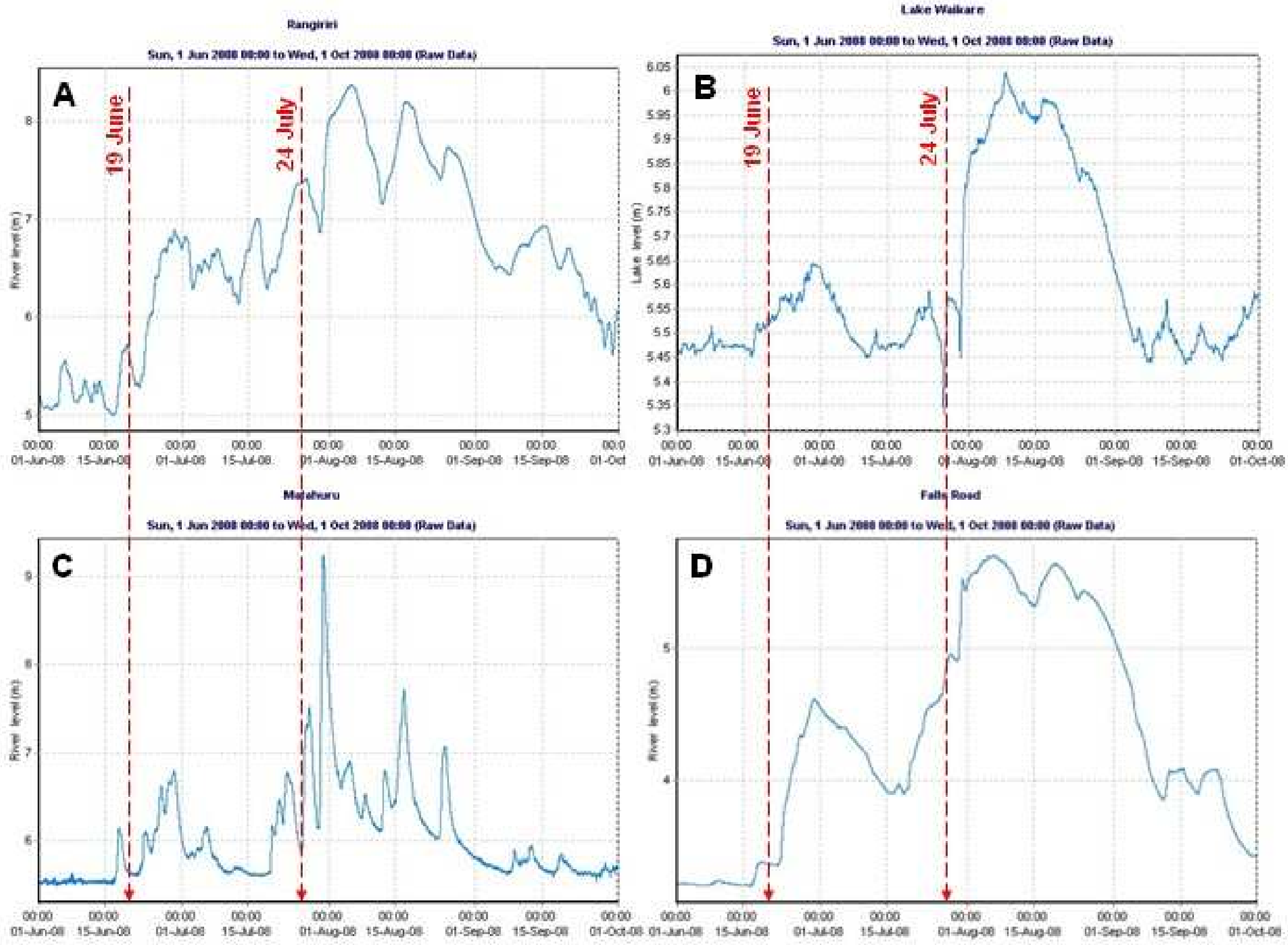



**Figure 10:** Relational comparison of water level changes in A) the Waikato River at Rangiriri, B) Lake Waikare, C) the Matahura River inflow to Lake Waikare, and D) the Whangamarino River at Falls Road from 1 June to 1 October 2008 as the period of the winter 2008 flood event. Red broken arrows indicate the sediment sampling occasion (19 June) and the suspended solids water sampling on 24 July 2008. (Environment Waikato water level records).

## 3.3 Bulk stable isotopes $^{13}C$ and $^{15}N$.

### 3.3.1 Deposited sediment

The bulk stable isotope data from the deposited sediment in the catchment were compared with the stable isotopic data from the 3 soil sites in the Whangamarino wetland (Fig. 11). It is assumed that the isotopic signatures of the deposited sediment in each tributary are representative of that tributary. It is also assumed that the isotopic signatures of the soil samples from the wetland reflect a mixture of sediment from the tributaries. Both of these assumptions have been found to be reasonable in other CSI studies and are also the basis for interpretation in all food-web studies. Consequently, the expectation would be for a greater level of similarity between the isotopic signatures of the wetland soils and the tributary sources contributing to those soils. The tributaries with isotopic signatures most similar to the wetland soil, S2, are grouped within the ellipse in the scatter graph (Fig. 11). These data show that the deposited sediments most likely to be contributing to soil at wetland site 2 were from sites 6, 7, 8, 9, 10 and 13A. Sites 8, 9, and 10 are main channel sediments downstream from the confluence between the main stem of the Waerenga Stream at site 7, and the first tributary (Taniwha Stream) at site 6 (Fig. 6). Site 13A was also a headwater tributary , the Pokaewhenua stream sub-catchment. Sites 11 to 15 are tributaries which appear to be having little direct influence on the wetland soils.

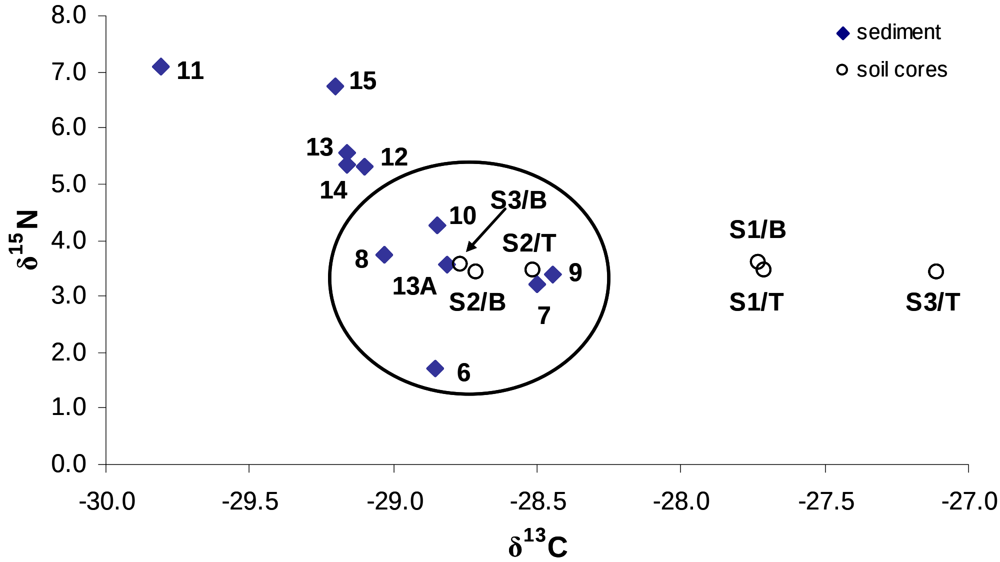



**Figure 11:** Scatter plot of the $^{13}$C and $^{15}$N stable isotope signatures of all deposited sediment samples from the Whangamarino catchment tributaries relative to those of the soil core sections dug from within the Whangamarino wetland. Numbers refer to the deposited sediment sample codes from Table 1. Sites within the circle are most likely sources.

