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# Farm gate nutrient balances in south west Western Australia – An overview

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## Abstract
Farm-gate nutrient budgets can be used to identify the efficiency of nutrient use within and between individual enterprises and catchments, and may be used to represent a component of the risk that particular landuses represent to water quality.
Over the past 5 years, more than 400 farm-gate nutrient balance audits have been conducted across a range of catchments and landuses in southwest Western Australia (WA). Values for nutrient use efficiency and surpluses across landuses and catchments are reported.
Patterns of nitrogen and phosphorus signatures closely reflect one another across landuses, though nitrogen input, output and surplus values are consistently higher than those for phosphorus. High intensity landuses with high levels of input per hectare, such as annual horticulture and dairy systems, also show higher outputs than extensive landuses such as broadacre grazing and cropping systems. However, surpluses per hectare are also higher than for other landuses. Cropping systems were found to be less variable and more efficient in nutrient use than other animal based landuses. Annual horticulture displayed interesting disparity with other data by having relatively high N efficiency concurrent with low P efficiency, defying the trend of N and P signatures reflecting one another closely.
The general surpluses and efficiencies for different landuses were also reflected in catchment nutrient use efficiencies, based on the landuse makeup in those catchments. Catchments dominated by animal based landuses such dairy and other grazing systems tended to have higher nutrient surplus and lower efficiency than catchments dominated by plant based cropping systems.
**Keywords:** Nutrient balance, nutrient budget, farm-gate balance, phosphorus, nitrogen, surplus, efficiency

## 1. Introduction
Over the last half-century, agricultural and urban development in the south-west of Western Australia (WA) has been accompanied by increases in nutrient export to rivers, wetlands and estuaries [1]. This increased nutrient export presents an environmental threat to receiving waterways from algal blooms and fish kills and consequently there has been interest in identifying sources of nutrient pollutants so that management strategies can be more targeted.
The threat of nutrient contamination has been realised mostly in higher rainfall coastal catchments of Western Australia, such as the Peel-Harvey catchment [2]. In these areas significant investment has been directed at better understanding and managing this threat. Major policy responses to date have dealt with short term symptomatic treatment of the issue through engineering works such as the harvesting of algal biomass, or construction of channels to improve ocean exchange, flushing of estuarine systems, and altered salinity regimes. Whilst these approaches have provided short term positive responses, longer term catchment management to deal with nutrient exports is still required to deal with emerging nutrient pollution threats as the estuarine systems adapt to new environmental regimes. Previous catchment management research has concentrated on identifying the sources and processes of nutrient delivery [3], and assessing the effectiveness of a select few management actions such as vegetated stream buffers [4] to reduce or delay nutrient export. In contrast, little research in south-west Western Australia has been carried out into farm nutrient use efficiency and whether there are opportunities for more efficient nutrient use, even though it is clear that agriculture is a major source of nutrients [5] and that fertilisers provide much of the agricultural nutrient inputs [6].
Nutrient use efficiency has been used to identify nutrient surpluses in catchments and associate these with water quality concerns [7], and using a source, transport and delivery framework of a risk index [8], nutrient surpluses have been used to represent the source component of risk indices [2] in a range of catchments. Additionally farm-gate nutrient budgets have been used as a policy instrument in Holland in the ‘Mineral Accounting System’ (MINAS), which is used to assess farm phosphorus (P) and nitrogen (N) surplus on dairy farms [9]. The results from the MINAS system, where farmers fill in an annual assessment form, are used as the basis of regulation of

farm nutrient levels and losses. In their own right, farm-gate nutrient budgets can also provide an interesting and useful insight into different landuses and catchments in which these budgets have been undertaken. Different landuses (grazing systems, cropping systems, intensive agriculture) are characterised by varying management and nutrient inputs, and the nature of the different outputs and their varying nutrient contents will lead to variations in nutrient surplus and nutrient use efficiency. The nutrient signatures that characterise each will also depend on the environmental, catchment and management situation in which each is located. These signatures can provide insight into the inherent biological limits to, and opportunities for improved nutrient use efficiency for different landuses and catchments, as well as perceived risk of inadequate nutrient use. These signatures may also indicate whether particular landuses or enterprises operate within a similar domain despite differences in location.

