The response of some New South Wales coastal floodplain soils to irrigation of high strength organic wastewaters

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Abstract

The coastal floodplains of New South Wales have many characteristics potentially unfavourable to wastewater application such as a complicated pattern of soil variation across the landscape, frequently high watertables, poor profile drainage, occasionally high salinity and the presence of acid sulfate soil materials. Annual rainfall is high (>1000 mm generally), the landscape is low lying and flood prone to a variable extent. There are also many wetlands sensitive to change in water quality. On the other hand, the high content of organic matter in the surface soils and the level to gently undulating terrain are favourable features.

Saline, nutrient-rich wastewater generated by food-processing industries in coastal towns has been used to irrigate farmland for decades. Soil salinity has not increased linearly but has fluctuated from year to year, apparently in response to variations in effluent salinity, rainfall, flood frequency and the depth of shallow groundwater. Nutrient concentrations have risen, especially in surface soils where Bray P concentrations now reach over 1000 mg/kg in some irrigated paddocks. Downward leaching of P has been minimal, mainly because of high P sorption capacities, especially in acid sulfate soil areas. Sodicity has increased but topsoils remain crumbly and well structured. Aggregates resist slaking and clay dispersion remains low, in some cases assisted by higher soil salinity.

The main disadvantage for irrigators is the need to control applications carefully to prevent surface waterlogging and the subsequent generation of foul odours. Careful site selection, laser levelling and well managed irrigation can reduce some of these unfavourable impacts. Coastal floodplains are natural sinks for nutrients and salts, and if loading rates are not excessive, can provide some buffering against potentially adverse impacts of waste applications.

Key Words

Effluent irrigation, waste reuse, salinity, nutrients, sodicity

Introduction

Most of the NSW population lives within 50 km of a coastal floodplain. With urban development largely restricted by the threat of major floods to the adjacent higher land, agriculture is the dominant land use. Grazing of dairy and beef cattle are the major types of production, with areas of intensive cropping (particularly sugarcane) important in some districts. Many of the wetlands are set aside as national parks or nature reserves and have high biodiversity.

There is a complicated soil distribution pattern on the floodplains arising from the interplay of depositional environments (riverine, estuarine, and marine) produced by post - glacial changes in sea levels (Umitsu *et al*. 2001). Fragments of earlier landscapes may also be preserved and these can have a major influence on the drainage system. The range of soils occurring on the floodplains has been described in some early surveys (Walker 1962, Walker 1963, Read 1974). Soils with minimal profile development (rudosols and tenosols) are typically on the elevated parts of the younger terraces. These have thick loamy or sandy profiles, while the lower ground at the rear of the levee bank tends to be more clayey. The degree of waterlogging increases as the elevation falls, and hydrosols are more common. Peat can accumulate on the surface of the swampy areas, burying sulfidic material in the subsoil. On the older, higher terraces the soil profiles are more strongly differentiated (dermosols, chromosols and kurosols).

Some of the farmland is used for irrigation of wastewater from both industrial and domestic sources. Dairy factories near several towns originally discharged high strength wastewaters into the nearby river but now have been irrigating onto pastures for decades. On the south coast, saline nutrient rich waste is applied to the Shoalhaven flood plain from a factory where starch is separated from wheat flour (Lawrie 1996). Communities all along the coast are also looking to irrigation as an alternative to river discharge of low strength sewage effluent and schemes have already been implemented on the Hawkesbury and the Shoalhaven. Some of the impacts arising from the use of high strength industrial effluent (Lawrie 1998) have made local coastal communities and regulators apprehensive over the long term effect on the floodplain of expanding wastewater irrigation schemes. Conventional irrigation farming is rare within these coastal landscapes compared to long established irrigation areas in inland NSW. The lack of previous experience of irrigation on the coast means it is difficult to predict long term impacts arising from irrigation in this high rainfall area. The objective of this study is to examine the data from environmental monitoring programs compiled by several wastewater generating industries to improve our understanding of any impacts on soil and water quality. These findings could be used to re-assess wastewater re-use guidelines used by environmental regulators, which appear to have been based on experience from conventional irrigation practices in inland locations.

