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EFFLUENT NUTRIENT MANAGEMENT AND RESOURCE RECOVERY IN INTENSIVE RURAL INDUSTRIES FOR THE PROTECTION OF NATURAL WATERS

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ABSTRACT

Intensive rural industry is developing rapidly in parts of inland Australia. The usually nutrient and salt rich effluent from these sources has traditionally been disposed to both land and water bodies. Since direct water discharge is no longer permitted, a challenge now exists when applying effluent to land especially where the rate of application exceeds crop requirements. Effluent of high volume and concentration of nutrients and/or salts can easily contaminate land and water resources. Predicting the optimum rate of land application of effluent is complicated by the physical, chemical and biological properties of soils.

This paper addresses the characteristics of effluents from various intensive rural industries and their potential environmental impacts when irrigated to agricultural land in New South Wales, Australia. To assess the environmental sustainability of effluent reuse in land application, a mathematical model (ERIM) has been developed based on a monthly water balance. ERIM includes historical rainfall and evaporation; the amount of nitrogen and phosphorus introduced; their yearly removal by plants to be grown; amount of applied organic matter; and water holding capacity of soil. © 1999 IAWQ Published by Elsevier Science Ltd. All rights reserved

KEYWORDS

Effluent; nutrient; salt; SAR; water pollution; environmental model.

INTRODUCTION

Intensive rural industries, such as piggeries, chicken farms, feedlots, dairy farms and processing plants, abattoirs, tanneries and wool scours are developing rapidly in parts of inland Australia. The usually nutrient and salt rich effluent from these sources has traditionally been disposed to both land and water bodies. The State Environmental Protection Policies direct that wastewater should be discharged to land in preference to water wherever practicable and environmentally beneficial. The management of effluent from sewage treatment plants in coastal cities is currently experiencing a trend away from the traditional practice of waterway discharge. Since direct water discharge is no longer permitted, both intensive rural industries and sewage treatment plants in rural New South Wales (NSW) have attracted the interest of community and regulating authorities because of their potential to contaminate land and water resources. Therefore, concern

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for environment and related regulations have made it possible to recycle these effluents for irrigating agriculture. In the past the objective of land treatment was simply to dispose of wastewaters, but the current trend includes utilisation of water and nutrients in effluents. However, effluent irrigation to land will be a viable treatment method only if the protection of land and groundwater from possible degradation is held as a prime objective.

Land treatment of effluent is receiving considerable attention as an alternative treatment to other existing processes so that nutrients (e.g. nitrogen and phosphorus) and organic matter in effluent can be beneficially used to grow crops or other vegetation. Over the years land application has been managed to protect human health and the environment from various potentially harmful constituents typically found in effluent, such as bacteria, viruses, pathogens, metals (eg cadmium and lead); toxic organic chemicals (eg polychlorobiphenyls); and nutrients. Considering the high level of concern regarding potential pollution of surface and ground waters from effluent irrigation schemes, there is little published evidence in NSW of the impacts.

Under planning legislation submission of an environmental impact statement (EIS) before any new disposal development is mandatory in NSW. Usually licensing requirements are imposed on operational practices once the schemes are in operation. The absence of a mutually acceptable set of assessment tools can cause difficulties between developers, environmental consultants and the Environmental Protection Authority (EPA) or other regulatory authorities. The NSWEPA has developed a computer model called ERIM (Effluent Reuse Irrigation Model) that can be used by designers of effluent reuse sites and government agencies to assess these sites.

EFFLUENT PRODUCTION AND USE IN NSW

Intensive rural industries: Large quantities of effluent are generated from agricultural production and processing industries such as feedlots, piggeries, chicken farms and processing plants, abattoirs, dairy farms and processing plants, tanneries, wool scours, vegetable processing plants, wood processing plants, and related factories. Effluent from these industries contains valuable nutrients that could be recycled back onto the land in order to improve soil fertility and increase the sustainability of farming systems. For example, there are over 748,079 pigs in the state that produce about 5,500 megalitres (ML) of effluent annually (PRDC, 1997), and this effluent contains enough nitrogen to fertilise about 400,000 ha of wheat or barley. According to the Meat Research Corporation (1996) the red meat industry releases about 15 million tonnes of polluted water annually which contains 2,000 tonnes of nitrogen and 600 tonnes of phosphorus. Estimated effluent volumes produced by a range of rural industries across the state are given in Table 1.