Agricultural enterprises use a range of nutrient inputs (feed, fertilisers, animal purchases, fixation and deposition) in a series of processes (pasture growth, animal grazing, cropping), aimed at producing products for sale (animals, feed, grain, milk). These products represent nutrient outputs from an agricultural system.

The difference between inputs and outputs may represent inefficiencies in a production system and is increasingly referred to as nutrient ‘surplus’. Nutrient surplus can also represent an important indicator of the potential for loss from an agricultural system to the environment [10]. Surplus and efficiency are representations of the inherent biological limits of a landuse, and are also influenced by land management and to some degree landscape characteristics and must be considered with a number of other factors (climate, soil type and topography) to understand actual losses to the environment [8], [11]. The information gathered from these farm-gate nutrient budgets can be used in conjunction with these other data to predict and assess the degree and spatial distribution of nutrient export risk within a catchment.

A range of studies have been completed in this area, dealing with what are variously called nutrient budgets or balances [12], [13], [10], element or farm-gate balances [14], or input:output (IO) accounting systems [15]. These balances have been carried out at a range of scales, from the farm [16], [17] to regional and even national scale [18], [19], [20], [10], [21].

Within farm systems three types of balance can be identified [14] from ‘farm-gate balances’ which are simple assessments of inputs and outputs using available data for nutrient contents of inputs and outputs [22], to ‘soil surface balances’ which require more-detailed data on fluxes across the soil surface. ‘System balances’ are more detailed, and deal with “partitioning of the changes in net loading between system components” [14]. The different levels of balance have specific benefits, but become progressively more difficult to undertake due to the uncertainties associated with the more detailed data requirements. Even at the scale of the farm-gate balance, the quantification of nutrient inputs and outputs allows the development of a number of indicators of farm nutrient performance.

‘Nutrient use efficiency’ can be described in a number of ways, such as partial factor productivity, agronomic efficiency, partial nutrient budget and recovery efficiency [23] but here it is expressed as the percentage of farm nutrient inputs that are exported as farm produce, and therefore characterises the nutrient conversion efficiency of particular land uses.

This paper presents general findings of farm-gate nutrient balance surveys conducted in spatially disparate catchments in south west Western Australia (WA). These catchments are occupied by different landuses, landscapes and climate and therefore offer an opportunity to explore how some of these factors influence nutrient use efficiency and potential offsite threats at a range of scales.

## 2. Methods

This study utilised a farm-gate budget assessment of nutrient inputs and outputs from a farm enterprise. The framework is a modification of previously documented processes (Figure 1) [24], [25], and uses survey information on material inflows and outflows and nutrient content values from a number of sources [22]. Nutrient content book values were sourced from fertiliser and feed manufacturers for a wide range of products, and published values for inputs of N from fixation.

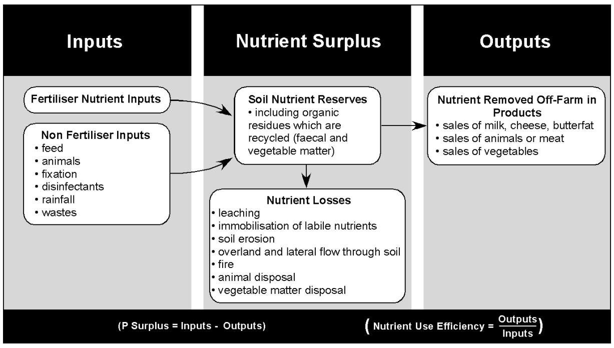


Figure 1. Farm-gate nutrient budget framework

Structured surveys were conducted by a trained interviewer with managers of agricultural and lifestyle properties of more than 2 hectares. Principal input data collected in the surveys included feed, fertilisers and animal transfers; outputs included animal and product sales off-farm. These surveys were conducted in a temporal context of 5 years to avoid influences of individual years where poor seasons limited inputs or outputs. In this sense the surveys were designed to capture average information over a 5 year period. All data was entered into a database system where nutrient surpluses were determined by subtracting

