Nutrient balance case studies of agricultural activities in south west Western Australia.

Simon D. Neville*, D.M. Weaver**, K. Lavell***, M.F. Clarke***, R.N. Summers***, H. Ramsey*** and J. Grant**

*Ecotones and Associates, RMB 1050, South Coast Highway, Denmark WA 6333 (Email: silou@denmarkwa.net.au)
**Department of Agriculture, Western Australia. 444 Albany Hwy, Albany, WA, 6330.
***Department of Agriculture, Western Australia, 120 South West Highway, Waroona, WA 6215.

Abstract
The ecology of estuaries on the south coast of Western Australia has been disrupted because of increased nutrient and sediment discharge from predominantly rural catchments. Given the strong link between landuse and nutrient export, it is important to evaluate nutrient balances and flows so that opportunities for intervention can be better targeted. Specific data on the levels of nutrient export, and the nutrient inputs that give rise, are often limited. The case studies reported here developed nutrient balances for a broad range of land uses in the Peel Harvey catchment, in part to provide nutrient data for associated BMP modelling work. The studies indicate that inputs exceed outputs in most instances, suggesting nutrient accumulation ('positive balance'). A range of nutrient balance and input:output signatures have emerged for different land uses, describing the general nutrient efficiency of each. Ratios vary significantly within land uses, possibly due to management practices, and environmental situation. The P input:output ratio provides some indicator of production P loss, but estimated levels of P loss to the environment are strongly correlated with farm P inputs. The selection and prioritisation of management practices needs to consider how each management action addresses the issue of "nutrient balance".

Keywords
Nutrient balance; nutrient budgets; farm-gate balance; nutrient input:output ratios; nutrient BMP modelling

INTRODUCTION

The last half-century of agricultural development in the south-west of Western Australia (WA) has been accompanied by increases in nutrient export to rivers, wetlands and estuaries (Hodgkin and Hamilton, 1993).Research has concentrated on identifying the sources and processes of nutrient delivery (Weaver and Reed, 1998), and assessing the effectiveness of a select few management actions such as vegetated stream buffers (McKergow *et al.*, 2002) to reduce or delay nutrient export. However, until recently little work has been carried out to estimate or measure the effect of improved management actions at the catchment-scale (Weaver *et al.*, 2003).

Recent modelling by Weaver *et al.* (2003) for four catchments on the south coast of Western Australia has begun to address that area. This modelling adapted the approach of Young *et al.* (1995) to evaluate the costs and benefits of different sets of Best Management Practices (BMPs) applied in various locations at different levels, as well as assessing the costs and benefits of individual BMPs. A significant input into models of this type is landuse data (National Land and Water Resources Audit, 2001) to which nutrient generation rates are ascribed to estimate P and N loss at source (Young *et al.*, 1996, 1997; Vanderholm, 1984).

In response to concerns that the export rates used in landuse nutrient generation rate models (Young *et a.*, 1995; Weaver *et al.*, 2003) may be unreasonably high, nutrient balance case studies of intensive agricultural activities were undertaken (Neville and Weaver, 2003) on the south coast of WA. The case studies assessed farm nutrient balances as a means to identify potential farm losses, and concluded that the model rates used were not unreasonably high. Nutrient balance assessments appear to offer opportunities for improving modelling efforts given that landuse specific monitoring data is very difficult and costly to obtain.

Agricultural enterprises use a range of nutrient inputs (feed, fertilisers, animal purchases, fixation and deposition) in a series of processes (pasture growth, animal grazing), 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 sometimes called 'nutrient surplus. Nutrient surplus can also represent an important indicator of the potential for loss from an agricultural system to the environment (Sacco *et al*., 2003). This difference can also be called the 'production loss' to clarify the source of the nutrient which is the production system. Production loss is the result of both landuse, 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 (Heathwaite, *et al*., 2003; Nord and Lanyon, 2003).

A range of studies have been completed in this area, dealing with what are variously called nutrient budgets or balances (Watson *et al*., 2002; Oenema *et al.*, 2003;, Sacco *et al.*, 2003, element or farm-gate balances (Öborn *et al*., 2003), or IO accounting systems (Goodlass *et al*., 2003). These balances have been carried out at a range of scales, from the farm (Moody, *et al*., 1996; Berry *et al*., 2003) to regional and even national scale (Cassell *et al*., 1998; Lord *et al*., 2002; Sacco *et al*., 2003; Keller and Schulin, 2003).

