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Heavy Metal Contamination of Pasture Soils by Irrigated Municipal Sewage

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The world's population is more than six billion and by some estimates expected to increase to ten billion the year 2050. The use of manufactured inorganic fertilisers will not ensure adequate sustainable agricultural production levels, and the recycling of sewerage and other wastes will be essential for economic and ecological survival (Cameron, et al., 1997). The nutrient content of municipal and some industrial wastewater makes it very economically, and in some cases culturally (e.g. New Zealand Maori), attractive for fertiliser. However, domestic sewerage, even after treatment, contains significant concentrations of potentially toxic contaminants, including heavy metals (e.g. cadmium, zinc, cobalt, nickel, lead, mercury, boron), other metal ions (e.g. sodium, potassium, magnesium, calcium), pesticide residues (e.g. atrazine and its degradation products), other endocrine disrupting organic compounds such as PCBs, PCDD/PCDFs, polycyclic aromatic hydrocarbons (PAHs), alkyl phenols, phthalates, phyto- and synthetic estrogens, and pathogenic micro-organisms. Leaching of these contaminants through the soil into water supply and groundwater is a major hurdle to the safe disposal of treated sewerage on land.

Australia produces one of the highest per-capita rates of agricultural, industrial and municipal wastes in the world (Cameron, et al., 1997). Historically, much of this waste, both treated and untreated has been disposed into the ocean. Increasingly, municipal authorities in Australia are required to dispose of their wastes locally on land. This paper presents results of a reconnaisance survey of heavy metal accumulation in soils from Australia s oldest sewerage farm located in Werribee just outside of Melbourne, Victoria.

MATERIALS AND METHODS

The Western Treatment Plant-Werribee Farm (WTP; Figure 1) is located 35 km southeast of Melbourne on the Werribee River delta. The WTP is situated between the Melbourne to Geelong Highway and the shore of Port Phillip Bay. There is a 21 km Port Phillip Bay frontage along a narrow shelly sand foreshore.

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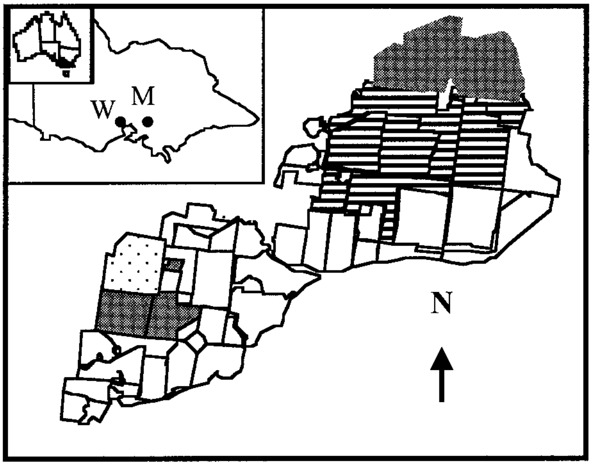
Figure 1. Location of the Werribee Treatment Plant. M, Melbourne; W, Werribee. Land Filtration Areas with date irrigation commenced

1893

1920

1944

Grass Filtration area and Lagoons



The WTP covers some 11,000 ha, and treats Melbourne's sewerage at an average rate of 500 ML per day. After being treated, effluent is discharged into nearby Port Phllip Bay. Currently, three methods of treatment are used: lagoon aeration, land filtration and grass filtration. Disposal-use patterns change depending on the season and the rate of sewerage flow. For instance, land filtration by irrigation of raw sewerage on permanent pasture paddocks occurs during the months of high evaporation (Oct.-Apr) on 3633 ha of the site. Each paddock operates on a 21 day cycle consisting of one or two days of irrigation (average seasonal hydraulic loading is 0.055 ML/ha/day), followed by 5 days drying and 14 days livestock grazing. About 40% of the applied volume is collected by sub-surface drains and discharged into the bay. The remainder is lost through evapotranspiration.