Materials and methods

Environmental monitoring reports from two dairy factories and one starch factory, dating back to 1991 were examined to assess responses of some coastal floodplain soils to wastewater irrigation. Surface and subsoil samples from a range of depths were collected annually at a number of sites from each of the 3 irrigation schemes (see Table 1). For the two Shoalhaven sites, representative soil monitoring locations were selected after detailed soil mapping of the irrigation areas.

Table 1. Details of irrigation schemes studied.

Characteristic	**Location (industry)**		
	Hunter (dairy)	Shoalhaven (dairy)	Shoalhaven (starch)
Irrigated area (ha)	86	32	498
Av. rainfall (mm/yr)	1144 (Newcastle)	1135 (Nowra Airport)	1135 (Nowra Airport)
Annual volume irrigated (ML)	192	108	1374
Effluent quality:			
Salinity (dS/m)	1.8 – 3.0	1.0 – 2.1	3
Total N (mg/l)	<0.05 – 1.4	11.5 - 270	1153
Total P (mg/l)	2.4 - 106	1.3 - 114	212

The two irrigated areas of the Hunter dairy factory (160 km north of Sydney) extend partly over a large stockpile of coalwash and also onto the adjacent floodplain, but only data from the irrigated floodplain area is reported here. The area extends over a level backslope (elevation 1-2 m above sea level – ASL) vegetated with swamp oaks and pastures, dominated by kikuyu and couch grass. The profile has a surface soil of dark crumbly clay (30-50 cm thick) which cracks when dry, over a subsoil of grey and yellow brown mottled sand containing sesquioxide concretions. The water table within the sand occurs at a depth which fluctuates with the rainfall.

The Shoalhaven dairy factory (150 km south of Sydney) also has 2 irrigation areas, but both are on the floodplain. One area extends over 18 ha of a local dairy farm containing a range of soils. Dark loamy topsoils predominate, over grey mottled clay subsoils (elevation of the irrigated area 2-6 m ASL, with a non-irrigated area 2-2.5 m ASL). The second irrigation area nearby (14 ha on Bolong Rd) is also low lying (1.5-2 m ASL), and has a dark light clay topsoil over a grey silty clay subsoil with rusty mottles. Both areas contain a mix of rye grass and kikuyu pastures, with some clover. Like the non-irrigated farm area, the Bolong road site has a shallow watertable within a metre of the surface.

Also on the Shoalhaven (2 km from the dairy factory) is the starch factory irrigation area (498 ha) which extends from the upper part of the backslope down onto very low lying former backswamps. The range in elevation is 0.5-2.5 m ASL. There are six profile monitoring sites and data from only three of these are reported here because their data set is more comprehensive and extends over a longer period of time. Two of these sites are in low lying former backswamps, only 0.5 m ASL (Soper and Walsh sites). They have dark loamy topsoils with rusty mottles over grey mottled clay subsoils that contain jarosite at depth. There is sulfidic clay at a depth of 1-1.5 m. The third site (Paper Mill) is more elevated (2 m ASL) and also has a dark loamy topsoil, but over a yellow brown and grey mottled clay subsoil containing tubular iron concretions below a depth of 1.2 m. The watertable is usually deeper than 1 m and is often 2 m below the surface. Rye grass is the dominant pasture of the centre pivot areas with kikuyu on most other paddocks. Under particular seasonal conditions, clover appears in many paddocks.

Effluent quality can vary on a daily basis. Although some balancing occurs in the storage ponds, the values in Table 1 should be considered only as a general guide.

Soils are sampled during the late spring at all three effluent irrigated areas for pH (in calcium chloride), electrical conductivity (1:5 soil/water suspension) and nitrate nitrogen (KCl extractable) down the profile to depths up to 1.5m (Rayment & Higginson 1992). The three starch factory profile monitoring sites were not sampled every year, unlike the two dairy effluent locations which were tested annually. The profile samples are composites of 5 undisturbed cores (50 mm diameter) collected in a cluster 5 m across, situated within a monitoring zone 20 to 30 m across.