outputs from inputs and used to calculate the surplus per cleared hectare (ha) for the farm. Nutrient Use Efficiency (NUE) was calculated for P and N separately, by dividing outputs by inputs, with values generally in the range 0 to 1. Statistically significant differences between catchments and landuses were explored using Analysis of Variance after re-expressing any of the nutrient signatures to approximate normal distributions according to the ladder of powers [26].

### 2.1. Study Location and Catchment Characteristics

Over 400 nutrient budget case study surveys were conducted in seven catchments across southwest WA, as shown in the map below. The seven catchments of Ellen Brook (E), Peel Harvey (PH), Leschenault (L), Geographe (G), Torbay (T), Bremer (B), and Lake Warden (LW) are all coastal draining, ranging in size from 32000 ha to 441000 ha, with between 40 (Bremer) and approximately 2700 (Peel-Harvey) agricultural and lifestyle landholders.

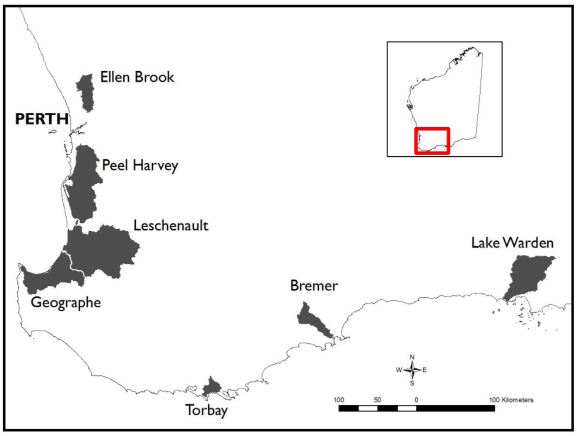


Figure 2. Catchment locations

Landscape and landuses of these catchments vary significantly, and these may influence nutrient surplus and efficiency. The major landuses in each catchment are listed below in Table 1.

Table 1. Landuse profile for each of the catchments

| | | E | PH | L | G | T | B | LW |
|---|---|---|---|---|---|---|---|---|
| Catchment area ('000 ha) | | 72 | 301 | 441 | 204 | 32 | 69 | 217 |
| % landuse in catchment | Sheep | 1 | 1 | | 1 | | 2 | 2 |
| | Beef cattle | 32 | 37 | 10 | 30 | 50 | | 3 |
| | Mixed grazing | 2 | | | 3 | 3 | | 6 |
| | Horses | 4 | 3 | | | | | |
| | Lifestyle | 3 | 2 | | 2 | | | 1 |
| | Dairy cattle | | 7 | 3 | 9 | 3 | | |
| | Grazing_cropping | | | | | | 70 | 30 |
| | Cropping | | | | | | | 20 |
| | Annual Horticulture | 1 | | 1 | 1 | 1 | | |
| | Trees/ perennial horticulture | 4 | 2 | 5 | 5 | 3 | | 6 |
| | Uncleared | 50 | 34 | 70 | 40 | 35 | 25 | 30 |
| | Other | 3 | 14 | 12 | 9 | 5 | 3 | 2 |

Table 2 indicates the proportion of surveys conducted in each catchment for each of the nine major landuses that were included in the study, as well as the proportion of land managers and total productive area that were covered in each of the catchments. The survey methodology was designed to cover a proportion of managers in each landuse in an attempt to acquire a statistically valid sample. Therefore for some landuses a large number of surveys may translate into a small spatial area, even though the number of managers is large.