The isotopic signatures from the 3 wetland soil cores were significantly different from each other. While S2 top and bottom fell within the range of the Whangamarino River tributaries signatures, S1 top and bottom and S3 top where more isotopically enriched in $^{13}$C. However, the S3 top and bottom signatures were also significantly different with S3 bottom signatures being similar to the S2 soil (Fig. 11). The soil sod from site S3 had a layer of different material through the middle (Fig. 12) which may indicate two or more distinct sediment deposition events.

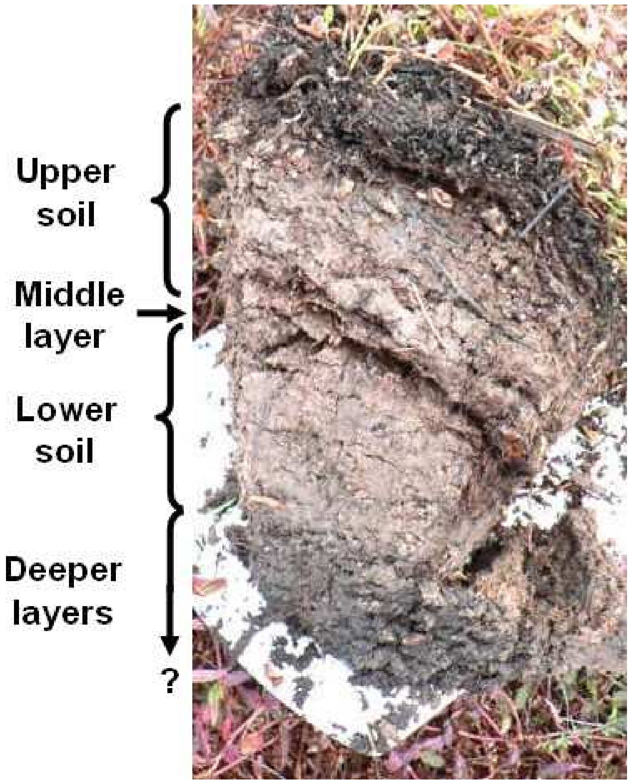



**Figure 12:** Soil sod dug from the wetland transect at site S3 showing a separation layer (Middle layer) near the mid spade depth and another darker layer below. (Photo: M. Gibbs)

### 3.3.2 Suspended sediment during a flood event

The bulk stable isotope data from the suspended sediment water samples collected during the flood event were also compared with the stable isotopic data from the 3 soil sites in the Whangamarino wetland (Fig. 13). In this comparison it was assumed that the wetland soil samples will have similar isotopic signatures to those of the suspended sediment from the source tributaries, allowing for the time difference between sediment mobilisation events (i.e., there could be an offset). These results show that the suspended sediments most likely to be affecting the soils, S2 top and bottom and S3 bottom, in the wetland came from the same headwater streams as the deposited sediment. The isotopic $\delta^{13}C$ signatures for the wetland soils at S1 and S3 top appear to be on a gradient between the headwater stream signatures and the signatures for suspended solids from Lake Waikare (Fig. 13). The additional data point from the Kopuku Road valley (site 13B), is also a steep slope sample and has an isotopic signature similar to that of S3 top. Because of the different intervening sediment signatures between these two sites, it is unlikely that there is a direct link between sites 13B and S3 top. The water inflow from Lake Waikare via the Pungarehu canal (sites 2 & 16) has very different isotopic $\delta^{13}C$ signatures to the tributaries to the Whangamarino River and the soil cores from the wetland. The isotopic signature of suspended sediments from the Waikato River inflow to Lake Waikare, site 22, are more similar to the Whangamarino tributary $\delta^{13}C$ signatures than those from Lake

Waikare. The isotopic $\delta^{13}C$ signatures from the 3 flat land-use samples show that the soil from the tilled maize land is isotopically closer to the suspended sediment $\delta^{13}C$ signatures from Lake Waikare, while the grass/maize and mustard crop soils are more closely related to the flatland suspended solids in the Whangamarino River tributaries. Maize was a major crop on the flat land within the Whangamarino River catchment.

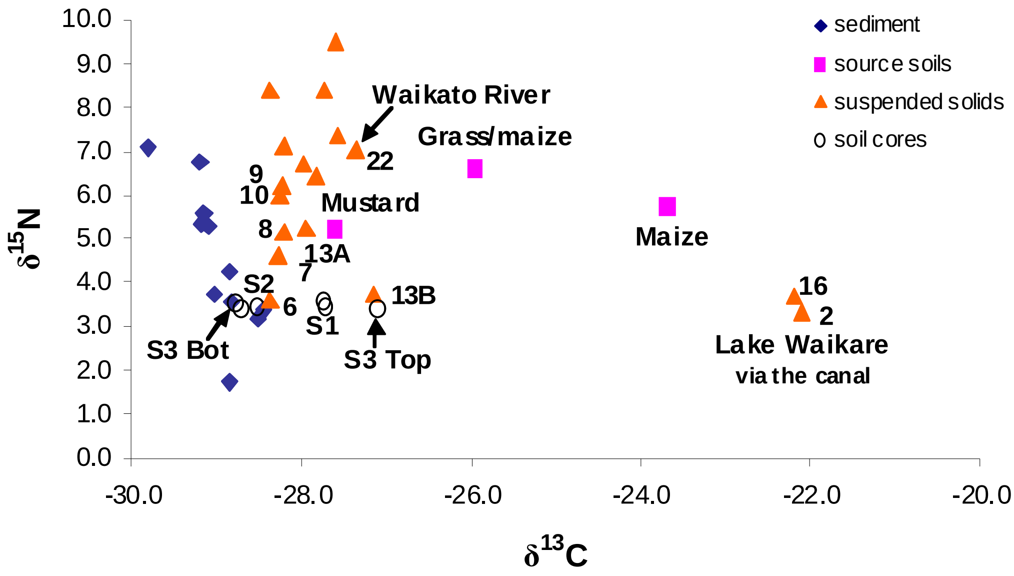



**Figure 13:** Scatter plot of the $\delta^{13}C$ and $\delta^{15}N$ stable isotope signatures of all suspended sediment (orange triangles) from the Whangamarino Catchment tributaries relative to those of the soil core sections (open circles) dug from within the Whangamarino wetland, the deposited sediments (blue diamonds) and three potential source crops (pink squares). Numbers refer to the suspended sediment and soil sample codes from Table 1.