The surface samples of soils receiving dairy factory effluent and adjacent non-irrigated control areas, are composites of 40 cores (0 – 10 cm or 0 – 15 cm deep), distributed in a random zig zag pattern across the 1ha site avoiding atypical spots (Brown 1999). They are tested for electrical conductivity (1:5 soil/water suspension), nitrate nitrogen (KCl extractable), extractable phosphate (Bray and Colwell) and exchangeable cations by compulsive exchange (method 15E1, Rayment and Higginson 1992). Clay dispersion of crushed samples was measured using the method of Bradley *et al.* 1982.

The large starch effluent application area is divided into over 30 paddocks, about a third of which are sampled in rotation annually. Composites of 10 cores are collected from 0 – 10 cm and 10 – 20 cm depth. Samples were subjected to a wide range of tests including Bray P and P sorption index (Methods in Bradley *et al.* 1982. In the environmental monitoring reports the range of tests and methods used can differ from year to year, depending on the particular requirements of the pollution control licence or the needs of management. This makes comparisons for statistical tests of significance very difficult. However some general comparisons are still possible.

Results

In the early years of starch effluent application salinity levels down the profile increased and then fluctuated from year to year (see Figure 1), and evidence of a clear rising trend is lacking. At the Hunter dairy effluent site salinity has increased slightly in the topsoil (see Figure 2) over the monitoring period, although there has been little change to subsoil salinity (see Figure 3).

Nitrate levels down the profile have also risen after irrigation with a high N content starch effluent, but there are marked fluctuations from year to year (see Figure 4). In contrast the subsoils where dairy effluent (lower N content) has been irrigated for decades (on the same Shoalhaven floodplain and under the same climatic conditions as the starch factory site) have barely experienced any increase in nitrate content (Figure 5).

High loadings of phosphorus in irrigated starch effluent have resulted in very high concentrations of extractable P in the top 10 cm, but the subsurface increase is much less. Shoalhaven soils generally have high P sorption and this has been effective in reducing downward P movement, but at the expense of a shrinking P sorption capacity in the topsoil (see Table 2a and 2b).

Sodicity levels have also increased after irrigation, but the impact on clay dispersion has generally been only slight (see Table 3).

Discussion

Despite high salinity, plant growth appears largely unaffected. Annual low altitude aerial surveys of ground cover on the Shoalhaven looking for signs of salting on irrigated pastures were discontinued after 7 years of failing to detect persistent areas of poor growth or bare ground. Salt does not accumulate incrementally, probably because of regular flushing by rainfall, flooding or water table movement. Since 1995 annual rainfall at north Nowra has ranged between 704 and 1223 mm, and there have been several minor floods. Studies of groundwater hydrology investigating the impact of acid sulfate soils on the Shoalhaven (Blunden *et al.* 1999) have revealed that groundwater levels and quality (salinity and pH) can change rapidly, over a few days. At the Hunter site the depth of the watertable is generally below 1.5 m in prolonged dry weather but fluctuates with rainfall and can rise to within 30cm of the surface at both the irrigated and non-irrigated sites because the sandy subsoil is very permeable. This process of rapid rise and fall can transfer salt out of saline subsoils. Evaporation from a shallow saline water table via the capillary fringe can increase topsoil salinity, and is the most likely reason for the elevated salinity of the non-irrigated soil at the Hunter. Leaching of salt following irrigation has reduced salinity in the topsoils receiving Hunter dairy factory effluent. Salt inputs from both effluent and groundwater and influences of flooding and rainfall, all contribute to the overall level of salinity on coastal floodplains.