There are two major soil types on the site: Deltaic deposits of the Werribee River system and newer volcanic basalts associated with the surface geology (McGuckian 1997). The charactersitics of each soil type are: newer volcanic basalts: red brown earth, shallow red duplex soils with shallow topsoil (10 cm) overlying reddish grey brown heavy clay subsoils, sub soils are sodic, and with variable pH; Werribee delta sediments: delta soils, red duplex with a top soils of 15-20 cm fine sandy loam to clay loams with medium clay or heavy clay subsoils. Clay sub soils are sodic and alkaline. It is these latter Werribee delta soils that have been used for the land filtration of sewerage. Particle size analysis and physical properties (Percentage Organic Carbon, Total Nitrogen and Phosporus and Cation Exchange Capacity) for this soil type are summarised in Table 1.

The soil and vegetation samples were collected from randomly selected sites in 21 paddocks in the land filtration area (Figure 1). Soil samples were collected from two depths : soil layer A from 0 to 20 cm depth, and soil layer B from 20 to 40 cm depth. The concentration of heavy metals in the two soil layers and in pasture

Table 1. Werribee delta soil characteristics (Croxford 1978). CS, coarse sand; FS, fine sand; Si, silt; C, clay.

Depth (cm)	pH	Particle size* %				Org C (%)	Tot N (%)	Tot P (%)	CEC (Cmol kg^{-1})
		CS	FS	SI	C				
2 - 5	6.8	11.2	20.2	20.6	25.3	11.8	1.17	0.13	27.5
5 - 35	7.2	10.8	30.6	27.4	28.5	2.2	0.26	0.07	14.7
35-60	7.7	1.4	14.7	23.2	60.4	0.9	0.13	0.05	25.0
60-80	8.5	1.5	13.0	39.2	43.6				15.7
80-105	8.7	7.9	34.0	28.2	28.4				9.9

* 1.1-2.6 % of particles lost in acid treatment

tissue was determined commercially by Australia Water Technologies. A standard analytical method (Code WEC 042) in the Guidelines for the Laboratory Analysis of Contaminated Soil (ANZECC 1996) was used to obtain the heavy metal extracts and an ICP-AES was employed to determine concentrations.

RESULTS AND DISCUSSION

Average concentrations and corresponding standard errors of six major heavy metals (Cu, Cd, Zn, Ni, Cr and Pb) in the land filtration areas and similar soils in the WTP not used for sewerage treatment are summarised in Table 2. The average concentration of Cr in sewerage treated soils significantly exceeds the ANZECC standard, while the average concentrations of Cu and Zn are close the standard (Table 2). The concentrations of other metals are also high enough for the land to be considered contaminated. The first irrigation of pastures with sewerage occurred in 1893 (Figure 2). The figure illustrates the steady increase in heavy metal concentrations in the soil over the last 106 years. The figure also illustrates the changing relative concentrations of each of these metals in the past 100 years, presumably due to changes in the composition of sewerage itself. For example, pastures paddocks irrigated before 1920 had high rate of accumulation of Zn, whilst paddocks which received irrigation after 1920 had higher relative accumulation of Cd. The input rate deceased substantially between 1970 and the 1990 s. In recent years the concentration of Cr has reached, and Cu almost reached, the guideline concentrations for metals in waste water (Cd, 0.01; Cr, 0.10; Cu, 0.20; Pb, 5.00; Ni, 0.20; Zn, 2.0 mg/L, respectively (EPA Victoria State, Australia 1991)). The historical data also suggests that the heavy metal input into the soil also decreased between 1968 and 1978 (Table 3). Concentrations appear to have reached a new equilibrium level as new industries in the region comply with the maximum allowable concentration of heavy metals in trade waste and therefore control discharge waste water carefully (Croxford 1978).

