Technical Note: T16-1

CALCULATIONS FOR PHOSPHORUS MANAGEMENT IN WASTEWATER:

Examples for consultants and regulators

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1. Introduction

Phosphorus (as phosphate PO_4^{3-}) is present in domestic wastewater (50% orthophosphate, 40% polyphosphate; 10% organic phosphates) and most passes through treatment systems such as septic tanks and aerated treatment systems (AWTS) in the effluent (discharge) without any significant lowering of the concentration. A minor component (<10%) may be removed with solids in the sludge and/or scum. The reduction in risk of off-site effects from the phosphorus (P) is to contain all the P within the soil treatment area and its buffer. Risk management needs to involve spreading the P (in the effluent) over a sufficiently broad area to account for plant requirements (P is an essential macro-nutrient) and immobilisation in the soil, known as measured P sorption capacity.

Annually, plants generally require about 30 kg P/ha (all plants - natives and exotics, grasses and weeds alike at varying rates), which equates to 3 g/m^2. This value will be discussed later.

Soil P adsorption (also called P sorption) is a unique property of the soil related to its clay mineralogy, the aluminium, iron, manganese and/or calcium, soil pH and other properties. At low pH, aluminium, iron and manganese are in ionic form and can bond strongly with the phosphate. Soil P sorption is measured in the laboratory by equilibrating soil samples with solutions of varying concentrations of phosphate and measuring the residual in the solution - that portion not adsorbed onto the soil minerals. The effects of P sorption can occur rapidly (hours to a few days) of effluent entering the soil and the reverse (desorption) is a very slow processed (years to decades), so plants have difficulty accessing the P sorbed onto the minerals/clays.

2. Questions and Calculations

Assume that the wastewater from a domestic dwelling passes through a septic tank (or AWTS) at the rate of 500 L/day.

A typical domestic effluent has a P concentration of about 10 mg/L.
(A) What area is required to contain the P for the next 50 years?
(B) Is an area of 150 m^2 (calculated for the hydraulic load) large enough to adsorb P for next 50 years?
(C) On an area of 150 m^2 for how many years will the soil adsorb the current application?

Inputs: Daily water load = 500 L (4 persons at 120 L/day – rounded to 500 L)
P concentration = 10 mg/L
Soil bulk density = 1400 kg/m^3 (either from measurement or estimate)
Soil depth = 1.0 m
Plant requirement = 30 kg/ha
Soil P sorption = 4000 kg/ha (measured or known from other sources)

Calculations:

Question A: What area is required to contain the P for the next 50 years?

A1. Annual load (kg)

$$= \frac{\text{daily load (L) x P concentration (mg/L) x 365 days}}{\text{1 000 000 (convert mg to kg)}}$$

$$= \frac{500 \times 10 \times 365}{1\,000\,000}$$

= 1.825 kg per year

(NOTE: THIS SOURCE OF THIS ANNUAL LOADING WILL BE CHALLENGED LATER)

A2. Calculate plant uptake and soil adsorption for 50 years
Plant uptake for 50 years = 30 kg/ha x 50 years
= 1500 kg/ha
Soil P adsorption for 50 years = 4000 kg/ha (measured)
Total P capacity for 50 years = 1500 (plant) + 4000 (soil)
= 5500 kg/ha

A3. Calculate area required for 50 years' life in land application area
50-year application P = 1.825 kg/year x 50 years
= 91.25 kg

Area required

$$= \frac{\text{Total load for 50 years (kg)}}{\text{P capacity for 50 years (kg/ha)}}$$

$$= \frac{\text{91.25 kg}}{\text{5500 kg/ha}}$$

= 0.0166 ha
= 166 m^2 (1 ha = 10 000 m^2)

Question B. An area of 150 m^2 was designed for the hydraulic load from a water balance. Is this area sufficient to accept P over 50-year life to application area?

B1. Calculate the annual uptake of P by both plants and soil.

Annual plant uptake P = 30 kg/ha
Annual soil P sorption uptake = 4000 kg/ha divided by 50 years
= 80 kg/ha
Total annual P capacity = (30 + 80) kg/ha
= 110 kg/ha
Total capacity for 150 m^2 = 110 kg/ha x 0.0150 ha
= 1.65 kg per annum

B2. Is the 150 m^2 large enough to sustain this annual load?