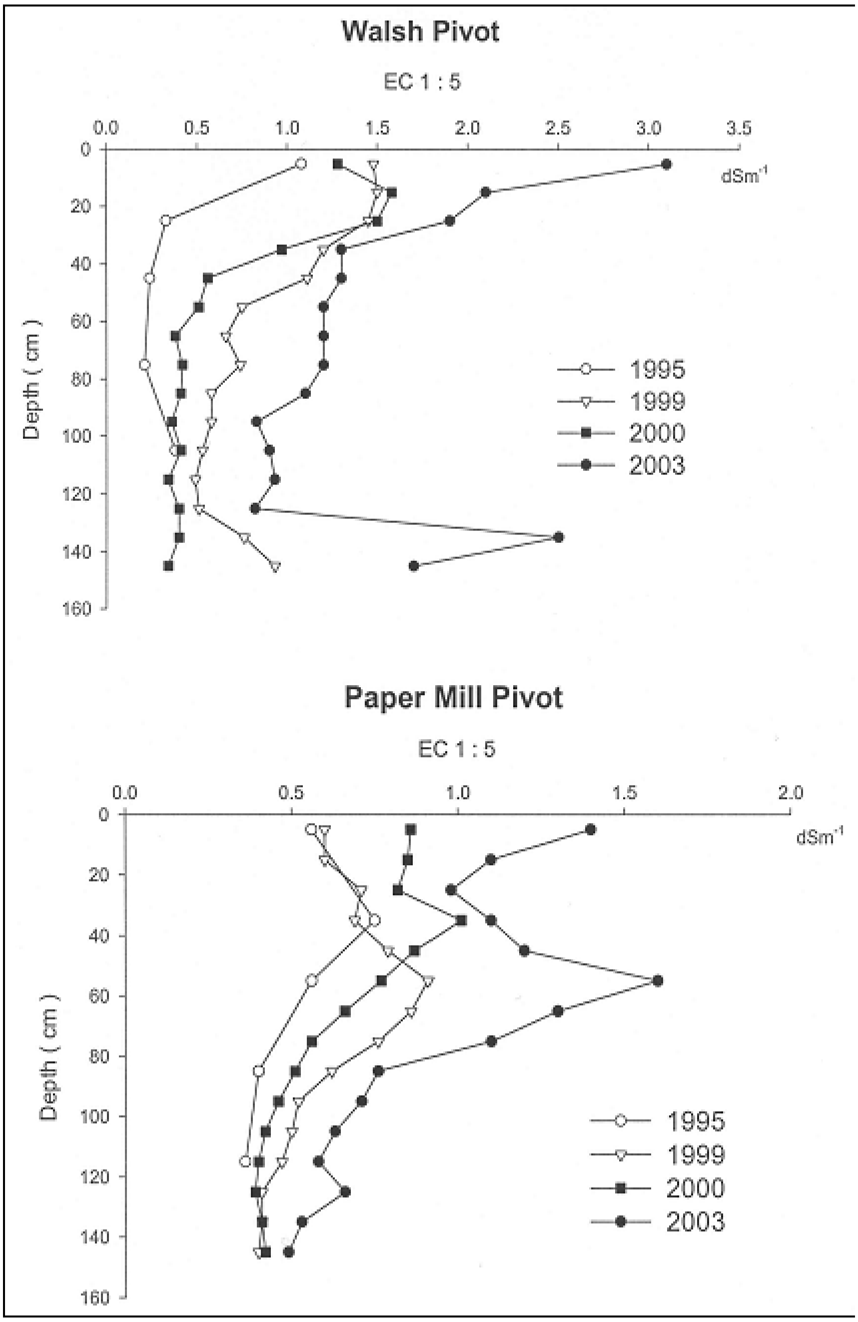

Figure 1. Changes in salinity down the profile at two starch effluent centre-pivot irrigation areas. (Soils sampled in October or November prior to the year of reporting. The first samples were collected after the paddocks were laser levelled, prior to irrigation).