### 3.4 Compound-specific isotopes

The compound specific isotopic values of Palmitic acid and Stearic acid were used with the bulk $^{13}C$ of potential sediment sources to apportion the likely contribution of each source to the sediments at the three sampling sites in the wetland (Table 3). For the purpose of the pilot study the sources selected were those representing the steep land at the head of the catchment, the low grassland, land currently growing maize and crops (e.g., mustard), and sediment from Lake Waikare entering the wetland via the Pungarehu Canal.

The graphed isotopic proportion data (Appendix Figs. A1 to A3) show that some sources are certain to be present as the range of the distribution curve occupies a finite range greater than 0% but less than 100%. The isotopic proportions for the Lake Waikare source contribution in the bottom sample (10-12 cm layer) at site S2 (Table 3; Appendix Fig. A2), shows a value of zero. This model output had only 10 solutions

(Table 3; S2-B, n = 10), which is a high confidence level, and all 10 solutions were zero for Lake Waikare. This means that the Lake Waikare source was not present in the soil at that depth at that site. A wider interpretation will be presented in the discussion. Details of how the data were interpreted are given in the methods (section 2.3).

**Table 3:** Summary of feasible isotopic proportions of 5 key potential soil sources contributing to the wetland sediments at the three sites along the DoC transect line. Results are mean % ± standard deviation (SD). (For graphed data, see Appendix).

| | Potential sources | | | | | |
|---|---|---|---|---|---|---|
| **Wetland soil sample** | **Lake Waikare** (%) | **Lowland grass** (%) | **Steep catchment** (%) | **Maize** (%) | **Mustard** (%) | **Feasible solutions** (n) |
| **S1-T** | 4.2<br>(4.1) | 67.9<br>(9.9) | 16.5<br>(6.7) | 6.3<br>(5.8) | 5.1<br>(4.9) | 1236 |
| **S1-B** | 6.3<br>(5.1) | 74.3<br>(10.0) | 6.9<br>(4.9) | 8.9<br>(7.2) | 3.6<br>(3.3) | 1483 |
| **S2-T** | 1.2<br>(1.5) | 20.1<br>(10.4) | 60.7<br>(7.9) | 8.7<br>(6.6) | 9.2<br>(8.0) | 1495 |
| **S2-B** | 0<br>(0) | 48.8<br>(3.0) | 48.2<br>(2.4) | 1.4<br>(2.1) | 1.6<br>(2.1) | 10 |
| **S3-T** | 22.8<br>(2.4) | 38.9<br>(5.1) | 32.8<br>(4.0) | 2.8<br>(2.9) | 2.7<br>(3.1) | 103 |
| **S3-B** | 0.6<br>(0.9) | 33.4<br>(5.1) | 60<br>(3.2) | 3.5<br>(3.3) | 2.5<br>(2.6) | 61 |

The soil proportions (Fig.14) show the relative contributions of the different land-use soils to the Whangamarino wetland in the three soil samples along the transect line. They also show that there is a marked difference between the site (S1) near the original Pungarehu Stream channel and the two sites (S2 & S3) further inland, and there is a difference between the surface 0-2 cm layer and the10-12 cm deep layer soils at sites S2 and S3. The apparent lack of sediment from Lake Waikare in the surface layer at the intermediate site (S2) may reflect a small ground elevation difference at that location.

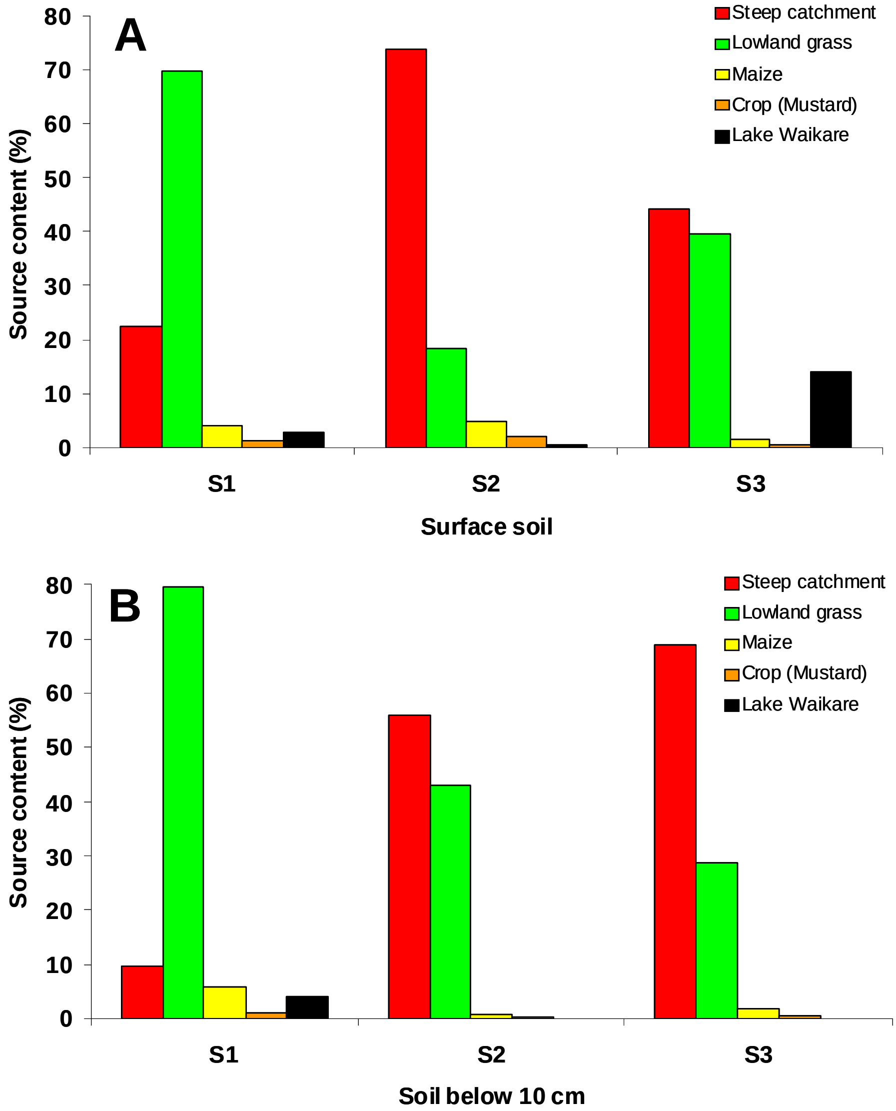



**Figure 14:** Source soil content (%) in the surface (0-2 cm deep) soil layer (A) and the 10-12cm deep soil layer (B) at the three wetland sites along the transect. Data represent the isotope proportions (Table 3) corrected by %C to give proportions of soil from each source in the soil at each site. Values are best estimates as means and have the same error term as the isotopic data (Table 3).

# 4. Discussion

## 4.1 Sediment sources

There are two main sources of sediment to the southern Whangamarino wetland

1) Lake Waikare via the Pungarehu Canal, and
2) the Whangamarino River inflow from the upstream catchment.