Annual load = 1.825 kg (Calculated in A1)
Annual capacity = 1.65 kg (Calculated in B1)
Area required = $\frac{\text{Annual load (kg)}}{\text{Annual capacity (kg)}}$
= $\frac{1.825}{1.65}$
= 1.106

Since this value is larger than 1, area of 150 m^2 is TOO small by 10%.
Ideal area from this calculation = 150 m^2 x 1.1 = 165 m^2

Question C: On an area of 150 m^2, for how many years will the plants and soil adsorb the current P application?

C1 Current annual application rate = 1.825 kg (From A1)
Annual plant requirement = 3 g/m^2 (equivalent 30 kg P/ha)
= $\frac{150\ \text{m}^2 \text{ x } 3\ \text{g/m}^2}{1000\ \text{(g in kg)}}$
= 0.45 kg/m^2
Excess plant P annually = 1.825 - 0.45 kg
= 1.375 kg (Required soil P sorption)
Potential capacity (years) = soil P capacity (kg/ha) x area (ha)
= 4000 kg/ha x 0.0150 ha
= 60 kg over land application area
Life of land application area = $\frac{\text{P capacity (kg)}}{\text{Annual excess (kg)}}$
= $\frac{60}{1.375}$
= 43.6 years

For many systems, 43.5 years will be close enough to 50 years to be acceptable. Why 50 years? No idea!

CAUTION: While the above calculations of daily water use and typical P concentration may be welcomed by regulators as providing a clear arithmetic solution to deducting a sustainable land application area for domestic wastewater, there is a real problem that disadvantages non-conservative water users. Why are calculations made on concentration at all, when LOAD is the limiting measure? Load (mass) = concentration x volume.

3. Concentration versus Load – which is correct?

The calculations above have been performed on the typical concentration of P (10 mg P/L) in domestic wastewater from numerous sources. The annual load is, therefore, the concentration multiplied by the volume and 365 days. The uncertainty of load arises because the amount of P discharged into the wastewater through the diet, kitchen wastes and laundry detergents, can vary significantly from one home to another. By using concentration, one assumes that P load increases with water use, when it is independent of water use. Rather, consumption of P depends upon the number of persons in the home and how much P they consume/use. For greater accuracy, the load calculations need to be done on a 'per person' or 'per household' basis and not on wastewater generation rate.

If we were to take the above calculations in A1 and use 600 L/day (reticulated water supply compared with rain water supply) for a different household, then the annual P load is 2.19 kg. From where did the extra 0.365 kg P come? Same household size (4 persons), assume typically same diet, same everything except the household uses more water. But the 20% increase in P cannot be explained. Why? Because working on concentration to determine nutrient assimilation rates is seriously flawed. Therefore, choose a different annual load for A1 above.

A range of P generation rates is shown below for several countries, but the range is significant because the data have been sourced from municipal sewage treatment rather than on-site system. Monitoring on-site systems is difficult because there are very little data on actual daily water use correlated with actual daily wastewater P analysis. The only analyses available are broad averages without necessarily monitoring household use of phosphate rich products. It would not be unusual for there to be a greater through-flow of P in the wastewater on days when the laundry was done using phosphate rich detergents, or to be less when the laundry was done with phosphate free detergents.

Per person P rate = 1.8 g P/capita.day (Alexander & Stevens 1976 – USA old data)
Per person P rate = 1.9 g P/capita.day (Gilmour *et al.*, 2008 – municipal samples Scotland)
4 person household = 2.8 kg P/year
Per person toilet waste = 1.6 kg P/yr (USEPA 2002 – older USA data)
4 person household = 6.4 kg P/yr
Average per dwelling rate = 2 kg P/yr (Environment Canterbury, 2012 – recent NZ data)

The data by Alexander & Stevens (1976) are likely to reflect laundry products with very high P concentration, as was the practice then. Over the last two decades there has been a significant decrease in the P in household laundry detergents (www.lanfaxlabs.com.au/laundry.htm) and more than half the powder and liquid laundry products in the supermarket, in 2016, have no added P (marked NP) or are very low in P (marked P). Where these ‘NP’ laundry products are used, the only contribution to the daily P load is from the diet (kitchen and toilet) and a very small contribution from bathroom in personal care products. The NSW Guidelines (1998) were written in the era when phosphate was the surfactant of choice, a thoroughly efficient surfactant, but a limit to sustainable effluent areas.