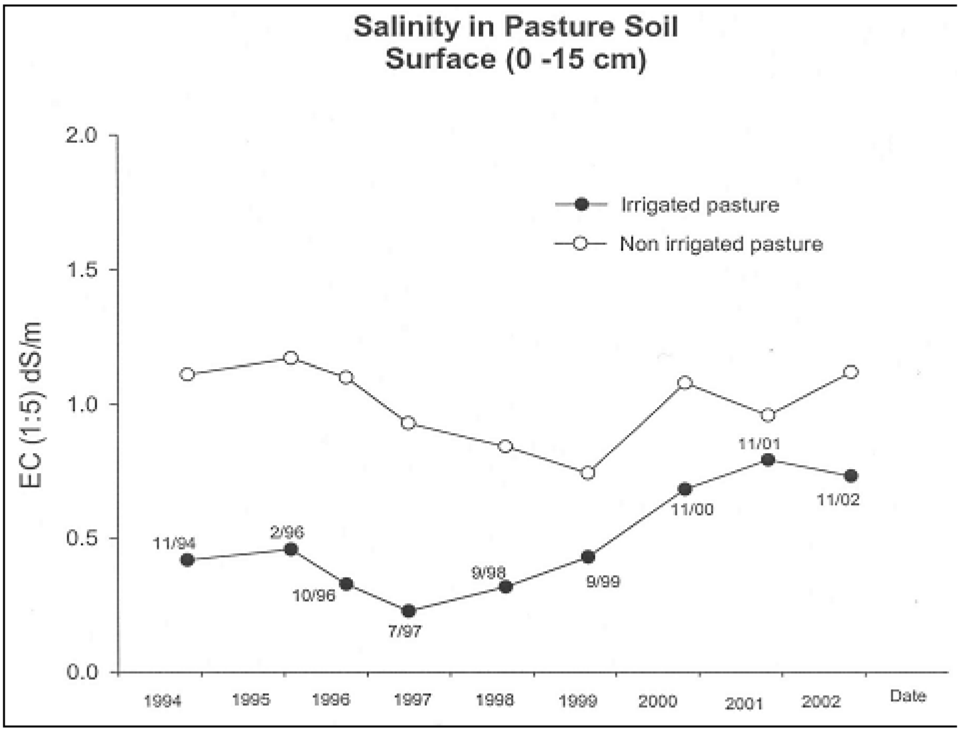

Figure 2. Changes in surface soil salinity 1994 – 2002 at the dairy effluent irrigation paddock on the Hunter floodplain, and on the adjacent non-irrigated control area.

