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Marine Sediment Core Profiles in the Waitemata and Manukau Harbours

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Marine Sediments Core Profiles in the Waitemata and Manukau Harbours

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Prepared for

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Contents

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1 Introduction

The Auckland Regional Council (ARC) has requested that city councils develop integrated catchment management plans (ICMPs), and part of these plans require councils to model the fate of contaminants in the marine receiving environment.

During the development of these ICMPs, concerns were raised within the councils that concentrations of some metals in the marine environment are elevated due to underlying volcanic rocks causing high background concentrations of these metals. Up to now, the high metal concentrations typical of volcanic rocks have not been observed in pre-urban sediments at the base of marine sediment cores. To extend the dataset of marine sediment pre-urban concentrations, the ARC invited NIWA to determine the metal concentration depth profiles in marine sediment cores from several locations in the Auckland region. These locations were typically intertidal mud flats in areas known to accumulate sediments.

1.1 Sampling sites

The following estuaries were sampled:

1. Upper Waitemata Harbour (Rangitopuni, Brighams).
2. Middle Waitemata Harbour (Whau, Motions, Meola, Hobson Bay).
3. South West Manukau Harbour (Puhinui, Auckland Airport, Wattle Downs, Takanini, Kauri Point).

The location of the sites sampled are shown in Figures 1 and 2 for Waitemata Harbour and Manukau Harbour, respectively.

During sampling of estuarine sediments, an opportunity arose to sample a volcanic soil at Pukaki and this was included in the analysis.

Figure 1. Location of sampling sites in Waitemata Harbour, 2006.
(Images from ARC online maps)

Figure 1 (cont). Location of sampling sites in Waitemata Harbour, 2006.
(Images from ARC online maps)

Figure 1 (cont.). Location of sampling sites in Waitemata Harbour, 2006.
(Images from ESRI World Imagery)

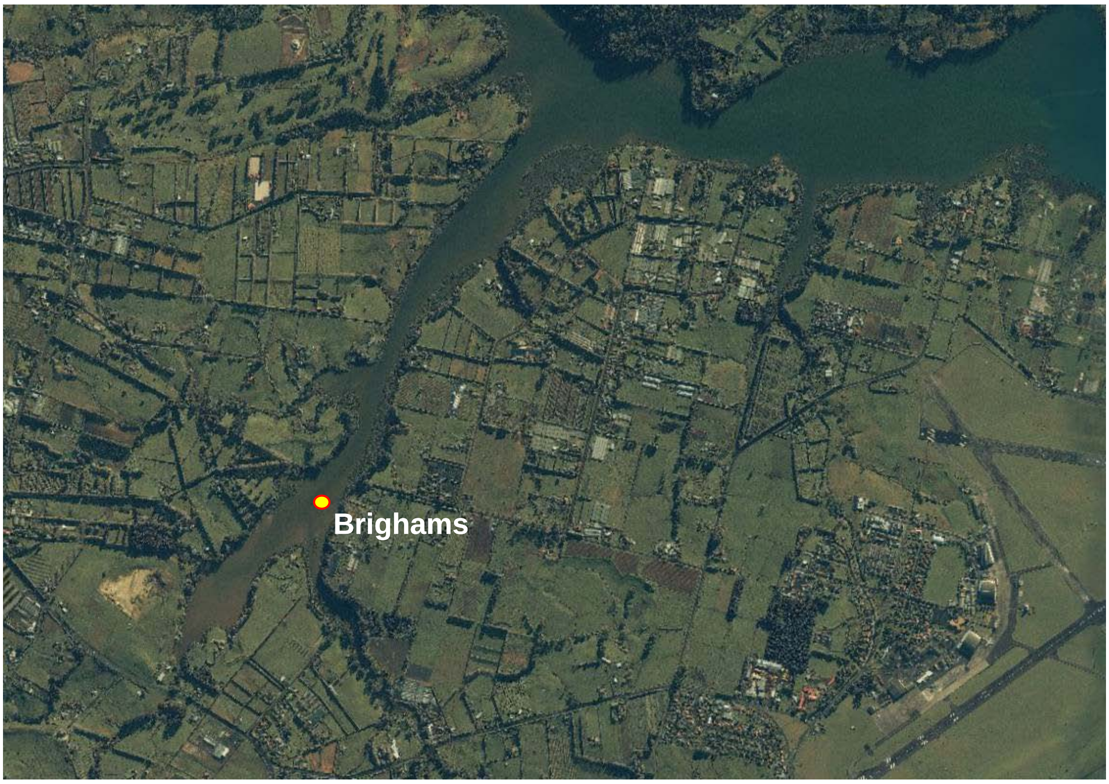


Figure 2. Location of sampling sites in Manukau Harbour, 2006.
(Images from ESRI World Imagery)

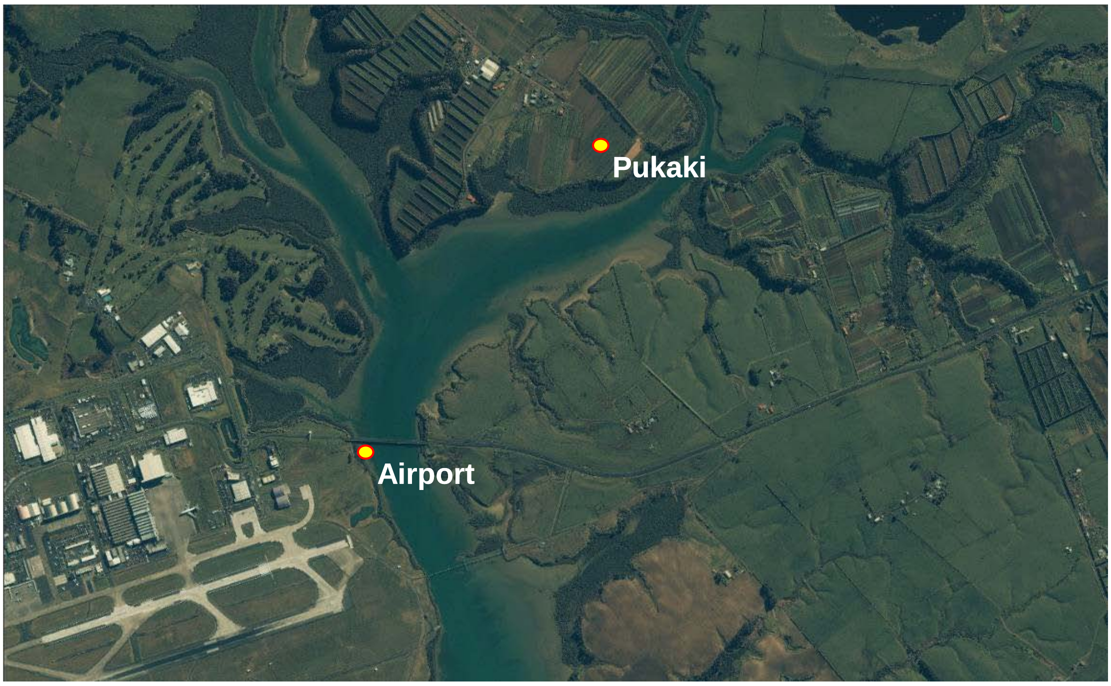


Figure 2 (cont.). Location of sampling sites in Manukau Harbour, 2006.
(Images from ARC online maps)

Figure 2 (cont.). Location of sampling sites in Manukau Harbour, 2006.
(Images from ARC online maps)

2 Methodology

At each estuary, two deep sediment cores were collected using a sediment corer and frozen immediately on return to the NIWA Laboratory, Auckland. One core was measured for total length (mm), observations of aerated zones were noted and then the whole core was sectioned into 25 mm lengths ready for analysis. The duplicate core was frozen intact for possible later analysis to confirm results obtained from the first core.

At each estuary, alternate sediment sections were chosen for metal analysis, commencing with the 0-25 mm section. These sections were wet sieved to <500 µm then dried at 60°C. The dry sections were homogenised and 1 g ± 0.001 g was taken as a sub-sample. These samples were digested for 30 minutes at 95°C in nitric/hydrochloric acid (4 mL HNO_3 : 0 mL HCl). Samples were diluted 10x with one per cent nitric acid prior to analysis to reduce acid strength and centrifuged at 2500 rpm for ten minutes to remove suspended solids. The extracts were decanted into clean plastic tubes and analysed for "total recoverable" concentrations for copper, zinc, lead, nickel, cobalt, vanadium, iron and manganese by Inductively Coupled Plasma-Mass Spectroscopy (ICP-MS). The digestion method followed the USEPA 200.2 method and the ICP-MS analysis followed method APHA 3125B.

The soil sample was collected with a sediment scoop. The surface 0-2 cm was sampled only.

Detection limits were; 40 mg kg^{-1} d/w for Fe, 1 mg kg^{-1} d/w for Mn, 0.04 mg kg^{-1} d/w for Co, 0.2 mg kg^{-1} d/w for Cu, 0.2 mg kg^{-1} d/w for Ni, 0.04 mg kg^{-1} d/w for Pb, 10 mg kg^{-1} d/w for Vn and 0.4 mg kg^{-1} d/w for Zn.

3 Results

Results in Table 1 show the length of the cores taken at each sampling site. The depth of each core was determined by the ability of the hand-held corer to penetrate sediments. Cores extended to either the bedrock or compacted sediments which were too hard to sample by the hand-held corer. A different method would be required to sample these sites to a greater depth.

Contaminants in sediments are described as the following: urban (U), pre-urban (PU) (eg contaminants are found at the base of the core before urban development), volcanic (V) (eg contain traces of volcanic metals in the core) and non-volcanic (NV) (see also Section 4).