Within farm systems three types of balance can be identified (Öborn *et al*., 2003) from "farm gate balances" which are simple assessments of inputs and outputs using available data for nutrient contents of inputs and outputs (Reuter and Judson, 2003) 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" (Öborn *et al*., 2003). 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 including nutrient input:output ratios, total farm production loss, and production loss normalised for area. These can be used to indicate the general nutrient efficiency of particular land uses, as well as assessing nutrient conversion efficiency. The latter can indicate that efficiency could improve through better management, through voluntary management tools for farmers to components of formal management systems (Öborn *et al*., 2003).

This study focussed on assessing P which unlike Nitrogen has no significant atmospheric exchange component, and for which a significant amount of work on storage and delivery mechanisms has been done (Weaver and Reed, 1998, Cassell *et al*., 2001, McKergow *et al*., 2002).

This paper reports on farm gate nutrient balance case studies conducted in the Peel-Harvey catchment located on the west coast of south western WA. These farm gate nutrient balances provide an opportunity to examine nutrient management scenarios, and support modelling efforts by acting as a substitute for generic published values of landuse specific nutrient generation rates (Young *et al*., 1996, 1997; Vanderholm, 1984) that may not apply to certain regions for a range of reasons. In addition to modelling uses, it is important to evaluate nutrient inputs and losses for various enterprises, and how these may be improved.

METHODS

Land use

Land use mapping for the study area was derived from ground truthing, aerial photography, consultation with local farming groups and unsupervised reclassification of urban fringe areas. The number of landholders in the major land use categories was determined by gathering information from databases and mailing lists of each industry that were supplied by state government agencies and industry groups. Sample populations were determined from these estimates to provide a statistically rigorous sampling framework using stratified random sampling (US EPA, 1997).

Surveys

The information required for the farm gate balances was collected in a series of surveys conducted by a trained interviewer using a structured interview with the farm manager. Actual survey numbers varied from the framework due to difficulties in property access and variations between estimated and actual population numbers. In addition, some land uses were added and other classifications modified.

Farm Balance Framework

Farm balances were conducted using a modification of the framework outlined by Reuter (1999) from SCARM (1998) using the survey information and nutrient content values from a number of sources, in particular the National Land and Water Audit (Reuter and Judson, 2003). Fertiliser information was sourced from fertiliser manufacturers for nearly 100 different fertilisers from three major and a number of minor manufacturers. Principal inputs were feed, fertilisers and animal transfers; outputs were animal and product sales off-farm. Unaccounted P (inputs minus outputs) we termed "production loss" reflecting the fact that it is lost from the production system and *may* be lost to the environment. We calculated the total loss for each operation, the loss per cleared hectare (ha) on the farm and for the whole farm, and the Input:Output (IO) ratio. The loss per ha is an indication of the potential environmental impact of the farm (subject to site, soil and locational considerations). The latter (input:output ratio) can be see as an indicator of farm nutrient efficiency. Differences between landuses were explored using analysis of variance.