Table 2. Survey statistics for each of the catchments

| | | E | PH | L | G | T | B | LW |
|---|---|---|---|---|---|---|---|---|
| Number of surveys | | 69 | 87 | 28 | 133 | 21 | 10 | 84 |
| %managers surveyed | | 8 | 4 | 1 | 4 | 5 | 25 | 20 |
| %target area surveyed | | 27 | 30 | 9 | 27 | 19 | 37 | 38 |
| % of surveys in landuse | Sheep | 1 | 1 | 7 | 1 | 5 | 10 | 8 |
| | Beef cattle | 33 | 44 | 61 | 30 | 86 | - | 21 |
| | Mixed grazing | 16 | 20 | 4 | 13 | 14 | | 18 |
| | Horses | 16 | 8 | - | 2 | - | - | 5 |
| | Lifestyle | 32 | - | - | 17 | - | - | 25 |
| | Dairy cattle | - | 25 | 29 | 25 | - | - | - |
| | Grazing_cropping | - | - | - | - | - | 90 | 14 |
| | Cropping | - | - | - | - | - | - | 8 |
| | Annual Horticulture | 1 | 2 | - | 12 | - | - | - |

For the purposes of this survey, mixed grazing system refers to a combination of sheep and cattle grazing or, less commonly, other ruminants such as goats or alpacas. Grazing-cropping systems are managed on a rotational basis and generally maintain a standard proportion of cropping area to either sheep or cattle grazing areas from year to year. Annual horticulture systems surveyed cover a range of fruit and vegetable crops, though more than half are potato farms.

## 3. Results and Discussion

Median values for nutrient input, output, surplus and efficiency for each catchment are shown in Table 3. From the table it is evident that there is large variation in the median nutrient signatures across the seven catchments. Inputs, outputs and surplus are greater for N than P, whilst nutrient use efficiency is greater for P than N. Overall N and P outputs per cleared hectare are relatively small in comparison to N and P inputs in each catchment. This is reflected in median N and P efficiencies of less than 0.24 and 0.32 respectively. Surpluses per cleared hectare therefore represent greater than 76% and 68% of N and P inputs respectively.

Table 3. Median values of P and N input, output and surpluses (kg/ha) and P and N use efficiencies in the surveyed catchments

| Catchment | P input | P output | P surplus | P use efficiency | N input | N output | N surplus | N use efficiency |
|---|---|---|---|---|---|---|---|---|
| B | 9.1 | 2.7 | 5.5 | 0.32 | 68.7 | 17.6 | 52.9 | 0.24 |
| E | 5.4 | 0.3 | 4.4 | 0.20 | 50.6 | 1.4 | 47.9 | 0.08 |
| G | 16.4 | 3.3 | 12.0 | 0.21 | 100.5 | 16.0 | 85.2 | 0.17 |
| LW | 10.2 | 1.0 | 6.2 | 0.14 | 77.7 | 3.9 | 64.2 | 0.08 |
| L | 15.8 | 4.5 | 10.8 | 0.21 | 100.4 | 17.0 | 88.3 | 0.15 |
| PH | 16.2 | 2.3 | 12.0 | 0.20 | 91.8 | 9.8 | 80.6 | 0.12 |
| T | 10.7 | 2.1 | 7.6 | 0.23 | 69.1 | 7.5 | 58.2 | 0.11 |

In general, N and P patterns correspond with one another, with higher N inputs, outputs and surpluses in catchments that also display higher P values. Patterns are also evident in the ranking of catchments in their inputs, outputs, surpluses and efficiency values. From Table 3 it can be seen that the Ellen Brook catchment has the lowest median value for all nutrient signatures, other than P efficiency, where it ranked second lowest. The Lake Warden catchment had the lowest value in this category, and showed the second lowest values for N use efficiency and both P and N outputs. In contrast, the Leschenault and Geographe catchments have values among the three highest in each category. Based on the inputs and surpluses, they are joined in the three highest values by the Peel-Harvey catchment, which displays very similar values in these categories. As surplus values represent a component of nutrient loss risk, the Geographe, Leschenault and Peel Harvey catchments are possibly under a greater degree of environmental threat from nutrient pollution. This is dependent, however, on the sensitivity of receiving systems as well as other risk factors [2]. In terms of outputs and efficiency, Peel-Harvey disappears from this top three, replaced by Bremer catchment, which has relatively low inputs and surpluses. This may be due in part to the nature of landuses in these catchments, and the relative nutrient use efficiency of each. Links between input and efficiency values within a landuse have been previously reported [23], where efficiency values increase with decreasing rates of input. Internal correlations between the nutrient signature variables at a catchment scale are likely to be a function of the inherent biological inefficiencies of the landuses within each catchment, and the landuse makeup in each.

