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Phosphorus sustainability on irrigation sites

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Executive Summary

In 2006 MLA sponsored the development of a risk management strategy for phosphorus loss from effluent irrigated sites. The project was initiated because of increased concern with the potential environmental impacts of phosphorus loss. The strategy was designed to address contamination risk 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.

Whilst the information used is numerical wherever possible, the results are aimed at identifying the *relative* differences among sites. The PI can also be used to 'test' different management options. For example PI estimates the benefit of having different widths of vegetated lands between the irrigation area and the receiving waters.

Much of the data relies on individual site assessment. Some soil analysis is also required. The calculations used to establish the PI are contained within an excel file that accompanies this report.

The system was used to assess relative risk of phosphorus loss from 9 sites at a northern NSW abattoir. The PI score ranged from 1.4 to 9.2, with an average of 3.4. Scores in excess of 4 were considered 'high'. The highest scoring sites had significant losses due to runoff of phosphorus enriched water.

It is concluded that the PI approach enables site managers to assess risks of unacceptably high export of phosphorus from their effluent irrigated lands towards receiving waters. The managers can then develop strategies to reduce this risk. It is now appropriate to demonstrate the value of this approach across a wide range of Australian sites.

Contents

Background

Phosphorus is a naturally occurring nutrient which is essential for both plants and animals. It is a key component of nucleic acids, of cell membranes and of the energy transfer molecule adenosine triphosphate (Moody and Bolland, 1999). In animals it is essential for bone and muscle growth, metabolic activity, and reproduction.

The majority of Australian soils are deficient in phosphorus. Reasons for this include low phosphorus content in original rocky parent material and long periods of insitu aging (McKenzie et al, 2004). Many Australian soils also have a marked ability to sorb phosphorus, and availability of applied phosphorus fall with time since application. Thus, in typical Australian agricultural systems, the issue of phosphorus deficiency is more of a concern than loss of phosphorus to waterways.

Typically, phosphorus rich material such as superphosphate and effluent is applied to alleviate phosphorus deficiency, thereby stimulating plant growth (Glendinning, 1999).

The phosphorus contained in abattoir effluent is especially useful to plants because over 80% of the phosphorus is in the highly available 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. However, over time the precipitate becomes more crystallised, substantially reducing 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.

Why is phosphorus a concern?

Phosphorus is an essential nutrient and is not toxic (ADWG, 2004, ANZECC, 2000). However, in many Australian situations, phosphorus concentration is the factor limiting plant growth (Correll, 1998, Boulton and Brock, 1999). Increasing phosphorus concentration in waterways typically increases growth of aquatic flora including algae, cyanobacteria and phytoplankton. These biota can be toxic in large numbers. Large blooms of algae can also reduce oxygen concentrations in water when they die off and decompose. This results in fish kills (See ANZECC, 2000 for more details).

Phosphorus accumulation in soil is not normally an issue. The key issue is the rate of transfer of the phosphorus to waterbodies where additional phosphorus could stimulate excess biological activity. Even transfer to ground water is not an issue unless the phosphorus is later returned to surface water at a rate that increases the phosphorus concentration of this receiving water body beyond the indicative trigger concentrations for this water body (See ANZECC, 2000 Table 3.3.2 for trigger concentrations). Therefore there is a real need to take corrective action if the rate of phosphorus ‘leakage’ from surrounding lands results in phosphorus concentrations in an adjacent water body increasing beyond values that cause excessive biological activity.

Effluent irrigation should be managed to minimise opportunities for phosphorus to be conveyed to susceptible waterbodies.

Phosphorus balance and reactions in effluent irrigated soils

The mass of phosphorus accumulated by various irrigated pastures is shown in table 1. While the data is from NSW it does provide a general guide to the mass of phosphorus that can be removed from an effluent irrigated site (NSW Agriculture, 1997).

Table 1. Annual phosphorus accumulation rate for pasture species irrigated with effluent. The volume of effluent required to meet that anticipated plant requirement is also shown (Data Sources: NSW Agric, 1997. Phosphorus concentration from Nash, 2004).

Pasture species	Phosphorus accumulation period	Typical yield (t/ha/season)	P concentration (%)	Uptake kg/ha/ year	ML/ha/y required to 'balance' uptake assuming 36 mg P/ L) in effluent
Kikuyu	Sept to March	20	0.3	60	1.7
Phalaris	Mar to Nov	12	0.3	36	1.0
Perennial ryegrass	Mar to Dec	12	0.3	36	1.0
Fescue	Annual	14	0.4	56	1.6
White clover	Sept-Feb	20	0.4	80	2.2

Table 1 illustrates several effluent irrigation issues.

- 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 an increasing accumulation of phosphorus in sites receiving abattoir effluent. The gradual increase in phosphorus suggests increased risk of phosphorus loss to the environment.
- Fourthly, the volume of water required to meet irrigation demand in Australia is 5 to 10 ML/ha/y. However applying this volume of effluent is also applying 2 to 10 times the amount of phosphorus that can be utilised by the pasture. The excess phosphorus remains in the soil.
- Finally the data is for 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.

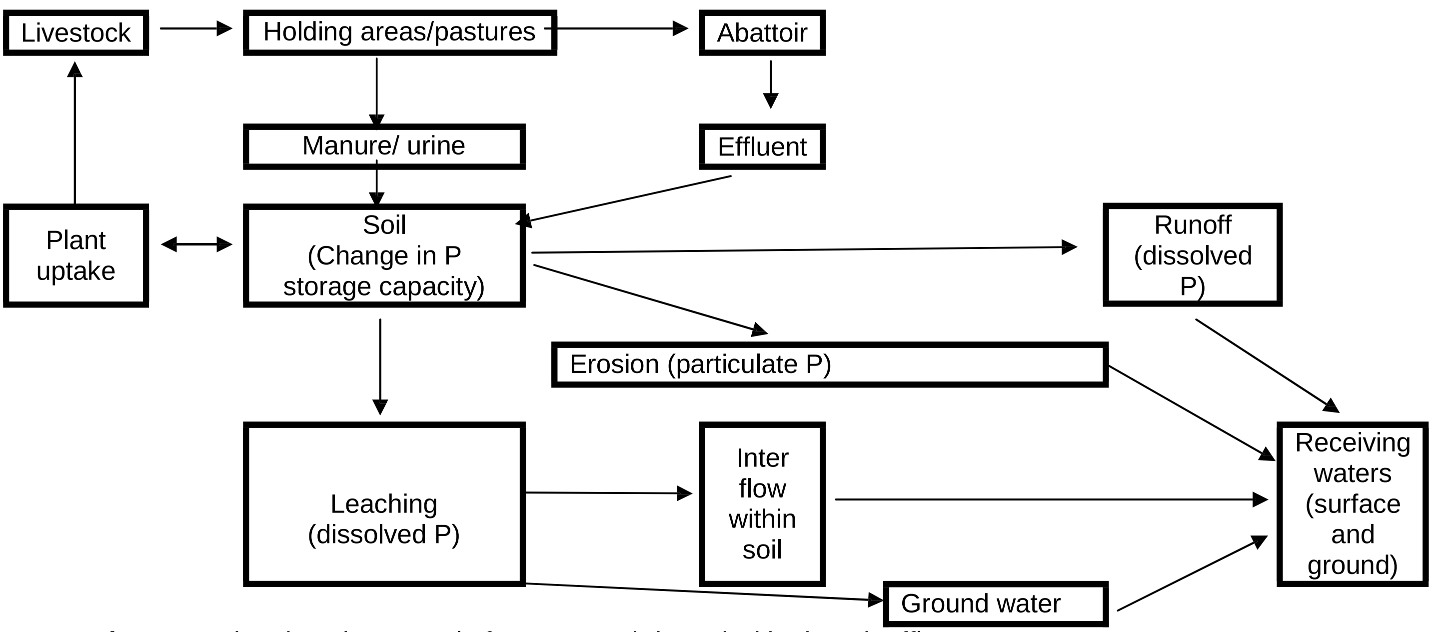

Figure 1. The phosphorus cycle for pastures irrigated with abattoir effluent.

Figure 1 shows the major pathways by which phosphorus can enter and exit the effluent irrigation areas. The key entry processes are animal excreta and phosphorus in the effluent. The key loss processes are as sorbed phosphorus on eroding sediment, dissolved phosphorus in runoff and soluble phosphorus leaching to ground water (Havlin, 2004). Some removal in animal tissue also occurs.

Animal excreta deposited onto the soil surface are 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 (NSW Primary Ind, 2004). 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, so a higher soil phosphorus test is required before a given phosphorus loss. 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). That is, a soil test phosphorus value will need to be 5 times higher in a clay soil to result in the same phosphorus concentration in runoff from a sandy soil.

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 there is a large sorption capacity.

Loss via surface runoff

Typically 80% of the phosphorus in runoff from pasture is in a form that is readily available (dissolved or less than 45 um diameter, Austin, 1998), so runoff management is essential.

Phosphorus sorption onto soil, and consequent reduction in availability, takes place over several weeks (3 to 4 days is a typical half life according to Nash, 2002) and during this time the ortho phosphorus can be conveyed from the site within runoff (Haygarth and Sharpley, 2000, Mundy et al, 2002). Abattoir fields are typically irrigated every 3 to 10 days, so there is insufficient time between irrigations to enable complete sorption of the previously applied phosphorus (Nash et al, 2000). This loss within runoff can be a major removal mechanism for phosphorus removal from high rainfall sites overlain with duplex soils (Flemming and Cox, 1998, Stevens et al, 1999, Nash, 2002).

Dissolved phosphorus is largely confined within the surface 5 cm, so irrigated effluent that penetrates below this depth is likely to be sorbed rather than lost via runoff (Sharpley, 1995, 1997). Rainfall or irrigation that results in runoff soon after application is likely to convey dissolved ortho phosphorus towards receiving waters (Austin et al., 1996, Bush and Austin, 2001, Hart, et al, 2004, Sharpley, 1997). A review by Hansen et al (2002), suggested a maximum of 10% of the applied phosphorus could be lost via this mechanism. Irrigation Best Management Practices (BMPs) such as preventing effluent runoff and avoiding irrigation on saturated soils will reduce this percentage. Additionally percolation of the effluent below the surface layer rapidly reduces the proportion of applied phosphorus that is susceptible to runoff loss (Sharpley, 1997).

MLA project 023b concluded that vegetated buffers were also useful in reducing the rate of phosphorus transfer from effluent irrigated fields to receiving waters. The ability of buffers to remove dissolved phosphorus from runoff leaving an effluent irrigated field is limited by infiltration rate and hydraulic retention time within the infiltrating buffer (Nash, 2002, USEPA, 1981).

Loss via percolation to ground water

Effluent percolation can bring the ortho-phosphorus into intimate contact with subsurface clays, and this results in phosphorus sorption (Uusitalo et al, 2001). Eventually the surface soil can become saturated with phosphorus, and the ortho-P will continue to move through the soil and may reach ground waters (Hansen, et al, 2002). Sites where this phenomena is most likely include sand dominant soils, soils that are receiving heavy application rates of ortho-P, soils low in Al and Fe oxides, thin soil overlying shallow ground waters and strongly structured clay soils where percolation occurs down large cracks (Hooda, et al, 1999, Sims et al, 1998, Novak et al, 2000). Depth to ground water and the connectivity of ground and surface waters determine if the leached phosphorus creates an environmental impact. Phosphorus in ground water is not a sustainable practice but unless the ground water is exposed to daylight it is unlikely to stimulate algal activity.

Loss via erosion

Once the phosphorus is sorbed onto the soil, the main mechanism for phosphorus removal is via erosion. The review of Hansen et al (2002) emphasised the fact that management practices which reduce erosion and runoff will reduce phosphorus loss. The net removal from a field is a function of the erosion rate, the mass of deposition within the field and the concentration of phosphorus on the eroding material (Havlin, 2004). Erosion rate from pasture sites is typically very low (less than 5 t soil /ha/y). Most Australian abattoirs maintain a thick vegetative cover on their irrigated lands. This greatly reduces erosion rate (Rosewell, 1993).

Erosion preferentially mobilises fine particles such as clays. The fine particles have elevated phosphorus concentrations, and phosphorus concentration in the eroding fine sediment can be 2 to 5 times higher than the bulk soil (Sharpley, 1985, McIssac, et al, 1991). Iowa PI suggests an enrichment ratio of 1.3.

According to Sharpley (et al 1992), phosphorus loss via erosion of phosphorus enriched soil and organic matter can constitute up to 90% of phosphorus loss from cultivated fields. Some of the eroded material will be redeposited within the field. Havlin (2004) suggested that at least 10% of any phosphorus mobilised from effluent would be retained within the field.

The bioavailability of phosphorus in eroded material is highly variable, ranging from 10 to 90% (Sharpley, 1993, Gburek and Sharpley, 1998, Eghball and Gilley, 1999 Uusitalo et al, 2001). On average, around 20% of the soil phosphorus is available (Hansen, et al, 2002). The bioavailability can be approximated using agronomic soil phosphorus availability tests (Sims et al, 2002). However only around 70% of the phosphorus reaching receiving waters is available (Mallarino, et al, 2005).