Figure 3 to 26 show the depth profiles of total recoverable metal concentrations of vanadium, zinc, manganese and iron (Fe concentrations are scaled by 1000) and cobalt, copper, nickel and lead for each site. Concentrations are in mg kg^{-1} dry weight.

Table 1. Core length and characteristics of cores taken at sampling sites.

Sample site	Core length (mm)	Contaminants
Rangitopuni	300	U
Brighams	100	U NV
Whau (Upper)	325	U NV
Whau (Wairau Arm)	200	U
Motions	620	U PU NV
Meola	280	U PU NV
Hobson Bay	610	U PU NV
Puhinui	510	U NV
Auckland Airport	595	U PU NV
Wattle Downs	220	U PU NV
Takanini	250	U
Kauri Point	450	U
Pukaki (surface soil sample)	n/a	V

Figure 3. Depth profile plots of "total recoverable" concentrations of vanadium, zinc, manganese and iron (Fe concentrations scaled by 1000) at Rangitopuni.

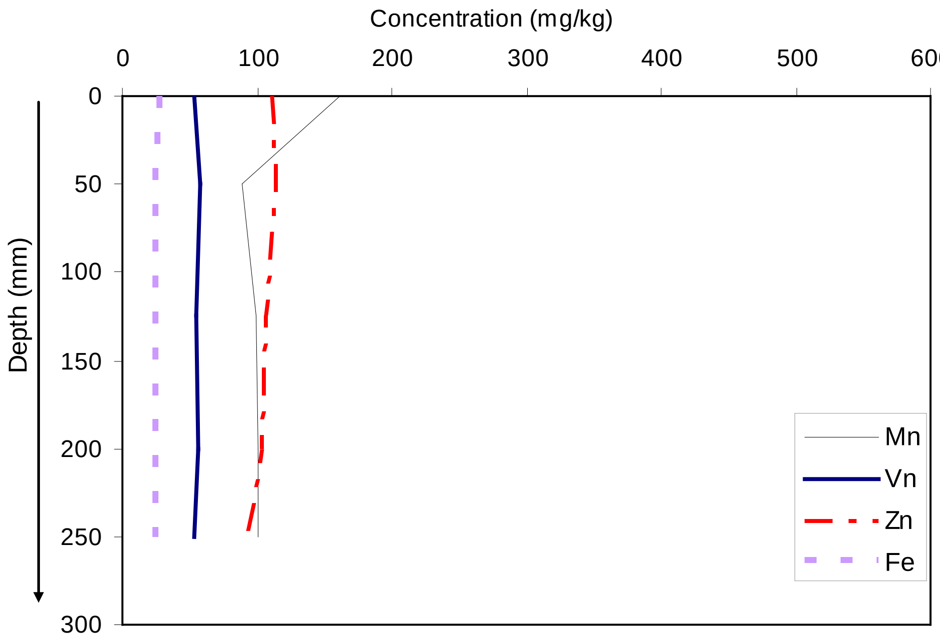


Figure 4. Depth profile plots of "total recoverable" concentrations of cobalt, copper, nickel and lead at Rangitopuni.

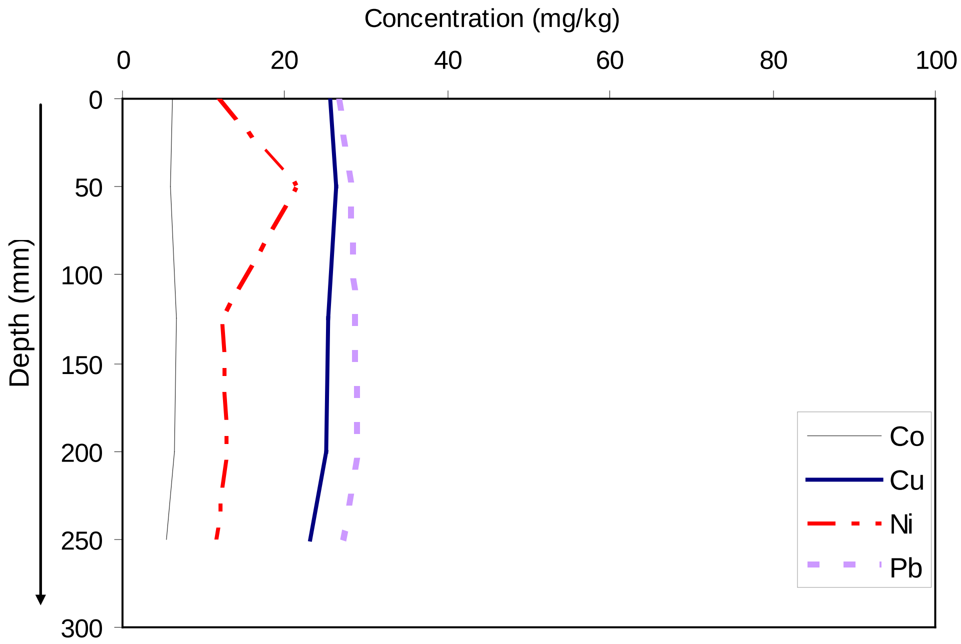


Figure 5. Depth profile plots of "total recoverable" concentrations of vanadium, zinc, manganese and iron (Fe concentrations scaled by 1000) at Brighams.

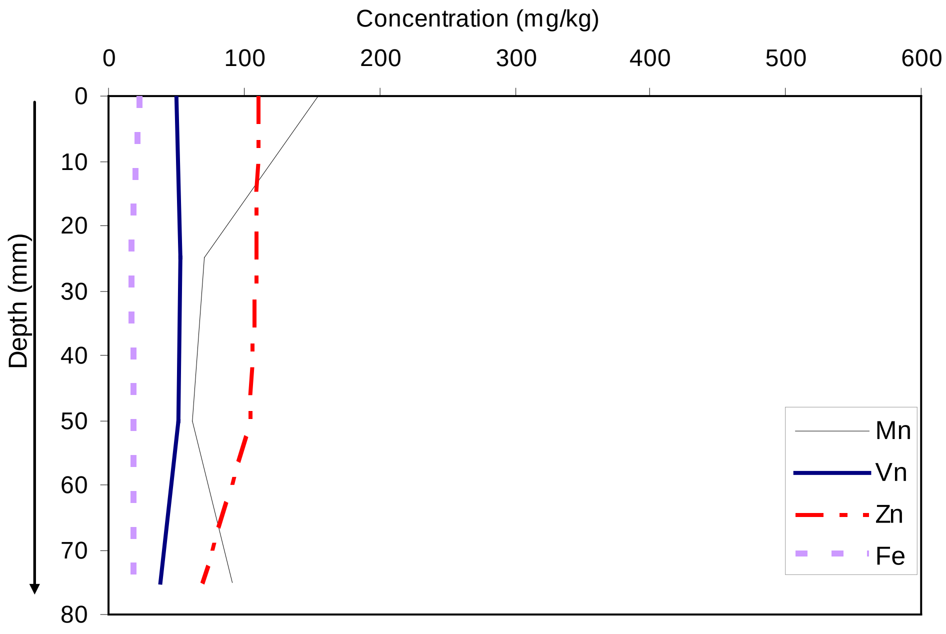


Figure 6. Depth profile plots of "total recoverable" concentrations of cobalt, copper, nickel and lead at Brighams.

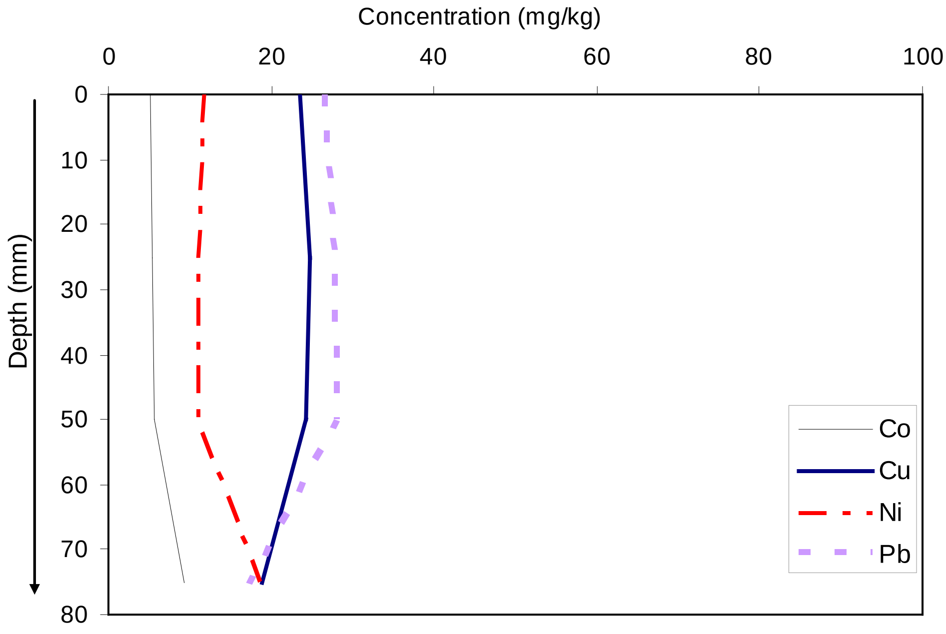


Figure 7. Depth profile plots of "total recoverable" concentrations of vanadium, zinc, manganese and iron (Fe concentrations scaled by 1000) at Whau Upper.