The results from this pilot study indicate that under extreme flood conditions in the Waikato River and with the Pungarehu canal control gate is open, most of the sediment load entering the Whangamarino wetland system comes from Lake Waikare. In 2008, this condition occurred between 23 June and early October, i.e., for around a quarter of the year. The sediment laiden water from the Pungarehu Canal overtopped the channel banks and dispersed across the wetland storing the flood water as the flood control scheme intended. During this storage phase, suspended solids in the flood water would settle out and deposit in the wetland.

At other times, with the control gates closed, stable isotope results indicate that the majority of sediment entering the wetland system is most likely to have come from the steep head water streams in the Whangamarino catchment, in particular, the Waerenga Stream catchment (Fig. 6). Visual inspection of that stream found in-channel earthworks which included bank clearing and bed forming on a sand bar in the stream channel (Fig. 15).

**Figure 15:** In-stream and bank earthworks in the upper Waerenga Stream catchment, 24 July 2008 (Photos: M. Gibbs).

Elsewhere in the Whangamarino River catchment, bank erosion (Fig. 16) was exacerbated by direct stock access to the stream bed (Fig. 17) and clearing of farm drains and stream banks, which left the soft alluvial soils bare (Fig. 18).

**Figure 16:** Bank erosion in the Waerenga Stream catchment 24 July 2008 (Photo: M. Gibbs).

**Figure 17:** Direct stock access to the stream bed exacerbates bank erosion and causes stream bed disturbance (Photo: M. Gibbs; 19 June 2008).

**Figure 18:** Clearing of farm drains and stream banks can leave soft alluvial soils bare and vulnerable to erosion during storm events (Photo: M. Gibbs; 19 June 2008)

Cropping to the edge of stream banks and leaving bare and sometimes tilled soil after harvest exposed to rainfall erosion appeared to be common. Of special interest was the high turbidity of water draining the soft alluvial plains at the foot of the steep headwater catchments compared with the low turbidity of surface flood water draining from area of volcanic soils closer to the wetland (Fig, 8). These sources and potential sources of sediment are all related to soil types, land slope, land-use practices.

## 4.2 Sediment loads and deposition

The Whangamarino River is the major source of water and thus sediment to the Whangamarino wetland system when the Pungarehu Canal control gates are closed. However, unless the water level in the Whangamarino River is high enough to overtop the channel banks, that sediment may not enter the wetland beyond the channel margins. For example, under low flow conditions in the Pungarehu Canal (control gate closed) water from the Whangamarino River remains within the river channel banks but can flow into the canal via the culvert at the confluence (Fig. 19), although the flow is likely to be relatively small. In contrast, under flood flow conditions, the culvert is a choke point for the Pungarehu Canal water which ponds behind the "causeway" formed by the access track to the culvert and floods across the swamp/marsh areas of the Whangamarino wetland. The canal flow moves along the old Pungarehu Stream channel (Fig. 5), which is constricted by fallen trees. As the water rises it inundates the Herb block study area (Fig. 4) and eventually overtops the causeway.

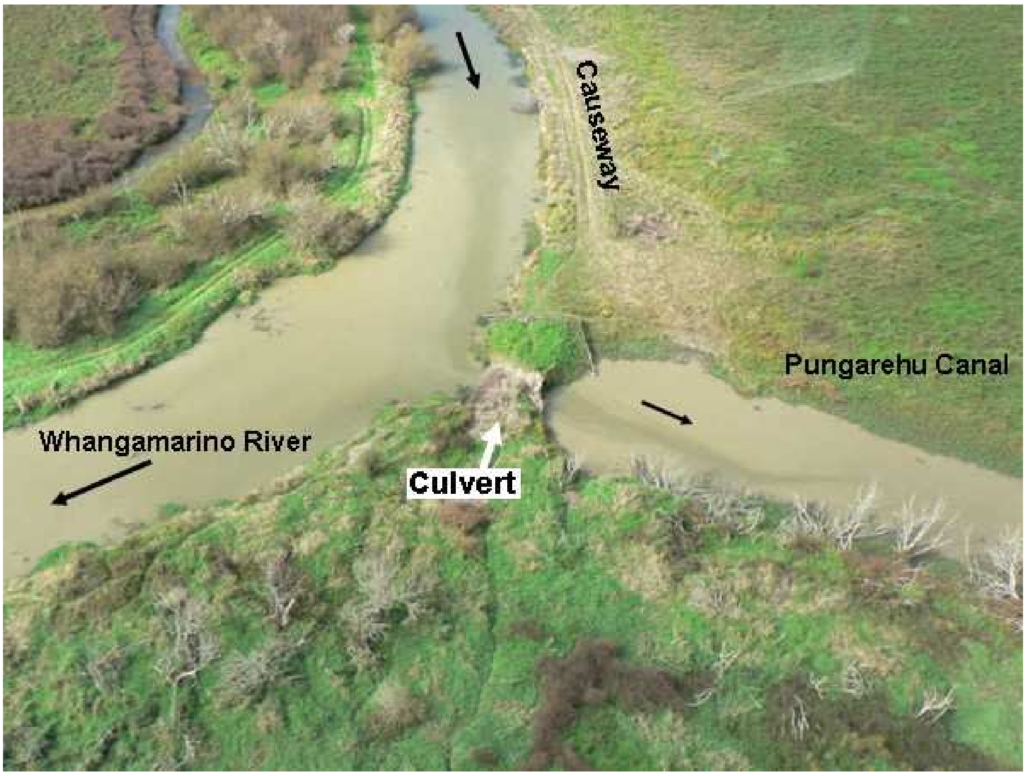



**Figure 19:** Water from the Whangamarino River flowing through the culvert into the Pungarehu canal under low flow conditions and the control gate closed 28 April 2008. Black arrows indicate flow directions. (Photo: M. Gibbs).

The synoptic survey of suspended sediment concentrations indicated that, on 24th July 2008, around 90% of the total sediment load entering the Whangamarino Wetland system came from Lake Waikare via the Pungarehu Canal. That was a "snapshot" "on-the-day" and the relative proportions of suspended solids from Lake Waikare and the Whangamarino River are likely to be substantially different on another day. This is because the suspended sediment concentrations in the Pungarehu Canal water were substantially higher than in any of the other water sources, implying that sediment resuspension in Lake Waikare was a significant source of the suspended sediment load in the Pungarehu Canal. On another day, with less wind-induced resuspension of sediment in Lake Waikare, the suspended sediment load in the Pungarehu Canal could be substantially less.

The lack of flow data and time-series suspended sediment data in the Pungarehu Canal and the Whangamarino River at Falls Road make it impossible to estimate the total annual sediment load to The Whangamarino Wetland from these two sources.

## 4.3 Changes in sediment dynamics since the Pungarehu Canal

The stable isotope data indicates a variable amount of sediment deposition in the Whangamarino wetland at the three locations sampled along the DoC transect line. The similarity between source soil composition in the 0-2 cm and 10-12 cm layers in the soil sample closest to the waterway system (Fig. 15; site S1) can be explained by higher sediment accumulation rates (SAR) near the water source. This would explain the higher proportion of lowland grass soil source in these samples as this site would be exposed to the Whangamarino River water for almost three quarters of the year.