Table 1. Estimated effluent volumes produced by rural industries and sewage treatment plants in NSW and Australia

Source	Volumes of effluent in ML/year	
	NSW[A]	Australia[B]
Feedlots	200	3,500
Piggeries	5,500	20,000
Abattoirs	15,000	62,000
STPs[C]	681,500	-
Dairy farms	15,000	28,000
Tanneries	-	2,000

[A] Bowmer and Laut (1992); EPA (1997); MRC (1996); NSWRWCC (1997); and PRDC (1997). [B] Gardner *et al.* (1996). [C] STPs = Sewage Treatment Plants.

Sewage effluent: There are 295 sewage treatment plants currently operating in NSW. Effluent from these plants has increased from 300, 000 to 681,500 ML/annum since 1989 (NSWRWCC, 1997) and is likely to increase in future. An increase in total effluent reuse of around 40% has also been observed. The total quantity of effluent being used for land irrigation increased from approximately 30,000 to 41,500 ML/annum, comprising only 6% of effluent generated annually in NSW. Barring the small amount that discharges to dunes, the remaining 640,610 ML goes to rivers, estuaries or oceans, potentially dumping about 14,500 tonnes of nitrogen and 5,000 tonnes of phosphorus (EPA, 1997). In its recent state of environment report, EPA (1997) compiled the discharges of both nitrogen and phosphorus from STPs to land and oceans across NSW (Figure 1). Whilst the largest quantity of N and P is discharged to oceans the effect of these nutrients on water quality is more significant in rivers where flow regimes are conducive to algal growth. It is apparent that there is an enormous recycling opportunity for effluent by land irrigation which will increasingly be used in future.

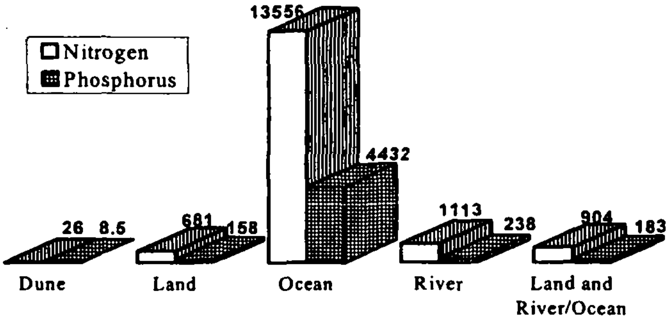

Figure 1. Nitrogen and phosphorus discharges (tonnes/year) from sewage treatment plants in NSW.

CHARACTERISTICS OF EFFLUENT

Organic matter

Biochemical oxygen demand (BOD_5) in Table 2 gives an indication of industry effluent quality compared with sewage and good quality river water.

Table 2. Composition of effluent from rural industries and communities in NSW, Australia[A]

Industry/ Source	Concentration in mg/L							EC (dS/m)	SAR[B]
	Total N	Total P	Na	K	Ca	Mg	BOD_5[C]		
Feedlot	900	150	478	180	142	2,000	6,000	23	2.3
Piggeries	440	30-80	230	500	21	1.0	1,700	5	11.6
Dairy	680	340	470	2-300	162	31	17,000	3.4	8.9
Abattoir	130	25	-	30	-	-	2,000	2.1	-
Winery	117	117	138	7,000	362	290	2,000	2-7	1.3
Scouring	400	133	253	14,000	440	26	8,000	11	3.2
Tannery	640	16	-	70	-	-	4,000	15	-
Starch	300-850	90-160	-	-	-	-	5,000	4.5	-
Sewage	10-50	5-15	207	3-40	54	49	30-50	1-2	10.7
River[D]	-	-	-	2	7.4	4.2	-	0.12	1.4
Potable water	<1	<10	-	-	-	-	-	0-4	-

[A] The values are indicative only; concentrations fluctuate with time and with treatment of the individual waste stream. Sources: Bowmer and Laut (1992); Gardner *et al.* (1996); and Lawrie (1996). [B] SAR (Sodium Adsorption Ratio) = $Na/\sqrt{[(Ca + Mg)]}$; concentrations of Na, Ca, and Mg are in mmol/L. [C] BOD_5 is the Biochemical Oxygen Demand after 5 days reaction at 20°C. [D] Murrumbidgee River in NSW.