Because of the shared laundry products, by detergent manufacturers in Australia and New Zealand, the Environment Canterbury (2012) rate is likely to reflect similar New Zealand and Australian loading rates for P. When the previous significant contribution from the laundry is factored into the calculation, that value is a reasonable estimate for a P conservative household. With current labelling of laundry detergents, any household can easily minimise the P use by selecting ‘NP’ or ‘P’ products, such that the only contribution to P in the wastewater is from human excreta (faeces and urine) and a very small contribution from the kitchen.

4. Unsupported assumptions about life of land application area

The NSW *Environment and Health Protection Guidelines On-site Sewage Management for Single Households* (DLG *et al.*, 1998) suggest 50 years as a design life for the P sorption of the effluent application area (pages 73 & 116) Further, they state that *soil absorption systems can have an expected life of 5 to 15 years* (page 82) and *septic tanks can have an expected life of 25 years.* These statements are not supported by facts and may simply be the authors’ assumptions, because they are unqualified by operational and maintenance issues and ignore site specific soil properties that may benefit from on-site effluent discharges.

The Guidelines suggest buffer distances of 3 m upslope and 6 m downslope for primary treated effluent (Table 5, page 66), which in many instances more than doubles the effective nutrient assimilation area around a series of trenches. For example, three parallel 25 m trenches, each separated by 3 m occupy an area of 200 m^2. When buffers of 3 m upslope and 6 m downslope are included, the combined treatment and buffer area is 630 m^2. It is on the 630 m^2 that the containment (assimilation) of nutrients needs to be managed, not just the area in and between trenches.

Further, there are no data or reference to literature to support the statement that *P sorption by the soil is expected to occur up to about a quarter to half of the P sorption capacity* (DLG *et al.*, 1998, pp 73, 113, 153). The only likely source of the discount factor is possibly in Kruger *et al.* (1995) relating to the use of high strength piggery effluent where ‘critical P sorption’ becomes important because of the strength of the piggery wastewater and its other constituents. That discount factor may have been picked up by the Guidelines and DEC (2004) without explanation as to the significance to low strength wastewaters as domestic wastewater. At such high application rates of P (70 mg P/L) in piggery effluent, as described by Dorahy *et al.* (2004), with other contributions from organics (BOD_5 900 mg/L), total nitrogen (600 mg N/L), potassium (270 mg K/L), sodium (130 mg Na/L) and EC (5.3 dS/m), the effluent is likely to cause ionic competition and desorption (loss of P from the adsorption sites) together with extremely high organic concentrations and other contributions from salinity. Comparison of the effects of piggery effluent, at 87 kg P/ha.yr, to domestic wastewater, at 30 kg P/ha.yr, is like ‘chalk and cheese’. Holford *et al.* (1997) stated that it is possible that soil will not sorb P to its full capacity before allowing it to leach beyond the sampled depth, and P may begin to leach well before the soil it saturated. The more P is added to the soil, the more P will remain in solution and any P in solution is vulnerable to leaching. They go on to say that unfortunately, little if any field research has been done to predict the degree of P saturation required before leaching will begin. Thus, the discount factor in the Guidelines is ill-informed.

Why are the regulators so keen on minimising P sorption of the land application area for domestic effluent simply by assuming a discount factor without understanding the specific implications for on-site effluent disposal for specific soil properties? One-size does not fit all because of specific soil properties that influence P sorption.

When the P sorption capacity is routinely measured in the laboratory on a soil sample taken from the proposed effluent application area, discounting that value is mere speculation as the specific test takes account of potential desorption through the increases in equilibrating solution P concentration. The laboratory analysis takes account of soil properties such as pH, iron, manganese and/or aluminium, calcium, organic carbon and clay type in determining the adsorption rate. Organic matter can compete with phosphates for adsorption sites resulting in surface A horizon generally having a lower P sorption than the mineral B horizon. But a blanket discount of measured P sorption cannot be justified, even on the basis of ultra-conservative issues.