The much higher proportions of steep catchment source soils in the other two soil samples (Fig. 15; sites S2 & S3) further inland from the water source and the differences between source soil proportions in the 0-2 cm and 10-12 cm soil layers indicates lower SARs at these locations. These source soil proportions show an absence of the Lake Waikare source in the 10-12 cm deep layer which implies that depth layer may have been sedimented before the Pungarehu Canal was constructed. Given the construction date of around 1960, this represents about a 50 year period which would indicate a possible SAR of around 2 mm per year. The actual SAR should be determined using radionuclide techniques ($^{210}$Pb, $^{137}$Cs) on sediment cores.

The differences in soil source proportions between surface and 10-12cm deep layer soils at sites S2 and S3 are consistent with different time periods in the history of the wetland. The deeper soils having no Lake Waikare sediment component may reflect the pre-canal condition of the wetland at those sites. The higher content of steep catchment soils than low grassland soils in the deeper soils would be consistent with higher erosion from the headwater catchments before catchment control schemes were fully implemented. Although soil from land used for maize was identified at the three wetland soil sites, it was not a major component of those soils at <5 % of the total.

Additional factors may affect the deposition of sediment e.g., small differences in ground elevation can cause floodwater to flow around one place relative to another. Soil "pugging" by stock can mix the surface soils with deeper layers, analogous to bioturbation in a lake or estuary. We noted extensive trampling by cattle around the middle site (S2) in the wetland but attempted to find a site which appeared to be free from trampling.

Note that the wetland soil samples were never intended to be used for definitive core analyses and hence were not sampled in a way to give better temporal definition. Without sediment coring to examine SAR, a better definition is not possible.

## 4.4 Hydrological considerations

The relatively low proportions (<14%) of Lake Waikare sediment in the 0-2 cm layer at the three locations in the wetland appears inconsistent with the synoptic total suspended sediment load estimates which showed that around 90% of the sediment load entering the wetland on 24 July 2008 came from Lake Waikare. However, what the synoptic survey data could not show was where that sediment deposited once it had entered the wetland. The Pungarehu Canal can be likened to a river inflow to a lake (the wetland being analogous to the lake). The sudden reduction in flow velocity as the canal water enters the open expanse of the wetland would cause the bulk of the suspended sediments to settle out in a "river delta" formation near the mouth of the canal. Evidence of this sedimentation pattern can be seen in the synoptic suspended sediment survey data as a reduction of about 20% at the mouth the Pungarehu Canal (site 16) compared with the suspended sediment load at the mid-point in the canal (site 2) (Table 1). Lateral dispersion into the wetland would also provide a large area where much of the Lake Waikare sediment could deposit before it reached the DoC transect line almost a kilometre away.

A similar deposition regime could be invoked for the suspended sediment in the Whangamarino River water. In this case the high banks of the river channel are sufficient to contain the Whangamarino River water until it reached the confluence with the original Pungarehu Stream. At that point the Whangamarino River water can spread out into the wetland with the associated sudden reduction in flow velocity and rapid settling of the sediment load. In this case, however, the "river delta" formation is much closer to the DoC transect line and a much higher proportion of sediment from the Whangamarino River catchment would be expected. Consequently, the maximum Lake Waikare contribution of 14% is entirely consistent with source proportion contributions at that location in the wetland.

Evaluation of the flood hydrographs (Fig. 10) provides further insight into the movement of water-borne sediment into the Whangamarino wetland. There is a significant difference between the flood hydrographs from the Matahura River inflow to Lake Waikare (Fig. 10C) and the Whangamarino River (Fig. 10D). The Matahura River hydrographs follow the classic pattern of a sudden rise and almost exponential fall in the tail. In contrast, the Whangamarino River has slow rises and falls with none of the peaks and tails of the Matahura River hydrographs that would reasonably be expected given the similarity between the size and topography of these two neighbouring catchments. The similarity between the Whangamarino River hydrograph (Fig. 10D) and the water level changes in Lake Waikare (Fig. 10B) suggest that Lake Waikare water levels are strongly influencing the Whangamarino River level, and causing it to back up. This is consistent with observations on the 24$^{th}$ July when the ponded water behind the causeway was flowing across the causeway at the Falls Road bridge car park and moving upstream in the Whangamarino River.

During the rising phase of the flood, flow velocity in the Whangamarino River would be greatly reduced allowing sediment to fall out of the water column in the river channel. This is consistent with the suspended sediment data (Table 1) which show an almost 50% reduction in SS load at Falls Road bridge compared with the main river channel sediment load at Jefferies Road (site14). After the water level peaked and began to fall, the Whangamarino River water would disperse through the adjacent wetland until it was constrained by the river banks once more.

## 4.5 Other water level manipulation effects

The construction of the Pungarehu Canal in the 1960s was designed as a flood control measure for downstream land along the Waikato River. Historical time-series water level data from the Falls Road water level recorder (Fig. 20) show that flood events occur almost every year with peak water levels reaching similar levels. These time-series data also show the effect of the construction of the weir on the outlet from the Whangamarino wetland.

After the Pungarehu Canal was commissioned in the 1965 to lower Lake Waikare (Boswell et al. 1985), the initially high base water levels began to fall (Fig. 20). In April 1994 a rock weir was constructed on the Whangamarino River below the confluence with the Maramarua River to increase minimum water levels in the wetland. A plant survey in December 1994, 8 months after the water level increase, showed an increase in species that preferred wetter conditions, a loss of species that preferred drier conditions, and an increase in plants that threatened the wetland, including grey willow (Reeves (2003). Species diversity was unchanged. The weir was washed out in a flood event in April 1995 causing the minimum water level to fall again (Fig. 20).

The vegetation was resurveyed in March 1998 before remedial work on the weir commenced in April 1998. Key findings were a decline in species preferring wet conditions, but there was an increase in grey willow and royal fern, and an overall decline in species diversity. The refurbished weir was completed in 2000 and the minimum water level, which increased by around 2 m has been held at that level ever since (Fig. 20).