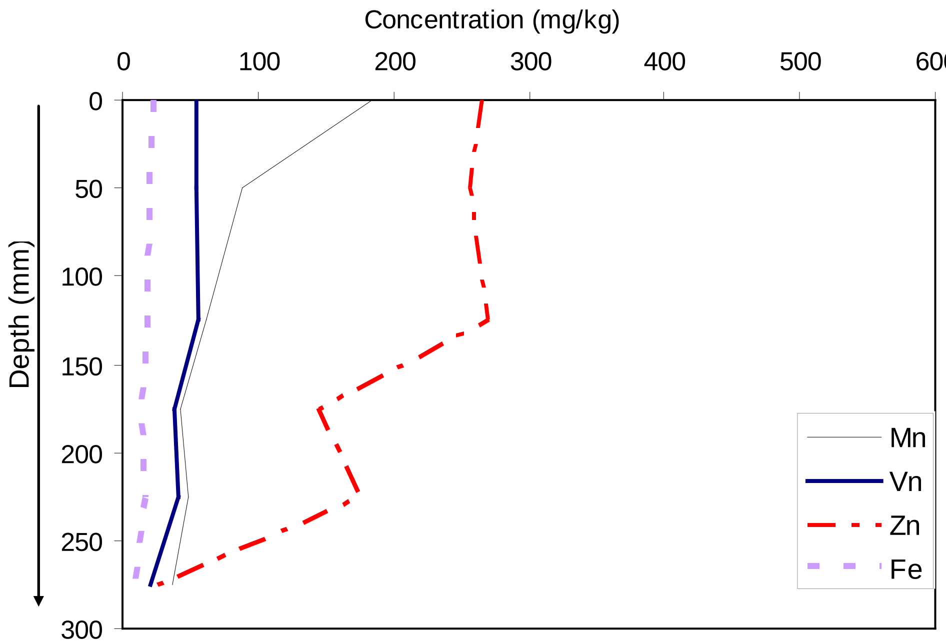


Figure 8. Depth profile plots of "total recoverable" concentrations of cobalt, copper, nickel and lead at Whau Upper.

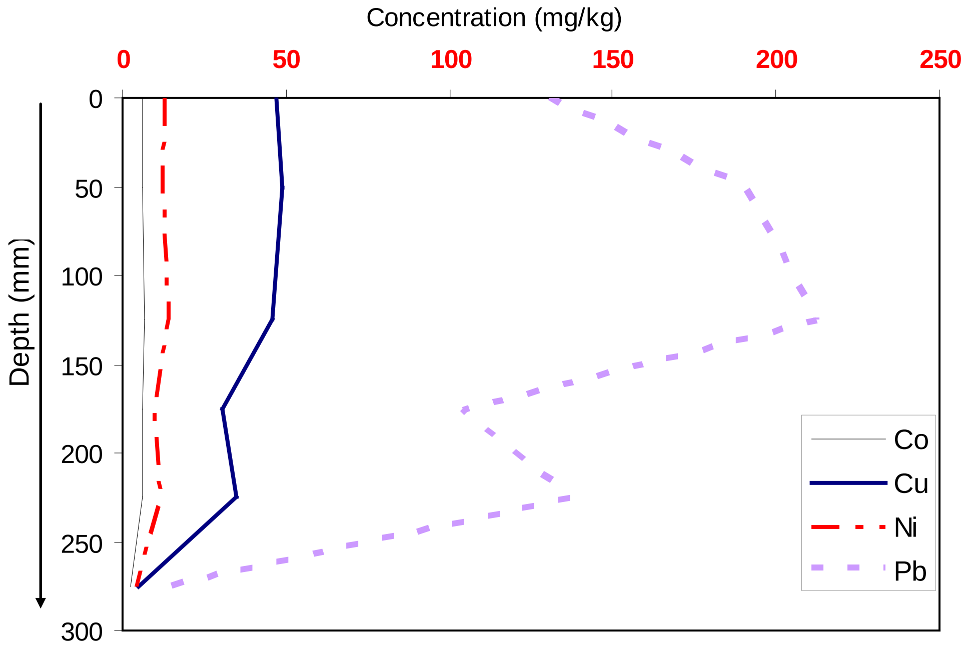


Figure 9. Depth profile plots of "total recoverable" concentrations of vanadium, zinc, manganese and iron (Fe concentrations scaled by 1000) at Whau Wairau Arm.

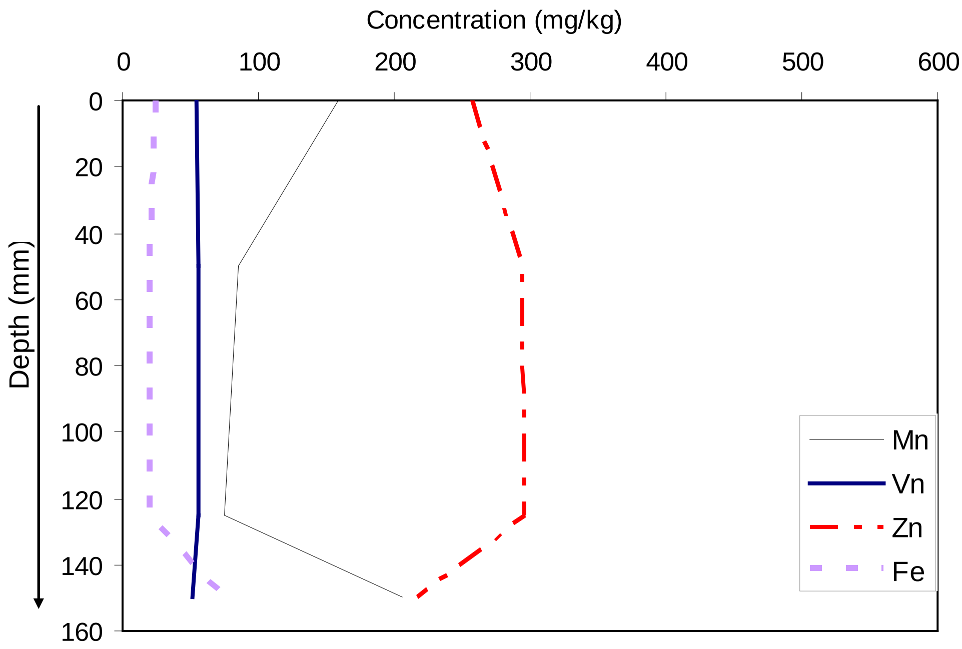


Figure 10. Depth profile plots of "total recoverable" concentrations of cobalt, copper, nickel and lead at Whau Wairau Arm.

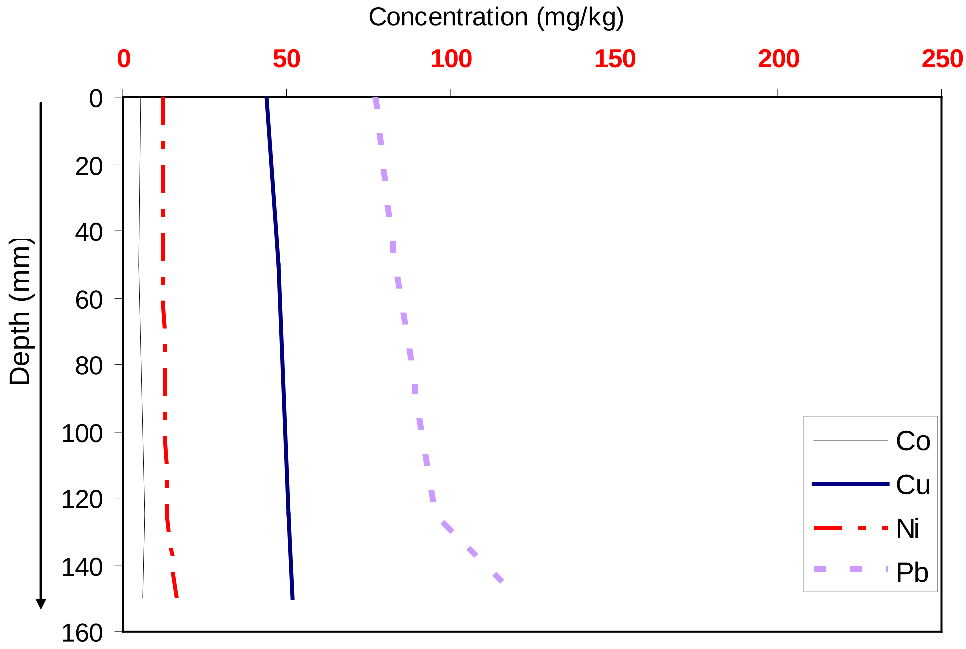


Figure 11. Depth profile plots of "total recoverable" concentrations of vanadium, zinc, manganese and iron (Fe concentrations scaled by 1000) at Motions.

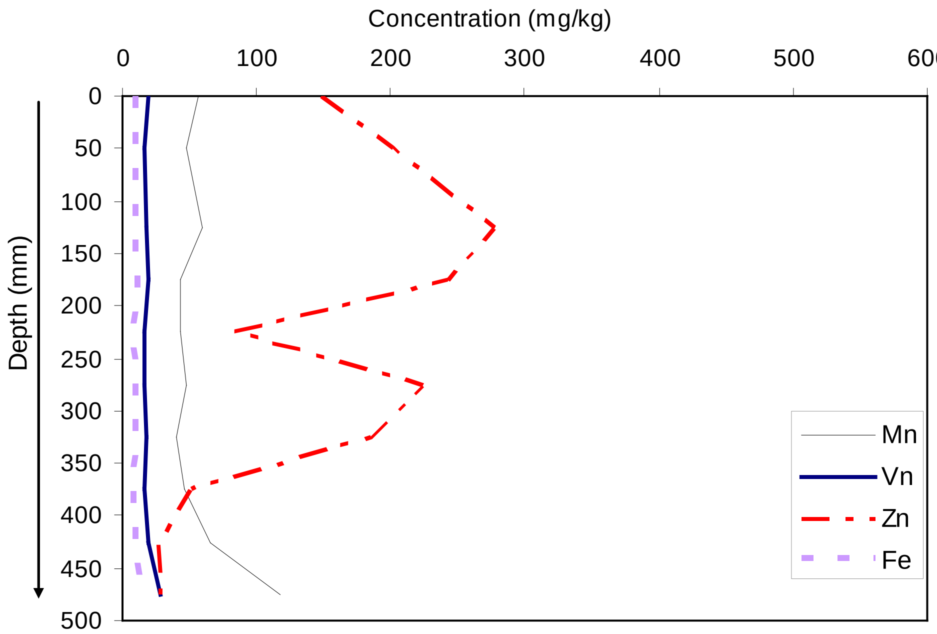


Figure 12. Depth profile plots of "total recoverable" concentrations of cobalt, copper, nickel and lead at Motions.