Management practices such as vegetated buffer strips that trap sediment will reduce the mass of sediment reaching drainage lines (Lee et al, 1989). For example, vegetative buffers between the effluent irrigated fields and any waterways reduce opportunity for the phosphorus to migrate off site by up to 80% provided the flow is not concentrated (Lee, et al, 2003, Dosskey, et al, 2002, Novak et al, 2002). Havlin (2004) suggested 15, 30, 60 and 90m wide buffer areas below an eroding slope would entrap 42%, 54%, 80% and 87% respectively of the sorbed phosphorus exiting the site. MLA Report 023b discusses this in detail. It is also apparent that the risk of phosphorus loss is not evenly spread across the landscape (Beegle, et al, 2000). A site specific assessment is required to ensure areas with greatest risk of phosphorus loss are targeted for more intensive management (Sharpley, 1997).

Project aims

This project aims to develop a simple, effective phosphorus Index (phosphorus Index) to manage environmental risks associated with irrigation of Phosphorous rich effluent. This approach aims to quantify the rate of transfer of phosphorus to receiving waters in a format that highlights the potential impacts of abattoir wastewater irrigation compared with other landuses.

This index will consider phosphorus source and transport components in a risk assessment. Development of a simple model requires integration of the numerous processes and reactions determining phosphorus loss into a series of field based questions (Sharpley, et al, 2002).

Current Australian approach to phosphorus management in effluent irrigated soils

National Guidelines

ANZECC Guidelines

The ANZECC (2000) Guidelines for Fresh and Marine Water Quality Volume 3, Paper 4, Chapter 9 Section 9.2.6.3 provides recommendations on the concentration of phosphorus in irrigation water. The issue addressed by these guidelines is *'to restrict environmentally significant concentrations of Phosphorus (i.e. concentrations which could cause algal blooms) moving in to water bodies (State Government of Victoria, 1995)*' (ANZECC, 2000).

According to these Guidelines the short term value for phosphorus concentration in irrigation water can range from 0.8 to 12 mg/L depending on site conditions. Beyond the short term horizon of 20 to 25 years, the concentration should be limited to being less than values that are unlikely to result in algal blooms in storages and bio-clogging of irrigation equipment. The recommended value is 0.05 mg/L.

The Guidelines discuss the challenges in developing site specific phosphorus concentration guidelines. The Guidelines emphasise the need to take all removal and retention mechanisms into account. It suggests the trigger value for algal blooms (0.05 mg/L) be used to determine the Short Term Trigger Value (STV) via the formula

$STV_p = P_{es} + P_{sorb} + P_{removed}$ (Eq1)

Where

STV_p=phosphorus in irrigation water (mg/L)

P_{es}=environmentally significant Phosphorus concentration (i.e. algal blooms occur at P>0.05 mg/L)

P_{sorb}=phosphorus sorbed in soil (mg/L)

$P_{removed}$=Phosphorus removed from irrigation water in harvestable portion of the plant and animal (mg/L).

The guidelines go on to demonstrate how the P_{sorb} is calculated. Inputs include soil depth, soil phosphorus sorption capacity and any additional phosphorus fertiliser. (Appendix 1 contains the methodology from the Guidelines). However there are several important limitations to applying these guidelines to abattoir effluent.

Firstly abattoir waste water typically contains 30 to 40 mg/L of phosphorus. This is around 800 times the equilibrium value of 0.05 mg/L suggested for the extractant suggested in the Guidelines. The method relies on short term sorption-desorption reactions to estimate soil sorption ability. A very low equilibrium concentration will therefore significantly underestimate the ability of the soil to sorb Phosphorus from the surrounding solution over a period of days or weeks that can occur between runoff or percolation events.

The effect of changing the concentration of the equilibrating solution is illustrated by figure 9.2.6 from the Guidelines shown in Appendix 1. Based on the equation given in figure 9.2.6, the sorption capacity of the example soil is 57 mg P/kg soil when in equilibrium with a 0.05 mg/L solution and 376 mg/L if the typical concentration of the effluent is used (40 mg/L). The impact of allowing for the high concentration of the phosphorus in the irrigated effluent is shown in Table 2.

Additionally increasing the soil depth to 2m, the bulk density to 1500 kg/cubic m and the phosphorus export rate to 10 kg/ha/y to reflect typical field conditions increases the STV_p to from 3.6 to 18.6 mg/L for a 0.05 mg/L equilibrium solution and from 13.6 to 65.1 mg P / litre of irrigation water when the actual concentration of effluent P is considered. This is up to 20 times the STV_p suggested In the Guidelines.

Table 2. Change in the Short Term Value of Phosphorus when different soil depths, bulk densities and phosphorus sorption capacities are taken into account.

STVp (concentration of P in irrigation water in mg/L)	Psorb from water by soil (mg/L)	Depth (m)	Bulk density (kg/cubic m)	Psorb capacity (mg/L)	Irrigation rate (m/year)	Assumed duration of irrigation (years)	Additional fertiliser application rate (kg P/ha)	Harvest and removal of P(kg/ha)
3.6	0.6	0.15	1300	57	1	20	0	3
18.6	12.8	3.00	1500	57	1	20	0	10
13.6	3.6	0.15	1300	367	1	20	0	10
65.1	82.6	3.00	1500	367	1	20	0	10

A second issue is that the guideline calculations do not take into account the conditions between the irrigation site and the receiving waters. If there is no runoff of effluent from the application to the receiving waters then no contamination has occurred. Instead sorption reactions will continue to occur until either equilibrium is reached or another rainfall or irrigation event occurs.

Rainfall after effluent irrigation may convey desorbed phosphorus from the field to receiving waters, but this assumes there is minimal opportunity for infiltration and sorption reactions during the conveyance period. Infiltration even for short periods facilitates resorption. The extent of resorption and removal of dissolved phosphorus during overland flow is highly dependant on the infiltration rate (USEPA, 1981).

The ANZECC Guidelines do not refer to phosphorus being sorbed onto soil particles and then transported to receiving waters attached to eroding soil. This mechanism can be significant if the irrigated site is inadequately vegetated and the site is adjacent to receiving waters. However not all particulate bound phosphorus is biologically available. US studies suggest around 70% should be considered biologically available to the receiving waters.

It is reasonable to conclude the ANZECC Guidelines are extremely conservative and imply that any phosphorus in soil solution that is in excess of 0.05 mg/L could cause an algal bloom. The potential for this to actually occur is a function of the soil conditions and the extent to which the dissolved phosphorus is transferred to receiving waters.

NWQMS Guidelines

There are two documents in the National Water Quality Strategy relevant to effluent irrigation.

The document ‘Guidelines for Sewerage Systems. Use of Reclaimed water, (NWQMS, 2000) is largely concerned with public heath. No specific guidance is provided for phosphorus application.

The second document ‘Australian guidelines for Sewerage Systems. Effluent Management, (NWQMS, 1997) states *‘The discharge of effluent should be managed to avoid excessive nutrient levels* (being discharged to waterbodies)*’* (page 18). The document refers to the need to avoid algal blooms.

It is concluded that the two NWMS documents referred to above do not have specific guidance for determining phosphorus application rates.

NSW Guidelines

The NSW Effluent Irrigation Guidelines have been in draft format for over a decade. In 2004 a fully citable version was published by Department of Environment and Conservation (DEC). The Guidelines classify effluent strength on the basis of constituent concentrations. Effluent with less than 10 mg/L total phosphorus is considered low strength, while medium strength effluent contains 10-20 mg/L. Consequently typical abattoir is considered high strength. The strength of the effluent is used to adjust wet weather storage capacity. Storage should be sufficient to contain high strength effluent in all but the 10 %ile wet year (DEC, 2004 p39).

According to the Guidelines '*Where nutrient budgets show that more P is being applied than is capable of being removed by the crop management system, assessments of P sorption capacity should be made'.(DEC, 2004 p45).* The guidelines go on to present information from a pig industry report (Kruger et al, 1995) that suggests phosphorus leaching commences when 25 to 50% of the soil sorption capacity is saturated. Elevated phosphorus concentrations in runoff and in deep drainage are anticipated at this point. The critical sorption capacity/m of soil ranges from 50 kg/ha for sand dunes to 5000 kg P/ha on red podsolic soils (Kruger et al, 1995).

An obvious difficulty in applying this information is the unknown distance and travel time between the application area and the receiving waters. Phosphorus contamination is unlikely in areas where the water table is many metres below the soil surface or where there are several kilometres between the application site and the receiving waters. Additionally no guidance is presented on the relationship between soil phosphorus saturation and the proportion of the applied phosphorus likely to exit the site.

Queensland Guidelines

QLD EPA (2005) guidelines emphasise the mass balance approach. Th guidelines state the application rate of phosphorus (and other constituents), should not exceed the combined mass of plant uptake and removal, plus mass of safe storage plus mass of allowable losses. The guidelines recommend use of MEDLI modelling to determine the mass balance. A difficulty with MEDLI is that is does not estimate erosion losses or losses in runoff. Buffer distances or conditions needed to waterbodies are not clearly specified.

Victorian Guidelines

The Victorian guidelines (Vic EPA, 2002) recommend buffer distances of 100m from sensitive waterways if the sewage effluent is Class A. The class category is based on biological contamination rather than nutrient loads. The Victorian wastewater irrigation guidelines (Vic EPA, 1992) provide more information. They state

'*As a rule, the annual application of phosphorus should not exceed the crop and pasture requirements'* (page 34). The guidelines also recognise the need to minimise erosion. The guidelines suggest up to 80 kg/ha/y can be harvested from a ryegrass pasture.

The guidelines do not refer to phosphorus sorption capacity nor do they refer to the potential for phosphorus loss to waterbodies within runoff.

South Australian Guidelines

The South Australian guidelines (SA EPA/DHS, 1999) is aimed at municipal effluent It requires proponents to consider issues such as effects of runoff on adjacent surface waters, percolation to shallow water table and impacts on soil fertility.

The guidelines require consideration of a mass balance with application rate meeting crop requirements. If this is not possible then a monitoring program is needed to account for the fate of the nutrients.

Tasmanian Guidelines

Tasmania has a very comprehensive irrigation guideline (DPIWE, 2002). The guideline combines information from Vic EPA (1992) with local input and the approach in ANZECC (2000). This approach is designed to ensure the concentration of phosphorus exiting an irrigation area does not exceed 0.05 mg/L the threshold for encouraging algal blooms in waterways). An important implication in this approach is that the concentration in the soil solution exiting the site does not change between the irrigation area and the receiving waters. Additionally soil solution phosphorus throughout the soil profile is equally available to removal to surface waters. Both these assumptions are highly unlikely so the concentration of phosphorus in runoff to receiving water is likely to be much less than that suggested by the Tasmanian guidelines.

The Tasmanian guideline state "*as a rule, the annual application of phosphorus should not exceed the crop or pasture removal rates……nor should phosphorus be applied at a rate that will overload the Phosphorus Adsorption Capacity of soil during the life of the irrigation scheme'.*

The desired maximum concentration of phosphorus in effluent is calculated in the guideline as:

Nutrient loading= area of irrigation (ha)-say 160* anticipated P uptake rate (kg/ha/y) say 27 = 4320

Assume 1120 ML of wastewater/year

Required effluent concentration to balance plant needs= 4320/1120 or 3.9 mg/L.

Conversely if the effluent phosphorus concentration was 35 mg/L, and there was 1120 ML of effluent to be utilised, the required irrigation area based plant removal would be 1452 ha. Irrigation at less than a ML/ha/y is usually uneconomic, so this approach is not viable for typical abattoir wastewater. (It is noted in passing that few abattoirs have major problems with downstream algal blooms. It is therefore likely that the Tasmanian approach does not fully take into account phosphorus sorption processes inside and outside the irrigation area).

Conclusions

Wastewater irrigation guidelines in most states aim for a mass balance approach where the phosphorus applied is balanced by the phosphorus removed in harvested material. Application of this approach to wastewater with 30 to 40 mg/L of phosphorus results in very large irrigation areas with an application rate of less than 1ML/ha/y. This is not viable.

However most wastewater guidelines also accept that the soil has capacity to store phosphorus. The storage capacity varies greatly with soil type, but capacities in excess of 15 t/ha/m of soil can occur. Phosphorus sorption capacity is an equilibrium reaction and desorption is apparent once 25 to 50% of the phosphorus sorption capacity is saturated. Nevertheless, a 3m deep soil with 5t/ha/m initial storage capacity will retain 150 years of phosphorus application at a rate that exceeds plant removal by 100 kg/ha/y.

Approach of the ANZECC Guidelines is too conservative as it does not allow for phosphorus sorption throughout the soil profile and it does not allow for sorption and infiltration processes removing solution phosphorus as it is conveyed to waterways.

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Key findings of PRENV.032 phosphorus sustainability during irrigation (Nash, 2004)

The MLA commissioned a review of phosphorus sustainability during irrigation (Nash, 2004). Factors influencing mobility of these different phosphorus types through and across soils were also evaluated. It also commented on the types of regulatory approaches and the tools for regulating application of meat processing wastewaters to lands. An important observation was that the US EPA has not mandated treatment of abattoir effluent to remove phosphorus (EPA, 2004). Apparently this reflects the practical difficulties in reducing phosphorus concentration in such wastewaters. The key conclusions and implications for the phosphorus sustainability program derived from Nash are annotated in Table 3.

