Managing risks of phosphorus export from sites irrigated with abattoir effluent

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Abstract
Meat and Livestock Australia sponsored the development of a risk management strategy for phosphorus loss from sites irrigated with abattoir wastewater. The project was initiated because of increased concern with the potential environmental impacts of phosphorus loss. The strategy was designed to quantify the relative risk of contamination to both surface and groundwaters. The assessment of effluent irrigated sites was based on the Phosphorus Index (PI) approach developed in the USA.

The key reason for using the PI system is that traditional agronomic and soil test approaches are inflexible and fail to take into the importance of transfer mechanisms in the rate of phosphorus export from irrigated lands.

The PI approach considers both the extent of phosphorus accumulation (source factors) and its rate of transfer through the soil to groundwater and across the site to surface waters (transfer factors). Mechanisms considered include:
- The ability of the soil profile to sorb and retain phosphorus,
- Phosphorus removed in plant harvest,
- Phosphorus export via erosion,
- Dissolved phosphorus lost in runoff, and
- Direct losses such as pond overtopping and effluent runoff in wet weather.

This paper identifies the likely relative importance of the various mechanisms across a range of Australian abattoir sites. A similar approach could be used for other contaminants and for other industries. It also offers the opportunity to extent risk assessment to a catchment wide basis.

Key Words
Phosphorus, PI, effluent, leaching, runoff, erosion.

Introduction
This project developed a Phosphorus Index (PI) for fields irrigated with abattoir wastewater. A PI is a risk management tool that can assess the extent of phosphorus export from irrigated fields to nearby surface and groundwaters. The PI concept was originally developed in the USA in response to concerns that agricultural activities were resulting in environmentally significant contamination of waterways (Sharpley 1995a). According to Weld and Sharpley (2007), the PI is more useful than a soil test or a blanket restriction on application rates because a PI can take into account both the availability of the phosphorus and the transport mechanisms by which phosphorus is delivered to waters. The approach is also relevant to other industries where large quantities of nutrient rich wastewater must be irrigated.

PI has not been used to any extent in Australia, largely because most Australian soils have a high ability to retain phosphorus compared with typical phosphorus fertilisation rates. Additionally the applied phosphorus fertilizer is usually buried. Consequently the risk of export of significant quantities of phosphorus is low. However the application of relatively high rates of dissolved phosphorus application to effluent irrigated pasture means a PI approach is relevant to abattoir sites.

The phosphorus contained in abattoir effluent is highly available to plants because over 80% of the phosphorus is in the able ortho-phosphate form. These orthophosphates are dissolved in the soil solution (and the irrigated effluent) and can be readily taken up by vegetation. They can also move through the soil within the infiltrating water (Nash 2004; Stevens *et al.* 1999). However movement into the soil is short lived and the dissolved phosphorus compounds precipitate or become held on clay particles. The type of precipitate varies with soil characteristics, especially pH and aeration. Aluminium, iron and manganese based precipitates form in acidic soils, while calcium and magnesium based precipitates form in alkaline soils. Recently formed precipitates are labile and plants can access the phosphorus to a limited extent. Over time the precipitate becomes more crystallised and this substantially reduces phosphorus availability (Barrow and Shaw 1975). In typical Australian soils less than 1% of the total phosphorus is readily available, less than 10% is labile and up to 90% is non-labile (Glendinning 1999). Additionally a significant proportion of the soil phosphorus can accumulate in the organic component in long term pasture sites. Mineralisation of this organic-P can provide orthophosphate for plant uptake as well as create the potential for phosphorus loss from the site.

There are a number of issues influencing risk of phosphorus loss from field irrigated with abattoir wastewater:

- Firstly in most parts of Australia, pasture growth is seasonal, and there can be periods of more than 6 months where there is minimal growth or phosphorus uptake. This increases the risk of loss via leaching should effluent irrigation occur throughout the year.
- Secondly, the seasonality of pasture growth also increases the risk of overgrazing, leading to bare paddocks and increased erosion risk.
- Thirdly the quantity of phosphorus accumulated by plants is often small compared with the application rate. That is, there is likely to be accumulation of phosphorus in sites receiving abattoir effluent. The gradual increase in phosphorus in the surface soil suggests increased risk of phosphorus loss to the environment.
- Fourthly, the volume of water required to meet irrigation demand in Australia is typically 5 to 10 ML/ha/y. However applying this volume of effluent also applies 2 to 10 times the amount of phosphorus that can be utilised by the pasture. The excess phosphorus remains in the soil and could eventually be leached or lost via erosion or in runoff.
- Finally the data is for plant uptake NOT removal. In many pastures the dry matter production is ingested by grazing animals. Subsequent excretion redeposits the phosphorus onto the land surface. Net removal via weight gain in grazing animals is typically 3 to 10 kg P/ha/y. This can be equivalent to a few percent of the phosphorus applied in the effluent.