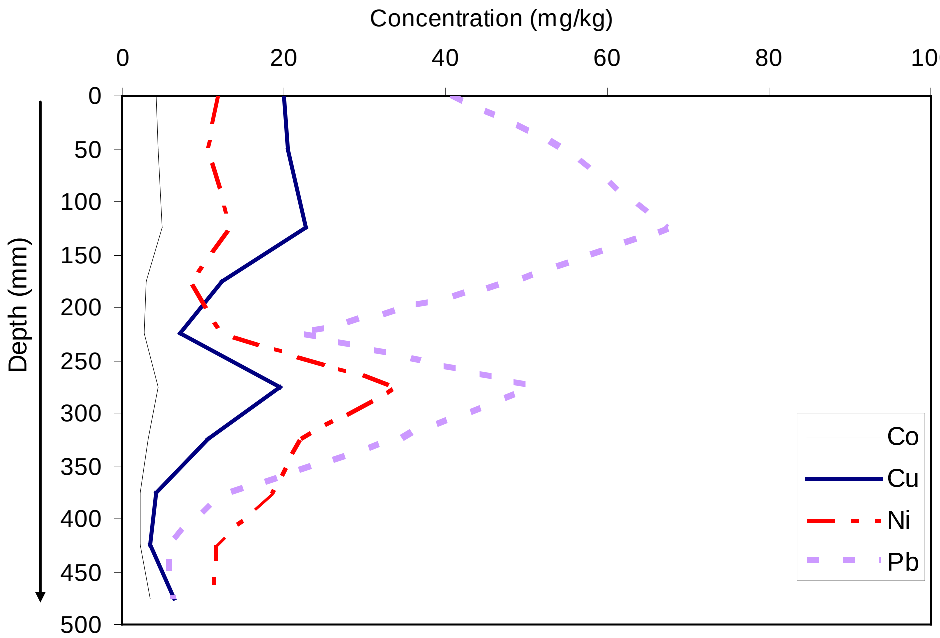


Figure 13. Depth profile plots of “total recoverable” concentrations of vanadium, zinc, manganese and iron (Fe concentrations scaled by 1000) at Meola.

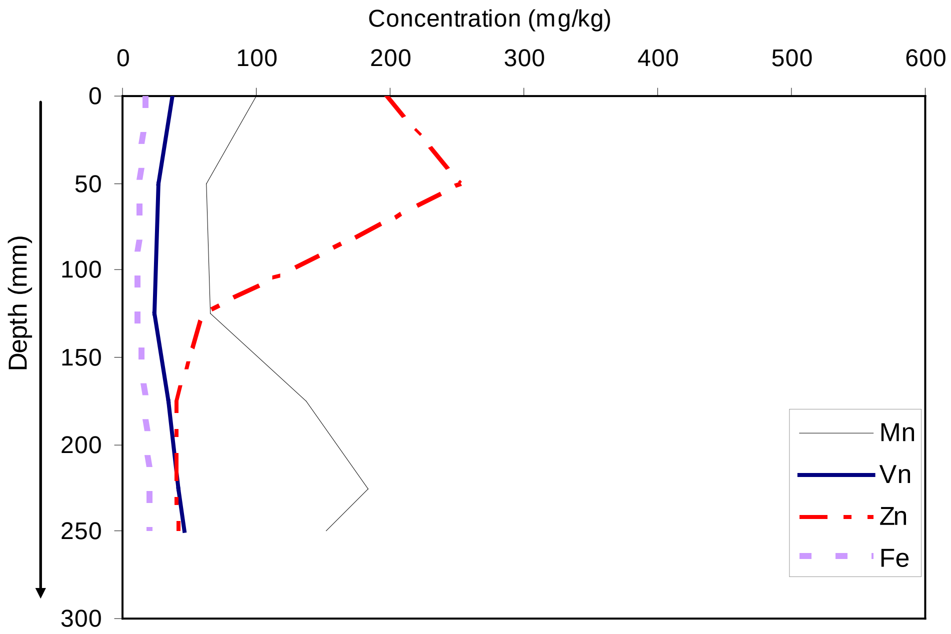


Figure 14. Depth profile plots of “total recoverable” concentrations of cobalt, copper, nickel and lead at Meola.

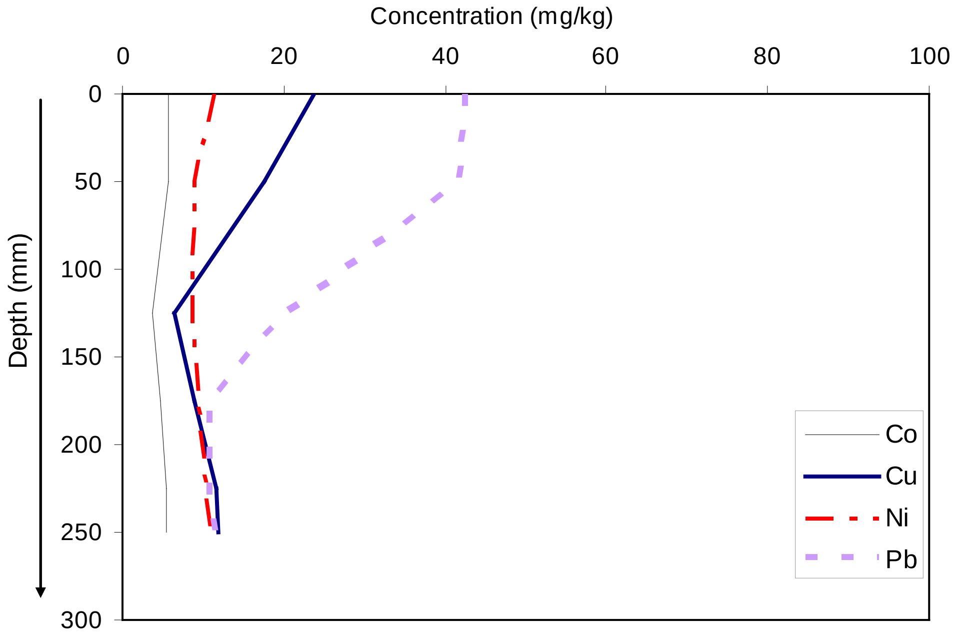


Figure 15. Depth profile plots of "total recoverable" concentrations of vanadium, zinc, manganese and iron (Fe concentrations scaled by 1000) at Hobson Bay.

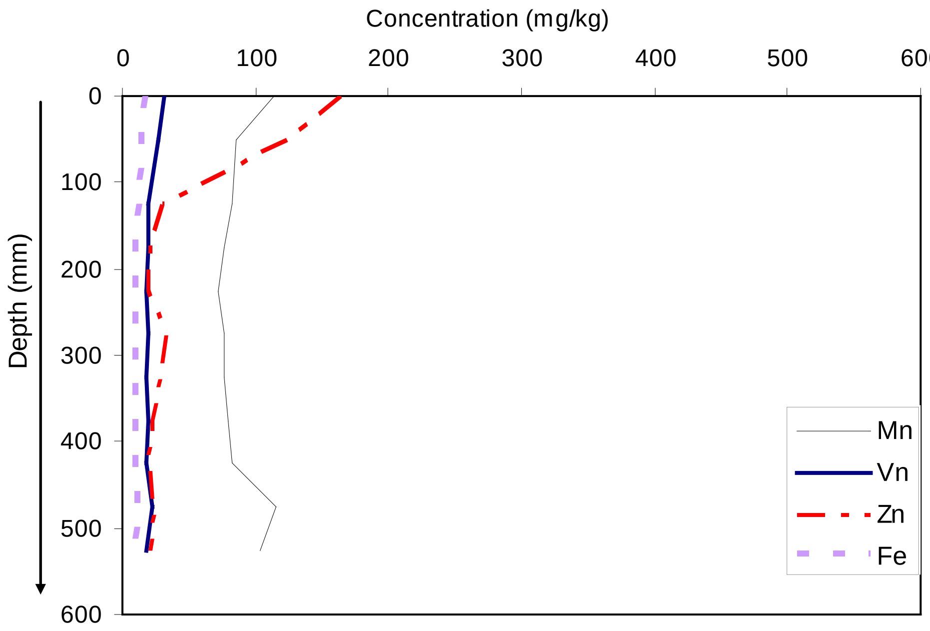


Figure 16. Depth profile plots of "total recoverable" concentrations of cobalt, copper, nickel and lead at Hobson Bay.