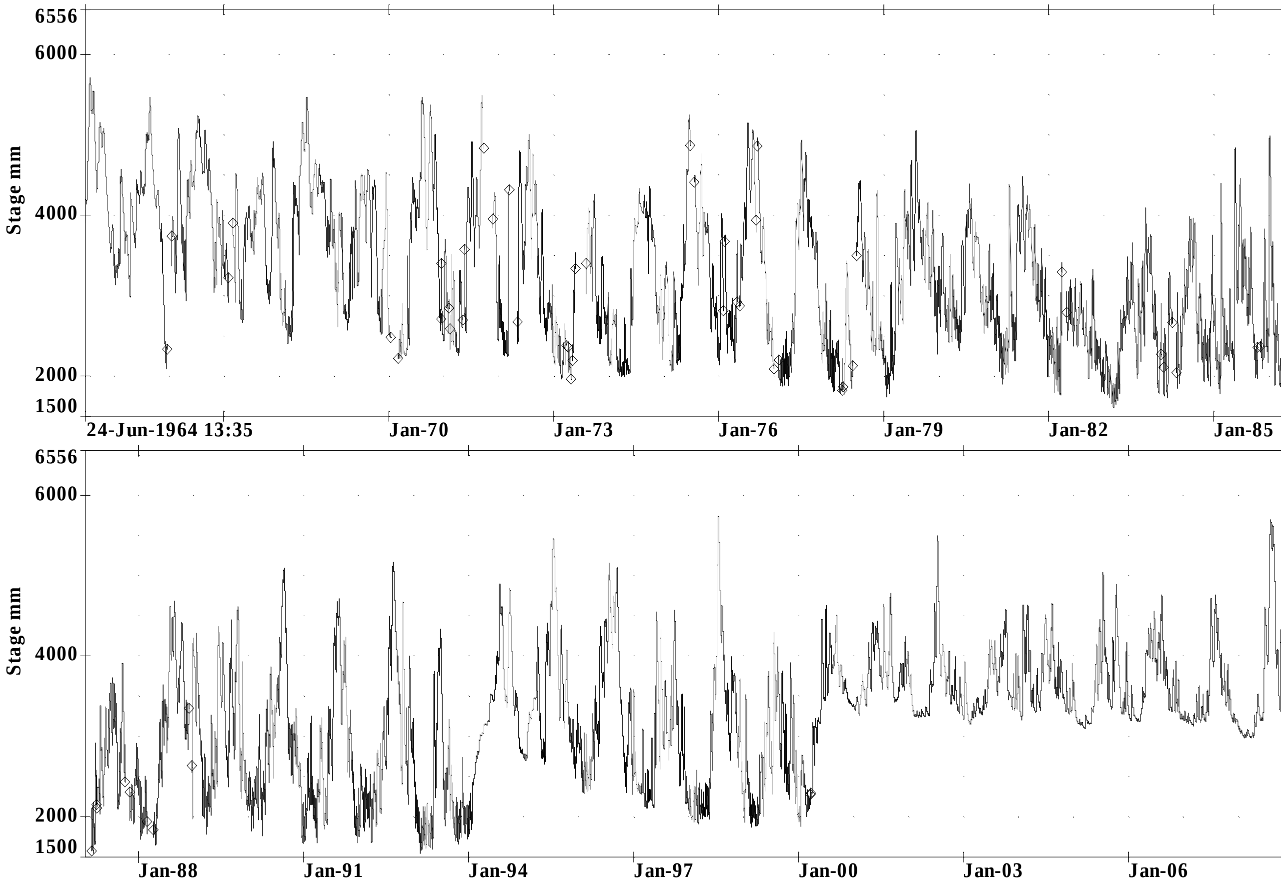



**Figure 20:** Water level changes in the Whangamarino wetland since the construction of the Pungarehu Canal in the early 1960s and the weir on the Whangamarino River near the outlet in 1994 to raise minimum water levels. The weir was washed out in 1995 and reinstated in 2000.

## 4.6 Knowledge gaps

These changes in water level will have affected the extent of flood water intrusion into the Whangamarino wetland and thus the rate of sediment deposition from the various sources and in different periods. During the periods of low minimum water level (1973-1994 and 1997-2000;Fig. 20), floods in the Whangamarino River may have had been the dominant source of sediment with less input from Lake Waikare in the Herb Block transect site. This may mean that the middle depth layer observed at site S3 (Fig. 12) could have been from either of those periods rather than pre-1965. This means that the absence of Lake Waikare sediment identified by the stable isotope results could have been from pre-1965, pre-1994 or pre-2000. Sediment coring for determining SAR would resolve this issue and should verify the effects of the different water lever regimes indicated that have been in effect since 1965.

# 5. Conclusions

This pilot study has demonstrated that it is possible to determine the most likely sources of soils being deposited at different locations in the Whangamarino wetland. It has identified three major sediment sources and has shown that the technique is capable of separating land-use sediment source contributions from sediment derived from Lake Waikare dispersed laterally across the wetland and vertically over time. Expanding the source soil library would enable specific land-uses within the catchment that produce disproportionately high sediment loads to be identified, and subsequently be managed to mitigate those sediment loads.

Interpretation of these results coupled with historical water level data at Falls Road gives a tentative understanding of how the Pungarehu Canal operation and the weir on the outlet of the Whangamarino River affects the sediment deposition in the wetland. More work incorporating measurement of SARs in sediment cores is required at different locations within the wetland to refine that understanding.

Issues: Quantification of sediment transport from the different sources is limited by the lack of SAR and accurate flow data. As a minimum requirement, accurate flow data is required from Lake Waikare and from the Whangamarino River upstream of Falls Road. As there was evidence of the backing up of flood water in the Whangamarino River during the June to October 2008 flood event, selection of the flow recording station is critical and should be upstream this influence. Recording turbidity data by optical back scatter (OBS) instruments calibrated for suspended sediment concentrations, would provide a continuous record of the sediment discharged into the Whangamarino wetland from these two source waters.

# 6. References

Boswell, J.; Russ, M. & Simons, M. (1985). Waikato small lakes: Resource statement. Waikato Valley Authority.

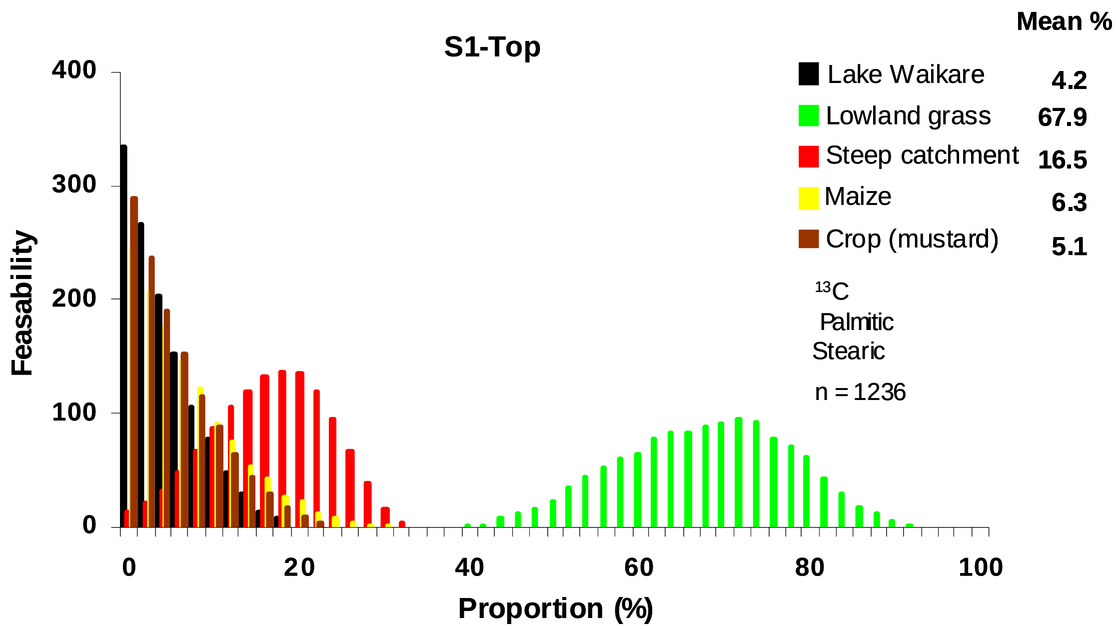
Gibbs, M.M. (2008). Identifying source soils in contemporary estuarine sediments: a new compound-specific isotope method. *Estuaries and Coasts 31*: 344–359.

