

# Using nutrient budgeting and environmental monitoring to assess the sustainability of effluent reuse from piggeries in New South Wales, Australia

Chris Dorahy<sup>1,2</sup>, Grant Harper<sup>2</sup> and Peter Marczan<sup>2</sup>

<sup>1</sup>Current address: NSW Department of Primary Industries, Locked Bag 4, Richmond, NSW 2753, Australia. Email: [chris.dorahy@agric.nsw.gov.au](mailto:chris.dorahy@agric.nsw.gov.au)

<sup>2</sup>Department of Environment and Conservation NSW, PO Box A29, Sydney South, NSW 1232, Australia.

## Abstract

The sustainability of effluent reuse at a piggery in New South Wales (NSW) was assessed by analysing historical monitoring data collected as part of regulatory requirements, constructing nutrient budgets and applying an environmental risk assessment framework. The nutrient budgets indicated that the rate of nitrogen (N) and phosphorus (P) in effluent applied to the utilisation area exceeded the rate of removal from the system by up to 719 and 78 kg/ha/yr, respectively. This has resulted in high soil nitrate (90 mg/kg, 45-75 cm) and Bray-1 available P (160 mg/kg, 0-15 cm) concentrations in the utilisation area, indicating that the reuse activity is not sustainable with respect to N and P. Similarly, soil electrical conductivity (EC<sub>1.5</sub>) and pH<sub>1.5</sub> (aqueous) were 0.42 dS/m and 5.4 pH units, respectively, suggesting soil acidity and salinity also have the potential to impact on the sustainability of the system.

It is suggested the effluent loading to the utilisation area should be decreased, whilst the rate of nutrient removal should be increased, to reduce soil nitrogen and phosphorus accumulation and increase the sustainability of the system. Lime application is also recommended to reduce soil acidification.

The role of environmental monitoring and reporting as a management and regulatory tool is also discussed within the context of these and other findings of a compliance audit of the pig industry, conducted by the Department of Environment and Conservation NSW in 2003. Approaches for improving how monitoring data is collected, presented and interpreted are also identified to demonstrate effluent reuse is sustainable and ensure soil and water resources are protected.

## Key Words

Effluent irrigation, environmental monitoring, regulatory frameworks, sustainability indicators.

## Introduction

The effluent and solid waste generated from intensive livestock operations, such as piggeries, can be beneficially reused to improve soil chemical and physical fertility. However, the high concentrations of salt, nitrogen and phosphorus in these by-products have the potential to impact on soil and water resources if not managed appropriately (Cameron *et al.* 1996). Hence, it is important to balance the input of nutrients and salts in effluent and solid waste applied to land, with the rate of utilisation and removal of these constituents from the system to ensure the reuse activity is sustainable.

In 2003 Australian Pork Limited, Meat and Livestock Australia and the Department of Environment and Conservation NSW (formerly NSW Environment Protection Authority), completed a joint project aimed at developing sustainability indicators for the reuse of effluent and solid wastes generated by piggeries and cattle feedlots (McGahan and Tucker 2003). The project derived in-soil trigger levels for nitrogen, phosphorus, salt, sodicity and pH, which could be used to assess the potential for an effluent reuse activity to impact on soil or water quality and trigger further investigation and/or a change in management. The project also developed a risk assessment framework based on site characteristics, the information from mass balances, management of the reuse area and the sustainability indicators to determine if adverse environmental impacts are likely.

Under the Protection of the Environment Operations Act 1997 (PoEO Act 1997) in NSW, an Environment Protection Licence is required for piggeries that are intended to accommodate more than 2000 pigs or 200 breeding sows (NSW EPA 2000). Where by-products of production are applied to land, licences often contain conditions, such as requirements to monitor effluent, solid waste and soil, which aim to protect air, land and water quality. In 2003, the Department of Environment and Conservation

NSW conducted a Pig Industry Sector Audit to assess the compliance of individual premises with environment protection licences and evaluate the environmental performance of the Pig Industry in NSW.

The objectives of this paper are to (1) analyse the effluent and soil monitoring data collected from one of the audited piggeries, (2) evaluate the sustainability of effluent and solid waste reuse at this premise using nutrient budgeting and a risk assessment approach and (3) discuss the role of environmental monitoring and reporting as a management and regulatory tool, within the context of the broader findings of the Pig Industry Sector Audit.