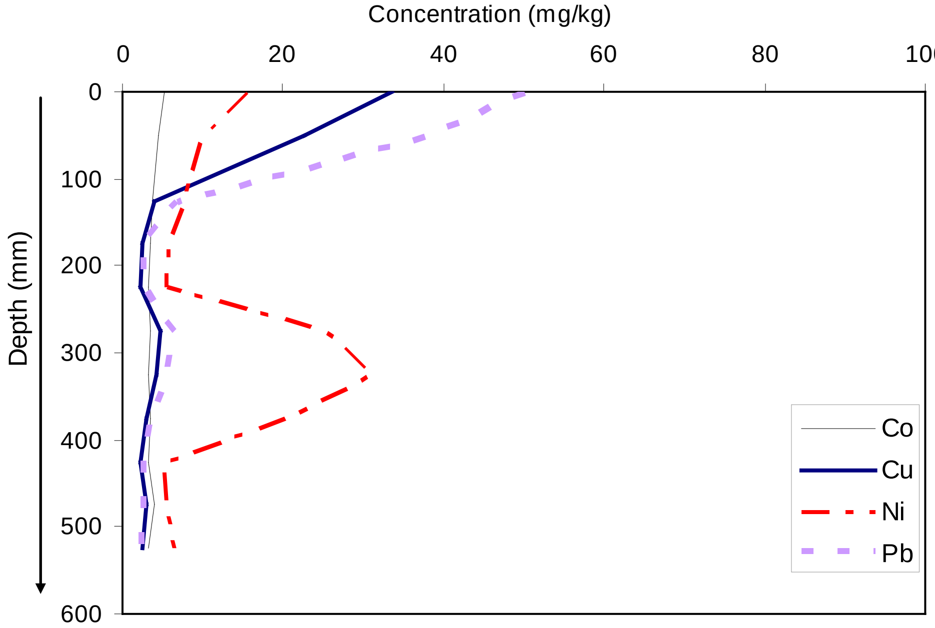


Figure 17. Depth profile plots of "total recoverable" concentrations of vanadium, zinc, manganese and iron (Fe concentrations scaled by 1000) at Puhinui.

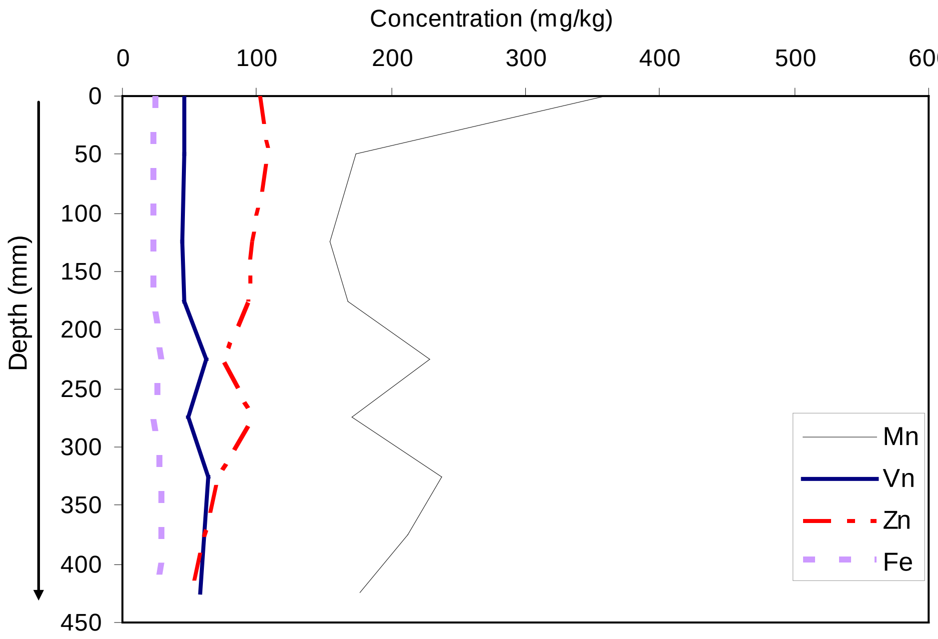


Figure 18. Depth profile plots of "total recoverable" concentrations of cobalt, copper, nickel and lead at Puhinui.

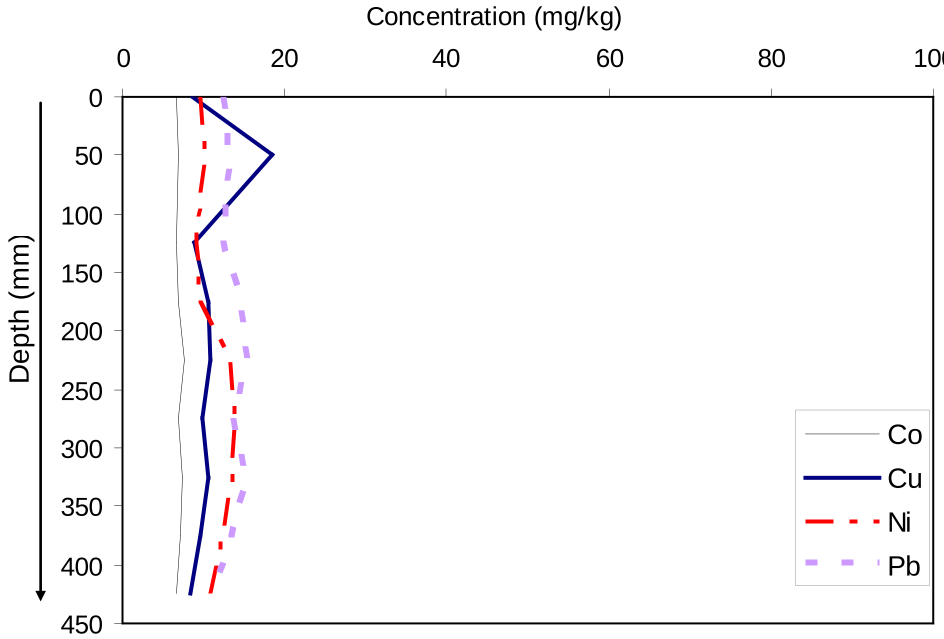


Figure 19. Depth profile plots of "total recoverable" concentrations of vanadium, zinc, manganese and iron (Fe concentrations scaled by 1000) at Auckland Airport.

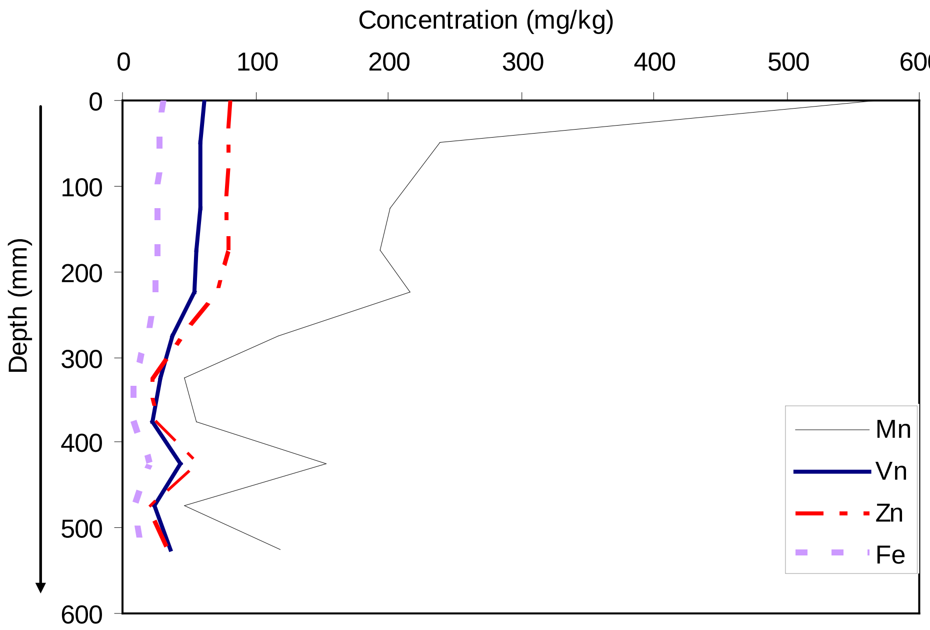


Figure 20. Depth profile plots of "total recoverable" concentrations of cobalt, copper, nickel and lead at Auckland Airport.

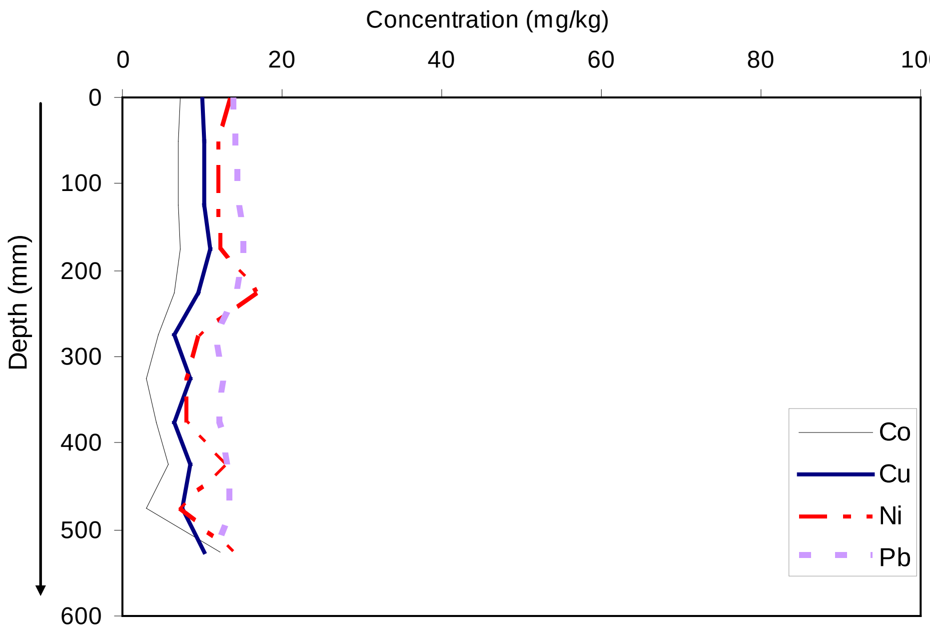


Figure 21. Depth profile plots of "total recoverable" concentrations of vanadium, zinc, manganese and iron (Fe concentrations scaled by 1000) at Wattle Downs.