The Guidelines statement, suggesting discounting, ignores precipitation of phosphate soon after the effluent meets the soil in the land application area or drainfield. Together with P sorption mechanisms, P can be effectively immobilised with a significantly low risk of leaching from the land application area. When the assimilation area, as the example above suggests, is taken into account, the land application area (including buffers) is significantly oversized.

Acid soils have an abundance of iron (Fe^{3+}) and aluminium (Al^{3+}) ions that very strongly adsorb P. Saturated soils may have significant manganese nodules that have high affinity for P sorption. The *Guidelines* regard soils with pH 4.5 to 6 (Table 6) as having a 'moderate limitation', yet one of the requirements of the land application area is to immobilise P, but expect soils with a pH >6 to have a high P sorption (>6000 kg/ha) to both have 'minor limitations'. Without any priority ranking of the soil features, there seems to be a problem with the Guidelines authors' understanding of P sorption as more or less important than the other parameters. For Councils to simply take the discounting as mandatory (it is a guideline only), it would be preferable that they understand the specific soil test parameters. A blanket discount of measured P sorption cannot be justified, even on the basis of ultra-conservative issues.

5. Measurement of phosphorus sorption capacity

P can be present in the soil in three forms: solution where the P is readily available to plants; labile P, more plentiful than solution P, that is not strongly adsorbed to the soil and may move into solution quickly; and non-labile P in adsorbed forms that is unavailable to plants. It is the non-labile P, the largest fraction of soil total P that is of interest in maximising the retention of P in the land application area and so prevent its loss to the wider environment.

Phosphorus sorption isotherms relate mathematically the amount of P sorbed by soil to the concentration remaining in corresponding equilibrating solutions under a specified set of conditions (Rayment & Lyons, 2011). For agricultural purposes, the agronomist needs to know how to maintain a workable level of plant available P in the soil to avoid P deficiency in the pasture or crop.

The phosphorus soption isotherm, as set out in Rayment & Lyons (2011) Method 9I1 provides a phosphate sorption index, reported as an index without units. Method 9I2 describes a P buffer index (PBI) that includes extractable P and P sorption for equivalent soil content of 20-160 mg P/kg in five increments. Method 9J leads to the construction of a phosphate sorption curve using equilibrating solutions yielding 2.5-250 mg P/kg. These methods provide valuable insight into the requirements of plant available P and fertiliser strategies but are poorly related to soil retention of P. Allen *et al*., (2001), indicated three other single point indices, plus variations, for deriving P sorption for fertiliser application, yet found these methods underestimated the total amount of P sorbed. The work by them was not suitable for adsorption rates for wastewater disposal. Holford ((1979) stated that in his research on 30 Australian soils, 'there was no correlation at all between any of the buffering indices and phosphate uptake on these soils. His results suggest that a 4 to 5 point isotherm, giving final solution concentrations up to and including 5 mg P/L, is adequate to determine the most useful buffering indices'. This concentration is well below domestic wastewater (10 mg P/L) and shows how the indices are related to plant available P rather than immobilisation of P for environmental protection.

In a wastewater treatment system, the desired outcome is to understand the capacity of the soil to bind P to prevent its movement out of the land application area, not the minimum concentration to support vigorous plant production. The two purposes are at opposite ends of the soil P sorption spectrum. Thus, the equilibrating solutions, used to determine a numerical value for the P sorption of a soil from effluent, are higher than used for agriculture (Patterson, 2001), and equilibrating solutions up to an equivalent of 1500 mg P/kg are required, six-fold higher than the Methods referenced above.

The Guidelines state that "a simple test to distinguish soils on the basis of high and low P retention is described in Rayment & Higginson (1992)", a book superseded by Rayment and Lyons (2011). The problem with this statement is that it is unclear as to whether the reference is to Method 9I1, 9I2 or 9J. Just knowing whether the value is high or low is insufficient, since later in the Guidelines (page 113) and Table 6 specific guidance values for minor, moderate and major limitations are given. Method 9I uses only one solution to give the phosphate buffer index, originally used for wheat-growing soils – that is, sufficient P in solution to sustain a wheat crop. Method 9J is used to derive an equilibrium P concentration, not the ultimate potential for P sorption. Do the regulators know which one applies? If so, it would be convenient for the laboratories and consultants to have some direction so as not to waste valuable resources on tests that have no meaningful value. But the regulators may not know which test, or amended test is applicable.