Table 3. Key findings from Nash (2004) and their implications for the phosphorus sustainability project.

Finding/conclusion **(page number in review)**	**Implication and comment**
Effluent chemistry varies markedly among sites (Table 1 of Nash, 2004)	Effluent needs to be characterised for each site. However effluent usually contains over 80% of its phosphorus in the ortho-phosphate form. That is, it is largely dissolved and can be conveyed into or across the soil within percolating effluent. Phosphorus concentration is typically 20 to 40 mg/L, but this needs to be verified at each site.
Effluent has a range of attributes that could impact on soils and waters. These include TSS, BOD, Nitrogen (especially ammoniacal-N), salinity, SAR and phosphorus (Table 1).	Phosphorus is not the only issue. There is an array of contaminants in the effluent that should be retained on site as far as practical. Some of them, eg salt, can influence sustainability of phosphorus application. The concentrations of these key contaminants need to be verified at each site.
Little information was found on the different types of phosphorus in effluent (p11-18), yet different types of phosphorus are likely to have major differences in mobility (p17)	A research based program to distinguish phosphorus types and their mobility is required; (beyond scope of present project).
Could not distinguish between risks of phosphorus loss via drainage, erosion and direct conveyance.	Production of a risk matrix is an essential aim of the current project
Chemistry of phosphorus interaction with soil and plants is complex and dynamic, however phosphorus ‘retention’ capacity can be estimated (at least on a pragmatic basis).(p13-16)	P sorption capacity information is required for ground water risk assessment. P sorption capacity utilising a base concentration of around 40 to 50 mg/L of P is a good starting point (ANZECC, 2000).
Erosion loss may be significant (was not quantified) (p17-18)	RUSLE (Revised Universal Soil Loss Equation) or similar approach components should be included in the risk model.

Table 3 continued

Finding/conclusion **(page number in review)**	**Implication and comment**
De-mobilisation/sorption processes within the property can determine the mass of phosphorus moving towards site boundaries (p18)	Include distances and travel time to drainage lines and to sensitive ground water in risk models. The presence of unfertilised land between the effluent irrigated field and the waterway can be important.
Loss by direct runoff of phosphorus enriched water can be important (p19-22)	Competent management of the irrigation system is essential. Effluent runoff simply should not occur except during extreme wet weather when the contribution of effluent derived phosphorus would be minimal compared with other sources. . Any model should include soil, landscape and hydrological attributes to quantify risk of above-surface flows
Loss to ground water due to phosphorus saturation and/or subsurface flow may be important (p21)	Key issue is risk to ground or surface water values. Include • Soil P sorption capacity as kg P/ha in the whole profile is critical. This may have BOTH vertical and horizontal components (for example when flow moves towards receiving waters along the surface soil/ subsoil interface). • A soil residence time surrogate, eg field texture & structure. (Note potential impacts of preferential flows)
Soil properties influence the relative distribution of phosphorus between surface and subsurface environments. These soil properties may change with effluent irrigation (p8)	Use effluent chemistry and basic soils information such as texture to identify risk of increased runoff. Note development of an organic thatch which can develop into a significant store of phosphorus.
Regulatory Approaches to managing abattoir wastewaters	
European regulators acknowledge practical difficulties with managing wastewaters (p29-31)	Emphasis should be on off site contamination risk and site longevity rather than 'balancing' phosphorus supply and demand in a two dimensional model. This is important as phosphorus accumulation in soil is not intrinsically bad. Rather it is the risk that the phosphorus may escape into phosphorus deficient waters encouraging algal growth that is the issue.
USA regulators more interested in Nitrogen as the key contaminant (p31)	US regulators are very aware that phosphorus is not the only likely contaminant from agricultural industries However the current project will concentrate on phosphorus as it is a contaminant that is being applied at rates in excess of plant requirement and is considered to be a key contaminant in Australian inland waters.
Australian Regulators typically require no water pollution and no harm. But not specifically aimed at abattoir wastewater irrigation (p32-34)	This requirement is consistent with risk based management developed within the current project. It is achievable with a combination of good site management and innovative, pragmatic thinking.

Table 3 continued

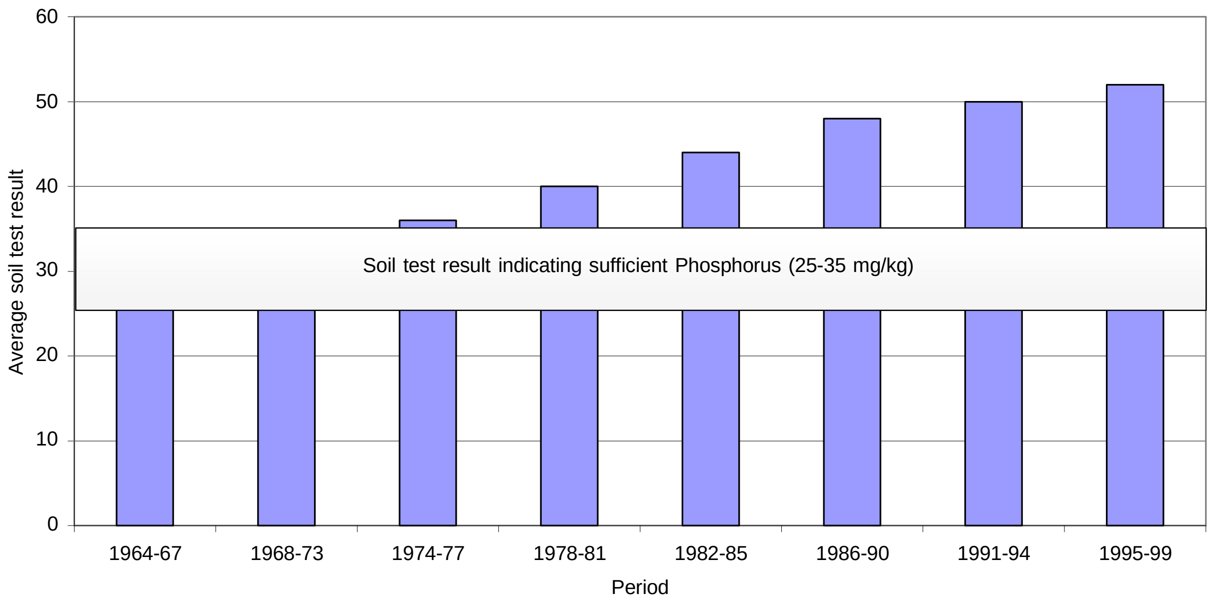
Finding/conclusion **(page number in review)**	**Implication and comment**
Soil testing	
Soil testing widely used, but has significant limitations (p35)	Simple availability indicates potential for contamination if erosion occurs. (Total P could also be considered). P sorption capacity can be used to estimate the capacity of the soil profile to retain additional phosphorus. Analysis should include entire soil column above ground water, not just top metre of soil. Additionally it should consider likely distance to receiving waters. These could be both surface and subsurface sites.
Phosphorus testing and indices include a range of source and transport factors (p36-38).	Phosphorus Index should separate source and transfer functions, as both factors are necessary precursors of significant off-site risk.
Modelling phosphorus behaviour	
Models can be useful, but at an individual site they are usually qualitative rather than quantative (p40)	Model such a MEDLI cannot predict phosphorus behaviour. (Limitations include no slope function, no distance to surface or ground water functions, no erosion functions). The apparent ease of use of some models can encourage unintentional misuse, especially if the assumptions and algorithms are not clearly evident and understood by the practitioner.
Bayesian networks may provide useful future tools, based on simple and updatable algorithms (p40).	Still a garbage in = garbage out issue, but the approach is more transparent than in typical models. Clarity of the assumptions is important. In its simplest form Excel spreadsheets can be used to test sensitivity.
Need to assess all the available phosphorus monitoring and interpretative data that have been collected from meat processing and other relevant sites (p43).	A good idea but beyond the scope of the current project. (Possibly consider in any project involving assessment of a large proportion of Australian meat processing sites)

The principles of phosphorus Indices

Background

Fertilizer cost in the USA and Europe is low compared with the prices received for produce. Consequently there has been a trend to over-fertilise to ensure crop productivity is not nutrient limited. Figure 2 shows an example of how phosphorus availability has increased in some areas above the values required to maximise crop growth.

Figure 2. Change in soil P test values in Wisconsin between 1964 and 1999. (mg/kg). (Source: NRCS)



A large proportion of American beef is raised in feedlots. Feedloting results in large quantities of manure that must be removed. Typically the material is applied to surrounding farmlands. The application rate is usually designed to ensure crop needs for Nitrogen are met in full. Unfortunately this results in applying phosphorus at two to five times crop needs (Crouse et al, 2001). Additionally the imprecise nutrient availability in the manure encourages landholders to over fertilise and this further increases the risk of off site impacts.

Over fertilization has resulted in increased phosphorus concentrations in surface waters, leading to algal blooms, and making eutrophication the most widespread water quality issue in the USA (USEPA, 1996). Agriculture is considered the primary cause of the phosphorus in the surface waters (USGS, 1999). As a consequence the USDA and the USEPA created a joint strategy whereby comprehensive nutrient management plans for intensive livestock operations must be implemented by 2008. Under the joint strategy the USDA's Natural Resources Conservation Service (NRCS) has decided what approach should be used in each US state (Sharpley, et al, 2003). By 2003, 47 states had adopted a P index designed to rank fields in accordance with the risk of phosphorus loss to receiving waters (Sharpley, et al, 2003). Three other states rely simply on soil test results.

Development of the phosphorus Index (phosphorus Index)

The phosphorus Index was developed because it was recognised that a single soil test could not take into account all the variables influencing the risk of off site contamination (Mallarino, et al, 2002). The key function of the phosphorus Index is to use readily available field management information to indicate the potential for a field to deliver P to nearby surface water. It is NOT a research tool; rather it integrates research results into a risk assessment system.

The phosphorus Index is designed to assess the risk of phosphorus loss from individual fields to surface waters (Lemunyon and Gilbert, 1993). It was not intended to be quantative; it enables a field by field assessment of the risk that phosphorus could move from a specific site and reach nearby surface waters. It was also designed to identify key factors determining the risk of phosphorus loss (NRCS, Iowa, 2001). This system can also be used to assess change in phosphorus contamination risk with change in site management practices.

Sharpley et al, (2003) summarised some of the reasoning behind selecting a P index approach rather than simply relying on soil P test results. :

1. Agronomic soil tests to predict fertilizer requirements have limited ability to predict likelihood that the phosphorus in the soil will reach receiving waters (Kleinman et al, 2000).
2. Phosphorus content of runoff waters is correlated with soil test P values in fields that have NOT been fertilized, but have minimal correlation with soil test results in recently fertilised areas. Sharpley et al, (2001) suggested the reason for this is that the majority of the phosphorus exiting the site in runoff originated from the fertiliser or manure application rather than from the soil.
3. Runoff from non irrigated areas is largely confined to a few points in the landscape where infiltration-excess overland flow is generated (Gburek and Sharpley, 1998).
4. Subsurface movement of phosphorus towards surface waterbodies can occur in soils that have low phosphorus sorption capacity and that have a strong hydrological connectivity to the local surface drainage network (Schoumans and Breeuwsma, 1997).
5. Transport of phosphorus in eroding soil is a major transport mechanism in some sites (Kronvang, et al, 2003).

The practical importance of using a phosphorus Index approach was illustrated in a Pennsylvania study that compared management recommendations based on
1). Soil test results,
2). The threshold at which phosphorus enriched runoff is likely to be environmentally significant, and
3). A phosphorus Index approach (McDowell, et al, 2001).

McDowell, et al, (2001) reported that use of a soil test approach to regulate fertilisation would prevent fertilisation on 55% of the sites investigated. Use of a contaminated runoff threshold would limit application to 32% of the sites. However an assessment based on the phosphorus Index showed none of the sites were at high risk, and the only medium risk sites were close to streams. McDowell, et al (2001) concluded that for sites in their study, the phosphorus Index approach was the most useful predictor of phosphorus pollution risk. Additionally the phosphorus Index approach highlighted fields where remedial management was needed to minimise phosphorus export.

Phosphorus Index components

The original phosphorus Index utilised a simple qualitative scoring system that did not recognise the independent importance of source, transport and accessibility to sensitive receiving waters (Lemunyon and Gilbert, 1993). This original phosphorus Index has been modified over time to more closely reflect risk of phosphorus pollution.

A key issue in most recent phosphorus Indices is the recognition that phosphorus export requires BOTH a

1. Phosphorus source

and a

2. Phosphorus transport mechanism in order for the phosphorus to reach receiving waters.

The distance and connectivity to surface waters is also critical in determining the probability that mobilised phosphorus will reach receiving bodies (Gburek, et al, 2000).

Recent phosphorus Indices typically use continuous data, such as anticipated erosion rate in t/ha/y rather than qualitative terms such as low, medium and high erosion rates.