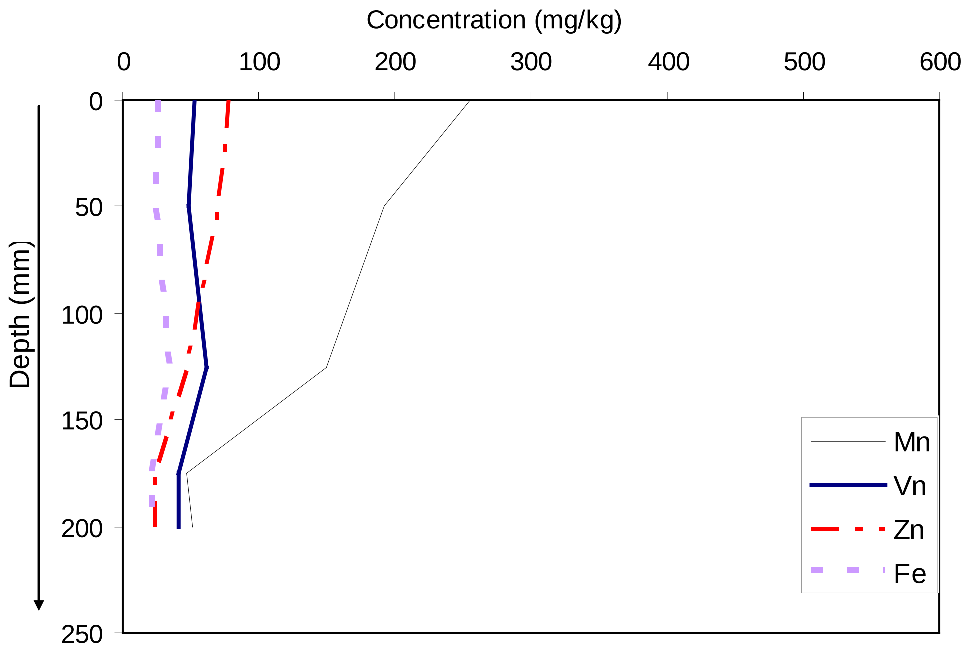


Figure 22. Depth profile plots of "total recoverable" concentrations of cobalt, copper, nickel and lead at Wattle Downs.

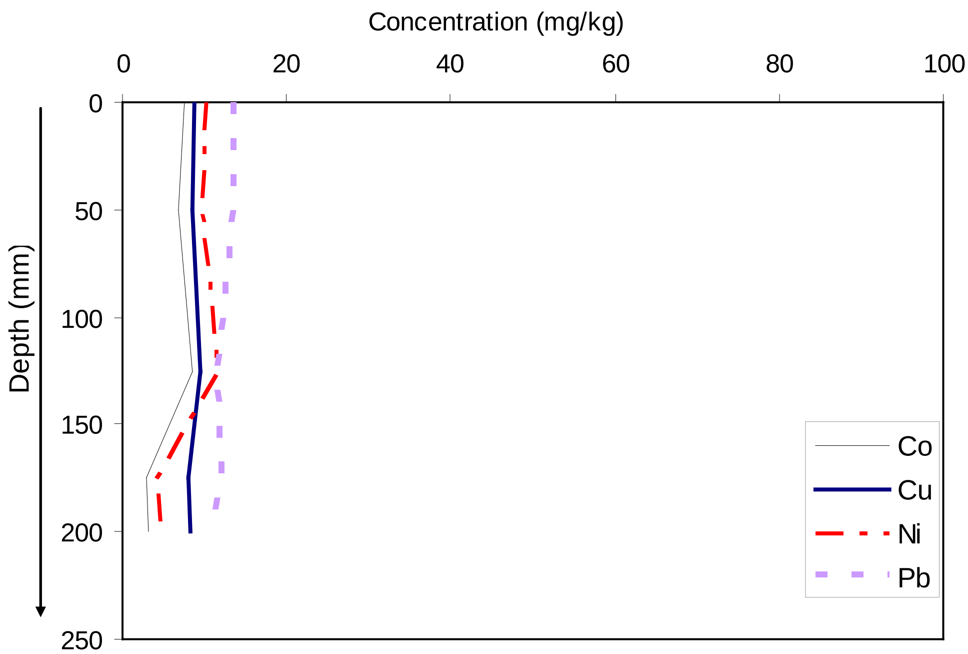


Figure 23. Depth profile plots of "total recoverable" concentrations of vanadium, zinc, manganese and iron (Fe concentrations scaled by 1000) at Takanini.

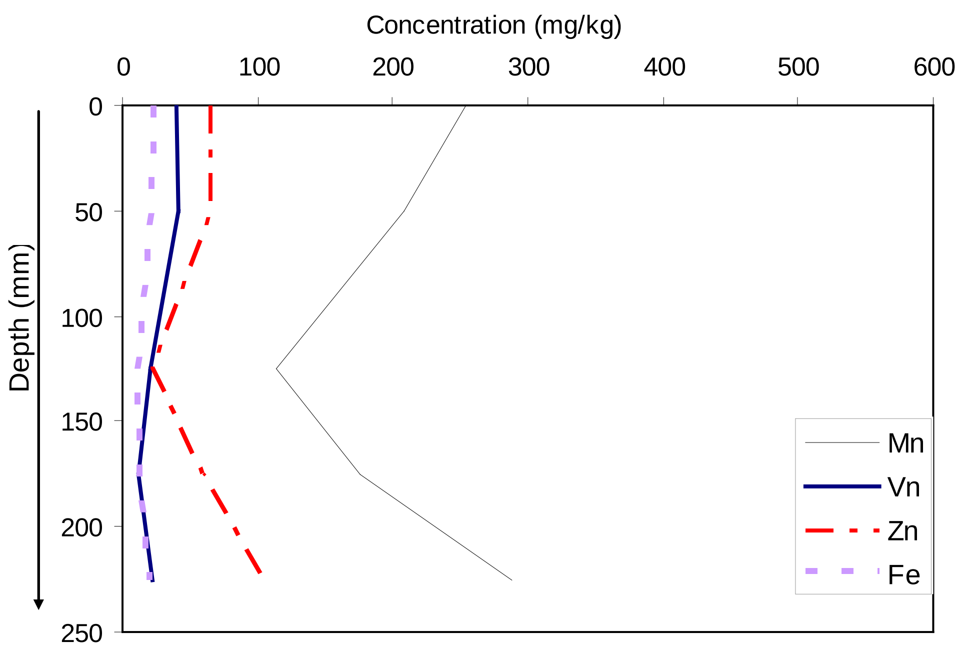


Figure 24. Depth profile plots of "total recoverable" concentrations of cobalt, copper, nickel and lead at Takanini.

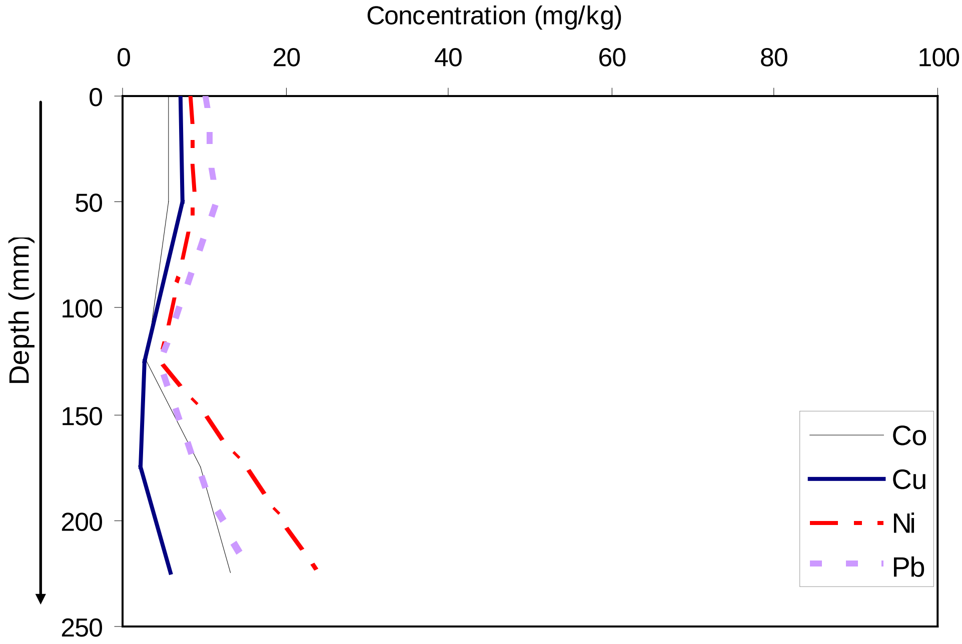


Figure 25. Depth profile plots of "total recoverable" concentrations of vanadium, zinc, manganese and iron (Fe concentrations scaled by 1000) at Kauri Point.