BOD_5 must be balanced with nutrients for heterotrophic bacterial action, a ratio of BOD:N:P of about 20:5:1 being considered ideal (Bowmer and Laut, 1992). The BOD_5 and suspended solids of tertiary treated sewage effluent make it suitable for discharge to water bodies. Many rural effluents are very high in BOD_5 and are much more concentrated than sewage, pigs 3.4 and cows 16.4 times greater than human. From Table 2 it is apparent that effluents from rural industries are unacceptable for discharge to water bodies.

Nutrients

Effluent containing total nitrogen (N) of 3-10 mg N/L and total phosphorus (P) of 0.3 to 1 mg P/L is allowed to discharge to sensitive river or estuarine environments. However, concentrations above 0.1 mg P/L are considered to be sufficient to trigger algal growth in fresh water systems (ANZECC, 1992). Table 2 shows that only tertiary treated sewage effluent can meet this criterion and all others must be land applied or subjected to further processing. Piggeries, feedlots, dairies, wool scouring, tanneries and starch factories are all large producers of nitrogen. Conversely, effluent from abattoirs and tanneries are low in phosphorus. For example, if 5 ML of feedlot effluent were irrigated on a one hectare re-use area, then annually about 4500 kg N and 750 kg P would be added to that 1 ha of land which is likely to cause nitrate contamination of ground water by leaching and P and N movement to adjacent surface water by runoff.

Sodium and other salts

Both salts and sodium limit the use of effluents. The salinity of effluent, which is either expressed as electrical conductivity (EC) or total dissolved solids (TDS), is an important determinant of its suitability for irrigation. Except for sewage effluent, the EC values in Table 2 are many times larger than that of potable water (EC ≈ 0.5 dS/m). The use of effluent containing high amounts of salts can adversely affect plants, soil and water. Sodium salts are particularly important because excessive sodium (Na) in irrigation effluent can cause soil dispersion particularly those having swelling clays. The sodium absorption ratios (SAR) of piggeries, dairies and sewage effluent are between 8.9 and 11.9. Soil permeability and aeration problems may occur when the SAR of irrigated effluent exceeds 8. This effect is particularly severe with an effluent having a low EC, such as sewage, where soil dispersion and structure loss can occur. Even with a high SAR both piggery and dairy effluents can maintain soil structure due to their high EC, however, salinity may limit crop production and in due course of time can deteriorate surface and groundwaters.

Many effluents are high in potassium (K), such as wool scouring and wineries, and have a concentration of K that is up to 3,500 to 7,000 times higher than Murrumbidgee River water. This high amount of K can have deleterious effects on both soil and crops. If K^+ on exchange site of clay exceeds 30% it then behaves like Na^+ and disperses clays.

Normally pesticides, heavy metals and synthetic organic compounds are not found in intensive rural industries effluent, while in the processing industries, these contaminants, if present at all, are often in negligible concentrations except for Chromium VI in tannery sludge (Gardner *et al.*, 1996).

MANAGEMENT AND MONITORING OF REUSE AREAS

Monitoring of land treatment systems involves the observation of significant changes from the application of effluent. The data is used to confirm the environmental assessment and to determine if any corrective action is necessary to protect the environment. Strange though it may seem, the management of effluent irrigation has more to do with managing the supply of nutrients than water. The management of the land and how it is cropped or grazed will dictate how much effluent can be applied from year to year. Considering the high level of concern about potential pollution of surface and ground waters from intensive industries' effluent irrigation schemes, there is little published data on monitoring in the whole of NSW.

In general spray irrigation is by far the most popular method, the aim being to balance nutrient and water application rates with plant uptake. Guidelines for achieving theses aims are given by NSW EPA (1995) in its "utilisation of treated effluent by irrigation" guidelines.

Soil nitrogen and phosphorus

Land application of effluent containing high amounts of N can significantly increase soil N. The rate of effluent application has a considerable influence on the N leaching, and excessive application rates can pose a significant threat to water quality. While studying the impacts of high strength effluent irrigation for

9 years to crops and pasture on the Shoalhaven alluvial plain at Nowra in NSW, Lawrie (1996) summarised that high rates of nutrient addition (over 1000 kg N and 200 kg P/ha), and low rates of removal have resulted in a considerable accumulation of nitrogen and phosphorus in the topsoil. Nitrate levels, particularly in the top 7.5 cm soil, rose significantly. Even though there is evidence of nitrate leaching in the profile, there was no sign of groundwater contamination. A sample of the water table at 80 cm depth collected in the swamp soil profile contained 1.3 mg NO_3-N/L; the soil NO_3 concentration at that depth was 9.1 mg N/kg compared to 93.9 mg/kg in the top 10 cm. The degree of groundwater contamination with nitrate depends on many factors, including denitrification, which at this site played a major role due to frequent waterlogging and significantly reduced the nitrate surplus.