DEC (2004) also simply refers to P sorption as high, moderate and low for slight, moderate and severe limitations respectively (Table 2.2) without any definitive numerical value in sorption as kg P/ha. The document makes no reference to a suitable P sorption test method, so across a number of consultants, a range of uncorrelated values may be submitted to rank as meaningless low, moderate or high. How can you calculate an area without numerical P sorption values?

Patterson (2001) defined a modified P sorption index for domestic wastewater using five equilibrating solutions, a soil to solution ratio of 1:10 and a 17-hour equilibration period. The residual P in solution, that which has not been adsorbed by the soil, is measured and used to calculate the P sorption capacity. This method is similar to Methods 9I and 9J in Rayment & Lyons (2011), except the equilibrating solutions are many times higher. Figure 1 shows a typical low level P sorption capacity and Figure 2 a high P sorption capacity. The closer the measured curve to the straight line of the standards, the higher the potential P sorption. Rayment & Lyons (2011) suggest that the steeper the slope, the lower the plant available P in the soil. Higher P sorption characteristics are often measured in soils high in iron or aluminium. Blast furnace slag can be added to increase the P sorption in a low P sorption soil. Other high P sorbing products/soils can be sourced to add to the land application area, or incorporate in the trenches.

The MEDLI Model (Model for Effluent Disposal using Land Irrigation) (DSITI, 2015) uses the multi-point form of the Freundlich isotherm to describe the equilibrium between adsorbed and soil solution P. MEDLI version 2 is for "designing and analysing effluent disposal systems for rural industries, agri-industrial processors (e.g. abattoirs) and sewage treatment plants using land irrigation". In a similar approach to Figures 1-4, the user must provide numerical values as input to the modelling of plant available P in the soil solution and P adsorption. The P sorption curve is derived using six or more equilibrating solutions, together with measuring extractable P to give the Y-axis starting point. Burkitt *et al.*, (2008) dispute the addition of the exchangeable P to the soil buffering measures. While MEDLI is used extensively in Queensland for domestic wastewater assessments, possibly for dubious reasons, the model parameters are only specific for kikuyu and tropical pasture, ryegrass and temperate pasture and sorghum pasture, with no suggested inputs for lawns and small domestic irrigation areas. A significant data set is required to run MEDLI, a costly exercise for domestic systems.

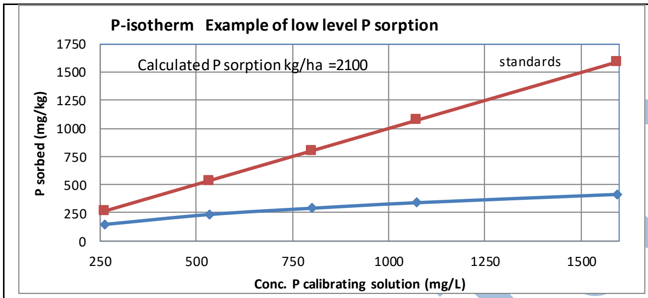

Figure 1 Low level P sorption

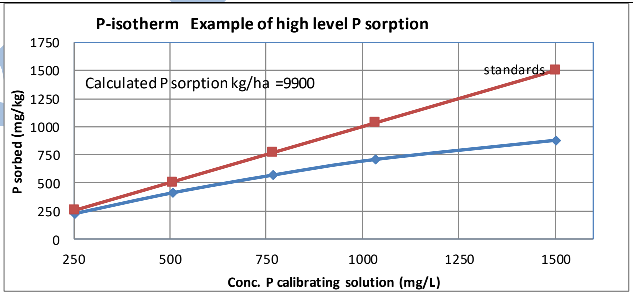

Figure 2 High level P sorption

Note: the calculated P sorption capacities, in Figures 1-4, are for an equivalent depth of soil of 1 m, for an assumed bulk density of 1400 kg/m^3. It will be necessary to alter the P sorption capacity for shallower or deeper soils.