## Methods

### *Pig Industry Sector Audit*

In NSW, approximately 64 piggeries are licensed under Schedule 1 of the PoEO Act (1997). Twenty two of these premises were audited during 2003 based on scale, type, age and location of operation, to obtain a representative cross section of operations throughout NSW. The audits were designed to assess compliance with licence conditions, as well as to identify areas where licences could be improved from a practical, regulatory and administrative perspective. Further details, including a summary of the audit findings on the Pig Industry Sector Audit are described in DEC (In Prep).

### *The Piggery*

The piggery has been in operation for over 30 years and is a breeder and grower enterprise, which houses approximately 9900 pigs and turns off 500 pigs per week. The premise was originally a “wet” piggery, although some of the grower sheds have been converted to a deep litter system, which has reduced the volume of effluent generated. A run down screen is used to separate solids from the waste slurry. The solids from the run down screen are either composted using earthworms or applied to a neighbouring property. Solids generated from the deep litter system are stockpiled on-site and transported to a neighbouring property and applied to land. The piggery generates approximately 209 kL/day of effluent, which is passed through two facultative treatment ponds and stored in a dam, before it is irrigated onto a 60 ha utilisation area using a travelling irrigator. The utilisation area is gently undulating and is established with a kikuyu grass (*Pennisetum clandestinum*) based pasture, which is used for grazing beef cattle. The soil of the utilisation area was classified as a Red Chromosol (Isbell 1996). For the purposes of this study it was assumed the soil of the utilisation area had a clay content of 10-20% (McKenzie *et al.* 1999).

The licensee is required to collect effluent and soil samples as a condition of his Environment Protection Licence. The licensee samples effluent quarterly at the point where it is irrigated onto the utilisation area. The samples are analysed for biochemical oxygen demand (BOD), electrical conductivity (EC), nitrogen (total Kjeldahl- (TKN), oxidised- ( $\text{NO}_x\text{-N}$ ) and ammonia- ( $\text{NH}_3$ )), total P, potassium (K), calcium (Ca), magnesium (Mg), sodium (Na), copper (Cu) and faecal coliforms in accordance with DEC (2004). The licensee is also required to collect composite surface (0-15cm) and sub-surface (45-75 cm) soil samples annually from the ridge, slope and flat of the utilisation area. The soil samples are analysed for pH, EC, TKN, nitrate-N ( $\text{NO}_3\text{-N}$ ), ammonium-N ( $\text{NH}_4^+\text{-N}$ ), Bray-1 available phosphorus, exchangeable calcium ( $\text{Ca}^{2+}$ ), magnesium ( $\text{Mg}^{2+}$ ), potassium ( $\text{K}^+$ ) and sodium ( $\text{Na}^+$ ), in accordance with the methods described by Rayment and Higginson (1992). The effluent and soil monitoring data provided by the licensee during the audit was used to construct nutrient budgets and identify any changes in soil characteristics with time.

### *Nutrient Budgeting and Interpretation of Soil Monitoring Data*

Nutrient budgets for N, P and K were calculated from the difference between nutrient inputs to, and outputs from, the system. Nutrient inputs were calculated by multiplying the concentration of Total N, P and K in the effluent by the total volume of effluent irrigated onto the utilisation area each year and dividing it by the area treated (60 ha). Outputs were calculated by assuming that cattle grazing the utilisation area achieve a live weight gain of 1.25 t/ha/yr and remove approximately 34, 9 and 2.5 kg N, P and K/ ha/ yr, respectively (Kruger *et al.* 1995).

The averages of the results for soil pH, EC and nitrate-N and Bray-1 available P from the ridge, slope and flat of the utilisation area were plotted against time to observe if any trends were apparent. The results were also compared with the sustainability indicators developed by McGahan and Tucker (2003) (Tables 1 and 2).