Some US states use a 2 part test, with an initial screening designed to prevent unnecessarily detailed assessment of low risk sites. In Pennsylvania the screening uses soil available phosphorus and distance to streams as indicators of potential loss of phosphorus from the site. The Pennsylvania phosphorus

Index does not require detailed site assessment if there is less than 200 mg/kg of available phosphorus and there is more than 45m to streams.

Pennsylvania Phosphorus Index (PI) as an example of the US system

The Pennsylvania Phosphorus Index (PI) has a series of components that are weighted on empirical results developed from experiments under local conditions. This PI is given as an example of indices used in intensively farmed areas of the USA. Table 4 identifies these components and comments on their relevance to Australian abattoir irrigation systems. The Pennsylvania phosphorus Index is shown in Appendix 2.

Table 4. Components in the Pennsylvania phosphorus Index and their relevance to Australian sites irrigated with Abattoir effluent.

Component	Penn test	Comment
Soil available P	Mehlich-3	Mehlich-3 soil test is rarely used in Australia. Australian tests will need calibration, possibly by using data from US states that that use both Mehlich-3 and tests common in Australia (eg Bray, Olsen & Colwell)
P application method	Included depth, winter application and effect of snow	Effluent is normally surface applied in relatively small doses (eg a 25 mm irrigation containing 40 mg/L of P applies 10 kg/ha of P). The relatively small doses facilitate sorption of recently applied phosphorus before a subsequent irrigation.
Manure P availability	Different coefficients for sludge, dairy and swine manure	It is reasonable to assume abattoir effluent will contain >80% of phosphorus as ortho phosphorus. Therefore the availability coefficient will be the same as fertilizer derived phosphorus
Erosion	t/ac/y	RUSLE can be used to determine predicted loss in t/ha/y. Data is already standardised throughout Australia.
Runoff potential	Scale of zero to 8	There is a need to separate risk of effluent runoff from risk of rainfall runoff. If local information is available then use a combination of texture (sand, clay, etc), slope (%) and rainfall (seasonality is an issue, esp. in N Australia). Australian computer programs such as SOILOSS (Rosewell, 1993) use field values and regional maps. NSW has rainfall runoff coefficient maps (DLWC, 1999). Soil Hydrological Properties of Australia (Western and McKenzie, 2004) could be used for reconnaissance.
Subsurface drainage	Scaled zero to 2	Sub surface tile or piped drainage is not common in Australia. But the Pennsylvania phosphorus Index includes a scaled score of 2 for permeable sites near streams.
Contributing distance	Scaled from zero for>150m to 8 for <45 m	Value and scale can be read from map. Can be based on distance between lower edge of field and defined drainage system (shown as line on topographic map)
Modified connectivity	Scaled for riparian buffer	Riparian buffer (0.7), grassed swale (1), direct connection to stream that is >45 m away (1.1). A similar system can be used in Australia.

According to Sharpley et al (2001) numerous US states have adapted the phosphorus Index concept to suit their particular concerns and needs. For example the Iowa phosphorus Index is designed to address the risk of phosphorus loss from cropped lands. In 2001 Sharpley et al tabulated the differences among the different states. Their table is reproduced as Appendix 3.

Table 5 summaries the key differences among the states and comments on the component relevance to Australian abattoirs.

Table 5. Comparison of different approaches to the phosphorus Index and the relevance to Australian abattoir sites.

Component	Variations	Comments
	SOURCE FACTORS	
Soil P availability	Most states use Mehlich-3. Az, Co, Mt, Ne, NM, ND, Oh, Or, Tx, Wa, Wi and Wy uses tests similar to Australia	Colorado, North Dakota, Texas tests use several tests, enabling comparison among US and Australian test values. Bray and Olsen tests are the most relevant. Mehlich test is similar to Bray, while Olsen is similar to Colwell P Moody and Boland, 1999). The relationship between phosphorus application rate and change in soil test P is extremely variable, but tends to be closer to a 1:1 ratio as the soil becomes saturated with phosphorus. Only a few states use soil P storage capacity (e.g. Vermont). Yet this is considered critical as a measure of site longevity in several Australian states.
Application rate	Most states express rate as lbs P_2O_5/ac/year (multiply by 0.4885 to get kg P/ha/year) Ak uses Soluble P/ac, Fl uses waste water volume, Mi uses mass of manure P,	Fl is useful. Otherwise simply kg P/ha/y as the availability of phosphorus in abattoir effluent is similar to that in many fertilisers.
Application method	States' phosphorus Indices typically include the range of methods likely to be encountered for fertilizer application. Sprinkler application is included in Al, Ak, Fl and Ga,	The indices of that include sprinkler application are likely to be more relevant to abattoir sites
Application timing	Days to incorporation is used where cropping is anticipated. Ak, Co, De, Ga use application season Illinois uses incorporation before or after runoff event, while SC uses time to irrigation. rainfall Ak and Tn use cover at planting	Assume no incorporation of abattoir effluent
Site management	Components vary among state and include: animal access to surface water (Al), grazing management (Az, Ak, and NM), cover crop (Co), soil conservation practices (Ia, Ne), filter strips (ND), irrigation efficiency (Ut), Soil P sorption capacity based on pH and texture (Wy).	Relevant components include animal access into drainage lines, grazing management (% vegetative cover), irrigation efficiency and P sorption capacity. Some states are largely concerned with cropping impacts.
TRANSPORT FACTORS		
Erosion	RUSLE is used in most states. Irrigation is included in Ak, Az, Fl, Mt, Na, ND, Or, Wa, Wy. Wi includes an enrichment factor	Data to use RUSLE is available for most of Australia. Irrigation component is relevant as is the enrichment factor (this can be an assumed value of 1.5 suggested by Sharpley et al (2002) and reflects the presence of permanent pasture where phosphorus accumulates near the surface.

Surface runoff class	Many US states have detailed information placing soils into surface runoff classes. Slope, permeability and precipitation are important components. NY includes presence of concentrated flows. NC and SC, Tx and Ut include estimated runoff/y. Ok includes soil depth. RI includes surface runoff incidence. Wi phosphorus Index considers movement of particulate (sediment-bound) P, soluble (dissolved) P, and acute (single runoff event) P losses.	Information on annual rainfall and slope are readily obtainable. Calculation of the K Factor (Soil erodibility), required for estimating erosion rate, also provides information on soil structure and permeability. The risk of direct runoff of effluent should be considered and addressed.
Subsurface drainage/flooding	Components include; Flood frequency (Ak, NH, NY, Ok, Or, RI, Vt), Water table depth (Del, Ga, La, Ma, SC, Ut), Drainage (De), Leaching rating (De, Fl, Ga), Soil properties (Fl, Or), Percolation index (Ga, La, Ma, NY, RI), Tile drainage (Il, Io, La, NC, Or, Pa), Soil texture (La), Rainfall (Ia), Subsurface flow (NC), S Subsoil permeability (SC), Water holding capacity (Ut) Depth to sand or rock (UT)	Flood frequency should be readily available. Surface soil texture, structure and permeability are required as part of RUSLE. Subsurface permeability information is uncommon, yet it is a key determinant of P mobility. Depth to rock rather than depth to water table is likely to be important for most Australian abattoirs.
	CATCHMENT CHARACTERISTICS	
Distance to receiving waters	Distance to water is used by Al, De, Il, Ia, Ks, Ky, La, Me, Mn, Ms, NJ, NM, NY, Oh, Ok, Or, Pa, RI, SC, Ut. Existence of discharge(Ak, Fl,). Presence of surface water (Mi), Distance to concentrated surface flow(Mt, Ne, Tn), Distance to channel (ND), Distance to named stream or lake (Tx)	Commonly use distance from edge of field to surface water. However downslope travel distance from the lower edge of the field to a connected drainage line or lake is a preferred description.
Connectivity	Presence/ width of buffer or filter strip (Al, Ak, Az, Co, Dl, Fl, Ga, Ia, Ky, La, Md, Mi, Mn, NH, NM, NC, Oh, Ok, Pa, SC, Tn, Vt), Discharge to waters (Ill). Connection to stream (Ks, Pa, RI). Grassed water way (Mt, Ne), Runoff class (SC). Most states include buffer or filter strip widths. Some include wetlands and detention treatment areas	Filter strips are efficient for sediment attached P but less so for dissolved P (Nash, 2004). Some US states specify required distances (Oh uses 10m). Others specify classes e.g. <45m buffer, 45-140m,>140m. Residence time within the buffer zone is important but it will vary with runoff volume, rainfall intensity, catchment size, thickness of vegetation and slope. Surrogates such as requiring thick vegetation, and an allowance for slope can be included.
Receiving water priority	Different states use different criteria, including Distance to critical habitat (Al), Value of water body (Ak, Fl) are common, other states have water bodies classified according to their perceived value.	In view of national concern with waterway quality it is reasonable to assume all waters should be protected.
	INDEX VALUE DETERMINATION	

	Additive risk assessment is used by Ala, Ak, Az, Co, Ga, Io, Ky, Mi, Mt, Ne, NJ, NM, ND, Oh, Or, RI, Tx, Wa, WV and Wy Multiplicative risk assessment is used by Ar, De, Fl, Ks, La, Md, Ms, NH, Pa, SC, Tn and Vt	A multiplicative index is preferred as it emphasises both the need for a phosphorus source AND the potential for the phosphorus to be mobilised and be transported from the site to sensitive receiving waters.

Application of phosphorus Indices to Australian sites irrigated with abattoir effluent

The information package provided with the Wisconsin phosphorus Index identifies a series of attributes that a phosphorus Index should include. These have been adapted below to suit Australian abattoir sites.

- It must be relevant to conditions at each abattoir. A series of indices may be required to address regional differences. For example the impact of the Wet in Northern Australia.
- It should accurately rank fields within effluent irrigated areas based on their potential to add phosphorus to a water body
- It should be based on the best science available, and be easily modified as better science becomes available
- It should be easy for the user to interpret, and apply
- It should be useful educationally to enhance understanding of factors leading to phosphorus loss to water bodies.
- It should direct the user to selection of improved management practices that will lower the overall risk of P loss from the site most efficiently.
- It should be applied over the whole farm enabling ranking on the basis of current risk.
- It should provide maximum flexibility in managing rotations and individual fields around the farm.
- Ideally is should have a chemical and physical basis rather than be empirical.
- It should address both source and transport factors.

Sharpley et al (2003) produced a table identifying factors that influenced phosphorus loss. Table 6 adapts some of their concepts to Australian conditions.

Table 6. Factors influencing phosphorus export from effluent irrigated Australian soils (adapted from Sharpley et al (2003)).

Factor	**Component**	**Potential responses**	**Potential component for the phosphorus Index**	**Component measured**
SITE MANAGEMENT	Source management	• Keep phosphorus concentration in effluent to a minimum, e. g. by screening, pondage, etc. • Keep application rate onto field to a minimum by increasing irrigation area where practical • Keep stock numbers to a minimum consistent with abattoir logistics • Grow and export fodder with a high phosphorus demand • Select pastures with year round potential for growth. Irrigate to maximise growth • Encourage development of organic layer on topsoil	phosphorus loading rate Estimate of Bioavailable P, (Sims et al, 2002) Capacity of soil to retain phosphorus within the profile	Phosphorus concentration in the effluent (mg/L). Soil available P (mg/kg) Soil profile P sorption capacity (kg/ha)
SITE MANAGEMENT	Irrigation management	• Well designed, maintained and managed irrigation systems are essential. • Key components include: irrigation rate reflects local soil characteristics (irrigation<soil infiltration rate), no irrigation runoff (auto shut down during and immediately after rain events), no irrigation near or over drainage lines, effluent evenly applied, application rate adjusted to meet evapotranspiration demand	Irrigation and P loading rate Irrigation management level- Evidence of runoff. Seasonality of application compared with seasonality of rainfall	Application rate ML/ha/y phosphorus application rate kg/ha/y Runoff mm/y (including effect of irrigation on runoff) Include estimate of effluent runoff (should be zero mm/y)

Table 6 continued.

Factor	Component	Potential responses	Potential component for the phosphorus Index	Component measured
TRANSPORT MANAGEMENT	Minimise runoff	• Ensure Irrigation rate < soil infiltration rate (adjust to suit field configuration, for example irrigate hilltops in preference to saturated bottom lands)) • Do not irrigate if runoff risk is obvious • Install auto shutoff for rain events	Irrigation rate is/ or is not<soil infiltration capacity (yes/no) Runoff rate Presence and use of auto shutoff for rain events (yes/no) Size of any fields conveying runon to the irrigation area	Yes/no Base on local maps or assume 20% of rainfall plus effluent in mm/y Yes/no ha/ha of irrigation field-from map
TRANSPORT MANAGEMENT	Minimise dissolved phosphorus concentration in runoff	Avoid effluent irrigation immediately before during or after significant rain events. Ideally do not irrigation if rain is predicted. Is there sufficient buffer storage to avoid need to irrigation during rain events?	Presence of adequate buffer storage (months based on average effluent volume)	Is there sufficient wet weather storage to avoid the need for irrigation during the average year?
TRANSPORT MANAGEMENT	Minimise erosion	• Prevent stock congregating in lower portions of the paddocks • Ensure runoff from laneways is dispersed onto grassed areas rather than into drainage lines • Check for salt scalds. Fence off and revegetate if required • Ensure grass cover of at least 70% and preferably 100%. • Ensure drainage lines are kept well vegetated. Fence off if necessary	RUSLE in t/ha/y. Pastures coverage as a % of the ground surface area. Drainage lines fenced off? Evidence of salinisation?	RUSLE components: • Slope, slope length (field data), • Soil erodibility (lab data), • rainfall erosivity (available maps), • erosion control practice (look up table) • Groundcover and management (look up table Field observation, noting bare areas near drainage lines Note animal access to drainage lines.