Phillips, D.L. & Gregg, J.W. (2003). Source partitioning using stable isotopes: Coping with too many sources. *Oecologia 136*: 261–269.

Reeves, P. (2003). Whangamarino Wetland Vegetation Monitoring. Department of Conservation, Waikato. 30 p.

# 7. Appendix

Graphed isotopic feasible proportion data.



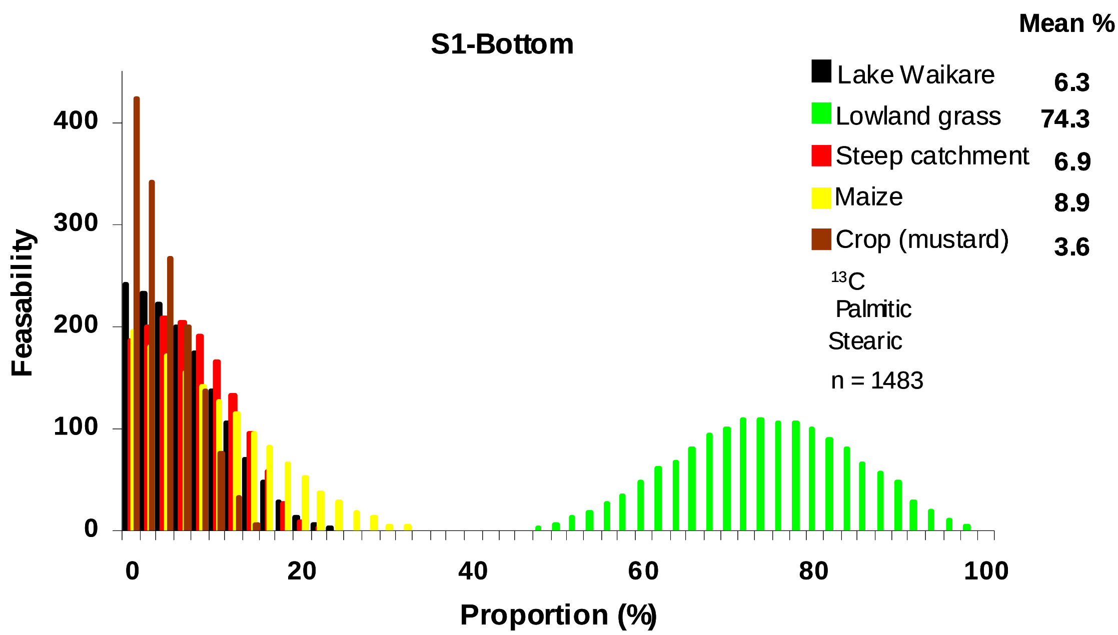
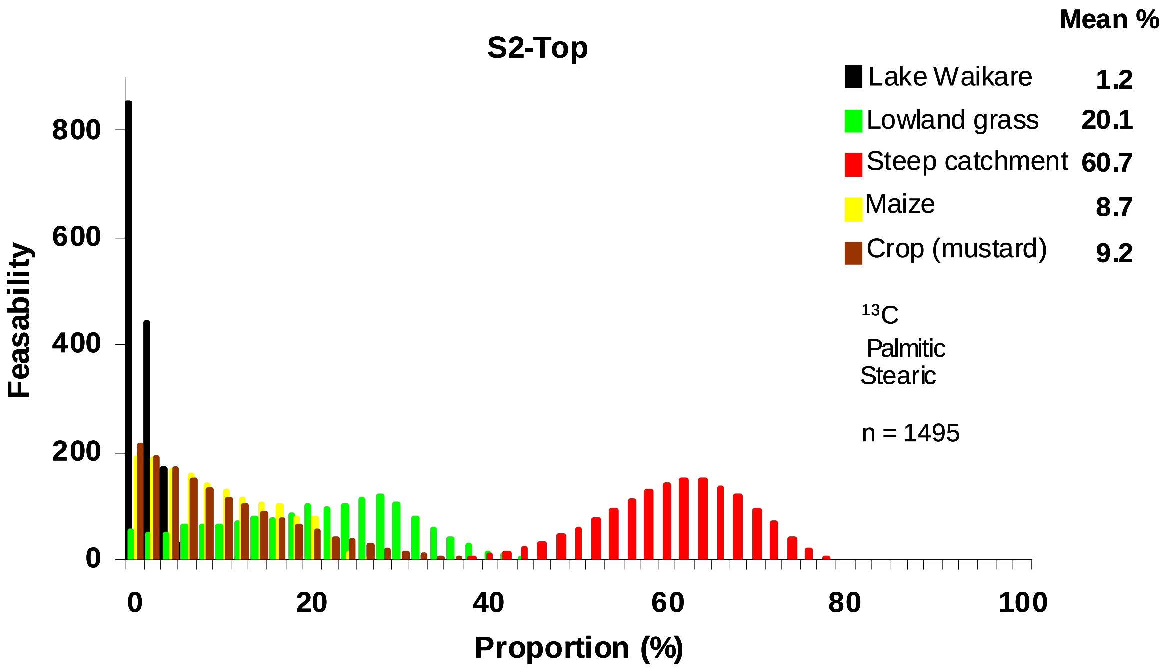




**Figure A1:** Feasible proportions of 5 key potential sediment sources contributing to the wetland sediments at site S1. "Top" refers to the 0-2 cm soil layer. "Bottom" refers the soil from 10-12 cm below the surface. The distribution of results reflects the range of feasible contribution from each source with the highest feasibility value as the most likely proportion. Mean % values are the arithmetic mean of the distribution curve. The "n" value is the total number of feasible solutions to the mixing model as an indication of confidence. Confidence levels increase as n decreases with n = 1 being a unique solution. (See Table 3 for standard deviations).