The nutrient that has received the most environmental attention in Australia is phosphorus as it is often implicated as the limiting nutrient for blue green algal outbreaks in river systems. Phosphorus retention mechanisms in most Australian soils are considered to result in low risk of P leaching (White and Sharpley, 1996). For example, the depth of P leaching was reported to be less than 0.025 m after 2.5 years of application of treated effluent at Flushing Meadow, Wagga Wagga, NSW (Falkiner and Polgase, 1996). However P leaching is a concern in some sandy soils or where cumulative P loading exceeds the soil's P sorption capacity (Gardner *et al.*, 1996). On the other hand, erosion from effluent reuse sites can be a major export pathway of P to water bodies, for example, in the Peel-Harvey estuary of western Australia an export level of 0.4 kg P/ha/year was correlated with rampant algal growth (Birch, 1982).

In the same starch effluent irrigation scheme, Lawrie (1996) found that high amounts of phosphorus accumulated in the topsoil but the concentrations of orthophosphate in the groundwater were still below 0.04 mg/L after 9 years of operation. While the Colwell P concentrations reached 1000 mg/kg in two topsoil samples, concentrations at 15-30 cm depth at both sites were much lower, ranging between 50 and 100 mg/kg. Bray P measurements down the profile confirmed that available P was below 5 mg/kg. Due to high P sorption capacity of subsoil the downward movement of effluent P was low.

Soil salinity and sodicity

Irrigation management must consider the question of managing salt. Salinity build-up in effluent irrigated soil can occur and reduces crop yields due to toxic and osmotic effects. Lawrie (1996) reports that irrigation of starch effluent (EC of 2.5-4.5 dS/m) at Nowra for 10 years resulted in substantial accumulation of salt although it did not reach the point where it was affecting maize and forage crops growth (Figure 2). Smith *et al.* (1996) found that irrigation for over 5 years at Flushing Meadow, Wagga Wagga, with sewage effluent (EC 0.5 to 1.2 dS/m) also resulted in a substantial build-up of salt (Figure 2) which was sufficiently high to reduce transpiration in tree plantations of *Eucalyptus grandis* (Benyon *et al.*, 1996). The lack of salinity effect in the swamp soil profile at Nowra was attributed to the presence of a shallow water table, high soil permeability and flushing effect. This allowed subsoil to be regularly flushed.

A high concentration of sodium in soil is of concern because it can cause a reduction in soil aggregate stability. Johns and McConchie (1994) reported that the application of secondary treated dilute sewage effluent to soil growing bananas at Woolgoolga, NSW more than doubled the soil sodium concentration from 0.11 to 0.31 cmol(+)/kg. Despite the low EC of the effluent (0.44 dS/m), the soil exchangeable sodium percentage (ESP) values reached 4% during the trial. Similarly, at the Flushing Meadow site the ESP of the surface 60 cm increased from 2% to greater than 25% after five seasons of irrigation (Balks *et al.*, 1996). A rise in the ESP of more than 10 favours clay dispersion and is an undesirable side effect of effluent irrigation (Craig and Thompson, 1996), but in both Flushing Meadow and Nowra there was no measurable decrease in permeability. To substantiate his claim of favourable effects of effluent irrigation, Lawrie (1996) added that there was increased soil organic matter level that decreased bulk density, increased porosity and aggregate stability. However the high level of ESP coupled with low level soil EC in the winter may produce swelling and dispersion of clay reducing the permeability of soil and increasing the volume of runoff.