While P sorption can occur in a period of a few hours or days, desorption (the loss of soluble P from the adsorbed site) is a lengthy process that requires specific soil conditions and whether iron, aluminium or calcium ions are involved. The testing with elevated P concentrations accounts for a desorption that may have occurred during the testing, particularly that due to the high strength equilibrating solution.

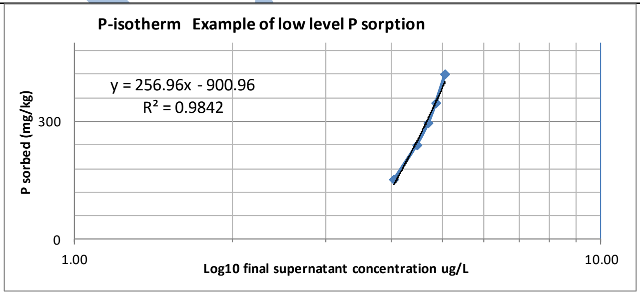

Figure 3 Psorbed (mg P/kg) against log C (ug P/L)

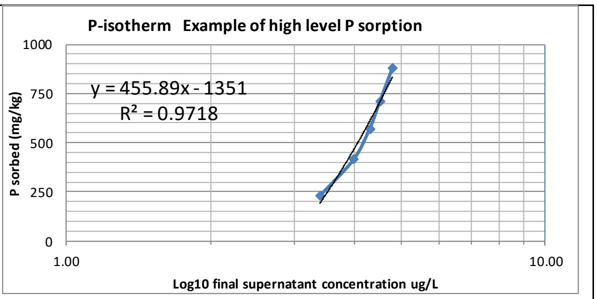

Figure 4 Psorbed (mg P/kg) against log C (ug P/L)

In Figures 3 and 4, the curve is extrapolated to the X-axis to determine the critical P concentration for agricultural purposes (soil solution P for adequate plant growth). The phosphate buffer index is taken as the slope of the line.

6. P in wastewater

P, as the anion phosphate (PO_4^{3-}), exists in several forms in wastewater.

Inorganic phosphate from laundry detergents and household cleaning products: Orthophosphate, sometimes referred to as *soluble reactive P* (SRP); and the polyphosphates made up of chains of phosphates such as pyrophosphate and tri-polyphosphate (TPP). These polyphosphates are unstable in water and break down into orthophosphate. This contribution is about 85% of the household's wastewater flow.

Organic phosphate sourced from human excreta (faeces and urine) and food wastes (kitchen sink).

Nearly all (80-100%) the phosphates in domestic raw wastewater are present in the effluent from septic tanks (Crites and Tchobanoglous 1998). The same applies to aerated wastewater treatment systems (AWTS) unless there is an active means of removing P, which in most cases, there is not.

When plant removal, precipitation and P sorption are taken into account, it is possible to design a land application area that can minimise the risk of transport of P outside the buffers to the area. The most likely cause of P moving off-site is through hydraulic failure and surfacing of effluent from trenches, or failed irrigation systems connected to AWTS. Erosion of surface soils removes soil particles to which P is adsorbed as well as the P in organic matter.

Because orthophosphate is an ion (an anion to be correct), it is free to move with the percolating effluent through all the soil pores – macropores and micropores. As the water carrying the ions passes P sorbing properties, the phosphate ion is attracted and rapidly immobilised (adsorbed). Thus, all of the wetted zone from the effluent has the potential to immobilise the phosphate, not just the zone around roots or macropores, but throughout the soil profile.

7. Uptake of phosphorus by plants

How much P a plant will uptake from the soil is related to the type of plant, its vigour and the availability of P in the soil and other growing conditions such as plant available water (PAW), balance of other nutrients (N, K, S, Ca), as well as temperature and sunlight. Moody (2011) suggests that biologically available P consists of dissolved reactive P (DRP) as dissolved and colloidal organic and inorganic P, and bioavailable particulate P (BPP) as that which is immediately available to microorganisms. The methods used to determine these fractions are not in routine use in Australia even though these fractions are important to agriculture and environmental risk analysis. While single point P sorption index is applicable to growing crops it does not quantify the immobilisation of P in wastewater management.