Table 6 continued.

Factor	Component	Potential responses	Potential component for the phosphorus Index	Component measured
TRANSPORT MANAGEMENT	Maximise opportunity for sediment removal from runoff	• Divert runoff onto grassed areas • Establish and maintain well vegetated buffers between irrigation area and surface water (ideally this area should be flat and runoff distributed evenly across it rather than in concentrated stream flow)	Width and slope of non-irrigated, vegetated land below edge of irrigation areas in metres and % slope (from map) Concentrated or non concentrated flow from irrigation area?	Presence, width and slope of vegetated land between the lower edge of effluent irrigated fields and permanent or intermittent streams, lakes or wetlands. Yes/no
TRANSPORT MANAGEMENT	Maximise distance to surface water	• Where practical avoid locating holding paddocks close to drainage lines • Do not irrigation over or near drainage lines • Minimise connectivity between phosphorus source and receiving waters by maintaining buffer zones between effluent irrigation area and surface waters		
TRANSPORT MANAGEMENT	Reduce connectivity between effluent irrigation area and water bodies	• Establish vegetated buffers downslope of irrigation area. • Ensure irrigation 'runs' avoid drainage lines. • Check irrigation does not occur over or near drainage lines.		Field assessment
TRANSPORT MANAGEMENT	Reduce opportunity for phosphorus leaching below root zone	• Irrigate sufficiently frequently to avoid deep crack development in clay soils • Irrigate soils to replenish root zone moisture. Do not over water.	Use daily water balance to manage irrigation	Irrigation scheduling used?

Table 7 shows the components of the proposed phosphorus Index. The first column shows the component while the second column explains the role of this component in developing the phosphorus Index. The shaded components are items that an abattoir would either be readily able to measure itself or have it measured in a laboratory.

Field conditions

Field conditions define the phosphorus loading rate, application method the rainfall runoff rate and the level of management. The level of management is not used in the proposed PI. It simply highlights areas that may influence actual phosphorus export rate.

Soil test

Soil test type varies both among and within Australian states. Soil test selection is typically based on local considerations such as pH (Moody and Bolland, 1999). There has been extensive research in the USA and elsewhere to correlate soil test values with the concentration of phosphorus likely to be eluted during rain events.

Soil P sorption capacity is a measure of the profile's ability to store phosphorus within a known depth. A combination of profile depth, field texture, bulk density (typically estimated) and phosphorus sorption capacity is used to establish maximum storage capacity in kg P/ha.

Estimated particulate transport

Erosion rate is expressed as t/ha/y based on RUSLE. There are Australian wide estimates for the rainfall erosivity component; soil erodibility is based on analysable soil characteristics while L-S, P and C are based on individual site assessment. The resulting number is a very widely accepted estimate of erosion rate in tonnes/ha/year.

The erosion rate is corrected for enrichment and for retention within lands between the irrigation area and receiving waters.

Dissolved phosphorus transport factor

Dissolved phosphorus concentration includes an estimate of the dissolved phosphorus concentration, the contribution of dissolved phosphorus from the abattoir effluent and the effect of any buffer lands between the effluent irrigation area and the receiving waters.

Site export of particulate bound and dissolved phosphorus

These components arte both expressed as kg/ha/year.

Table 7. Attributes proposed for a phosphorus Risk index for Australian abattoirs using effluent irrigation. Comments are provided to explain the attributes. Shading indicates the information required to generate results. Calculated outputs are shown in capital letters. Time to soil P saturation (years), Dissolved transport yield (kg/ha/y), particulate transport yield (kg/ha/y) and Total P yield from surface transport are italicised (Sources Iowa PI, Rosewell, 1993, Reed et al, 1995).

Attribute	Comment
FIELD CONDITIONS	
Area (ha)	Obtain from farm maps. Break farm into sections with similar characteristics such as irrigation history, distance from streams, soil types, slopes ,etc.
Volume of effluent applied (ML/y)	Estimate total volume onto each farm section
Phosphorus concentration in effluent (mg/L) default is 40 mg/L)	Arrange for a Total and Ortho-Phosphate P at least once every 2 years. Sample at irrigation outlet.
PHOSPHORUS APPLICATION RATE (KG/HA/Y)	Simply phosphorus concentration * volume/ha
Irrigation system (Sprinkler =0.8, Flood or furrow=1)	Used to correct for deeper penetration and less runoff risk from sprinkler systems
Typical irrigation interval (days) OR	Used to assess change in phosphorus availability between irrigations
Number of irrigations/year (Number or zero if not used)	Used to assess irrigation management
Irrigation depth (mm) (Number or zero if not used)	Used to calculate phosphorus loading in kg/ha/irrigation
Is there any wet weather storage? (Y/N)	Used to assess overtopping risk
How many days per year is effluent production discharged via dam overtopping or direct flow	Volume lost directly to waterways.
Does runoff ever occur during irrigation (Y/N)	Used to assess runoff risk
Rainfall (mm)	Used to assess phosphorus loss in runoff
RUNOFF ESTIMATE (mm/y)	Used to assess phosphorus loss in runoff (assumes 20% of total rainfall +effluent)
SOIL TESTS	
Type of test-(select one)-Colwell, Olsen, Bray	Used to estimate soil P concentration and dissolved soil P
Depth tested (if 10 cm 10, if 15 cm 15, if 20 cm 20)-example 20	Used to estimate soil P mass in kg/ha
Test result (mg/kg)	
Top soil depth (cm) ---check colour and texture, typical depth 10 to 20 cm.	These are examples of information required to determine site P sorption capacity (and risk to ground water)
Top soil Texture (eg sand, loamy, clay, organic)	
Top soil P sorption capacity (mg/kg)	
Subsoil 1 depth (cm) typically from 20 to 80 cm--example 20 to 80 cm	These are examples of information required to determine site P sorption capacity (and risk to ground water)
Subsoil 1 Texture (eg sand, loamy, clay, organic)	
Subsoil 1 P sorption capacity (mg/kg)	
Subsoil 2 depth (cm) typically from 80 to 200 cm-example 80-205	These are examples of information required to determine site P sorption capacity (and risk to ground water)
Subsoil 2 Texture (eg sand, loamy, clay, organic)	

Attribute	Comment
Subsoil 2 P sorption capacity (mg/kg)	
Subsoil 3 depth (mm) typically from 200 to 300 cm-example 205-330 cm	These are examples of information required to determine site P sorption capacity (and risk to ground water)
Subsoil 3 Texture (eg sand, loamy, clay, organic)	
Subsoil 3 P sorption capacity (mg/kg)	
TOTAL SOIL P SORPTION CAPACITY (KG P/HA) (ASSUMING A BULK DENSITY OF 1.5 T/CUBIC M)	This is the sum of the P sorption capacity from each layer
RISK OF GROUND WATER CONTAMINATION	
• ***Time to soil P saturation (years)***	Divides total P sorption capacity by the annual P loading rate (kg/ha/y)
PARTICULATE P TRANSPORT FACTOR	
Rainfall erosivity (LOOK UP MAP)	A measure of the rainfall's ability to cause erosion
Soil erodibility (LOOK UP TABLE)	A measure of the susceptibility of soil particles to detach and be transported
Slope length (m horizontal length)	The distance measured on the ground, from the origin of the flow to the point where gradient decreases to the extent that deposition occurs or where runoff becomes concentrated.
Soil slope (%) (From local topographic map)	Grade expressed as %
LS Factor (LOOK UP TABLE)	See Soil conservation table
Support practice (assume 0.8 FOR PERMANENT PASTURE with contour banks)	A measure of erosion control features such as contour banks
Ground cover (use soil loss equation) (assume 90% IN EXAMPLE 1), 60% in example 2 look up table	A measure of the effect of grass cover on erosion (Look up table available)
CALCULATED SOIL LOSS (T/HA/Y)	RUSLE calculated as Rainfall erosivity* Soil erodibility*LS Factor*Support factor*Ground cover factor
Enrichment ratio (Perennial pasture, Iowa)	An estimate of the phosphorus enrichment in exported sediment compared with the concentration in the bulk soil (from Iowa PI)
TOTAL P IN TOPSOIL (FUNCTION OF SOIL TEST, BASED ON IOWA). ASSUMES 200 MG/KG NATIVE SOIL P	An estimate of total Soil P based on Iowa PI
P MOBILISED IN EROSION (KG/HA/Y)	RUSLE*enrichment*soil P concentration
Distance between lower edge of irrigation area and any lake, wetland, permanent or intermittent stream (m)	Measured in the field
Vegetated buffer distance (m)	Measured in the field
Percent sorbed particulate P retained in the buffer zone	Calculated from data of Havlin (2004)
DISSOLVED P TRANSPORT FACTOR	
DISSOLVED P SOIL TEST (ADAPTED FROM MCDOWELL, ET AL, 2001) RANGE 0 TO 190 MG/L AVAIL P	Estimates dissolved P concentration from soil P test results.
EFFLUENT P (KG/HA/Y)	Estimate of P loading rate (kg/ha/y)

Attribute	Comment
CONTRIBUTION TO DISSOLVED P FROM EFFLUENT (MG/L) P APPLICATION RATE*100*.5*.005*10/ (15 CM DEEP SOIL *B DENSITY (ASSUME 1.5 T/CUB M) OR 2250T/HA). COEFFICIENTS FROM IOWA PI	Estimate of effluent P concentration in soil solution (using Iowa PI parameters).
TOTAL ESTIMATED DISSOLVED P IN SOIL SOLUTION (MG/L)	Estimate of soil plus effluent P concentration in soil solution
PERCENT DISSOLVED P RETAINED IN BUFFER (ASSUME KSAT 1m/DAY)	Percent of dissolved phosphorus retained in the buffer downslope of the irrigation area. (Derived from Reed, et al, 1995). Removal is virtually all via infiltration.
SITE PHOSPHORUS EXPORT	
• ***P loss via effluent discharge***	An estimate of phosphorus loss in effluent discharge
• ***Dissolved transport yield (kg/ha/y)***	An estimate of phosphorus loss as dissolved P
• ***Particulate transport yield (kg/ha/y)***	An estimate of phosphorus loss as particulate P
• ***Total P yield from surface transport***	Total P loss via surface transport in kg/ha/y.

Table 8 shows an example of the proposed phosphorus Index applied to two sites.

Table 8. Phosphorus Index applied to two contrasting sites.

SOURCE FACTORS	**Paddock number/ name (Example 1)**	**Paddock number/ name (Example 2)**
FIELD CONDITIONS		
Area (ha)	23	23
Volume of effluent applied (ML/y)	122	122
phosphorus concentration in effluent (mg/L) default is 40 mg/L)	38	38
phosphorus application rate (kg/ha/y)	202	202
Irrigation system (Sprinkler =0.8, Flood or furrow=1)	0.8	0.8
Typical irrigation interval (days) OR	7	7
Number of irrigations/year (Number or zero if not used)	0	0
Irrigation depth (mm) (Number or zero if not used)	25	25
Is there any wet weather storage? (Y/N)	Y	Y
How many days per year is effluent production discharged via dam overtopping or direct flow	0	3
Does runoff ever occur during irrigation (Y/N)	Y	Y
Rainfall (mm)	903	903
Runoff estimate (mm/y) (assumes 20% of total rainfall +effluent)	287	287
SOIL TESTS		
Soil test results (select one)		
Type of test-(select one)-Colwell, Olsen, Bray	Bray	Bray
Depth tested (if 10 cm 10, if 15 cm 15, if 20 cm 20)-example 20	15	15
Test result (mg/kg)	58	180
Top soil depth (cm) ---check colour and texture, typical depth 10 to 20 cm.	12	5
Top Soil Texture (eg sand, loamy, clay, organic)	loam	sand
Top soil P sorption capacity (mg/kg)	32	25
Subsoil 1 depth (cm) typically from 20 to 80 cm--example 20 to 80 cm	68	35
Subsoil 1 Texture (eg sand, loamy, clay, organic)	clay	clay
Subsoil 1 P sorption capacity (mg/kg)	119	85
Subsoil 2 depth (cm) typically from 80 to 200 cm-example 80-205	125	0
Subsoil 2 Texture (eg sand, loamy, clay, organic)	clay	clay
Subsoil 2 P sorption capacity (mg/kg)	128	0
Subsoil 3 depth (mm) typically from 200 to 300 cm-example 205-330 cm	125	0
Subsoil 3 Texture (eg sand, loamy, clay, organic)	clay & rock	clay & rock