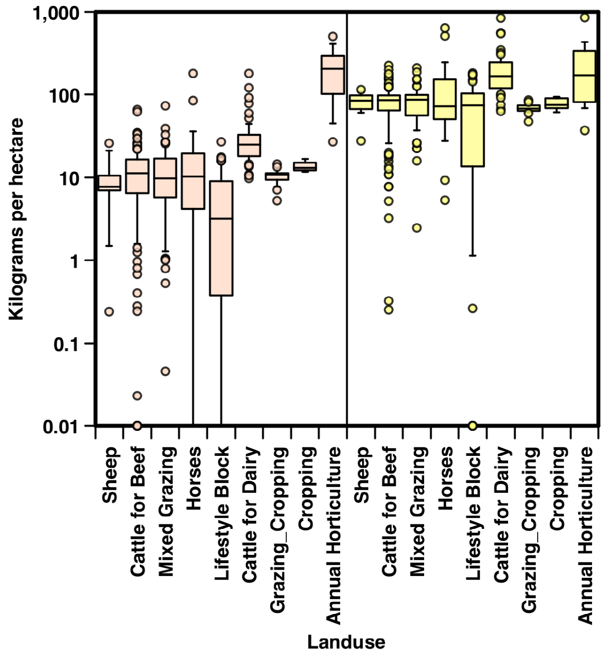


Figure 3. Box and whisker plots showing the variation in P input (left pane) and N input (right pane) in kilograms per hectare across surveyed landuses. Boxes show 25th, 50th and 75th percentiles. Whiskers extend to 10th and 90th percentile and points show outliers.

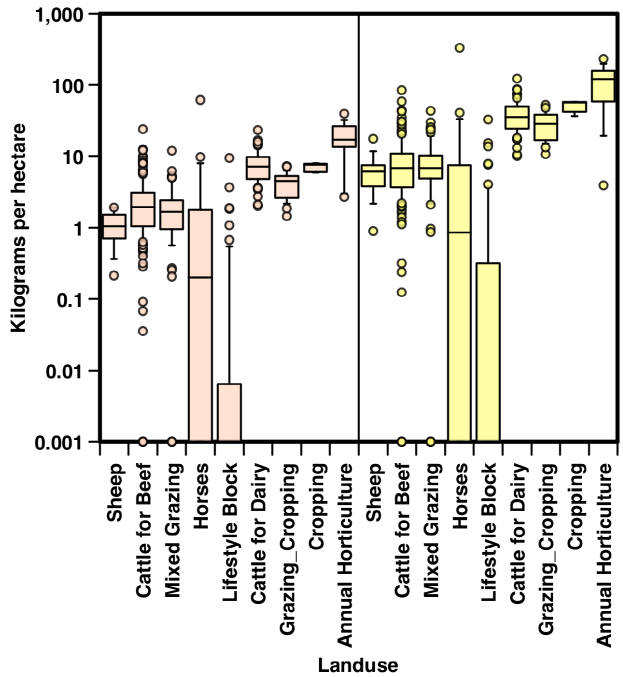


Figure 4. Box and whisker plots showing the variation in P output (left pane) and N output (right pane) in kilograms per hectare across surveyed landuses. Boxes show 25th, 50th and 75th percentiles. Whiskers extend to 10th and 90th percentile and points show outliers.

Each of these catchments had an individual makeup of various landuse practices surveyed, as categorised in Table 2. A closer examination of the nutrient signatures of individual landuses can provide insight into the catchment nutrient results. Figures 3 and 4 below compare N and P inputs and outputs for each of the landuse classes across the catchments.