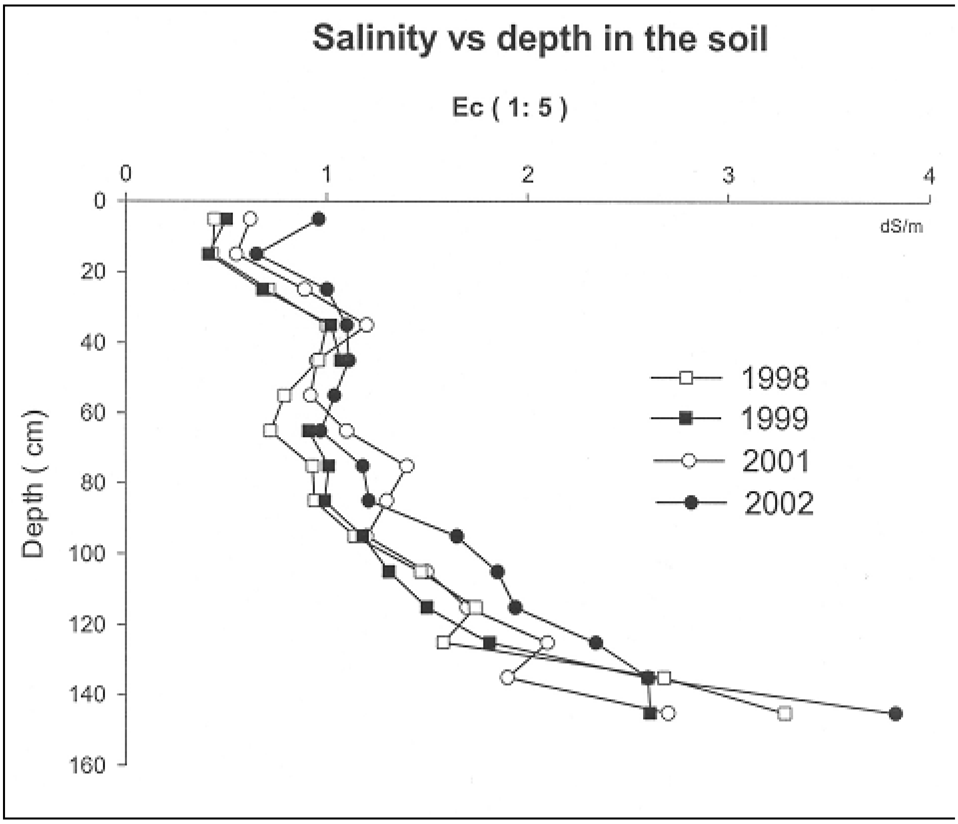

Figure 3. Changes in salinity down the profile on the dairy effluent irrigation paddock on the Hunter floodplain 1998 – 2002.

Nitrate levels down the profile can also be influenced by hydrological conditions at the site (as well as the N loading rate). Dry weather favours mineralisation of organic nitrogen, while wet weather can favour volatilisation. Flushing of soluble nitrates via watertable movements is probably preventing a build up in some of the soils receiving the high N loading of starch effluent. Monitoring of groundwater nitrate levels on the Shoalhaven has not found any persistent rising trend in concentration beneath irrigated paddocks until 2003, possibly because of the large groundwater flows in and out of the floodplain. The concentrations are lower in the deep subsoil of the low lying Walsh pivot site than in the Paper Mill site which is 1.5 m higher.

High P sorption levels associated with very acid soil profiles and sulfidic layers in the subsoil, have largely prevented effluent – derived P from leaching down the profile. While this process cannot continue indefinitely, it does extend the lifetime of the irrigation areas, possibly over many decades.

Soil sodicity increases have yet to have a direct impact on aggregate stability. Applications of gypsum by irrigation managers have not produced any response in infiltration rates. Permeability appears to be maintained, and aggregates remain stable to wetting. In contrast to inland irrigation soils, surface soils on the coastal floodplains generally have higher concentrations of organic matter (up to 18% carbon on the Shoalhaven, Lawrie & Eldridge 2002). Organic matter concentrations often rise under permanent pasture irrigated with effluent. Many coastal soils including these irrigated with effluent also have elevated salinity which encourages flocculation, rather than dispersion.

The complicated pattern of soil variation across the landscape beneath coastal floodplains makes site selection for effluent irrigation difficult. The high watertables, poor profile drainage, occasionally high salinity and the presence of acid sulfate soil materials are often seen as unfavourable features. On the other hand the level to undulating terrain lends itself to irrigation and reduces the risk of erosion and runoff and associated offsite movement of nutrients. The high organic matter content of the surface soil in these settings is favourable for effluent irrigation by counteracting the detrimental effect on soil structure arising from sodicity increases. The naturally high salinity of some parts of the coastal floodplain (and the proximity to tidal influences) can reduce the salinity impact of effluent irrigation that might be experienced in drier more elevated areas further inland. High rainfall along the coast and unconfined shallow watertables can reduce any high effluent derived nitrate concentrations in the soil and also in ground and surface waters. The very high P sorption associated with extremely acidic subsoils that occur beneath some areas of coastal floodplains can greatly extend the lifetime of an effluent irrigation scheme receiving high P loadings.