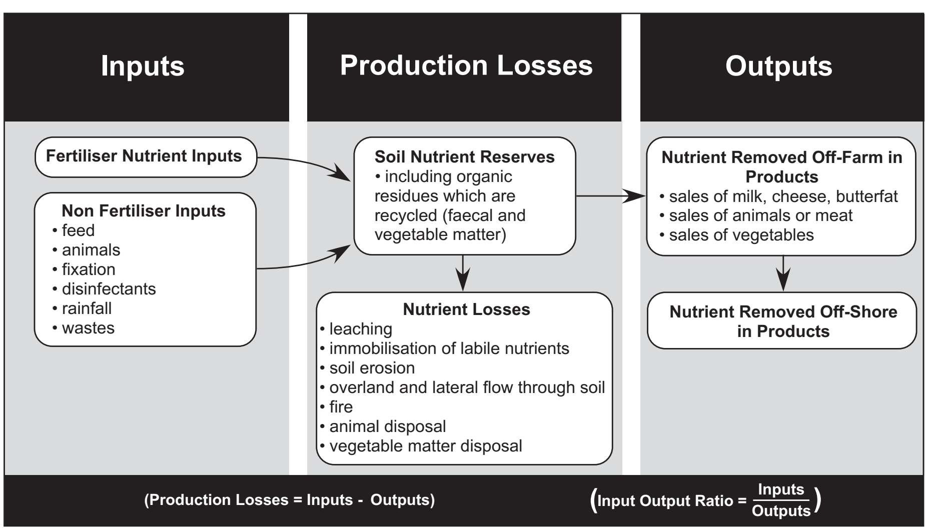

Figure 1. Farm gate balance framework (adapted from Reuter, 1999)

RESULTS & DISCUSSION

Input:output ratios and production P losses

The median input:output ratio varies within and between landuses, with some statistically significant differences (Table 1). The most efficient users of nutrients brought in through the farm gate are the more intensive land uses such as feedlots and poultry farms, which reflects the feed-based, sometimes short term and heavily managed nature of these activities. The median IO ratio for grazing systems ranges between 3.8 for cattle for dairy and 6.0 for cattle for beef. This may reflect differences of P input method with P in feed going directly to animals whereas P ingested from pasture has been derived from landscape applied nutrients (fertiliser) that can be lost to soil or the environment. The lower P ratios for piggeries, feedlots and poultry, all feed-based systems are in line with this. Annual and perennial horticulture, horses and viticulture are statistically similar with high IO ratios.

Area weighted production losses vary according to land use (Table 1), reflecting the relative nutrient use and efficiency for different enterprises. Results for land uses with large sample sizes showed low variation and median figures of 9.5 kgP ha^{-1} yr^{-1} for cattle for beef, and 17.8 kgP ha^{-1} yr^{-1} for cattle for dairy. This corresponds with our understanding of nutrient use within these operations. Mixed grazing (properties with a mix of cattle and sheep or other animals) was significantly lower at 6.3 kgP ha^{-1} yr^{-1}. Sheep feedlots showed much higher losses, with a median production loss of 34.1 kgP ha^{-1} yr^{-1}.

Table 1. P Input:output ratios and production P losses. (Within columns, values with different letters are significantly different and increase alphabetically, $P < 0.05$).

		IO Ratio			**Production P loss (kg ha^{-1})**		
Landuse	Count	**Median**	Range	Group	**Median**	Range	Group
Annual Horticulture	2	**15.0**	10.5	e	**26.5**	34.2	ab
Beef feedlot	3	**2.3**	1.0	abc	**300.2**	1167.2	c
Cattle for Beef	31	**6.0**	75.0	d	**9.5**	32.8	a
Cattle for Dairy	18	**3.8**	11.2	cd	**17.8**	88.6	a
Horses	7	**7.4**	36.0	e	**12.9**	392.2	ab
Mixed Grazing	16	**4.7**	12.6	cd	**6.3**	19.4	a
Perennial Horticulture	7	**n/a**	11.1	e	**0.3**	165.9	a
Piggery	5	**3.2**	11.5	bcd	**73.8**	726.8	b
Poultry Eggs	2	**3.3**	4.8	ab	**34.3**	74.4	ab
Poultry Meat	9	**0.9**	0.2	a	**-35.5**	464.9	a
Sheep Feedlot	2	**1.0**	0.03	a	**34.1**	8.4	ab
Viticulture	6	**17.4**	90.5	e	**25.5**	47.1	ab

Other land uses showed very large ranges and variations reflecting wide variability in potential P losses, such as for horses or beef feedlots (Table 1). In a number of cases, the farm-gate balance resulted in negative P production loss values and may indicate incomplete data for the nutrient balance, or drawdown on existing nutrient reserves whilst maintaining low input levels. A number of the poultry meat operations had negative P Production values and this may be due to several factors including imprecision in audit figures such as manure quantity and nutrient content at some poultry farms. Some operations import and export very large numbers of animals, especially poultry farms and in these cases, small errors in P content of birds may be sufficient to produce significant imbalances in the audit.

