Modelling Nutrient Loads in Large-Scale River Networks for The National Land And Water Resources Audit

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INTRODUCTION

As a part of the National Land and Water Resources Audit (NLWRA), sediment and nutrient transport were modelled in large-scale networks across Australia. This report describes the nutrient transport model and its validation at the national scale. The model – ANNEX (Annual Network Nutrient Export) is a static model that predicts the average annual loads of phosphorus and nitrogen in each link in a river network under given catchment conditions. ANNEX is based on a node-link representation of a river network and because of its dependence on the suspended sediment budget, it is run in conjunction with the SedNet model (Prosser *et al.*, 2001) For each link ANNEX requires values for the sediment-bound and dissolved nutrient inputs from the immediate catchment of the link. ANNEX then routes nutrient loads through the river network estimating the losses associated with floodplain and reservoir sedimentation and instream denitrification. While the sediment-bound and dissolved nitrogen budgets are calculated separately, for phosphorus, the exchanges between the sediment-bound and dissolved phases during transport are modelled.

ANNEX has been calibrated for "current conditions" at a national scale using nutrient load estimates from flow and water quality measurements at 93 stations. Improved predictions of nutrient loads at a regional or catchment scale are probably attainable by calibrating to local load estimates, and by using better local input data.

NUTRIENT BUDGETS

ANNEX calculates static budgets of phosphorus and nitrogen loads for a node-link representation of a river network, with each link have a spatially explicit "internal" catchment area, and a spatially explicit floodplain extent. On-river reservoirs are represented as separate links in the river network. For a description of the river network used in the NLWRA and its derivation, see Prosser *et al.* (2001). The nutrient budgets calculated by ANNEX are average annual budgets. All budget terms have dimensions of $M\ T^{-1}$ (mass per unit time). ANNEX considers only the physical (not biological) stores of nutrients in the river system, and is also primarily concerned with the physical nutrient transport processes. It does however, consider denitrification – a biological process mediated by physical conditions, and phosphorus adsorption-desorption a physical process influenced by biological activity. ANNEX therefore assumes that at the annual time scale the changes in biological nutrient stores with a river network link, and the fluxes between river network links due to biological transport processes are small in comparison to the fluxes due to physical nutrient transport processes and the changes in physical nutrient stores.

Nutrient Sources

ANNEX explicitly includes the following separate nutrient source terms to each network link:

- sediment-attached nutrient load from tributary links (*TSN*)
- dissolved nutrient load from tributary links (*TDN*)
- sediment-attached nutrient load from internal catchment hillslope erosion (*HSN*)
- sediment-attached nutrient load from internal catchment gully erosion (*GSN*)
- sediment-attached nutrient load from link channel bank erosion (*BSN*)
- dissolved nutrient load from internal catchment surface and sub-surface runoff (*RDN*)
- dissolved nutrient load from point source discharges (*PDN*)

The total nutrient load (*TNL*) to a link is therefore:

$$TNL = TSN + TDN + HSN + GSN + BSN + RDN + PDN \qquad 1$$

In the implementation of ANNEX for the NLWRA, data for *HSN*, *GSN*, *BSN* and *RDN* were derived from other models, as described below. Data for *PDN* were obtained from the National Pollutant Inventory (NPI, 2001) as described below.

Hillslope Erosion – *HSN*

The nutrient loads to a link from hillslope erosion are estimated as the product of the fine sediment load and nutrient concentrations of this load. For the NLWRA the fine sediment loads to network links from hillslope erosion were estimated in SedNet as the product of the total hillslope erosion generated in the internal catchment area of a link and a sediment delivery ratio (SDR) (Prosser, *et al., 2000*). The total hillslope erosion load was based on the USLE predictions of Lu *et al.*, (2001) summed across the grid cells within a internal catchment of a link (Prosser *et al.*, 2001). The nutrient concentration of the fine sediment load is determined from the percentage clay (%C) of the hillslope soil, and the nutrient concentration (SC) in the bulk hillslope soil. ANNEX uses a two-part mixing model that assumes that all the nutrients in the soil are associated with the clay fraction. For the NLWRA implementation, values for the percentage clay and the nutrient concentrations of the bulk soil were the means of the grid cell values across the internal catchment of the data in the Australian Soil Resources Information System (Bui *et al.*, 2001). For internal link-catchments where the percentage clay is greater than the sediment delivery ratio, all the sediment delivered to the channel is assumed to be clay, and the nutrient concentration of this delivered fraction (NC) is the bulk soil nutrient concentration divided by ('enriched by') the percentage clay of the hillslope soil:

$$If\ \%C > SDR,\ NC = \frac{SC}{\%C} \qquad 2$$

Where the percentage clay is less than the hillslope delivery ratio, only a proportion of the delivered load is clay, and so the above nutrient load is reduced by the ratio of the percentage clay to the hillslope delivery ratio:

$$If\ \%C < SDR,\ NC = \frac{SC}{\%C} * \frac{\%C}{SDR} = \frac{SC}{SDR} \qquad 3$$

Gully and Stream-bank Erosion – *GSN* and *BSN*

The nutrient loads to a link from each of gully erosion and stream-bank erosion, are estimated as the product of the fine sediment load and the nutrient concentration of these loads. For the NLWRA modelling the fine sediment loads from gully erosion and bank erosion were assumed in SedNet to be 50% of the total sediment load from each of these sources (Prosser *et al.*, 2001). The predictions of total gully erosion and total bank erosion loads used in SedNet and ANNEX are described in Prosser *et al.* (2001). In the NLWRA implementation of ANNEX spatially constant nutrient concentrations were assumed for the fine sediment fraction of the gully and bank erosion loads: for phosphorus a value of 0.25 g/kg was used, and for nitrogen a value of 1.0 g/kg was used.

Surface and Sub-surface Runoff – *RDN*
The dissolved nutrient loads associated with surface runoff and sub-surface drainage to the river are combined into a single input term. For the NLWRA implementation of ANNEX values for this term were derived from the BIOS modelling of the soil-plant atmosphere nutrient fluxes of Raupach *et al.* (2001). The BIOS modelling estimated an average annual loss to leaching and runoff on a 5 km grid across Australia. The sum of the grid cell values of this term within the internal link-catchment were calculated and multiplied by a nutrient delivery ratio. The nutrient delivery ratio accounts for the nutrient losses that occur due to adsorption of nutrients onto soil particles during sub-surface flow, and the biological uptake of dissolved nutrients from surface runoff passing through the riparian zone. As data to quantify the magnitude of these losses were not available, the nutrient delivery ratios were treated as calibration parameters for the model.

Point Source Discharges – *PDN*
The dissolved nutrient loads associated with point sources are summed to a single term for each link. For the NLWRA implementation of ANNEX the only point source data used were those of NPI (2001) that provides estimates of nutrient loads discharged from industrial and other urban point sources during 1999-2000. Only point sources that were mapped to be located within 5 km of a river were included, and it was assumed that these loads discharged directly to the nearest river link and were not reduced by land disposal or other treatment measures. Point sources located more than 5 km from a river were omitted as it was assumed they would be greatly modified by land disposal or other treatment. Point sources located close to estuarine river links were omitted, as these point sources generally have coastal or off-shore discharge point. Data for the nutrient loads from agricultural point sources were not available for the NLWRA modelling.

Nutrient Sinks

ANNEX includes three sink or loss terms: (i) deposition of sediment-attached nutrients on floodplains, (ii) deposition of sediment-attached nutrients in reservoirs, and (iii) denitrification of dissolved nitrogen to atmospheric nitrogen gas. SedNet assumes no long term net accumulation of fine sediment in the river channel itself (Prosser *et al.*, 2001) and so ANNEX assumes no net long term accumulation of nutrients in river channel stores. It should be noted however, that in spite of no net long term accumulation, transient in-channel stores of nutrients are likely to be considerable, and can be an important nutrient source to instream biological production.

Deposition of suspended sediment on floodplains is predicted by SedNet using particle settling theory (Prosser *et al.*, 2001) and a floodplain extent delineated for each network link by steady flow hydraulic modelling (Pickup and Marks, 2001). The nutrient load deposited with the fine sediment is estimated in ANNEX as the product of the fine sediment load deposited and the nutrient concentration of the suspended sediment in the network link.