**Table 1. Soil pH, nitrate concentration and exchangeable sodium percentage (ESP) for triggering further investigation into the potential for these parameters to impact on plant yield, soil and/or water quality as a consequence of effluent irrigation (Adapted from McGahan and Tucker 2003).**

Soil Parameter	Indicator	Trigger level
pH	pH <sub>1.5</sub> (aqueous)	<5 or >8
Sodicity	ESP (%)	>6 %
Nitrogen	Nitrate-N (mg/kg) <sup>A</sup>	>2.5

<sup>A</sup>Nitrate-N concentration at the base of the plant rooting zone of a light clay soil.

**Table 2. Likelihood that further investigation is required to assess the potential for soil phosphorus or salinity to impact on plant yield, soil and/or water quality as a consequence of effluent irrigation (Adapted from McGahan and Tucker 2003).**

Soil Parameter	Indicator	Very Low	Low	Moderate	High	Very High
Salinity	EC <sub>1.5</sub> (dS/m)	<0.07	0.07-0.15	0.15-0.34	0.34-0.63	0.63-0.93
Phosphorus	Bray-1 P (mg/kg)	<5	5-10	10-20	20-25	>25

Soil salinity ratings based risk of EC<sub>1.5</sub> causing plant yield reductions in soil with clay content of 10-20%.

### *Environmental Risk Assessment*

An environmental risk assessment was also performed to assess whether the effluent reuse activity at the premises was sustainable. This was achieved by using information on the size of the utilisation area, nutrient mass balances, soil and effluent characteristics and the procedure outlined by McGahan and Tucker (2003) to derive risk weightings for each of the parameters of concern. The risk weightings were then applied to a matrix to determine the level of risk to the environment and whether additional monitoring or a change in management is required (McGahan and Tucker 2003).

## **Results and Discussion**

### *Effluent characteristics*

The characteristics of the piggery effluent are summarised in Table 3. The EC of the effluent was  $5.3 \pm 0.1$  (dS/m) (Table 3), suggesting it is generally unsuitable for irrigation unless the soils are permeable and salt tolerant species are grown (Kruger *et al.* 1995). The sodium adsorption ratio (SAR) of the effluent was  $3.5 \pm 1.3$ , indicating it is unlikely to cause problems with soil sodicity (Kruger *et al.*, 1995). The total N and total P concentrations in the effluent were  $599 \pm 4$  mg/L and  $69 \pm 1$  mg/L (Table 3), respectively, making it high strength with respect to N and P (NSW EPA 1995). The effluent was classified as intermediate strength with respect to BOD (NSW EPA 1995).

**Table 3. Characteristics of piggery effluent at the point of irrigation to the utilisation area.**

Effluent parameter	Mean $\pm$ s.e.
EC (dS/m)	$5.3 \pm 0.1$
SAR	$3.5 \pm 1.3$
BOD (mg/L)	$901 \pm 41$
TKN (mg/L)	$558 \pm 38$
TN (mg/L)	$599 \pm 4$
NO <sub>x</sub> -N (mg/L)	$1.0 \pm 0.6$
NH <sub>3</sub> -N (mg/L)	$485 \pm 3$
TP (mg/L)	$69 \pm 1$
K (mg/L)	$270 \pm 70$
Ca (mg/L)	$71 \pm 4$
Mg (mg/L)	$25 \pm 9$
Na (mg/L)	$129 \pm 41$

### *Nutrient mass balances in the utilisation area*

The nutrient budgets indicated that N, P and K are accumulating in the utilisation area at the rate of 719, 78 and 337 kg/ha/yr, respectively (Table 4). The N budgets did not account for nitrogen lost from the system, due to volatilisation, denitrification or leaching and therefore represent a maximum possible loading in the utilisation area. Nitrogen losses due to ammonia volatilisation from soils treated with piggery effluent have been reported to range from 3% (Harper *et al.* 2004) to approximately 20% (Kruger *et al.* 1995). Smith (2001) observed that N loss from denitrification was insignificant when piggery

effluent was irrigated onto a maize-oat cropping system in south-eastern Australia. Further, Cameron *et al.* (1995) found that N volatilization and leaching from piggery effluent applied to a shallow stony soil in New Zealand at the rate of 200 kg N/ha, was 10% and 5%, respectively, in the first year after application.