As was identified in the comparison of catchment nutrient balance characteristics, patterns in P inputs and outputs are closely reflected in N input and output patterns (Figures 3 and 4). Between landuses however, there are significant differences in the scale and variability of nutrient input and output values. Relative to other landuses in the study catchments, annual horticulture was shown to have exceptionally high nutrient inputs and outputs, for P in particular (median P input of 205kg $ha^{-1}$, median P output of 17kg $ha^{-1}$). Whilst P inputs were significantly lower for dairy properties ($P$<0.05), N inputs (167kg $ha^{-1}$) were not significantly different than those for annual horticulture. Both inputs and outputs of P and N for dairies are significantly higher than those for other grazing landuses ($P$<0.05). These results would have contributed to the high input and output values seen for the Geographe, Leschenault and Peel-Harvey catchments, where a significant proportion of the surveys were undertaken with dairies, and in the case of Geographe catchment, with annual horticulture landuses.

All non-dairy based grazing landuses (sheep, beef cattle and mixed grazing) have similar median values and ranges in P and N inputs and outputs. When grouped for analysis, median inputs for non-dairy grazing systems (median P input of 11 kg $ha^{-1}$, median N input of 85 kg $ha^{-1}$) were not significantly different to those for cropping and integrated grazing-cropping systems, though there is a lot less variability between landholders within the cropping landuses. Outputs for these cropping systems also show low variability, but in contrast to inputs are much higher than non-dairy grazing system outputs, with values more similar to the P and N output values of dairy systems (P output of combined cropping and integrated systems of 5 kg $ha^{-1}$, N output of 35 kg $ha^{-1}$). This is reflected in the median values for Bremer catchment, a catchment dominated by cropping landuses, which showed relatively low inputs coupled with high outputs.

As may be expected, the landuses of lifestyle blocks and horses display low output values for P and N. Inputs to lifestyle blocks are also generally low, whilst inputs to horse properties show no significant difference to non-dairy grazing systems. There is a large amount of variability in the inputs and outputs for these non-productive systems.

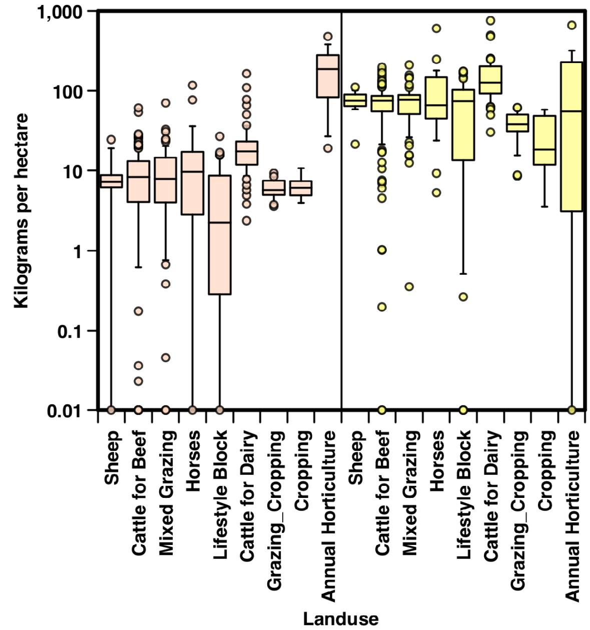


Figure 5. Box and whisker plots showing the variation in P surplus (left pane) and N surplus (right pane) in kilograms per hectare across surveyed landuses. Boxes show 25th, 50th and 75th percentiles. Whiskers extend to 10th and 90th percentile and points show outliers.