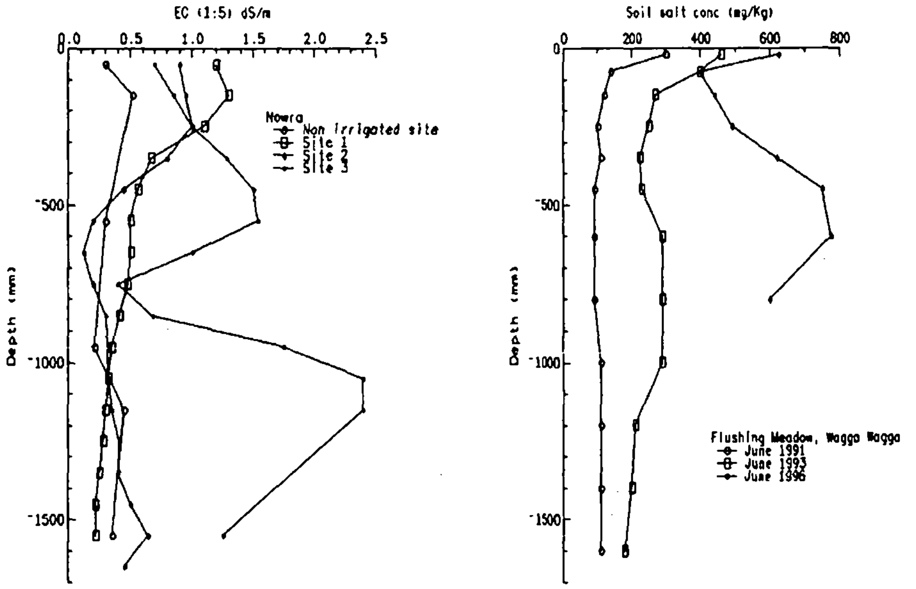

Figure 2. Soil salinity vs soil depth: Nowra site is treated with starch factory effluent and Flushing Meadow is treated with sewage effluent.

To remain flocculated, clay requires a threshold electrolyte concentration (Rengasamy *et al.*, 1984). To maintain this electrolyte concentration, strategic soil and water management practices are required. The current guidelines with respect to effluent irrigation of sodic soils are general and do not allow for the variability in the physico-chemical properties of different soils. Since the impact of effluent irrigation on soil structure is related to many properties such as type of clay, amount of clay, pH, Ca/Mg ratio, K, ESP, EC, organic matter, and iron and aluminium oxides, an understanding of major soil processes is important.

Quality of surface and ground waters

Monitoring of water quality for land application systems is generally more involved than for conventional treatment systems because of non-point discharges of contaminants. According to current guidelines, surface application of effluent is excluded from catchments where the surface water is used for domestic water supply. However no such consideration is afforded to areas where groundwater is used for domestic purposes. Protection of groundwater for other users is an important component of sustainable effluent disposal design. Effluent containing elevated levels of contaminants may, when applied to the ground, contaminate the underlying groundwater unless its passage through the unsaturated zone above the water table achieves attenuation of contaminants before the groundwater is reached.

Nitrate is highly mobile and can very easily leach to groundwaters and may concentrate there, making the water unsafe for drinking. In Australia nitrate is often regarded as the contaminant of most concern although there are many case histories of point source pollution by more toxic contaminants. This is because of the ubiquity of nitrate, its toxicity and indications that the concentration of nitrate in groundwater is rising. While reviewing effluent management in intensive rural industries in Australia, Bowmer and Laut (1992) indicated that in NSW elevated nitrate concentrations have been found in ground water near piggeries, poultry farms, feedlots, dairies and septic tanks. Nitrate concentration in the underlying groundwaters over a 270 km^2 area near Mount Gambier exceeded 45 mg/l, whereas another 8000 km^2 showed more than the potable standard for groundwater of 10 mg/l. Some exceptions are the data from Lawrie (1996) who reported that the water table in the swamp soil profile located only 80 cm from the surface contained 1.3 mg NO_3-N/l even after 9 years of irrigation with starch effluent loading of about 1600 kg of N/ha/annum.

EFFLUENT REUSE IRRIGATION MODEL (ERIM)

For the designers of effluent reuse sites and the government agencies that assess these sites, the NSW EPA has developed this ERIM computer model. The model is based on a water balance equation, rainfall + effluent applied = evapotranspiration + runoff + drainage. It includes historical rainfall and evaporation; the amount of nitrogen and phosphorus introduced, their yearly removal by plants to be grown; amount of applied organic matter; and water holding capacity of soil.

The model uses this information to estimate the trade-off between the land area required for irrigation and wet weather storage based on volume and strength of effluent applied. For this the phosphorus, nitrogen and BOD_5 loadings are determined for calculating minimum irrigation areas required for each of these parameters for sustaining the practices.

There are a number of computer models commercially available that have been recently assessed by Dougherty (1996) for determining the impact of intensive livestock farming systems. Models that are similar to ERIM and based on water balance, nitrogen and phosphorus dynamics are AGNPS (USDA, 1995); CREAMS/GLEAMMS (Kinsel, 1980; and Leonard *et al.*, 1987) and MEDLI (Gardner *et al.*, 1996).