**Table 4. Nutrient budgets for nitrogen, phosphorus and potassium in the utilisation area irrigated with piggery effluent.**

Parameter	Effluent Quality (mg/L)	Nutrient <sup>A</sup> Loading (kg/ha/yr)	Nutrient Removal (kg/ha/yr)	Nutrient Balance (kg/ha/yr)
TN	599	752	34	719
TP	69	87	9	78
TK	270	340	2.5	337

<sup>A</sup> Nutrient loading based on irrigating 209 kL effluent/day on 60 ha.

#### *Soil characteristics in the utilisation area*

##### (a) Nitrogen and phosphorus

The high rates of N and P accumulation in the utilisation area predicted by the nutrient budgets (Table 4) were reflected in the soil monitoring data, which revealed high concentrations of nitrate and Bray-1 available P were present (Fig. 1). In 2002, surface and sub-surface soil nitrate-N concentrations were 92 and 90 mg/kg, respectively, whilst Bray-1 P concentrations were 160 and 4 mg/kg, respectively (Fig. 1). The volume of effluent generated at the piggery and subsequently applied to the utilisation area has decreased in recent years due to a reduction in the number of pigs at the premise and the conversion of some of the piggery to a deep litter system. These operational changes have reduced soil nitrate-N and Bray-1 available P concentrations in the utilisation area (Fig. 1), although the concentrations of these parameters are still in excess of pasture requirements. Further, McGahan and Tucker (2003) suggest that soil nitrate-N concentrations at the base of the rooting zone and Bray-1 available P concentrations greater than 2.5 mg/kg and 25 mg/kg, respectively, should trigger further investigation to identify whether effluent irrigation is sustainable (Tables 1 and 2).