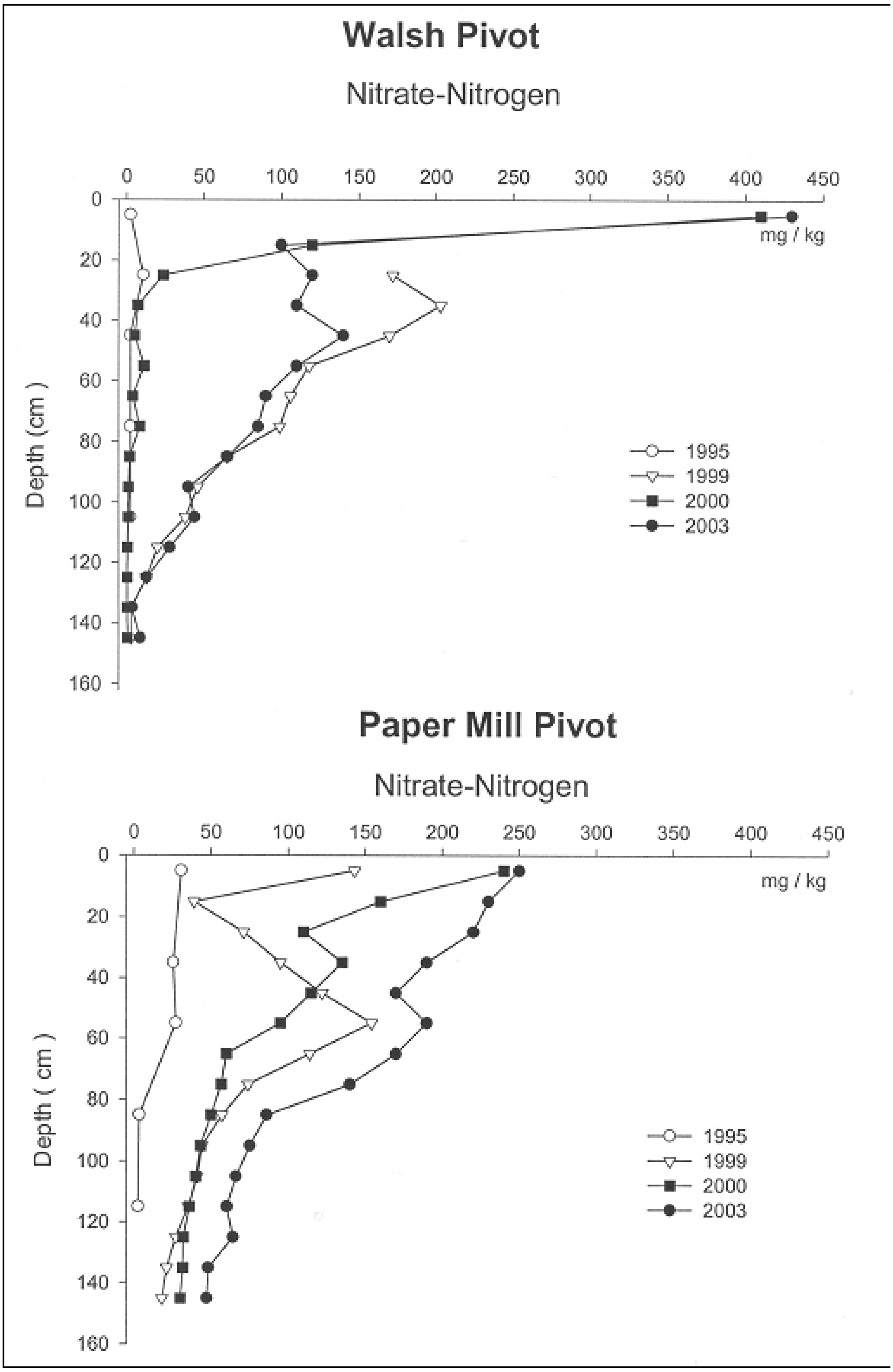

Figure 4. Changes to nitrate nitrogen levels down the profile at two starch effluent pivot irrigation sites, 1995-2003.