Mondoro piggery development - a case study

In late 1996, the EPA received an application from a piggery which intended to expand its operation from 700 to 1000 sows (10,000 pigs). The property is situated on an alluvial river flat, having heavy dark reactive silty clays, adjacent to Dyrabba creek that flows to the Richmond River system in Casino, northern NSW. The location has average rainfall and evaporation of 965 mm and 1563 mm respectively. A yearly generation of about 73 Ml (daily effluent supply of 0.2 Ml) of effluent was proposed to be spray irrigated onto 90 ha wheat/pasture paddocks located on this piggery property.

The neighbours expressed strong concern about odour nuisance, ponds overflowing into a nearby creek and contamination of ground water with nitrogen. The local aquifer is used for potable, stock and irrigation purposes. The EPA was concerned about similar issues with a further interest in degradation of the irrigated area by salinity and the land available for reuse of sludge from the lagoon. ERIM was used for this design.

The effluent contained 410 mg/l of BOD_5, 308 mg/l of organic N, 120 mg/l of ammonium N, 12 mg/l of NO_3-N and 30 mg/l of total P. A critical BOD_5 loading rate of 28 kg/ha/day was accepted. Half the total organic N applied was assumed to mineralise and 50% of the total ammonia was assumed lost by volatilisation. The site's P sorption capacity was 158 mg/kg for a sorption depth of 1 m with bulk density of 1.3 tonnes/m^3.

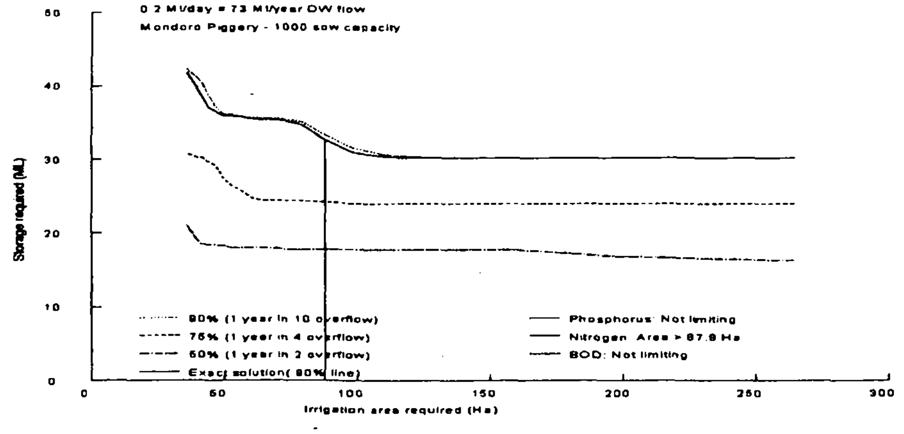

Figure 3. Results from ERIM simulation runs for Mondoro piggery with 1000 sows for various combinations of pond volumes and land areas. *Note*: Graph 5 stands for effluent storage vs irrigation area required, and is one of ten different simulation graphs that ERIM produces during its run.

The model was run using historical rainfall and evaporation data obtained from the closest meteorological station. Neither phosphorus nor BOD were limiting in the solution region (Figure 3). Using the remaining part of the relationship a storage of 33 Ml and land area of 88 ha, or a storage of 30 Ml and land area of 120 ha were feasible solutions. Further reduction in storage below 30 Ml was not possible even with increases in land area above 120 ha. This is due to the fact that the storage requirements are driven by the rainfall pattern and a minimum size is required to last through the cold/wet winter periods. Having available irrigated land of 90 ha, 90 days wet weather storage of about 33 Ml is a feasible solution.

CONCLUSION

Rapid development of rural industries in parts of inland NSW, and expanding coastal cities will increasingly generate effluent in future. Due to current EPA discharge regulations and increased community awareness, discharge of effluent to rivers or oceans is unacceptable. Land treatment of effluent is receiving considerable attention at present as an alternative treatment to other costly processes. There is no doubt that effluents are potentially valuable nutrient sources, but land application of effluent provides potential for contamination of surface and groundwaters and land degradation. However proper planning and management of land application processes including agronomic considerations can substantially reduce or stop such contamination. Experiments in NSW have demonstrated that well managed irrigation with both high and low strength effluents have not deteriorated the land and waters.

In order to assess the environmental sustainability of effluent reuse in land application, the designers of effluent reuse sites and the government agencies can use a computer model ERIM developed by NSW EPA to predict the suitability of these sites.

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