In Section 1, the uptake used for modelling purposes was 30 kg P/ha, a value commonly attributed to grasses growing under favourable conditions, that is, no limiting P concentration in the soil water, adequate nitrogen, adequate plant available water and favourable weather. Since the effluent application area is not usually water limited, and has a mixture of nitrogen, P, potassium and sulphur (although imbalanced), the growth of plants is more akin to irrigated agriculture. Perhaps the need to mow the effluent application area more often than non-effluent areas is a practical expression of the greater plant production expected.

The NSW Guidelines (p.153) suggest 2-4 mg P/m^2.day is the rate of plant uptake of P, equating to 4.3 – 14.6 kg P/ha, in the effluent application area. AS/NZS 1547:2012 does not provide any guidance on plant uptake of P, as if it is not a limiting factor to land application area assessment. DEC (2004) Table 4.2 (p. 42) tabulates the P removed in effluent irrigated kikuyu and perennial rye as 60 kg and 48 kg P/ha respectively, about 0.3-0.4% of dry matter. No data are available for a typical domestic effluent irrigation area, but both grasses are used in domestic lawn mixtures. The significant difference between the NSW Guidelines and DEC (2004) is not readily explained.

The most important consideration is that the effluent disposal area (surface or sub-surface) is an irrigated pasture, not a rain-fed pasture, so comparisons of P loading rates with other effluent re-use projects is more reliable as to the performance of the land application area. Comparing the domestic irrigation with commercial piggery wastewater is not a reasonable road to take. The second important aspect is that P is an essential plant macro-nutrient and where water and other nutrients are not limited, greater vegetation mass will be produced. That's why the production of vegetation with effluent will produce more grass than rain-fed areas, and uptake more P and other nutrients. Removing those cut grasses harvests the P for use in other areas, such as composting for garden use.

Sergeant (2009) indicated that for the establishment of perennial pasture, an initial application rate of 20-30 kg P/ha was required at establishment and thereafter on an annual basis. The effluent application area needs to be considered a perennial pasture, with mowing replacing hungry mouths.

To reverse-engineer the size of the effluent irrigation area, using the 0.3-0.4% P in grasses/pasture/lawns, then to remove the calculated P load in Calculation A1 (1.825 kg P), one has to remove 608 kg dried grass per year. When effluent re-use data show 20 t/ha grass production (APL 2010, Table 14.4), then 304 m^2 of irrigation area is required, without accounting for any P sorption. When only the difference between half of the P sorption (2000 kg P/ha) is taken into account in Calculation A3, then 260 m^2 of irrigation area is required to produce 520 kg grass. The question to ask is whether the effluent irrigation area can produce that mass of grass.

8. Improving soil phosphorus sorption capacity

When the soil in a land application area, whether for surface irrigation or sub-soil drainfields, has a low P sorption capacity a large area is required for assimilation of that P to minimise risk of loss off site. If the calculations in A2 and A3 were applied to Figures 1 and 2, then the required land application areas would be 253 m^2 and 80 m^2 respectively. Thus, the actual determination of P sorption is required to address the P assimilation.

Amelioration of effluent for the surface soil for irrigation or the trench for sub-surface disposal is always an opportunity. Adding aluminium or iron to increase the P sorption will only make the soil very acid and impede plant nutrition and needs to be done with cation. Adding calcium in the form of agricultural lime (calcium carbonate) or gypsum (calcium sulphate) is preferred. Lime will slowly increase the pH of the soil (make more alkaline) but gypsum has almost no effect upon shifting pH. Application rates of up to 0.5 kg/m^2 (5 tonne/ha) of lime/gypsum can be applied. For irrigation areas, the lime/gypsum is simply spread on the surface and allowed to wash into the soil.

Holford (1983) showed that for acid soils, the addition of lime increased the exchangeable phosphate (plant nutrition) while also increasing sorptivity. He also showed that for very acid soils (pH<4.5), iron and aluminium increased phosphate precipitation and as pH increased with liming, the activity of the adsorption sites increased. When limed above pH 5.8 most soils tended to decrease in sorptivity and affinity without a corresponding decrease is sorption capacity. Thus, liming not only make P more available to the plants, it also prevents off-site losses through increased sorption capacity.