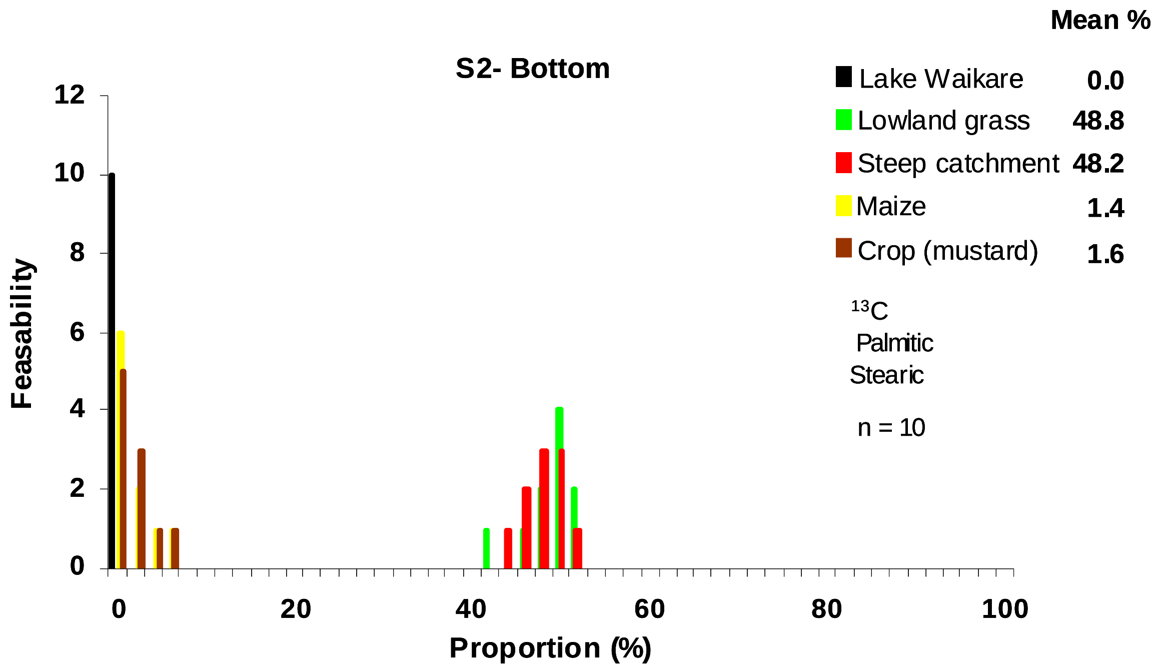
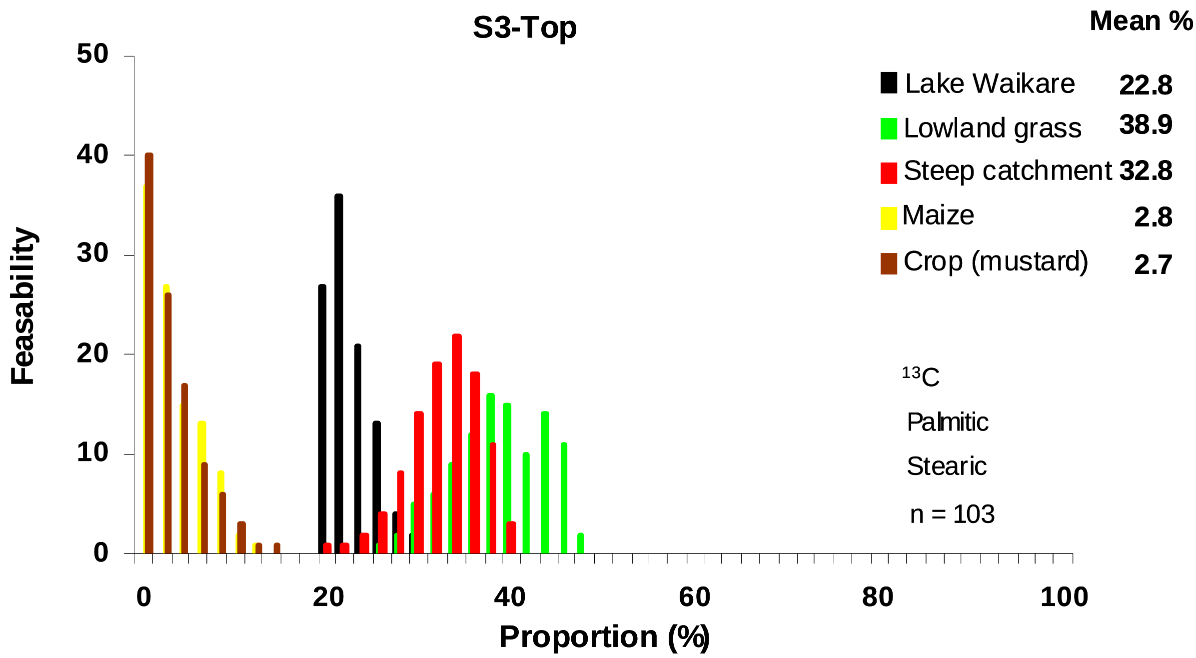




**Figure A2:** Feasible proportions of 5 key potential sediment sources contributing to the wetland sediments at site S2. "Top" refers to the 0-2 cm soil layer. "Bottom" refers the soil from 10-12 cm below the surface. The distribution of results reflects the range of feasible contribution from each source with the highest feasibility value as the most likely proportion. Mean % values are the arithmetic mean of the distribution curve. The "n" value is the total number of feasible solutions to the mixing model as an indication of confidence. Confidence levels increase as n decreases with n = 1 being a unique solution. (See Table 3 for standard deviations).



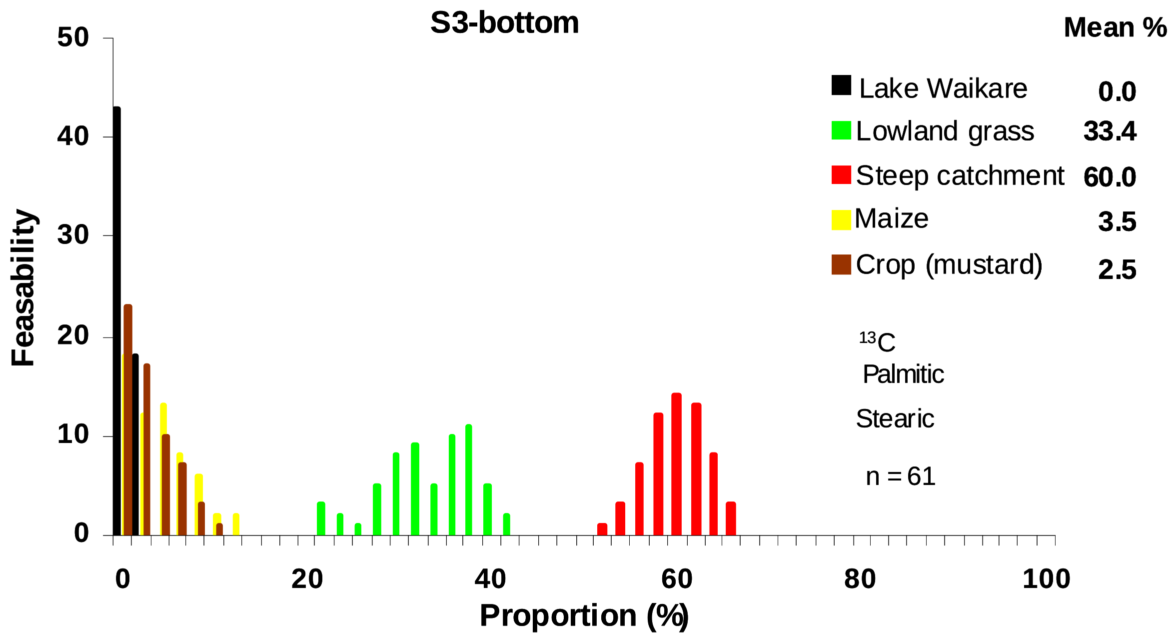




**Figure A3:** Feasible proportions of 5 key potential sediment sources contributing to the wetland sediments at site S3. "Top" refers to the 0-2 cm soil layer. "Bottom" refers the soil from 10-12 cm below the surface. The distribution of results reflects the range of feasible contribution from each source with the highest feasibility value as the most likely proportion. Mean % values are the arithmetic mean of the distribution curve. The "n" value is the total number of feasible solutions to the mixing model as an indication of confidence. Confidence levels increase as n decreases with n = 1 being a unique solution. (See Table 3 for standard deviations).