Subsoil 3 P sorption capacity (mg/kg)	35	35
Total soil P sorption capacity (kg P/ha) (assuming a bulk density of 1.5 T/cubic m)	36891.5	4702.5
RISK OF GROUND WATER CONTAMINATION		
Time to Soil P saturation (years)	183	23
PARTICULATE P TRANSPORT FACTOR		
Rainfall erosivity (LOOK UP MAP)	2000	2000
Soil erodibility (LOOK UP TABLE)	0.03	0.03
Slope length (m horizontal length) *Slope (%) factor (LOOK UP TABLE)	250	250
Soil slope (%) (From local topographic map)	10%	10%
LS Factor (LOOK UP TABLE)	5.75	5.75
Support practice (assume 0.8 FOR PERMANENT PASTURE with contour banks)	0.8	1
Ground cover (use soil loss equation) (assume 90% IN EXAMPLE 1), 60% in example 2 look up table	0.013	0.042
Calculated soil loss (t/ha/y)	3.6	14.5
Enrichment ratio (Perennial pasture, Iowa)	1.3	1.3
Total P in topsoil (function of soil test, based on Iowa PI). Assumes 200 mg/kg native soil P	374	740
P mobilised in erosion (kg/ha/y)	1.74	13.94
Distance between lower edge of irrigation area and any lake, wetland, permanent or intermittent stream (m)	113	25
Vegetated buffer distance (m)	50	10
Percent sorbed P retained in the buffer zone	76	26
DISSOLVED P TRANSPORT FACTOR		
Dissolved P soil test (adapted from McDowell, et al, 2001) range 0 to 190 mg/L avail P	0.279	0.34
Effluent P (kg/ha/y)	202	202
Contribution to dissolved P from effluent (mg/L) P application rate*100*.5*.005*10/ (15 cm deep soil *B Density (assume 1.5 t/cub m) or 2250T/ha). Coefficients from Iowa PI	0.22	0.22
Total estimated dissolved P in soil solution (mg/L)	0.50	0.56
Percent dissolved P retained in buffer (assume Ksat 1m/day) Reed et al (1995)	62	17
SITE PHOSPHORUS EXPORT		
P loss via effluent discharge (kg/ha/y)	0	6
Dissolved transport yield (kg/ha/y)	0.6	1.3
Particulate transport yield (kg/ha/y)	0.4	10.3
Total P yield from surface transport	1.0	17.6

Estimates of phosphorus export from agricultural activities in Australia

The previous section provided estimates of phosphorus export expressed as kg/ha/year. While the ideal is for the effluent irrigation to not result in rates higher near natural export rate, it is more practical to set performance criteria based on estimated exports for comparable intensive agricultural industries.

Export of contaminants from various landuses has been extensively investigated in Australia since the outbreaks of algal blooms along the Murray-Darling River system in 1990. In some investigations emphasis has been on Australia wide conditions (Young et al, 1997); however the results from such a wide range of climate, management and geographic conditions can result in very generalised results. While these can be useful at a catchment level they provide little guidance for assessing specific industries at specific locations. Marston, (1993), produced a series of diffusion nutrient generation rates for different industries within a specific catchment. An important feature of her work was to provide error estimates, explicitly acknowledging the uncertainty of such data. Table 9 presents some of her results. It also contains results from other investigations.

Table 9. Diffuse phosphorus generation rate estimates from different Australian investigations. Note that land use terminology varies among authors. Landuses have been given similar names where the terminology seems to refer to the same land use type.

Land use	Data source					
	Marston (1993)	McNamara and Cornish (2001)	Young et al 1996	Nash and Murdoch (1997)	Baginska et al (1998)	QDNR (1997)
Location of study	Hawkesbury-Nepean	Hawkesbury-Nepean	Estimates for tropical and subtropical Australia	Victoria		Modelled estimates for Johnstone River Catchment, Innisfail
Bushland	0.1± 0.1	0.04				2
Intensive vegetable growing	8±4	9	7.1 (range: 2.7-14.3)		15.3	7
Turf farming	8± 4	10				
Fertilised grazing	1.25± 0.5	1 to 2 (higher if near stream)	1.1 (0.1-1.9)			2
Unfertilised grazing	0.25± 0.1	0.43 to 1.5 (higher if near stream and gullying occurs)	0.1 (0.002-0.4)			2
Extensive arable agriculture	2.5± 2.3		1.9			
Dairy		6.8 to 10 (higher if near stream)		0.3 to 6.6	16.4	2

Export rates from natural areas in southern Australia averaged less than 0.1 kg P/ha/y. However QDNR (1997) estimates average losses of 2 kg P/ha/y from rainforest. The higher rate may be due to North Queensland soils having higher total phosphorus content and to higher erosion rates during intense rain events.

It is obvious from the data in table 9 that intensive agriculture markedly increases phosphorus export rates compared with natural bushland. Export rates from intensive dairying and vegetable growing can exceed 15 kg P/ha/y (Baginska et al, 1998). Fertilised grazing is likely to generate up to 2 kg P/ha/y.

Preliminary phosphorus export criteria

The results above suggest that calculated phosphorus export of fewer than 2 kg/ha/y is similar to many other grazing based agricultural systems. Export rates of 2 to 4 kg P/ha/y are similar to those likely from grain cropping. Rates between 4 and 16 kg P/ha/y are similar to intensive rural activities such as dairying and vegetable growing. Rates in excess of 16 kg P/ha/y suggest major management issues that should be addressed as a mater of urgency.

Management needs in response to different PI values

Table 10 shows the management needs for sites based on the estimates of site longevity and phosphorus export from to nearby waterbodies. The management responses to different mass exports reflect the potential impact of effluent irrigation compared with other agricultural activities.

Table 10. Management needs matrix based on the results of the phosphorus Index as shown in table 7, 8 and 9.

Total P export (kg/ha/y)	Soil P sorption capacity (years)			
	<25	25-50	50-100	>100
	Response: Examine risk from subsurface flow as a matter of urgency	Response: Examine risk from subsurface flow.	Response: Ensure phosphorus loading onto irrigation area is as low as possible	Response: Avoid increasing phosphorus concentration in irrigation water
<1	• P in runoff is not an issue, as impact is less than that expected for fertilised grazing.			
1-2	• P in runoff is a minor issue.			
2-4	• P in runoff is higher than most agricultural sites. • Examine options for reducing exports, eg grass cover or increased vegetative buffer.	• P in runoff is higher than most agricultural sites. • Examine options for reducing exports, eg grass cover or increased vegetative buffer.	• P in runoff is higher than most agricultural sites. • Examine options for reducing exports, eg grass cover or increased vegetative buffer.	• P in runoff is higher than most agricultural sites. • Examine options for reducing exports, eg grass cover or increased vegetative buffer. • Encourage more retention of phosphorus on site
4 to 8	• P in runoff similar to dairy farms. • Examine options for reducing exports, eg grass cover or increased vegetative buffer.	• P in runoff similar to dairy farms. • Examine options for reducing exports, eg grass cover or increased vegetative buffer.	• P in runoff similar to dairy farms. • Examine options for reducing exports, eg grass cover or increased vegetative buffer. • Ensure phosphorus loading onto irrigation area is as low as possible.	• P in runoff similar to dairy farms. • Examine options for reducing exports, eg grass cover or increased vegetative buffer. • Install land management options such as contour banks to retain runoff on site as far as practical
>8	• P in runoff similar to intensive agriculture e.g. turf and vegetable farms. • Urgently examine options for reducing exports, eg reduce P application rate, increase grass cover or increased vegetative buffer.	• P in runoff similar to intensive agriculture e.g. turf and vegetable farms. • Urgently examine options for reducing exports, eg reduce P application rate, increase grass cover or increased vegetative buffer.	• P in runoff similar to intensive agriculture e.g. turf and vegetable farms. • Urgently examine options for reducing exports, eg reduce P application rate, increase grass cover or increased vegetative buffer. • Ensure phosphorus loading onto irrigation area is as low as possible.	• P in runoff similar to intensive agriculture e.g. turf and vegetable farms. • Urgently examine options for reducing exports, eg reduce P application rate, increase grass cover or increased vegetative buffer. • Install land management options such as contour banks to retain runoff on site as far as practical

Role of management practices in reducing risk of phosphorus loss

The proposed Phosphorus Index can be used to identify management changes that increase site longevity and reduce phosphorus export. A number of studies have recently assessed the performance of the phosphorus Index for agricultural sites. In 2005 Brandt and Elliott undertook a sensitivity analysis to assess the effect on the phosphorus Index score of changing input variables. They found that the variables that had the greatest variation in impact were phosphorus application rate, application method (incorporated or not), and the presence of a riparian buffer between the field and the surface water.

Gitau, et al (2005), examined the effectiveness of various Best Management Practices (BMPs) in reducing phosphorus pollution. An important feature of their investigations was the separation of phosphorus export into particulate and dissolved phosphorus. They found management of yard runoff, filter strips and riparian forest buffers were the most effective BMPs. However table 11 shows that all BMPs had a large range in effectiveness and the effectiveness also varied with the form of phosphorus examined. The results do however suggest that the effectiveness of the BMPs in reducing total phosphorus loss is similar, and around 50% reduction can be anticipated.

Table 11. Effectiveness of different BMPs in reducing loss of different phosphorus forms (Source: Derived from Gitau et al, 2005).

BMP type	**Variable used to measure effectiveness**	**Number of studies**	**Average effectiveness (%)**	**Std Dev (%)**	**Minimum effectiveness (%)**	
Runoff management	Dissolved phosphorus	4	30	35	5	
	Total phosphorus	7	53	23	23	
	Particulate phosphorus	1	33	-	33	
Filter strips	Dissolved phosphorus	18	26	25	-56	
	Total phosphorus	23	56	18	22	
	Particulate phosphorus	2	41	4	38	
Riparian forest buffers	Dissolved phosphorus	8	62	26	28	
	Total phosphorus	9	43	36	2	
	Particulate phosphorus	1	84	-	84	

A recent MLA commissioned investigation (23b, 2005), also concluded that buffer strips can reduce phosphorus exports.

Conclusions

Phosphorus is a key nutrient, essential for life. However excess phosphorus in waterways can overstimulate growth, creating algal blooms. Consequently there is pressure on industries to reduce phosphorus export to waterways.

Phosphorus is tightly retained in many Australian soils; once the effluent infiltrates below the surface the phosphorus is sorbed onto soil particles. Sorption is however an equilibrium reaction, so not all the phosphorus is retained. Additionally changes in phosphorus concentration due, for example to infiltrating rainwater, can result in desorption and subsequent leaching. The importance of this leaching is a function of sorption capacity to ground water, uses of this ground water and connectivity of the ground water to surface water. The proposed Phosphorus Index includes an estimate of site longevity.

Erosion is a major phosphorus loss mechanism in many cropping systems. However, most abattoir sites have a thick cover of grass. Consequently phosphorus loss via erosion is usually very low.

Phosphorus conveyance in runoff water is likely to be the most significant export mechanism. In the proposed Phosphorus Index it is a function of soil phosphorus test value, soil texture, rainfall and irrigation system. The width of buffering downslope of the irrigation area is included as a modifier.

The proposed Phosphorus Index includes an estimate of phosphorus export via erosion and runoff.

Unlike the indices developed in the USA, which typically give a qualitative result; the proposed index uses estimates of phosphorus export rates to compare the performance of each abattoir wastewater irrigation site with other agricultural industries.

This approach explicitly recognises that rural industries all result in increased phosphorus exports. The issues are

1. Is a specific abattoir irrigation area generating more phosphorus than expected from other intensive rural industries?
2. What can be done at this specific site to reduce phosphorus exports?

The recommended methodology addresses each of these questions.

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(NOTE to be finalised)

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Appendix 1. Extract from Section 9.2.6.3 of ANZECC, (2000) explaining the Short term Trigger Irrigation Value calculations for phosphorus.

Below is an interim model for calculating site-specific STVs for phosphorus. This model attempts to balance phosphorus inputs and output as a means of restricting excesses entering water bodies (Daniel et al. 1998). However, good irrigation management should also be adopted to restrict water movement and soil erosion (Daniel et al. 1998).

$$STV_P = P_{es} + P_{sorb} + P_{removed} \tag{9.35}$$

where:

STV_P = phosphorus in irrigation water (mg/L)

P_{es} = environmentally significant phosphorus concentration, i.e. algal blooms occur >0.05 mg P/L

P_{sorb} = phosphorus in irrigation water sorbed by soil (mg/L)

$P_{removed}$ = phosphorus removed from irrigation water in harvestable portion of the plant (mg/L)

For calculation of P_{sorb}:

$$P_{sorb} = \frac{\left[\dfrac{\left(\dfrac{Depth \times BD \times P_{ssc}}{100}\right) - P_{fert}}{I_w \times 10}\right]}{Years} \tag{9.36}$$

where:

P_{sorb} = total P sorbed from water by soil (mg/L)

Note: Phosphorus sorption capacity of soils could change with time through the slow irreversible absorption of phosphorus (Barrow 1974). A continual (annual) assessment of soil P sorption capacity is recommended.

Depth = soil depth (m)

BD = soil bulk density (kg/m³)

P_{ssc} = phosphorus soil sorption capacity (mg/kg) with 50 μg P/L in solution at equilibrium. Sorption capacity should be representative of the soil depth used above.