For sub-surface discharges, lime or gypsum can be mixed into a watery slurry and funnelled into the outlet from the septic tank so that it moves into the drainfield. Other proprietary products such as superfine eco-flo™ lime or eco-flo™ gypsum are easier to handle than agricultural products. Regular dosing of lime and/or gypsum may improve the P sorption as well as the soil permeability while overcoming the effects of sodium in the effluent. There is nothing to prevent the occupants regularly dosing the superfine products through the toilet, where there will be benefits in the primary treatment system and in the land disposal area.

Many soils in NSW have a high affinity for P sorption at rates of 15 000 kg/ha and above. Sourcing some of these soils for addition to sandy low P sorbing soils may be an opportunity. Blast furnace slag has excellent P sorbing properties and can be used as the gravel in drainfields or blended with soil below the surface soil. Transport costs may be a limiting factor. Mineral peat, an acidic blend of organic peat and natural minerals also provides high P sorbing capacity, sphagnum peat has no such properties.

9. Conclusion

P, present in wastewater in the inorganic (orthophosphate, pyrophosphate and polyphosphate) and organic forms, varies according to the eating and laundry habits of the occupants of the household. While the concentration of P in the wastewater stream may vary, it is the load of P that needs to be judged. One simple solution to decreasing P concentration is to use more water for dilution, but that does not change the load. Unfortunately, the NSW Guidelines calculate the household's contribution to its output of P by multiplying an average P concentration by the daily volume of water used. The problem is that for a normal four-person household on rainwater that equates to 1.83 kg P/yr, compared to 2.19 kg P/yr for a similar household on reticulated water. So from where does the extra P materialise? Does an average four-person household on tank water eat less than a similar household using reticulated water? Surely that's not the depth of understanding by the authors of the Guidelines!

The premise, in the Guidelines, that we have to discount the measured value of P sorption in a particular location by 50-75% has no foundation. Since the phosphate ion moves with the percolating effluent, into macropores and micropores alike, it is farcical to assume that for whatever reason only 25-50% will be adsorbed without any evidence compared to the laboratory analysis of site specific soils. Discounting simply to be conservative is not a valid reason. While there are many analytical methods of assessing P sorption capacity, most are related to estimating the soluble P available for plant nutrition and the availability of P following application of superphosphate. Most methods do not relate to estimating the maximum P sorption capacity of an effluent application area.

The calculations set out in Section 2 need to commence at choosing a reliable and consistent approach to determining the annual load of P from the household. Simply selecting an average P concentration of 10 mg P/L and multiplying by the daily water use has been shown to be nonsense because it assumed that the more water that is use the more P discharged. Therefore, calculation A1 simply needs to be the average daily P discharge per person calculated for the household for the year. The NZ household estimate of 2 kg P/year is probably a reasonable estimate given the similar current practice of using 'NP' and 'P' detergents in Australia and NZ. Certainly, where P sorption capacity is low, the household needs to be encouraged to favour a low P regime.

The Guideline selection of a 50-year period for immobilising P is a thought bubble as even our consumption of P in laundry detergents has gone more than 8 g P/wash a decade ago to mostly 'NP' and 'P' products today. For new system designs we need to rely upon the realities of household P consumption, not the publications of last century. However, as an ultra-conservative approach, 50 years may be a suitable period, as used in the calculations above. In reality, unless we monitor the land application area, we will never know how the P sorption characteristic is functioning.

P is an essential plant nutrient that has concerned agriculturalist for generations, specifically with securing a minimum available phosphate level in the soil for the growing around the crop. For wastewater management, it is not the limiting level of phosphate that is important, rather the capacity of the soil to bind P in the effluent from moving outside the land application area. Only through modifying the P sorption analysis are we able to determine that potential, hence an amended test regime, using elevated equilibrating solutions is required.

Thus the particular components of the P budget include:
Annual household generation of P – preferably load.
Annual plant uptake of P from the land application area.
Annual P sorption capacity of the soil in the land application area – based on 50-year life.
Calculated land application area including required buffers.

10.References

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