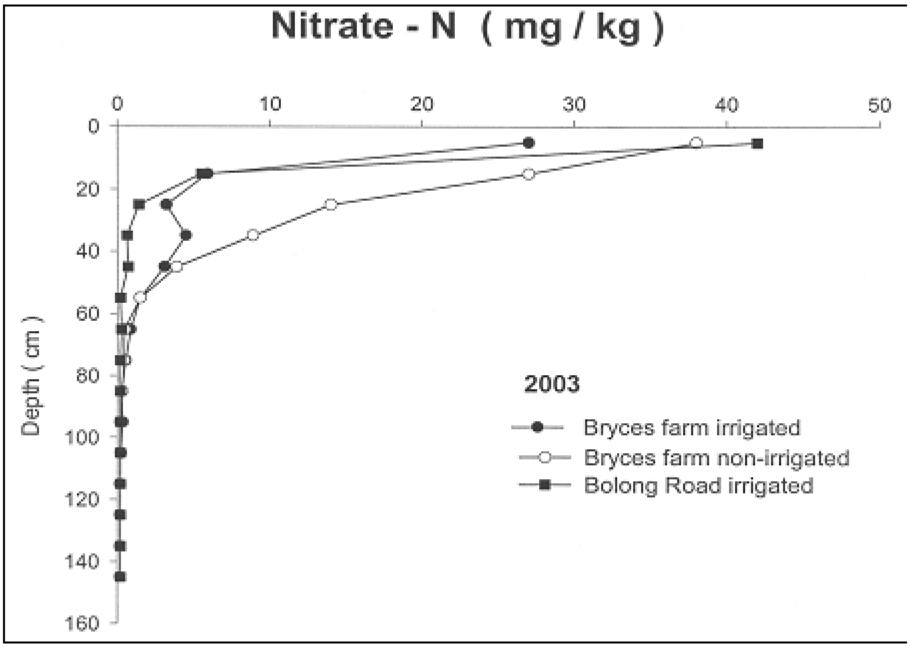

Figure 5. Changes to nitrate nitrogen levels down the profile at the three dairy effluent monitoring sites on the Shoalhaven floodplain 2003.

Table 2(a). P sorption indices of soil profiles at two Shoalhaven monitoring sites, sampled in 1993 prior to commencement of the effluent irrigation program.

Site (Soil Order)	Depth (cm)	P sorption Index	P sorption rating
Paper Mill paddock 9 (Tenosol)			
	0 - 10	6.8	very high
	30 – 40	9.4	very high
	50 – 60	8.7	very high
	80 – 90	7.6	very high
	110 – 120	6.1	very high
Sopers' paddock (Hydrosol)	0 – 10	8.1	very high
	20 – 30	8.1	very high
	50 – 60	6.9	very high
	65 – 75	3.4	low
	90 - 100	4.9	medium - high

Table 2(b). Extractable P and P sorption in 2003 (Rayment and Higginson 1992) at a range of soils irrigated with starch effluent for 3 to 10 years.

Sample Depth:	0 – 10 cm			10 – 20 cm		
Paddock No.	**Bray P mg/kg**	**P sorp. index**	**P sorp. rating**	**Bray P mg/kg**	**Psorp.index**	**Psorp. rating**
9	329	3.5	low	48	3.8	medium
18	142	4.4	medium	18	4.9	medium-high
25	939	4.1	medium	631	5.0	medium-high
32	815	4.6	medium-high	105	6.0	very high
41	1170	4.2	medium	97	5.9	high
45	207	3.6	low	25	4.4	medium

Table 3. Sodicity and dispersion in topsoils (0-10cm composites of 40 cores) of Shoalhaven farm receiving dairy factory effluent.

Paddock number	Exchangeable sodium %	% clay dispersion	Dispersion rating
1	5.2	0.90	negligible
2	4.6	1.32	low
3	8.8	2.94	medium
4	7.5	0.63	negligible
5 (4)	10.5	1.54	Low
6	12.9	1.35	Low
7	12.9	1.14	Low
8	13.0	1.04	Low
13	9.6	1.16	Low
14	8.5	1.13	Low
15 (2)	2.0	0.35	negligible

Notes: ( ) results are means of 2 or 4 replicate samples.
- Paddocks 1 – 14 have been irrigated since 1991; Paddock 15 has not been irrigated.
- Clay dispersion measured after 24 hours of immersion in demineralised water (Bradley et al. 1982).

The main disadvantage for irrigators is the need to control applications carefully to prevent surface water logging and the subsequent generation of foul odours. Coastal floodplains are natural sinks for nutrients and salts, and if loading rates are not excessive, can provide some buffering against potentially adverse impacts of waste applications. The results from environmental monitoring programs need to be taken into account by management and regulators so that not only the impacts of existing schemes are reduced, but also to ensure that future schemes are evaluated effectively. Careful site selection remains a prime criterion for successful wastewater irrigation in the coastal floodplain environment.

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