Nonetheless, the nutrient balance data demonstrate that some intensive land uses have high production losses and therefore potential for high environmental losses. These include beef feedlots and piggeries, and to a lesser extent sheep feedlots, poultry for eggs, and annual horticulture and viticulture. All of these are quite intensive enterprises, and this result is not unexpected. The production loss for horses is more surprising, especially as this is an increasing landuse that tends to be seen more as a peri-urban landuse than agricultural. The losses for beef and dairy cattle and mixed grazing appear consistent with intensity of feed and fertiliser regimes. While lower than the more intense landuses, the extensiveness of these uses in the catchment means that they are likely to contribute the most significant quantities at the catchment scale.

Use of farm gate balances as performance and environmental indicators

Oenema *et al.* (2003) note that farm gate budgets can function as measures of environmental pressure, and are the most suitable form of material budget for use as performance indicators. They integrate farm information, are user friendly and are more accurate than complex soil-surface budgets. Assessing the environmental impact of farm nutrients through traditional techniques of water quality sampling and load estimation requires training, expensive instrumentation and long time frames for data collection. The results to date suggest farm gate balances are useful performance indicators.

There was some variation in the median IO ratio of 6.0 and a production P loss of 9.5 kgP ha^{-1} for Cattle for Beef (Figure 2). Similar patterns are found in the other dominant land uses. To further our understanding of this variation within a land use we compared the IO ratio with the production P loss per ha, to see how these variables might influence potential environmental nutrient losses.

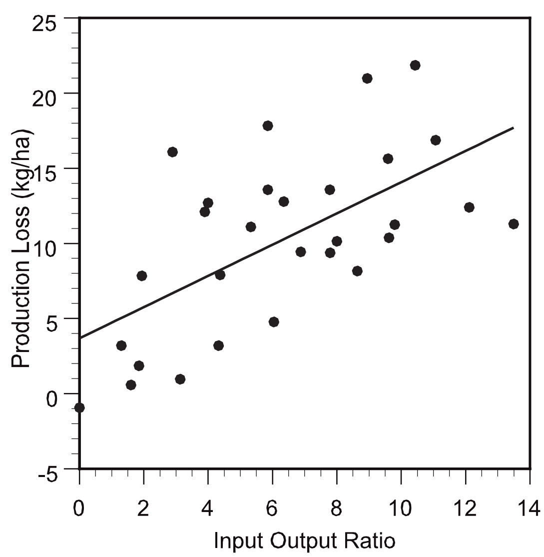

Figure 2. Production P loss compared to P IO ratio – cattle for beef.

Intuitively, we found a weak positive relationship between area weighted production loss and nutrient use efficiency (Figure 2) for cattle for beef (R^2 0.38, $P \leq 0.05$) suggesting that IO ratios should not be used in isolation to imply environmental performance. Similar but weaker relationships were found in cattle for dairy (R^2 0.34, $P \leq 0.05$), and for mixed grazing (R^2 0.13, $P \leq 0.2$), suggesting that other factors have an influence, but not ruling out the need to reduce P IO ratios.

Estimated environmental losses (Weaver *et al.*, [submitted]) were compared to farm nutrient inputs (Figure 3). A strong positive relationship (R^2 0.74, $P \leq 0.05$) indicated that the level of P inputs strongly influenced environmental losses. In other words, the higher intensity the cattle for beef system, the greater the likely level of P loss to the environment. Similar results were found with cattle for dairy (R^2 0.88 $P \leq 0.05$), mixed grazing (R^2 0.64 $P \leq 0.05$) and horses (R^2 0.99 $P \leq 0.05$).

While the link between inputs and estimated losses may appear obvious, and has analogies in human health (diet and weight), it has great significance when choosing BMPs for nutrient management. It appears that the P IO ratio from a farm gate nutrient balance can indicate P conversion efficiency and point the way to potential problems, and there may be savings for farmers involved if P IO ratios and production losses are reduced. Phosphorus IO ratios may be improved through the use of more productive farming systems (eg perennial pastures) without necessarily reducing the level of P inputs, but it is not known whether the relationship between inputs and loss (Figure 3) will change (reduce slope) under these systems. We suggest that to attain long term nutrient reduction the best BMPs will improve P IO ratio and reduce production losses by reducing farm P inputs and increasing outputs. This will clearly focus attention on reducing nutrient loss risks at their source, rather than relying on management actions further down the treatment train through the use of riparian buffers and wetland systems. This focus should also encourage more efficient use of limited nutrient resources.