Figure 1 shows the major pathways by which phosphorus can enter and exit the effluent irrigation areas. The key import processes are animal excreta and phosphorus in the effluent. The key loss processes are sorbed phosphorus on eroding sediment, dissolved phosphorus in runoff and soluble phosphorus leached to ground water (Havlin 2004). Some removal in animal tissue also occurs. Some abattoirs irrigate effluent onto pastures or crops which are later harvested and removed. This procedure can remove up to 60 kg P/ha/y; however 30 kg/ha/y is more typical (NSW Agriculture 1997).

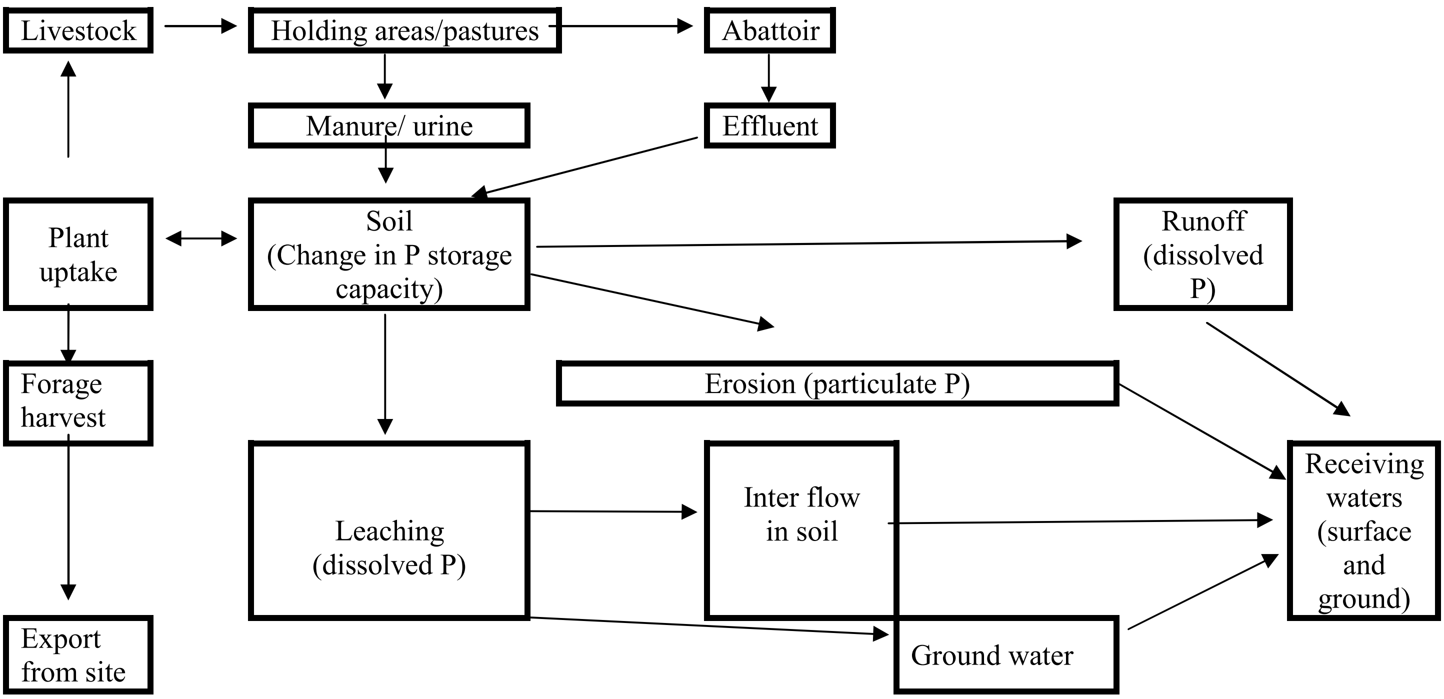

Figure 1. The phosphorus cycle for pastures irrigated with abattoir effluent.

Animal excreta deposited onto the soil surface contains a mix of organic phosphorus and ortho phosphorus. Some of the ortho phosphorus can be taken up by plants; however the bulk is sorbed onto clays and organic material at the top of the soil column. Permanent pasture will gradually increase phosphorus storage capacity in the topsoil. This is especially important in sandy soils where phosphorus sorption capacity is limited. Clays have greater ability to retain phosphorus than sands. Havlin (2004) summarised numerous investigations on clay content and phosphorus loss to suggest that the relationship between available soil phosphorus and runoff phosphorus concentration is in the ratio of organic soil (1): sands (2): loams (4): clay (10). As an example, runoff from a sandy soil with, say, 10 mg/kg of available phosphorus, will have a similar phosphorus concentration to runoff from a clay soil with 50 mg/kg of available phosphorus.

Dissolved phosphorus can runoff the site, or infiltrate the soil, and be sorbed. Bush and Austin (2001) applied 44 kg P/ha as single superphosphate and then irrigated the field. They found border irrigation significantly increased phosphorus concentration in soil water down to 0.3m in a soil containing 30 to 50% clay. That is, there can be significant movement of phosphorus even in soils where a large sorption capacity is anticipated.