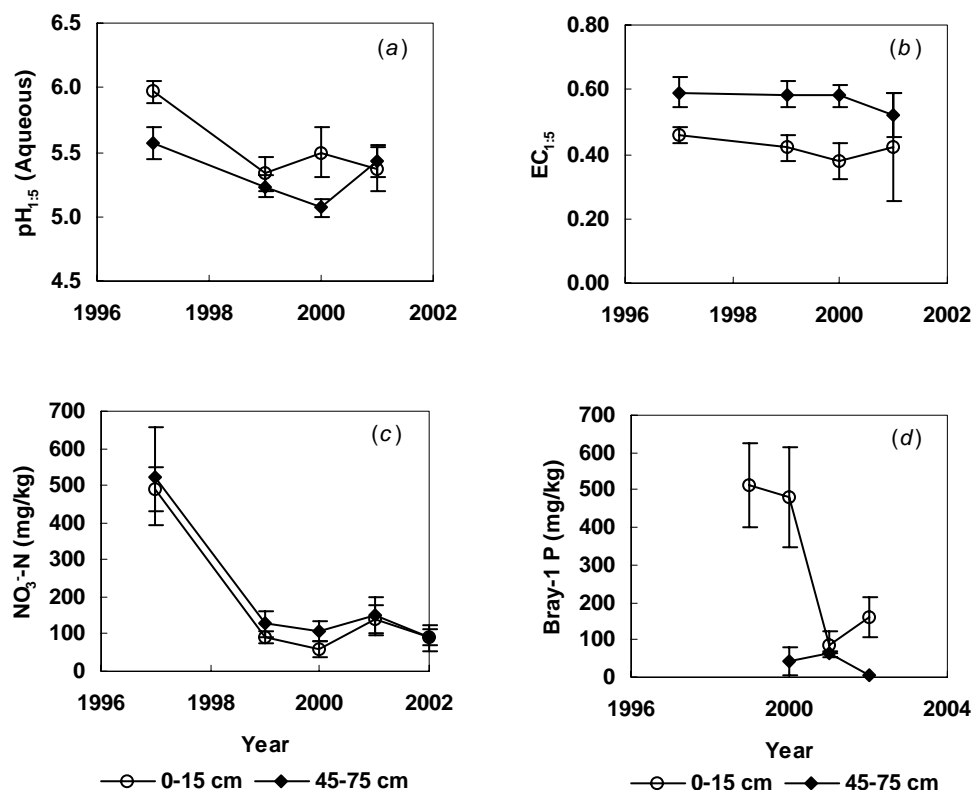
##### (b) Salinity and Sodicity

Consistent with the effluent monitoring data presented in Table 3, the soil monitoring data revealed EC<sub>1:5</sub> in the surface and sub-surface soils is currently 0.45 and 0.6 dS/m, respectively (Fig. 1). This suggests it would attract a high salinity rating (MacGahan and Tucker, 2003) and would reduce yield in some salt sensitive plant species. Kikuyu has a salinity threshold (EC<sub>se</sub>) of approximately 3.0 dS/m (Maas and Hoffman 1975; Russell 1976), which corresponds to an EC<sub>1:5</sub> of approximately 0.47 dS/m, assuming EC<sub>se</sub> = 6.4EC<sub>1:5</sub> (Talsma 1968, as appears in Shaw 1999). However, the kikuyu pasture did not exhibit any visual symptoms of salt sensitivity.

Soil monitoring data collected in 2002 indicated that average Exchangeable Sodium Percentage (ESP) in the surface soil was 2.3±0.1%, which is less than the commonly recommended threshold for soil sodicity of 6% (McGahan and Tucker 2003). This suggests effluent irrigation has not lead to the development of sodicity in the utilisation area, probably because of the low SAR of the effluent (Table 3). This may explain why symptoms of soil salinity have not become apparent given crop tolerance to salinity is higher in non-sodic soils (Stevens *et al.* 2003), which are more permeable and have a greater ability to leach salts. Further, average rainfall at the site is approximately 828 mm/yr, which would be expected to increase salt leaching from the plant root zone.

##### (c) Acidity

In 2001, surface and sub-surface soil pH was 5.4 pH units (Fig.1), indicating the soil on the effluent utilization area is acidic and is approaching the lower end of the optimal range of 5-8 suggested by McGahan and Tucker (2003). The lack of monitoring data for effluent pH and the absence of a reference site, which has not been irrigated, makes it difficult to determine whether the low soil pH is a consequence of inherent soil characteristics or effluent irrigation. However, Redding *et al.* (2002) and Smiles and Smith (2004) did not observe any relationship between soil pH and irrigation with piggery effluent across a range of Australian soils, suggesting the former explanation is more likely. Nevertheless, lime should be applied to the utilization area to increase soil pH and reduce the availability of aluminium and other potentially toxic elements to plants.



**Figure 1.** Changes in surface (0-15 cm) and sub-surface soil (45-75 cm) (a) pH (1:5), (b) electrical Conductivity (EC<sub>1:5</sub>), (c) nitrate-nitrogen (mg/kg) and (d) Bray-1 phosphorus (mg/kg), with time in a field irrigated with piggery effluent. Error bars are  $\pm$  standard error of the mean of composite samples collected from the flat, slope and ridge of the utilisation area.

#### Risk Assessment

The high rates of N and P accumulation in the utilisation area and the risk assessment identified that salinity, nitrogen and phosphorus attracted a high risk rating (9) (Table 5), which suggests that intensive monitoring is required for these parameters to determine the potential for these contaminants to impact on surface or ground waters (McGahan and Tucker, 2003).

**Table 5.** Risk assessment matrix for selected soil parameters on the effluent utilisation area at the piggery.

Design and Management Criteria	Risk weighting (Low=1, Medium=2, High=3)	Dispersion	Salinity	Nitrogen	Phosphorus
Nutrients in manure and effluent	3	3	9	9	9
Size of land area	1	1	3	3	3
Application method	1	1	3	3	3

#### Sustainability of effluent reuse at the piggery and future monitoring requirements

The results from the effluent and soil monitoring, nutrient budgeting and risk assessment indicate the current system of grazing the utilisation area with cattle is not fully utilizing the high loads of nutrients applied in the effluent. This has resulted in high soil nitrate and available P concentrations, which have the potential to impact upon water quality, either through surface runoff or leaching through the soil profile. The system could be brought more into balance by increasing the rate of nutrient removal from the system through cropping or mechanically harvesting the pasture instead of using it for grazing. Effluent application rates should be based on the most limiting parameter. The nutrient and salt loading could also be reduced by expanding the size of the utilisation area. In addition, options should be evaluated for reducing the salinity of the effluent and preventing any further increase in soil salinity. Lime should also be applied to increase soil pH.