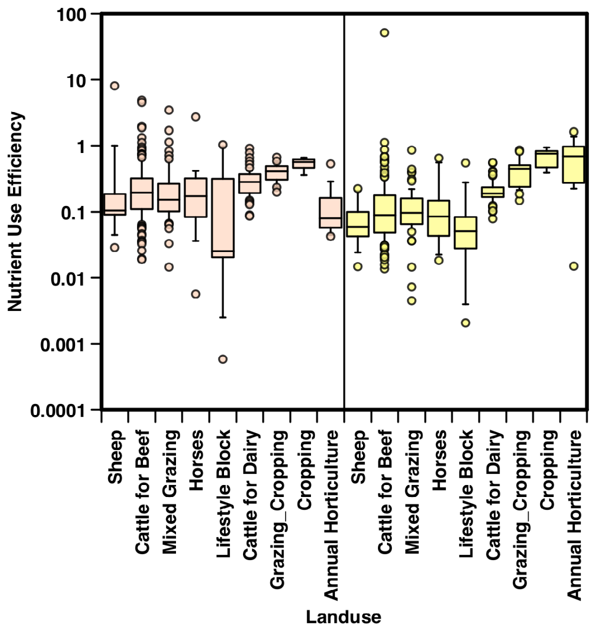


Figure 6. Box and whisker plots showing the variation in P use efficiency (left pane) and N use efficiency (right pane) across surveyed landuses. Boxes show 25th, 50th and 75th percentiles. Whiskers extend to 10th and 90th percentile and points show outliers. A value of 1 on the y-axis is 100%

Surpluses and efficiencies for each landuse are shown in Figures 5 and 6 respectively. As with input and output values, no significant difference was found in

the surplus or efficiency values between the various non-dairy grazing landuses (grazing systems). There was also no significant difference between cropping and integrated grazing-cropping systems (cropping systems). Cropping landuses showed the least variability in surplus and efficiency, as was the case with inputs and outputs and lifestyle properties again show high levels of variability.

The highest surpluses for P are from annual horticulture systems (Figure 5). With a median of 188 kg ha$^{-1}$, this value far exceeds that of any of the other landuses in the study ($P$<0.05). This suggests that where annual horticulture is a dominant landuse, a high level of environmental threat to waterways may exist where this surplus can interact with other landscape features that enhance rather than retard nutrient loss. Nitrogen surpluses from annual horticulture were not significantly different to those of other landuses.

In this study, a general trend appears with dairy systems exhibiting higher surpluses (median P surplus of 18 kg ha$^{-1}$, median N surplus of 128 kg ha$^{-1}$) than other grazing systems (median P surplus of 8 kg ha$^{-1}$, median N surplus of 76 kg ha$^{-1}$), which in turn have higher surpluses than cropping landuses (median P surplus of 6 kg ha$^{-1}$, median N surplus of 35 kg ha$^{-1}$). Dairy systems have N surpluses significantly higher than that for grazing, which are significantly higher than cropping systems ($P$<0.05). P surplus is significantly higher than both other grazing and cropping landuses ($P$<0.05).

A trend was also evident in efficiencies, though the order of the landuses was altered. Cropping landuses showed the highest N efficiency (median N efficiency of 0.47), which was significantly higher than dairy (median N efficiency of 0.19) which in turn was significantly higher than other grazing landuses median N surplus of 0.09) ($P$<0.05). For P, the efficiency of cropping landuses (median P efficiency of 0.44) was significantly higher than grazing systems ($P$<0.05) (median P efficiency of 0.17), whilst the median efficiency of dairy systems (0.28) fell between the two, as with N efficiency. The typically high efficiencies of cropping systems are reflected in Bremer efficiency values, where integrated grazing-cropping systems are the predominant landuse. These high efficiencies suggest that to achieve a reduction in surplus may require fundamental system changes as well as improved management.

Based on Figure 6 and significance testing, plant based systems (cropping and annual horticulture) appear to be more efficient users of N than those systems which rely on animals to convert nutrients to output products. For P however, annual horticulture was one of the least efficient users of nutrients, whilst cropping systems were the most efficient. Based on a Spearman Rank Correlation, N efficiencies increased with the proportion of N contributed by inorganic fertilisers in comparison to N delivered through non-direct means such as plant N fixation which showed a negative correlation.