According to Sharpley *et al.* (2001) the PI concept can be adapted to suit particular concerns and needs. The main components relevant to Australian abattoir irrigation sites are:

Source factors
- Soil phosphorus test value,
- Phosphorus sorption capacity,
- The volume of effluent irrigated,
- The phosphorus concentration in the effluent.

Site management attributes such as grazing intensity, irrigation efficiency and soil conservation practices require assessment of individual fields.

Transport factors
- Annualised erosion rates can be determined throughout Australia.
- Runoff Curve Number (RCN) is based on vegetation, soil type and physical condition.
- Daily runoff can be estimated from Bureau of Meteorology databases.
- Dissolved phosphorus concentration in the runoff can be estimated from established relations between soil test phosphorus, phosphorus sorption capacity and soil texture.
- Local flood history is typically common knowledge on farms.

Subsurface drainage of fields is uncommon on abattoir sites in Australia, so this factor is not relevant.

Catchment factors
- Distance to receiving water
- Connectivity between the phosphorus source and the receiving waters
- Vulnerability of receiving waters to phosphorus pollution. (in Australia, all water bodies are considered vulnerable to contamination).

Table 1. Variables used to calculate PI for Australian abattoir sites.

VARIABLE	COMPONENTS
Site management	
Vegetation	Type, species, graze/forage harvest, Fallow periods, P export
Irrigation	Area, type, frequency, volume, seasonality, runoff frequency, management level
Source factors	
Rainfall	Rainfall, effluent (mm/y), RCN, % runoff
Phosphorous in soil	For each horizon: depth, bulk density, total P, Bray 1 P& P sorption. P excretion estimate
Effluent	Volume/Y, P concentration, seasonality in quantity or quality
Risk assessment	
Overtopping of effluent storage	Volume/year
Groundwater risk	Years till P saturation
Particulate P export	RUSLE, Enrichment ratio, vegetative buffer
Dissolved P export	Dissolved P concentration (estimated), runoff volume, buffer conditions

Results

Sensitivity analysis was undertaken to identify the key variables. Key results were:

- Pond overtopping and effluent runoff were uncommon among abattoir sites, but where they did occur they were the major contributors to P export.
- Particulate P loss via erosion was normally trivial as most sites had 100% grass cover.
- Dissolved P export within rainfall runoff appears to be a significant issue at sites where rainfall plus effluent greatly exceeded evapotranspiration.

Conclusions

1. Improved management to reduce incidence of effluent pond overtopping and direct runoff of effluent is critical.
2. Vegetation management to ensure >80% ground cover is critical
3. There is insufficient evidence to accurately quantify the loss of P in runoff
4. It is obvious that even in a single field there can be large variation in the proportion of effluent/ rainfall that enters the soil. Management needs to target portions of fields especially susceptible to phosphorus loss.
5. There is a need to link modeled P export from single sites to catchment scale models.
6. Ideally PI should be expressed as kg P export/ ha/year

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References

Barrow NJ, Shaw TC (1975) The slow reactions between soil and anions: 3. The effects of time and temperature on the decrease in isotopically exchangeable phosphate. *Soil Science* **119**, 190-197.

Bush BJ, Austin NR (2001) Timing of phosphorus fertilizer application within an irrigation cycle for perennial pasture. *Journal of Environmental Quality* **30**, 939-946.

Glendinning JS (1999) Australian Soil Fertility Manual. CSIRO. Collingwood. Vic.

Havlin JL (2004) Technical basis for quantifying phosphorus transport to surface and ground waters. *Journal of Animal Science* **82**, E277-E291.

Nash, D (2004) Phosphorus sustainability during irrigation. MLA Report PRENV.032. Draft final report.

NSW Agriculture (1997) The New South Wales Feedlot Manual. Inter departmental committee on Intensive Animal Industries. Orange, NSW.

Sharpley, AN (1995a) Identifying sites vulnerable to phosphorus loss in agricultural runoff. *Journal of Environmental Quality* **24**, 947-951.

Sharpley AN, Kleinman PJA, McDowell RW, Gitau M, Bryant RB (2002) Modelling phosphorus transport in agricultural watersheds: Processes and possibilities. *Journal of Soil and Water Conservation* **57**, 425-440.

Sharpley AN, Weld JL, Beegle DB, Kleinman PJA, Gburel WJ, Moore PA, Mullins G (2003) Development of phosphorus indices for nutrient management planning strategies in the United States. *Journal of Soil and Water Conservation* **58**, 137-152.

Stevens DP Cox JW, Chittlebrough DJ (1999) Pathways of phosphorus, nitrogen and carbon movement over and through texturally differential soils, South Australia. *Aust. Journal of Soil Res.* **37**, 679-693

Weld J, Sharpley AN (2007) Phosphorus Indices. In 'Modelling Phosphorus in the Environment' (Eds. DE Radcliffe, Cabrera LM), pp. 301- 332. CRC Press. Boca Raton, Fla.