I_w = irrigation water height (m)

P_{fert} = phosphorus input from fertiliser (kg/ha)

Years = years water will be applied (i.e. 20 years assumed for STV)

Note: P_{ssc} should be calculated from a P sorption curve measured as described by Rayment and Higginson (1992, Method 9J1). An example is given below (fig 9.2.6). The P_{ssc} should be taken when the extractant P concentration is 50 μg P/L (i.e. the P_{es} value). Ideally this value should be included within the points determined by the buffer curve. From figure 9.2.6 if x = 50, y (mg P sorbed by soil/kg soil) = 57. The concentrations of 50 μg P/L in the extractant solution will generally be overprotective as this is assumed to be an estimate of the phosphorus concentration in soil solution. On leaching or surface flow this concentration may be diluted through rainfall, or diluted by entering a receiving water body with lower phosphorus concentrations. Site-specific soil sorption tests are required as soil sorption of P is dependent on soil type and can differ in orders of magnitude between soil types (Singh & Gilkes 1991, Sen Tran et al. 1988).

For example, if the soil depth was 0.15 m, the soil bulk density 1300 kg/m³, P_{ssc} calculated to be 57 mg P/kg soil, 15 kg P/ha was applied as fertiliser, this type of cropping was expected to last 20 years, and the annual irrigation water applied was 1.00 m:

$$P_{sorb} = \frac{\left[\dfrac{\left(\dfrac{0.15\times1300\times57}{100}\right)-15}{1\times10}\right]}{20}$$

$$= \quad 0.48\text{mg/L}$$

For calculation of $P_{removed}$:

$$P_{removed} = \frac{P_{harv}}{I_w \times 10} \qquad (9.37)$$

where:

$P_{removed}$	=	phosphorus removed from irrigation water through harvestable portion of the plant (mg/L)
P_{harv}	=	phosphorus removed in harvestable portion of crop (kg/ha). Calculated by multiplying the mean P concentration in the particular crop to be grown (kg/Mg; table 9.2.21) by the expected yield (Mg/ha; site-specific data)
I_w	=	irrigation water height (m)

For example, if cabbage were grown with 1.00 m of irrigation water:

$$P_{removed} = \frac{50\times0.6}{1\times10}$$

$$= \quad 3.0 \text{ mg/L}$$

Using the above assumptions, the STV from an environmental perspective would be as follows:

$$STV_P = 0.05 + 0.48 + 3.0 = 3.5 \text{ mg/L}$$

The model assumes that the non-harvested portion of crops will be returned to the soil and phosphorus in this portion contributes to the following crop's phosphorus demands.

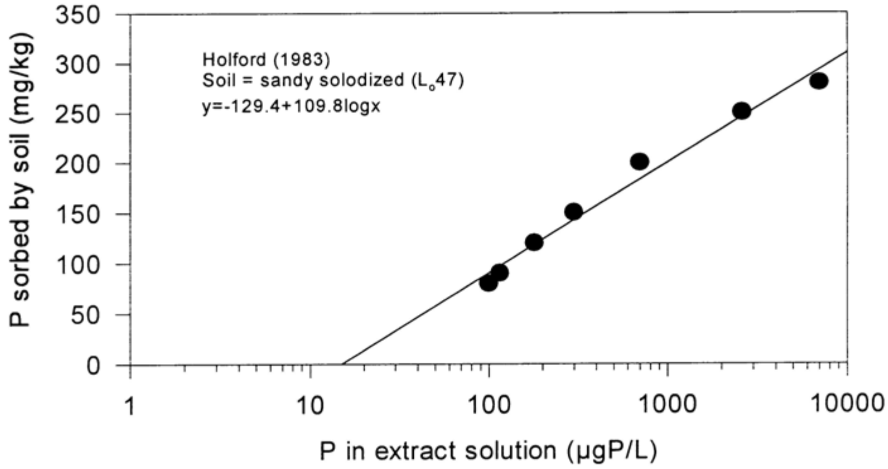

Figure 9.2.6 Soil phosphorus sorption curve (data modified from Holford 1983)

The STV range for P was calculated with the following assumptions:

Bulk density	=	1300 kg/m^3 soil, top soil depth = 0.15 m, irrigation height = 1.00 m
P_{ssc}	=	57 mg P/kg (typical more of a sandy soil and this value may be overprotective for soils with higher clay content and insufficient in other cases)
P_{fert}	=	0 kg/ha
Years of irrigation	=	20
P_{harv}	=	minimum (2 kg/ha) and maximum (116 kg/ha) P removal by crops listed in table 9.2.20 (excludes stubble crops)

Note:

1. In view of the range of values obtained for phosphorus sorption capacity and plant removal of phosphorus, it is recommended that site-specific data be assessed when assessing the STV for phosphorus.

2. Current research suggests that, in some soils, phosphorus can move overland or through some soils (preferential flow). This phosphorus will not be exposed to the soil matrix where sorption occurs. In this case, a large portion of the phosphorus sorbed (P_{sorb}) and phosphorus taken up by plants (P_{harv}) would not apply, and a more environmentally protective STV derived from the above equation would be 0.05 mg P/L. This would not be practical considering the nutritional requirements of plants for phosphorus, and current phosphorus fertilisation practices.

   It may also be appropriate to include a factor of soil texture or/and soil erodibility in to the model for determining the STV. However, there are currently insufficient data available to quantify such a factor.

Appendix 2. The Pennsylvania Phosphorus Index.

The Pennsylvania Phosphorus Index
Version 1.

USER'S NOTE

If a field has a soil test level greater than 200 ppm Mehlich-3 P
OR
is within 150 feet of a water body then continue with PART B.

PART A	Evaluation Category
Soil Test Mehlich-3 P	Greater than 200 ppm P
Contributing Distance	Less than 150 ft

PART B

SOURCE FACTORS

SOIL TEST	Soil Test P (ppm Mehlich-3 P)				
Soil Test Rating = 0.20 x Soil Test P (ppm Mehlich-3 P)					
FERTILIZER RATE	Fertilizer P (lb P_2O_5/acre)				
FERTILIZER APPLICATION METHOD	0.2 Placed or injected 2" or more deep	0.4 Incorporated in less than 1 week	0.6 Incorporated> 1 week or not incorporated April to October	0.8 Incorporated > 1 week or not incorporated Nov. to March	1.0 Surface applied during frozen or snow covered conditions
Fertilizer Rating = Rate x Method					
MANURE RATE	Manure P (lb P_2O_5/acre)				
MANURE APPLICATION METHOD	0.2 Placed or injected 2" or more deep	0.4 Incorporated in less than 1 week	0.6 Incorporated after 1 week or not incorporated April to October	0.8 Incorporated > 1 week or not incorporated Nov. to March	1.0 Surface applied during frozen or snow covered conditions
MANURE P AVAILABILITY	Refer to Table 2: Organic Phosphorus Source Availability Coefficients				
Manure Rating = Rate x Method x Availability					
Source Factor = Soil Test Rating + Fertilizer Rating + Manure Rating					

TRANSPORT FACTORS

EROSION	Soil Loss (ton/acre/year)				
RUNOFF POTENTIAL	0 Very Low	2 Low	4 Medium	6 High	8 V. High
SUB-SURFACE DRAINAGE	0 Low		1 Random		2** Patterned
CONTRIBUTING DISTANCE	0 > 500 ft.	2 500 to 350 ft.	4 350 to 250 ft.	6 150 to 250 ft.	8 < 150 ft.
Transport Sum = Erosion + Runoff Potential + Sub-Surface Drainage + Contributing Distance					
				Transport Sum / 22	
MODIFIED CONNECTIVITY	0.7 Riparian Buffer *Applies to distances < 150 ft.*		1.0 Grassed Waterway OR None	1.1 Direct Connection *Applies to distances > 150 ft.*	
Transport Factor = Modified Connectivity x (Transport Sum / 22)					
Phosphorus Index Value = 2 x Source Factor x Transport Factor					

** OR a rapid permeability soil near a stream

Table 2: Phosphorus index management guidance.

Value	Rating	Management Guidance
0 to 59	Low	**Nutrients can be applied to meet the Nitrogen crop requirement.** *Low* potential for P loss. Maintenance of current farming practices is recommended to minimize the risk of adverse impacts on surface waters
60 to 79	Medium	**Nutrients can be applied to meet the Nitrogen crop requirement.** *Medium* potential for P loss. The chance for adverse impacts on surface waters exists. An assessment of current farm nutrient management and conservation practices is recommended to minimize the risk of future P losses.
80 to 99	High	**Nutrients can be applied to meet the Phosphorus crop removal.** *High* potential for P loss and adverse impacts on surface waters. Soil and water conservation measures and P-based management plans are needed to minimize the risk of P loss.
100 or greater	Very High	**No Phosphorus can be applied.** *Very high* potential for P loss and adverse impacts on surface waters. Conservation measures and a P-based management plan must be implemented to minimize the P loss.

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vera: 11

PAR1A - SCREEINGTOOl

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PART B - SOURC:E FACTORS

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Appendix 3. Phosphorus Index components for American states (derived from Sharpley et al, 2003)

State	**Alabama (Al)**	**Alaska (Ak)**	**Arizona (Az)**	**Arkansas (Ar)**	**Colorado (Co)**
Key reference	USDA-NRCS (2001a)	USDA-NRCS (2001b)	Walther et al (2000)	DeLaune et al (2001)	Sharkoff et al (2000)
SOURCE FACTORS					
Soil P test	Mehlich-1P & local	Mehlich-3P	Bray P-1 (acid soil) Olsen-P (alkaline soil)	Mehlich-3P	Bray P-1 (acid soil) Olsen-P (alkaline soil) Mehlich-3P
Application rate	lb P2O5/ac/y	lb P2O5/ac/y	lb P2O5/ac/y	Lb soluble P/ac/y	lb P2O5/ac/y
Application method	Sprinkler, Surface applied injection, incorporation	Sprinkler, Surface applied, injection, incorporation	Surface applied injection, incorporation	Surface applied, incorporation	Surface applied injection, incorporation
Application timing	Days to incorporation	Season, cover at application	Time to planting	Season applied	Season applied, time to incorporation
Management	Animal access to surface waters	-	Grazing and feeding management	Organic P source availability, grazing intensity	Polyarcylamides, cover crops
TRANSPORT FACTORS					
Erosion	RUSLE, gully erosion	RUSLE, Wind via WEQ, irrigation	RUSLE, Wind via WEQ, irrigation (QS value)	RUSLE	-
Surface runoff class	Field slope, soil hydrologic group	Rainfall, field slope, soil hydrologic group	Field slope, soil permeability class	Field slope, rainfall, curve number	Field slope, soil permeability class
Subsurface drainage, flooding	Underground outlet systems	-	-	Flooding frequency	-
CATCHMENT					
Contributing distance	Distance to water	Existence of a discharge	-	-	-
Connectivity	Filter strip width	Buffer presence	Buffer width	-	Filter strip, Contour buffer strip
Receiving water priority	Distance to critical habitat	Value of water body	-	-	-
Index value determination	Additive risk assessment	Additive risk assessment	Additive risk assessment	Multiplicative loss assessment	Additive risk assessment

Appendix 3 continued

State	Delaware (De)	Florida (Fl)	Georgia (Ga)	Illinois (Il)	Iowa (Ia)
Key reference	Sims and Leyton (2002)	USDA-NRCS (2000a)	Cabera et al (2002)	USDA-NRCS (2002a)	USDA-NRCS (2001c)
SOURCE FACTORS					
Soil P test	Mehlich-1P	Mehlich-3P	Mehlich-1P	Bray P-1, Mehlich-3P	Bray P-1 (acid soil) Olsen-P (alkaline soil) Mehlich-3P
Application rate	lb P2O5/ac/y	Waste water volume, lb P2O5/ac/y	lb P2O5/ac/y	% of annual recommended rate	lb P2O5/ac/y
Application method	Surface applied injection, incorporation	Irrigation, surface, incorporation	Sprinkler, surface applied injection, incorporation	Surface applied injection, incorporation	Surface applied injection, incorporation
Application timing	Season, time to incorporation	Time to incorporation	Season, time to incorporation	Incorporation before or after runoff event	Season applied, time to incorporation
Management	Organic P source availability	Organic P source availability	P source solubility	-	Soil conservation practices, tillage
TRANSPORT FACTORS					
Erosion	RUSLE	RUSLE, irrigation	RUSLE, bioavailability factor	RUSLE	RUSLE, ephemeral classic gully
Surface runoff class	Field slope, soil permeability class	Field slope, soil hydrologic group, artificial drainage	Curve no., Location	Soil hydrologic group	Rainfall, Curve no.
Subsurface drainage, flooding	Drainage, water table depth, leaching rating	Leaching potential, soil properties	Percolation index, depth to water table, percolation index	Drainage into a tile drain	Tile drainage, slope, soil texture, rainfall
CATCHMENT					
Contributing distance	Distance to water	Existence of a discharge	-	Distance to water	Distance to stream
Connectivity	Vegetated buffer width	Wetlands, buffer strip, detention/ treatment	Buffer width	Discharge to waterway or surface drain	Buffer presence and width
Receiving water priority	State catchment categories	Value of water body	-	-	-
Index value determination	Multiplicative risk assessment	Multiplicative loss assessment	Additive, soluble, runoff and leachate assessment	No average phosphorus Index value. Individual risk assessment by field	Additive, erosion, runoff and sub surface drainage assessment