Annual horticulture defied the pattern of N and P trends closely reflecting one another, when it came to efficiency. In this particular case, P efficiencies (median of 0.08) are significantly lower than cropping, grazing and dairy landuses ($P$<0.05), whilst, median N efficiency (0.69) is second highest only to cropping and significantly higher than dairy and grazing landuses ($P$<0.05).

Low input lifestyle blocks, whilst having very low or zero efficiency due to their non-productive nature, also have low P surplus values (median P surplus of 2.2 kg ha$^{-1}$), contributing to the relatively low median surplus in Ellen Brook catchment. This indicates that relative to other landuses in the study the surplus based P loss risk for lifestyle properties is low.

Given that surveyed landuses do not represent the proportional landuse breakdown by area of each catchment, an estimate of total inputs, outputs and surplus was calculated based on the median input and output values of P and N for each landuse, and the areas of each landuse in each catchment from Table 1. Average catchment nutrient use conversions can be estimated from these numbers and are shown in Table 4. These figures relate only to the proportion of each catchment that is under the major agricultural and lifestyle landuses listed in Table 2, for which input and output figures were available. It therefore does not include the proportion of the catchments under silviculture and other perennial horticulture, remnant vegetation and other minor landuses.

Table 4. Estimated total inputs, outputs and surpluses of P and N (tonnes/yr) and overall P and N use efficiencies for the study catchments

| Catchment | P input | P output | P surplus | P use efficiency | N input | N output | N surplus | N use efficiency |
|---|---|---|---|---|---|---|---|---|
| E | 460 | 60 | 400 | 0.13 | 2660 | 260 | 2400 | 0.13 |
| PH | 1920 | 370 | 1550 | 0.19 | 14450 | 1530 | 12920 | 0.11 |
| L | 1280 | 210 | 1070 | 0.16 | 6380 | 1030 | 5350 | 0.16 |
| G | 1650 | 290 | 1360 | 0.18 | 9680 | 1370 | 8310 | 0.14 |
| T | 280 | 40 | 240 | 0.14 | 1670 | 190 | 1480 | 0.11 |
| B | 530 | 220 | 310 | 0.42 | 3400 | 1380 | 2020 | 0.41 |
| LW | 1510 | 660 | 850 | 0.44 | 9930 | 4480 | 5450 | 0.45 |

The figures listed in Table 4 provide information to catchment managers on the scale of annual nutrient surpluses that must be processed though each catchment annually, or accrue in the system, leading to deferred cumulative potential environmental risk. These figures could provide a baseline from which to set targets for decreased nutrient surplus. Lower catchment surpluses do not necessarily represent a reduced environmental threat, as this relates also to catchment size, as well as the characteristics of

receiving systems. Calculated catchment nutrient use efficiencies reflect the landuse composition of each catchment, reflecting the area based proportion of high and low efficiency landuses.

## 4. Conclusions

Farm-gate nutrient balances can provide an effective way to measure and monitor nutrient use signatures across and within catchments. Catchment N and P inputs, outputs, surpluses and efficiencies are a reflection of the proportional landuse makeup that comprises a catchment. Each landuse, whilst exhibiting varied levels of variability, has median P and N values which can be used to represent these landuse signatures.

This study characterised nutrient signatures across landuses in 7 catchments in south west WA. These values then enabled estimates to be calculated of total catchment inputs, outputs, surpluses and efficiencies, for the proportion of the catchment covering the surveyed landuses.

In most cases trends in N and P use signatures reflected each other closely, though inputs, output and surpluses for N were higher than those for P. Nutrient use efficiencies were generally found to be low, indicating a poor conversion rate from inputs to outputs. These efficiencies increased in catchments where landuse is dominated by cropping systems, which were found to be more efficient in nutrient use than grazing landuses. Cropping landuses also showed less variability in efficiency and surplus values than grazing landuses.

Conversely, grazing landuses exhibited higher surpluses for both N and P than cropping systems. These surpluses were far exceeded in relation to P by median surplus values of annual horticulture, which had the highest P surplus of any landuses surveyed.


## 5. Acknowledgements

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