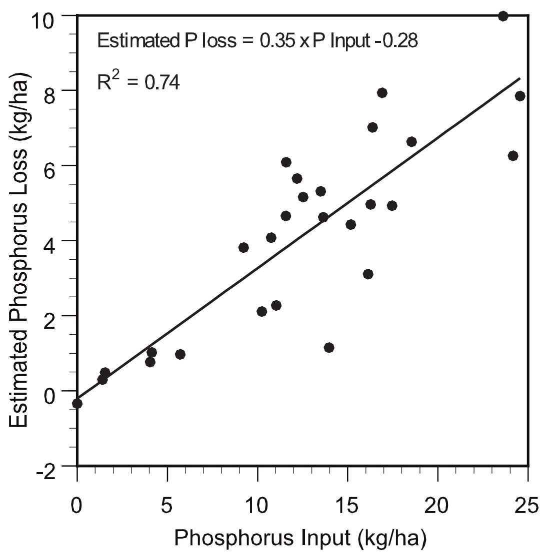

Figure 3. Estimated P loss compared to farm P inputs – cattle for beef.

CONCLUSIONS

Farm gate balances can be used to assess aspects of farm P efficiency, and as such are being used increasingly internationally. The simple form used in this study is relatively easy to conduct, although problems have emerged with small sample sizes and some land uses which may limit the applicability of the technique. For land uses such as cattle for beef and dairy, where large sample sizes can be obtained, accurate results can be derived.

This study suggests that farm-gate balances may also provide useful data for nutrient modelling work, which would be costly and difficult to provide through other conventional means such as water quality monitoring.

Finally, the results suggest that farm gate nutrient balances are useful tools in estimating individual farm performance, and as environmental indicators at an enterprise and catchment scale. Whilst it appears that farm P inputs drive P loss, the most effective BMPs will deliver P use efficiency improvements along with reduced P inputs to the farm gate, increased P outputs (products) from the farm without increasing inputs, and reduced production losses.

ACKNOWLEDGEMENTS
This research was funded through the Coastal Catchments Initiative with funds from the Natural Heritage Trust administered by Environment Australia.

REFERENCES

Berry P.M., Stockdale E.A., Sylvester-Bradley R., Philipps L., Smith K.A., Lord E.I., Watson C.A. and Fortune S. (2003). N, P and K budgets for crop rotations on nine organic farms in the UK. *Soil Use and Manage*, **19**(2), 112-118.

Cassell E.A., Dorioz J.M., Kort R.L., Hiffmann J.P., Meals D.W., Kirschtel D. and Braun D.C. (1998). Modeling phosphorus dynamics in ecosystems: mass balance and dynamic simulation approaches.*J. Environ. Qual.* **27**, 293-298.

Cassell E.A., Kort R.L., Meals D.W., Aschmann S.G., Dorioz J.M. and Anderson D.P. (2001). Dynamic phosphorus mass balance modelling of large watersheds: long-term implications of management strategies. *Wat. Sci. Tech.*, **43**(5), 153-162.

Goodlass G., Halberb N. and Verschuur G. (2003). IO accounting systems in the European community – an appraisal of their usefulness in raising awareness of environmental problems. *Europ. J. Agron.*, **20**, 17-24.

Heathwaite A.L., Fraser A.I., Johnes P.J., Hutchins M., Lord E. and Butterfield D. (2003). The Phosphorus Indicators Tool: a simple model of diffuse P loss from agricultural land to water. *Soil Use And Manage.*, **19**, 1-11

Hodgkin E.P. and Hamilton B.H. (1993). Fertilisers and eutrophication in southwestern Australia: Setting the scene. *Fert. Res.*, **36**, 95-103.

Keller A. and Schulin R. (2003). Modelling regional-scale mass balances of phosphorus, cadmium and zinc fluxes on arable and dairy farms. *Europ. J. Agron.*, **20**, 181-198.

Lord E.I., Anthony SG. and Goodlass G. (2002) Agricultural nitrogen balance and water quality in the UK. *Soil Use & Manage.*, **18**, 363-369.