In order to assess the potential for phosphorus to impact on surface or ground waters, P sorption capacity should also be included in future soil monitoring. Whilst sodium does not appear to be contributing to the

development of soil sodicity, the high rate of potassium ( $K^+$ ) accumulation in the soil of the utilisation area (Table 4) has the potential to degrade soil structure (Smiles and Smith 2004) and should be monitored more intensively.

#### *Outcomes of the Piggery Audit*

The outcomes of the Pig Industry Sector Audit are described in DEC (In Prep.). Generally, licensees complied with most monitoring and reporting conditions contained in their Environment Protection Licences relating to effluent, solid waste and soil monitoring. However, the greatest deficiency observed was that licensees did not analyse and interpret the monitoring data collected to calculate nutrient loadings and identify whether any changes in soil chemical characteristics are occurring as a consequence of effluent irrigation or solid waste application to land. This is reflected in the data presented in this paper, whereby effluent and soil monitoring clearly demonstrated that nutrients and salts were accumulating in the effluent utilisation area with the potential to cause water pollution. Whilst the analysis and interpretation of monitoring data collected is generally not a specific requirement of a licence, it is necessary for assessing the environmental performance of the operation.

The lack of data interpretation could also be attributed to the piggery waste management ethos of needing to dispose of the effluent rather than recognising it as a resource (Redding 2001). Similarly, many producers may view soil and effluent monitoring solely as an administrative requirement relating to their core business, which in this case, is pig production. However, soil and effluent monitoring generates valuable information which can also be used to better utilise the resources contained in liquid and solid wastes to improve crop or pasture productivity and reduce inputs of inorganic fertilisers, as well as protect soil and water quality.

#### *Regulation of Intensive Livestock Industries*

One of the difficulties in auditing and reviewing Environment Protection Licences relating to intensive livestock industries is a lack of defined environmental thresholds for assessing licence compliance. It is recognised that it is not possible to develop limits which will be appropriate for all soils, climates and production systems in NSW. This paper highlights how sustainability indicators, such as those developed by McGahan and Tucker (2003), when used in combination with monitoring and nutrient budgeting, are useful for determining whether further investigation or a change in management practices is warranted to ensure effluent reuse is sustainable. In contrast to specific limits, appropriate sustainability indicators can facilitate informed policy making by reducing complex systems, without oversimplifying them (McCool and Stankey 2004).

Similarly, Environment Protection Licences need to be designed to demonstrate environmental outcomes are being achieved without being overly prescriptive. The challenge regulators face is to strike the balance between imposing standard conditions across all licences, which may not be applicable to all situations, and tailoring licenses to individual premises, which makes administering licenses difficult and also creates the potential for inconsistencies to develop in the way premises are regulated.

#### **Conclusions**

Assessment of the soil and effluent monitoring data collected at the audited piggery suggests that effluent irrigation is not sustainable with respect to N and P, given the high application rates, the low rates of nutrient removal and the high concentrations detected in the soil. More sustainable reuse of the effluent could be achieved by mechanically harvesting and removing the kikuyu pastures from the premises to increase the rate of N, P and K removal. Options like establishing higher value pastures, such as lucerne, should also be considered if effluent irrigation is to continue in the long term. On-going management will be required to reduce the concentrations of these nutrients to avoid the potential for surface and groundwater pollution. Soil pH, salinity and sodicity monitoring data collected should be assessed to help ensure effluent irrigation does not impact on soil quality.

This paper demonstrates the need to integrate the information obtained from effluent and soil monitoring, nutrient budgeting and risk assessments to make better informed decisions about how liquid and solid wastes generated at piggeries should be managed. It also highlights the usefulness of these tools for regulating and operating intensive livestock enterprises. Licensees should analyse and interpret the information obtained in effluent and solid waste monitoring more thoroughly. Regulators should place

more emphasis on encouraging, or if necessary, requiring, licensees to interpret the information contained in soil and effluent monitoring.

Soil scientists are well placed to help achieve these objectives, by working with regulators to develop appropriate licence conditions, establish appropriate sustainability indicators, as well as collect, analyse and report monitoring information. In addition, soil scientists can also train producers to realise the resource value of these effluents, the importance of monitoring the impacts of effluent irrigation and develop management plans to help ensure reuse practices are sustainable. This will help protect our soil and water resources and contribute to making primary industries more productive, profitable and sustainable.

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