Appendix 3 continued

State	Kansas (Ks)	Kentucky (Ky)	Louisiana (La)	Maine (Me)	Maryland (Md)
Key reference	Davis et al (1999)	USDA-NRCS (2001d)	USDA-NRCS (2000b)	USDA-NRCS (2001e)	Coale (2000)
SOURCE FACTORS					
Soil P test	Bray P-1 (acid soil) Olsen-P (alkaline soil) Mehlich-3P	Mehlich-3P	Strong Bray P	Modified Morgan	FIV based on Mehlich-3P
Application rate	lb P2O5/ac/y	-	lb P2O5/ac/y	-	lb P2O5/ac/y
Application method	Surface applied injection, incorporation	Surface applied injection, incorporation	Surface applied injection, incorporation	-	Surface applied injection, incorporation
Application timing	Time to planting, time to incorporation	Season, Cover at application	Season applied, time to incorporation	-	Season applied, time to incorporation
Management	-	-	Weighting factors for organic P sources	Adequate land base to handle the quantity of manure	Organic P source availability
TRANSPORT FACTORS					
Erosion	RUSLE, sprinkler, furrow irrigation	Land cover %	RUSLE,	Highly erodible land designation	RUSLE,
Surface runoff class	Field slope, soil permeability class	Field slope, soil hydrologic group	Field slope, soil permeability class	-	Field slope, soil permeability class
Subsurface drainage, flooding	-	-	Depth to water table, soil drainage class, artificial drainage	-	Depth to water table, soil drainage class
CATCHMENT					
Contributing distance	Distance to stream	Distance from application to surface water	Edge of field distance to surface water	-	Edge of field distance to surface water
Connectivity	Connected to stream	Vegetated buffer width	Vegetated buffer width	-	Vegetated buffer width
Receiving water priority	-	Impaired catchment, County location	Ranked v. high to v. low	State Environmental Protection Classification	Maryland Clean Water Action Plan classification
Index value determination	Multiplicative risk assessment	Additive risk assessment	Multiplicative risk assessment	Manure Priority Matrix, Field decision tool	Multiplicative risk assessment

Appendix 3 continued

State	**Michigan (Mi)**	**Minnesota (Mn)**	**Mississippi (Ms)**	**Montana (Mt)**	**Nebraska (Ne)**
Key reference	Grigar et al (2002)	USDA-NRCS (2001f)	USDA-NRCS (2000c)	Fasching (2001)	Kucera (2000)
SOURCE FACTORS					
Soil P test	Bray P-1	Bray P-1 (acid soil) Olsen-P (alkaline soil)	Ms soil test	Bray P-1 (acid soil) Olsen-P (alkaline soil)	Bray P-1 (acid soil) Olsen-P (alkaline soil)
Application rate	lb Manure/ac/y	-	lb P2O5/ac/y	lb P2O5/ac/y	lb P2O5/ac/y
Application method	Surface applied injection, incorporation	-	Surface applied injection, incorporation	Surface applied injection, incorporation	Surface applied injection, incorporation
Application timing	Time to incorporation	-	Time to planting, time to incorporation	Time to planting	Time to planting
Management	Manure/ac/y N leach index, soil management group	-	-	-	Soil conservation BMPs
TRANSPORT FACTORS					
Erosion	Residue at planting	RUSLE	RUSLE	RUSLE, Furrow irrigation, sprinkler irrigation	RUSLE, Furrow irrigation, sprinkler irrigation
Surface runoff class	Field slope, soil hydrologic group	-	Field slope, soil permeability class	Field slope, soil permeability class	Field slope, soil permeability class
Subsurface drainage, flooding	-	-	-	-	-
CATCHMENT					
Contributing distance	Presence of surface water	Distance to surface water	Distance to water	Distance to concentrated surface flow	Distance to concentrated surface flow
Connectivity	Vegetated buffer width, application setbacks	Presence of a 30m filter strip	-	Presence of grassed waterway	Presence of grassed waterway
Receiving water priority	-	-	-	-	-
Index value determination	Additive risk assessment	Field decision matrix with no phosphorus Index value	Multiplicative risk assessment	Additive risk assessment	Additive risk assessment

Appendix 3 continued

State	**New Hampshire (NH)**	**New Jersey (NJ)**	**New Mexico (NM)**	**New York (NY)**	**North Carolina (NC)**
Key reference	USDA-NRCS (2001g)	USDA-NRCS (2001h)	Flynn et al (2000)	Czymmek et al	Havlin et al (2002)
			SOURCE FACTORS		
Soil P test	Mehlich-3P	Mehlich-3P	Bray P-1 (acid soil) Olsen-P (alkaline soil)	Morgan	Mehlich-3P
Application rate	lb P2O5/ac/y	-	lb P2O5/ac/y	lb P2O5/ac/y	lb P2O5/ac/y
Application method	Surface applied injection, incorporation	Surface applied injection, incorporation	Surface applied injection, incorporation	Surface applied injection, incorporation	Surface applied
Application timing	Season applied	Time to planting	Time to planting	Season applied, time to incorporation	-
Management	Mehlich-3P Calcium, soil pH	-	Grazing and feed management	-	Soil management group
			TRANSPORT FACTORS		
Erosion	RUSLE	RUSLE	Furrow irrigation	RUSLE	RUSLE, Fe-P soil fraction, field slope
Surface runoff class	Field slope, soil permeability	Field slope, curve number	Field slope, soil permeability class	Presence of concentrated flow	Estimated runoff (mm/y)
Subsurface drainage, flooding	Flooding frequency	-	-	Soil drainage class, flooding frequency	Estimated subsurface flow (mm/y), impact of artificial drainage
			CATCHMENT		
Contributing distance	-	Edge of field distance to surface water	Edge of field distance to stream or lake	Flow distance to a blue line stream	-
Connectivity	Buffer width	-	Vegetated buffer width	-	Buffer width, sediment retention practices
Receiving water priority	-	-	-	-	-
Index value determination	Multiplicative risk assessment	Additive risk assessment	Additive risk assessment	Particulate and dissolved P risk assessments	Particulate, soluble, leachate and source risk assessment

Appendix 3 continued

State	North Dakota (ND)	Ohio (Oh)	Oklahoma (Ok)	Oregon (Or)	Pennsylvania (Pa)
Key reference	USDA-NRCS (2002b)	USDA-NRCS (2002c)	USDA-NRCS (2001i)	USDA-NRCS (2001j)	Weld (2001k)
SOURCE FACTORS					
Soil P test	Bray P-1 (acid soil) Olsen-P (alkaline soil) Mehlich-P3	Bray P-1	Mehlich-P3	Bray P-1 wet areas) Olsen-P (dry areas)	Mehlich-P3
Application rate	lb P2O5/ac/y	lb P2O5/ac/y	-	lb P2O5/ac/y	lb P2O5/ac/y
Application method	Surface applied injection, incorporation	Surface applied, incorporation	Surface applied injection, incorporation	Surface applied injection, incorporation	Surface applied injection, incorporation
Application timing	Time to incorporation, season of application	Plant cover, time to incorporation	Time to incorporation	Season of application	Time to incorporation
Management	Filter strip, buffer strip, , no till, contour	-	-	-	Organic P source availability
TRANSPORT FACTORS					
Erosion	RUSLE, irrigation	RUSLE	RUSLE, soil surface loss potential	RUSLE, Furrow irrigation, sprinkler irrigation, wind	RUSLE
Surface runoff class	Field slope, soil hydrologic group	Field slope, soil hydrologic group	Field slope, soil depth, rock size and cover	Field slope, soil permeability class	Field slope, soil permeability class
Subsurface drainage, flooding	-	-	Flooding frequency	Tile drainage, soil P test, flood frequency class	Tile drainage
CATCHMENT					
Contributing distance	Application site to entry to a channel	Adjacent to a stream	Distance to pond, well, sinkhole, intermittent or permanent stream	Field edge to surface water	Field edge to surface water
Connectivity	-	Presence of a >10 m filter strip. Concentrated surface flow to channel	Established buffer strip	Buffer width and presence	Riparian buffer, direct discharge
Receiving water priority	-	-	Nutrient limited catchment	-	-
Index value determination	Additive risk assessment	Additive risk assessment	Risk assessment	Additive risk assessment	Multiplicative risk assessment.

Appendix 3 continued

State	Rhode Island (RI)	South Carolina (SC)	Tennessee (TN)	Texas (Tx)	Utah (Ut)
Key reference	USDA-NRCS (2001k)	USDA-NRCS (2001l)	USDA-NRCS (2001m)	USDA-NRCS (2000d)	Goodrich et al (2000)
SOURCE FACTORS					
Soil P test	Morgan	Mehlich-P1	Mehlich-P1	Bray P-1, Bray P-2, Mehlich-P3, Olsen-P, TAMU	-
Application rate	lb P2O5/ac/y	lb P2O5/ac/y	lb P2O5/ac/y	lb P2O5/ac/y	-
Application method	Surface applied, incorporation	Surface applied injection, incorporation	Surface applied injection, incorporation	Surface applied injection, incorporation	Surface applied injection, incorporation
Application timing	Time to incorporation,	Time to planting, time to rainfall /irrigation	Season of application, cover at application, time to incorporation	Season of application, time to incorporation	Time to incorporation
Management	Residue	-	Weighted according to P source,	-	Irrigation efficiency
TRANSPORT FACTORS					
Erosion	RUSLE	RUSLE	Erosion potential	RUSLE	Cover type, irrigation type, field surface, seasonal rainfall
Surface runoff class	Field slope, presence of runoff	Field slope, curve number	Soil hydrologic group	Field slope, soil curve number	Field slope, soil hydrologic group
Subsurface drainage, flooding	Drainage class, flooding class	Subsoil permeability, depth to water table	-	-	Water holding capacity, depth to water table, bedrock or coarse sand
CATCHMENT					
Contributing distance	Field edge to surface water	Field edge to surface water	Field edge to surface water conveyance	Field edge to named stream or lake	Field edge to downslope surface water
Connectivity	Buffer, potential for direct discharge	Buffer zone runoff class	Permanent vegetated buffer width	-	Runoff containment and discharge
Receiving water priority	-	-	-	-	-
Index value determination	Additive risk assessment	Multiplicative risk assessment	Multiplicative risk assessment	Additive risk assessment	Winter, Spring/summer/ autumn risk assessment

Appendix 3 continued

State	Vermont (Vt)	Virginia (Va)	Washington (Wa)	West Virginia (WV)	Wisconsin (Wi)	Wyoming (Wy)
Key reference	Jokela (2001)	Mullins et al (2002)	USDA-NRCS (2001n)	USDA-NRCS (2002d)	Jarrell and Bundy (2002)	USDA-NRCS (2002e)
SOURCE FACTORS						
Soil P test	Morgan	Mehlich-P1	Bray P-1 (wet), Olsen-P (dry)	Mehlich-P1	Bray P-1	Bray P-1 (acid), Olsen-P (alkaline)
Application rate	lb P2O5/ac/y	lb P2O5/ac/y	lb P2O5/ac/y	lb P2O5/ac/y	lb soluble P/ac/y	lb P2O5/ac/y
Application method	Surface applied injection, incorporation	Surface applied injection, incorporation	Surface applied injection, incorporation	Surface applied injection, incorporation	Incorporation	Surface applied injection, incorporation
Application timing	Time to incorporation, season applied	Time to incorporation	Season of application	Time to planting	Season of application	Time to planting
Management	Soil P test, reactive Al	Availability factor for P source	-	-	-	P sorption capacity based on soil texture and pH
TRANSPORT FACTORS						
Erosion	RUSLE	RUSLE	RUSLE, irrigation type, wind	RUSLE	RUSLE, enrichment ratio	RUSLE, irrigation efficiency, irrigation type
Surface runoff class	Field slope, Hydraulic conductivity	Location, crop, hydrologic soil group, curve no., runoff/y	Slope, soil hydrologic group	Runoff mm/y	Runoff mm/y, soil solution P	Field slope, soil permeability class
Subsurface drainage, flooding	Flood frequency	Location, crop, hydrologic soil group, average percolation mm/y, drainage class, soil texture	Tile drain, soil P test, flood frequency	-	Soil retention properties, depth to water table	-
CATCHMENT						
Contributing distance	-	Field edge to perennial or intermittent stream	Field edge to surface water	-	-	Field edge to surface water
Connectivity	Buffer width	Buffer width	Buffer presence and width	-	Buffer width	-

State	Vermont (Vt)	Virginia (Va)	Washington (Wa)	West Virginia (WV)	Wisconsin (Wi)	Wyoming (Wy)
Receiving water priority	-	-	-	-	-	
Index value determination	Multiplicative risk assessment	Particulate and dissolved P risk assessments	Additive risk assessment	Additive risk assessment	Soluble, leaching and particulate risk assessment	Additive risk assessment