McKergow L.M., Weaver D.M., Prosser I.P., Grayson R.B. and Reed A.E.G. (2002) Before and after riparian management: sediment and nutrient exports from a small agricultural catchment, Western Australia. *J. Hydrol.*; **270**, 253-272.

Moody P.W., Reghenzani J.R., Armour J.D., Prove B.G. and McShane T.J. (1996). Nutrient balances and transport at the farm scale – Johnstone River catchment. In: Downstream Effects of Land Use, H.M. Hunter, A/G. Eyles G.E. Rayment (eds.), Department of Natural Resources, Queensland. pp. 347-351.

National Land and Water Resources Audit (2001). http://www.nlwra.gov.au/atlas

Neville S and Weaver D.M. (2003). Avoiding the "fat" of the land: case studies of agricultural nutrient balance, *Riprap*, **25**, 10-13.

Nord E.A. and Lanyon L.E. (2003). Managing material transfer and nutrient flow in an agricultural watershed. *J. Environ. Qual*, **32**, 562-570.

Öborn I., Edwards A.C., Witter E., Oenema O., Ivarsson K., Withers P.J.A., Milsson S.I. and Stinzing A.R. (2003). Element balances as a tool for sustainable nutrient management: a critical appraisal of their merits and limitations within an agronomic and environmental context. *Europ. J. Agron.*, **20**, 211-225.

Oenema O., Kros H and de Vries W. (2003). Approaches and uncertainties in nutrient budgets: implications for nutrient management and environmental policies. *Europ. J. Agron.*, **20**, 3-16.

Reuter D. (1999). Regional audits of nutrient balance in farming systems. Methods Paper, National Land and Water Resources Audit. Canberra.

Reuter D and Judson G. (2003). Nutrient Concentration of Agricultural Produce. National Land and Water Resources Audit: www.potash-info.com/research/nutrientconc/nutrientconc.htm.

Sacco D., Bassanino, M. and Grignani, C. (2003). Developing a regional agronomic information system for estimating nutrient balances at a larger scale. *Europ. J. Agron.*, **20**, 199-210.

SCARM (1998). Sustainable Agriculture: Assessing Australia's Recent Performance. CSIRO Publishing, Melbourne.

Summers R.N., Smirk D., and Karafilis, D. (1996). Phosphorus Retention and Leachate From Sandy Soil Amended with Bauxite Residue (Red Mud). *Aust. J. Soil Res.*, **34**, 555-567

US EPA, (1997). Techniques for Tracking, Evaluating and Reporting the Implementation of Nonpoint Source Control Measures - Agriculture. United States Environmental Protection Agency, Office of Water.

Vanderholm D.H. (1984). Agricultural Waste Manual. NZAEI Project report No. 32. NZAEI, Lincoln College, Canterbury, New Zealand

Watson C.A., Bengtsson H., Ebbesvik M., Løes A-K., Myrbeck A., Salamon E., Schroder J. and Stockdale E.A. (2002). A review of farm-scale nutrient budgets for organic farms as a tool for management of soil fertility. *Soil Use and Manage.*, **18**, 264-273.

Weaver D.M. and Reed A.E.G. (1998). Patterns of nutrient status and fertiliser practice on soils of the south coast of Western Australia. *Ag. Ecos. & Environ.*, **67**, 37-53.

Weaver D.M., Neville S. and Deeley D.M. (2003). Addressing off-site nutrient pollution through conventional management actions: a modelling case study. 28th International Hydrology and Water Resources Symposium 10 - 14 November 2003, Wollongong, NSW. Vol 2, 123-130.

Weaver D.M., Neville S.D., Summers R.N., Deeley D.M., Clarke M. (submitted). Reducing nutrient discharge from agriculture through the implementation of BMPs – how far can we go? Submitted to *Wat. Sci. Tech.*.

Young W.J., Farley T.F. and Davis J.R. (1995). Nutrient management at the catchment scale using a decision support system. *Wat. Sci. Tech/*, **32**(5-6), 277-282.

Young W.J., Marston F.M. and Davis, J.R. (1996). Nutrient exports and land use in Australian catchments. *J. Environ. Man.*, **47**, 165-183

Young W.J., Marston F.M. and Davis J.R. (1997). NEXSYS: An Expert System for Estimating Diffuse Source Nutrient Export Rates. *AI Applications*, **11**(2), 11-18.