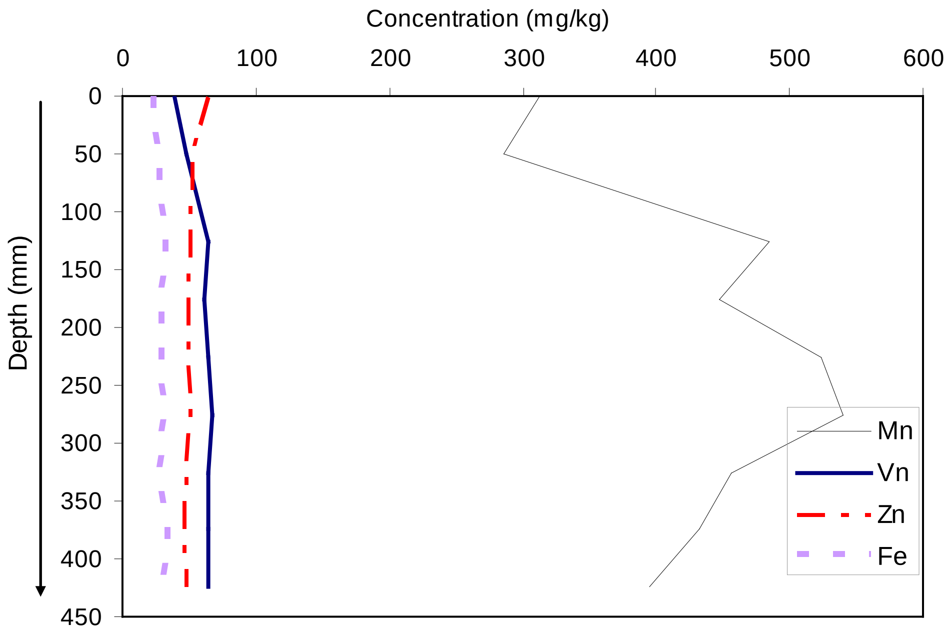
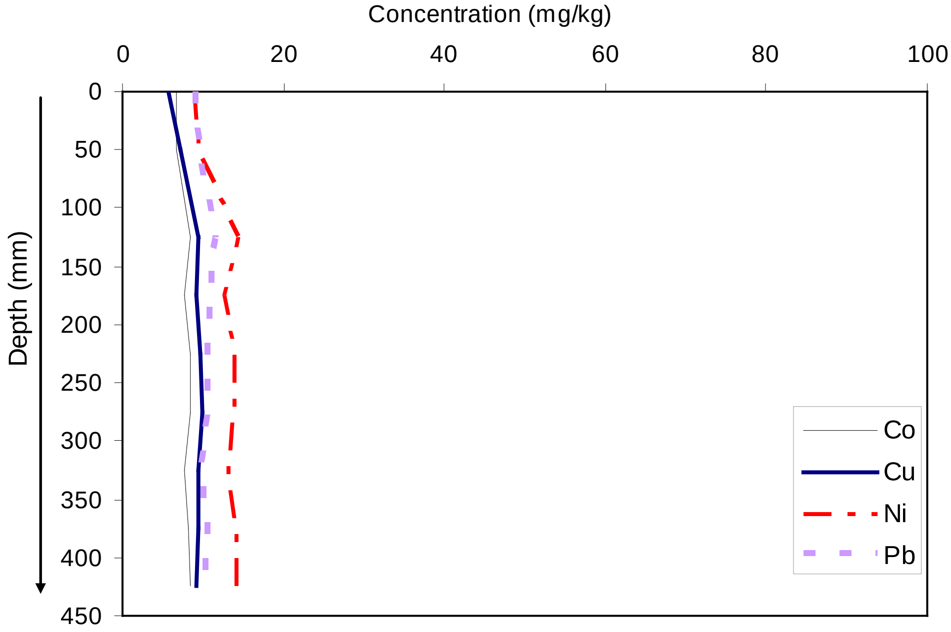


Figure 26. Depth profile plots of "total recoverable" concentrations of cobalt, copper, nickel and lead at Kauri Point.



4 Discussion and Conclusion

The sites can be divided into two groups:

1. Urban to pre-urban contaminant profiles based on the zinc concentration depth profile, and;
2. volcanic-derived concentration profiles or natural plus urban metal concentration profiles.

The urban to pre-urban profiles uses zinc as the "indicator" for urban development. The reason for using the zinc profile is that of the two metals originating in substantial quantities from urban activities, zinc and copper, the loads of zinc are typically eight-fold greater than are the loads of copper. The zinc depth profile is, therefore, much more sensitive than is the copper profile for detecting the influence of urban activities on sediment metal concentrations.

Group 1 sites are those that show a distinct profile of decreasing zinc concentrations with depth and a section of relatively unchanging concentrations at the base. Thus, because of the shape of the profile at these sites it is possible to reliably conclude that the section of the profile showing the higher zinc concentrations has been influenced by metals (and also other contaminants) from urban activities and that the section of low zinc concentrations at the base of the profile are sediments deposited before the loads of zinc (and presumably other contaminants) from urban activities increased much above the natural loads.

Group 2 sites do not show a profile where zinc decreases with depth. Their metal concentrations may have been derived from volcanic origins, mixed volcanic/urban origins, or may show non-volcanic natural and urban metal concentrations. Cobalt, vanadium and nickel are contaminants of volcanic-derived sediments. Copper and zinc originate from both volcanic and urban sources. By comparing the ratios of these metals and their inter-relationships it may be possible to tease out the origins. As explained in more detail below, for the latter sites, it is not possible to infer either the presence or the absence of metal loads from urban activities and, therefore, the measured concentrations cannot be interpreted as natural concentrations.

4.1 Group 1: urban and pre-urban metal concentration profiles

Of specific interest for this study are the metal concentrations at the base of Group 1 cores, ie the naturally occurring metal concentrations. As explained above, where these concentrations do not change markedly with depth, the concentrations can be assumed to be those due to natural sources, ie pre-urban. The best examples of decreasing zinc profiles are at the Motions, Meola and Hobson Bay sites. At the Meola site the zinc concentration decreased to between 40 and 42 mg kg^{-1} between 175mm and 275mm, at the Motions site concentrations of 28 and 29 mg kg^{-1} were measured between 425 and 500mm and at the Hobson Bay site the concentrations ranged between 20 and 33 mg kg^{-1} between 125 and 550 mm.

Using the urban zinc:copper ratio of 8:1 (see above) the other sites having Group 1 zinc profiles are Whau Upper and four sites Brighams, Puhinui, Auckland Airport and Wattle Downs with distinct but less extreme profiles than those in the cores from Whau Upper, Motions, Meola and Hobson Bay. The zinc concentrations at the Auckland Airport site average 33 mg kg^{-1} (range 20 to 55 mg kg^{-1}) over the lower 275mm of the core and the Wattle Downs core has concentrations of 24 and 23 mg kg^{-1} at the base of the core.

It would seem from the results for Motions, Meola, Hobson Bay, Auckland Airport and Wattle Downs, that typical pre-urban zinc concentrations range between about 20 mg kg^{-1} and 40 mg kg^{-1} irrespective of the catchment geology. None of these five sites, which are widely spread over the Auckland region, shows high natural zinc, nickel, vanadium or cobalt concentrations at the base of the core that would imply the presence of sediments derived from volcanic lithology.

The zinc concentration at the base of the Whau Upper core was 26 mg kg^{-1} but because this was only a single value (the concentration immediately above was 175 mg kg^{-1}) it is not possible to conclude that 26 mg kg^{-1} was the natural concentration. It is, however, consistent with the 20 to 40 mg kg^{-1} range for the five cores with distinct basal zones of natural concentrations. Similarly, the Brighams and Puhinui cores show distinct zinc profiles but the concentrations at the base of both cores are still decreasing and show no indication of having reached the natural concentration. Sampling to a greater depth, using a different sampling method, would be required to confirm whether zinc concentrations were decreasing or stable.

4.2 Group 2: volcanic and mixed volcanic/urban metal concentration profiles

The surface soil sample taken at Pukaki contains high concentrations of vanadum (90 mg kg^{-1}), cobalt (28 mg kg^{-1}) and nickel (44 mg kg^{-1}). The Pukaki soil is known to be volcanic.

Group 2 cores include those at Rangitopuni, Whau Wairau Arm, Takanini, and Kauri Point. The concentrations of cobalt, vanadium and nickel, indicators of volcanic origins, are much less than the Pukaki soils, and do not appear to be substantially different from Group 1 sediments. Statistical analyses of the concentration profiles for the metals measured at these four sites might enable the presence or absence of sediments from volcanic sources to be inferred, but such analyses have not been attempted as part of this project.

For the Rangitopuni, Takanini and Kauri Point cores the zinc concentrations ranged between about 30 mg kg^{-1} and 100 mg kg^{-1}. As explained above, however, because the zinc concentration depth profiles at these sites did not show distinct urban-influenced and natural zones, it is not possible to conclude either that the concentrations are volcanic, or that they are influenced by urban activities. This is also the case for the Whau Wairau Arm site but because this site is close to an intensely developed urban area and has no volcanic lithology in its catchment, it is reasonably certain that the high zinc concentrations are the result of urban activities and that the core did not penetrate pre-urban sediments. A different method is required to sample these more compact layers.

5 References

ARC, (1991). *Background concentrations of inorganic elements in soils from the Auckland Region.* Technical Publication 153. pp 68.

NIWA, (2007). *Modelling contaminant accumulation in South East Manukau Harbour: 2006-7 Year End Update Report.* Client Report to ARC, AKL2007-054. pp71.

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6 APPENDIX 1

Table 2. Total metal concentration (mg kg^{-1} dw) detected in sediments (<500µm) at depth at Rangitopuni, 2006.

Sample depth (mm) from the surface	Total recoverable iron	Total recoverable manganese	Total recoverable cobalt	Total recoverable copper	Total recoverable nickel	Total recoverable lead	Total recoverable vanadium	Total recoverable zinc
0-25	26200	162	6.1	25.6	11.7	26.6	54	111
50-75	23700	89	5.88	26.4	21.4	28.1	58	114
125-150	24200	99	6.69	25.2	12.4	28.6	55	106
200-225	23900	101	6.46	25	12.7	28.8	56	104
250-275	23500	100	5.52	23.2	11.5	27.1	53	94

Table 3. Total metal concentration (mg kg^{-1} dw) detected in sediments (<500µm) at depth at Brighams, 2006.

Sample depth (mm) from the surface	Total recoverable iron	Total recoverable manganese	Total recoverable cobalt	Total recoverable copper	Total recoverable nickel	Total recoverable lead	Total recoverable vanadium	Total recoverable zinc
0-25	22500	155	5.16	23.6	11.8	26.5	50	110
25-50	16700	71	5.35	24.8	11	27.6	53	109
50-75	17800	62	5.72	24.3	11.1	27.9	52	105
75-100	17000	91	9.42	18.9	18.7	17.1	38	68.7

Table 4. Total metal concentration (mg kg^{-1} dw) detected in sediments (<500µm) at depth at Whau (Upper), 2006.