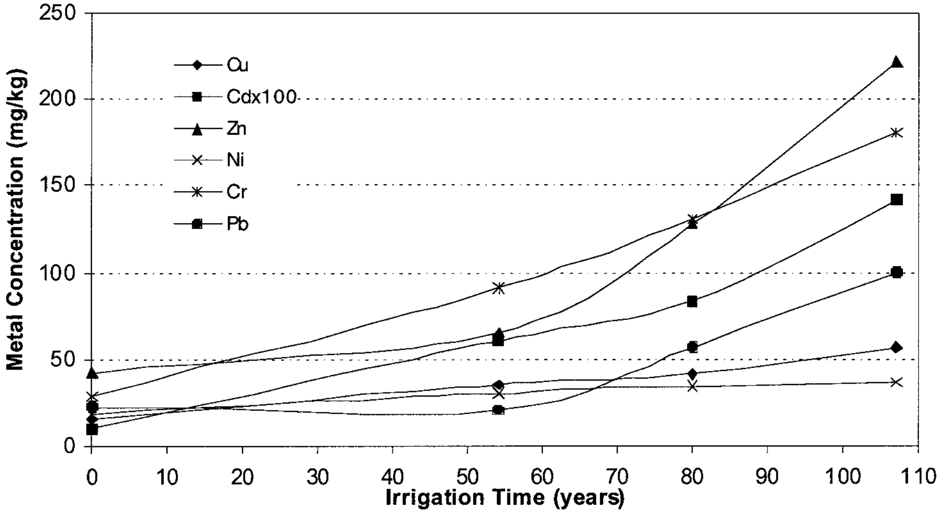


Figure 2 Heavy metals concentration in Werribee Treatment Plant soils as a function of the length of time of sewage irrigation.

Table 2. Average concentration of heavy metals in land filtration areas of werribee Treatment Plant in 1999 (mg/kg (standard error)).

Soil Sample	Soil Layer	Cu	Cd	Zn	Ni	Cr	Pb
SIA	A	54.5 (6.6)	1.49 (0.3)	193 (23)	39.5 (1.9)	164 (19)	87.6 (14)
	B	36.5 (3.8)	0.88 (0.2)	140 (18)	33.0 (2.3)	100 (11)	40.5 (7.6)
NSIA	A	15.6 (2.7)	<0.1	41.9 (5.5)	18.1 (1.9)	28.5 (1.9)	22.7 (1.5)
ANZECC	SS	60	3	200	60	50	300

SIA; n = 25; layer A, 0 —20 cm from surface; B, 20 —40 cm. Background values of average heavy metal concentrations (non-sewerage irrigated area (NSIA); mg/kg (standard error)) in soils that do not receive irrigation of raw sewerage (n = 10), and Australian and New Zealand Environment and Conservation Council (ANZECC) guidelines for heavy metal concentrations in soil (SS, mg/kg).

The reconnaisance soil survey at the WTP was designed to update the historical archive and explore the distribution patterns of heavy metals. The results of this study illustrated that long-standing application of sewerage to land is eventually leading to risk of soil contamination. Heavy metal concentrations in WTP were widely found to match and in some cases exceed environmental guidelines. Heavy metals, in particular Cr, Cu, Zn, Cd, are present in the soils at WTP at

Table 3. Average concentration of heavy metals in raw sewerage at the Werribee Treatment Plant (mg/L; N/M, not measured).

Metal	1968	1972	1977 - 1978	1991 - 1992	1992 - 1993	1993 - 1994	1999
Cu	0.65	0.45	0.35	0.2	0.157	0.150	0.16
Cd	N/M	0.001	0.015	0.002	0.001	0.002	0.001
Zn	1.0	1.3	0.80	0.342	0.316	0.205	0.32
Ni	0.2	0.2	0.15	0.031	0.049	0.031	0.05
Pb	N/M	0.55	0.30	0.029	0/021	0.031	0.02
Cr	0.55	1.0	0.40	0.105	0.100	0.069	0.1

Table 4. Heavy metal content of pastures in the land filtration area in 1999 (n=9; mg/kg) and their accumulation ratio, compared with a reference of average concentration of heavy metals in pasture (NPR, normal plant range; NIR, non-irrigated pasture; IR, irrigated pasture; mg/kg dry matter) (Source: Evans et al 1979).

	Cu	Cd	Zn	Ni	Cr	Pb
WTP (1999)	11.95 (1.5)	<0.5	51.3 (8.9)	<0.2	4.1 (1.6)	<0.5
RATIO*	0.2249	<0.4425	0.3019	<0.0054	0.0236	0.0589
NPR	4-15	0.2-0.8	8-15	1	0.2-1.0	0.1-10
NIR	11.0	0.19	45.0	1.9	2.3	3.4
IR	22.0	1.1	171.0	6.3	15.0	12.0

*Ratio = pasture concentration / corresponding soil concentration

concentrations high enough for the land to be considered as contaminated and in need of remediation (Table 4). The concentration of Cr, Cu and Zn in sewerage, soils and plant tissues are at a level that can be used as tracers of metal contamination in further studies, e.g., groundwater transport studies or studies to determine the fractionation of metals within specific paddocks.

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