Sample depth (mm) from the surface	Total recoverable iron	Total recoverable manganese	Total recoverable cobalt	Total recoverable copper	Total recoverable nickel	Total recoverable lead	Total recoverable vanadium	Total recoverable zinc
0-25	22800	185	6.14	47.2	12.7	131	55	265
50-75	19600	89	6.09	49.2	12.5	191	54	256
125-150	18400	62	6.86	45.8	14	212	56	270
175-200	13800	43	5.83	30.4	9.8	104	38	145
225-250	15700	49	6.22	34.6	11.4	137	41	175
275-300	9040	37	2.44	4.6	4	10.3	21	25.7

Table 5. Total metal concentration (mg kg^{-1} dw) detected in sediments (<500µm) at depth at Whau (Wairau Arm), 2006.

Sample depth (mm) from the surface	Total recoverable iron	Total recoverable manganese	Total recoverable cobalt	Total recoverable copper	Total recoverable nickel	Total recoverable lead	Total recoverable vanadium	Total recoverable zinc
0-25	23300	159	5.38	44.2	12	76.7	54	257
50-75	19000	86	4.95	47.4	12.2	82.8	56	294
125-150	19000	75	6.57	50.5	13.3	95.4	56	296
150-175	74900	206	6.35	51.8	16.5	121	51	216

Table 6. Total metal concentration (mg kg^{-1} dw) detected in sediments (<500µm) at depth at Motions, 2006.

Sample depth (mm) from the surface	Total recoverable iron	Total recoverable manganese	Total recoverable cobalt	Total recoverable copper	Total recoverable nickel	Total recoverable lead	Total recoverable vanadium	Total recoverable zinc
0-25	8710	57	4.1	20.1	11.8	40.4	19	147
50-75	8510	48	4.42	20.4	10.6	54.9	17	201
125-150	9560	59	4.88	22.7	13.3	67.5	18	277
175-200	9810	43	3.01	12.4	8.5	47.7	20	243
225-250	7800	43	2.68	7.2	12	21.4	16	82.7
275-300	8460	48	4.47	19.4	34.1	50.7	17	224
325-350	8430	40	3.22	10.7	22	33.7	18	185
375-400	7850	46	2.27	4.2	18.4	12.7	17	50.7
425-450	9090	66	2.32	3.4	11.7	5.33	19	27.5
475-500	13000	117	3.51	6.5	11.4	6.12	28	29

Table 7. Total metal concentration (mg kg^{-1} dw) detected in sediments (<500µm) at depth at Meola, 2006.

Sample depth (mm) from the surface	Total recoverable iron	Total recoverable manganese	Total recoverable cobalt	Total recoverable copper	Total recoverable nickel	Total recoverable lead	Total recoverable vanadium	Total recoverable zinc
0-25	17100	100	5.81	23.7	11.4	42.3	37	197
50-75	12300	62	5.8	17.5	9	41.7	27	252
125-150	10200	65	3.79	6.5	8.7	20.1	24	59.6
175-200	16500	137	4.7	9	9.5	10.6	35	40.2
225-250	19200	183	5.34	11.7	10.3	10.6	42	41
250-275	19500	152	5.45	11.9	10.8	11.4	46	41.7

Table 8. Total metal concentration (mg kg^{-1} dw) detected in sediments (<500µm) at depth at Hobson Bay, 2006.

Sample depth (mm) from the surface	Total recoverable iron	Total recoverable manganese	Total recoverable cobalt	Total recoverable copper	Total recoverable nickel	Total recoverable lead	Total recoverable vanadium	Total recoverable zinc
0-25	16500	114	5.28	33.7	15.5	50.1	32	164
50-75	13600	86	4.48	22.7	9.9	37.7	27	123
125-150	11600	83	3.61	4	7.8	6.61	20	30.6
175-200	9490	77	3.45	2.5	5.7	2.52	20	20.3
225-250	8680	72	3.25	2.2	5.5	2.41	18	19.7
275-300	9680	76	3.54	4.8	25.1	6.36	20	32.9
325-350	9300	76	3.24	4.2	31.2	5.29	18	28.2
375-400	9250	80	3.38	3	20.5	3.53	20	22.9
425-450	8670	83	3.2	2.3	5.3	2.44	18	20
475-500	11200	115	3.87	3	5.5	2.6	22	23.9
525-550	9500	104	3.34	2.5	6.4	2.24	18	20.4

Table 9. Total metal concentration (mg kg^{-1} dw) detected in sediments (<500µm) at depth at Puhinui, 2006.

Sample depth (mm) from the surface	Total recoverable iron	Total recoverable manganese	Total recoverable cobalt	Total recoverable copper	Total recoverable nickel	Total recoverable lead	Total recoverable vanadium	Total recoverable zinc
0-25	23800	360	6.77	8.5	9.7	12.3	46	103
50-75	22200	174	6.94	18.5	10.2	13.1	46	109
125-150	22000	154	6.55	8.8	9.2	12.4	44	96.7
175-200	22700	168	6.85	10.5	9.6	14.5	46	93.6
225-250	27900	229	7.52	10.8	13.2	15.3	63	74.2
275-300	22700	171	6.91	9.8	13.8	13.5	49	97.2
325-350	28300	238	7.37	10.7	13.6	15	64	71.9
375-400	27600	213	7.11	9.6	12.4	13.2	61	61.4
425-450	26000	176	6.7	8.4	10.9	10.9	58	52.3

Table 10. Total metal concentration (mg kg^{-1} dw) detected in sediments (<500µm) at depth at Auckland Airport, 2006.

Sample depth (mm) from the surface	Total recoverable iron	Total recoverable manganese	Total recoverable cobalt	Total recoverable copper	Total recoverable nickel	Total recoverable lead	Total recoverable vanadium	Total recoverable zinc
0-25	30100	568	7.18	10	13.5	13.8	62	80.6
50-75	26900	239	7	10.3	12.1	14	59	79.3
125-150	25400	202	6.99	10.3	12.1	14.4	59	78.1
175-200	24900	194	7.28	11.1	12.3	14.9	56	79.2
225-250	24800	217	6.48	9.6	16.8	14.2	54	71
275-300	17600	118	4.41	6.6	9.4	11.4	38	45.1
325-350	8160	47	3.1	8.4	7.9	12.4	28	22.8
375-400	6900	55	4.24	6.5	7.9	11.9	22	24.3
425-450	19700	153	5.7	8.4	12.7	12.9	44	55.2
475-500	7540	47	3.09	7.5	7.1	13.2	24	19.9
525-550	13300	119	12.2	10.3	13.8	11.4	36	32.6

Table 11. Total metal concentration (mg kg^{-1} dw) detected in sediments (<500µm) at depth at Wattle Downs, 2006.

Sample depth (mm) from the surface	Total recoverable iron	Total recoverable manganese	Total recoverable cobalt	Total recoverable copper	Total recoverable nickel	Total recoverable lead	Total recoverable vanadium	Total recoverable zinc
0-25	24500	255	7.5	8.8	10.2	13.5	53	77.7
50-75	24200	192	6.73	8.6	9.7	13.4	48	71.1
125-150	33300	149	8.51	9.6	11.6	11.4	61	46.6
175-200	20400	47	3.04	8.1	4.1	11.9	41	23.6
200-220	20100	51	3.23	8.3	4.8	10.7	41	23.3

Table 12. Total metal concentration (mg kg^{-1} dw) detected in sediments (<500µm) at depth at Takanini, 2006.

Sample depth (mm) from the surface	Total recoverable iron	Total recoverable manganese	Total recoverable cobalt	Total recoverable copper	Total recoverable nickel	Total recoverable lead	Total recoverable vanadium	Total recoverable zinc
0-25	21500	254	5.53	7.1	8.3	10	40	64.9
50-75	21200	208	5.6	7.4	8.9	11.2	41	64.6
125-150	10700	114	2.98	2.6	4.7	4.53	21	22.9
175-200	11800	176	9.65	2.3	15	8.88	12	58.7
225-250	19200	288	13.2	5.8	24.1	15.5	22	104

Table 13. Total metal concentration (mg kg^{-1} dw) detected in sediments (<500µm) at depth at Kauri Point, 2006.

Sample depth (mm) from the surface	Total recoverable iron	Total recoverable manganese	Total recoverable cobalt	Total recoverable copper	Total recoverable nickel	Total recoverable lead	Total recoverable vanadium	Total recoverable zinc
0-25	22700	312	6.6	5.6	8.9	8.83	39	64.2
50-75	25100	286	6.69	7.1	9.5	9.37	48	52
125-150	31800	485	8.34	9.4	14.4	11.3	65	51.1
175-200	27700	448	7.68	9.1	12.7	10.6	62	49
225-250	28800	524	8.36	9.6	13.9	10.5	64	48.8
275-300	29300	540	8.42	9.9	14	10.4	67	51.2
325-350	26900	456	7.76	9.5	13.1	9.8	64	47.4
375-400	32700	433	8.27	9.4	14.2	10.3	65	47
400-425	29500	395	8.56	9.2	14.2	10	65	48.2

Table 14. Total metal concentration (mg kg^{-1} dw) detected in surface soil sample (<500µm) at Pukaki, 2006.

Sample depth (mm) from the surface	Total recoverable iron	Total recoverable manganese	Total recoverable cobalt	Total recoverable copper	Total recoverable nickel	Total recoverable lead	Total recoverable vanadium	Total recoverable zinc
Surface soil sample only	40900	2040	28.1	34.9	44.3	13.3	90	88.6