Deposition of fine sediment in reservoirs is predicted by SedNet as a function of the reservoir volume and the mean annual inflow (Prosser *et al.*, 2001). Because of tributaries, most reservoirs are represented by multiple network links. SedNet associates all reservoir fine sediment deposition with the most downstream link of the reservoir. ANNEX estimates the nutrient load deposited in reservoirs as the product of fine sediment deposition load and the nutrient concentration of the suspended sediment in this network link.

ANNEX models the losses of nitrogen due to denitrification of dissolved nitrogen (assumed to be nitrate). The loss is modelled as an exponential decay process that is a function of the area of channel bed (*A*) and a representative flow (*Q*) for the network link, and a temperature dependent and substrate dependent assimilation rate coefficient (*k*):

$$DNL_{OUT} = DNL_{IN} e^{-\frac{kA}{Q}} \qquad 4$$

where *DNL* is the dissolved nitrogen load. The channel bed area over which the assimilation process occurs is estimated in ANNEX as the product of the link mean bankfull width (*w*) and the link length (*L*).

ANNEX uses the following functions for *k* (in m/day) in terms of substrate type and mean annual water temperature (*T*) in degrees Celsius, that are based on measurements of denitrification in Australia rivers from Ford (*pers. comm.*):

$$k_{SAND} = 0.0001 * T \qquad 5$$

$$k_{MUD} = 0.0002 * T \qquad 6$$

In the NLWRA implementation of ANNEX, the substrate type for a link was obtained assumed to be mud, except when SedNet predicted deposition of coarse sediment in the link, in which case the substrate was assumed to be sand. The mean annual water temperature was assumed to be reasonably estimated by the mean annual air temperature. Values for the mean annual air temperature for each link were determined from the ANUCLIM gridded surface of mean annual temperatures (Houlder *et al.*, 2000). The value for a link was the mean of the grid cell values for the cells in the internal link catchment. Link length was calculated from the 250 m digital elevation model on which the river network was defined, and the link mean bankfull widths values predicted by SedNet were used in the NLWRA implementation of ANNEX.

The representative discharge in Equation 4 is the single flow value that gives the same average proportional denitrification loss in Equation 4 as the full time series of daily flows. Using one hundred years of modelled daily flows for six different gauging stations on perennial rivers in New South Wales the representative discharge was found to be well related to the median daily flow. The stations used ranged in catchment area from 400 km^2 to 66,000 km^2. Across these stations the representative discharge averaged 1.09 times the median discharge, with a standard deviation of 0.04 times the median discharge. Data from the more ephemeral Warrego River indicated a representative discharge of 1.27 times the median discharge. In the NLWRA implementation of ANNEX a value of 1.10 times the median daily flow was used as the representative discharge for denitrification. Calculations showed that the denitrification loss is not highly sensitive to the choice of representative flow value. Using the median flow for perennial rivers would only lead to an average of 7% over-prediction in denitrification loss. Values for the median daily flow for each link were obtained using the hydrological regionalisations described in Young (2001).

Phosphorus Transformations

ANNEX assumes that the phosphorus in transport is mainly inorganic phosphate, and assumes that phosphorus exists in both the dissolved phase and in phases which represent fully reversible adsorption to the suspended sediments. The total phosphorus load (*TPL*) in a network link therefore depends on the suspended sediment concentration (*SSC*) and the concentration of phosphorus in the sediment (*SPC*, dimensions M M^{-1}), and on the flow volume – the mean annual flow (*MAF*) and the dissolved phosphorus concentration (*DPC*, dimensions M L^{-3}):

$$TPL = SPC * SSC + DPC * MAF \qquad 8$$

In the NLWRA implementation of ANNEX values of SSC were obtained from SedNet and values of *MAF* from the hydrologic regionalisations described in Young *et al.* (2001).

ANNEX also assumes that the concentration of phosphorus adsorbed to the suspended sediment is in equilibrium with the dissolved phosphorus concentration. A linear adsorption isotherm is assumed, and an adsorption coefficient (K_d) is used that describes the ratio of the phosphorus concentration in the suspended sediment to the dissolved phosphorus concentration (Webster *et al.*, 2001), as shown in Equation 9:

$$SPC = K_d * DPC \qquad 9$$

Equations 8 and 9 are used in ANNEX to partition the total phosphorus load in a link (from Equation 1) into a dissolved fraction and a sediment-attached fraction using the known values of *MAF*, *SSC*, and K_d.

Values for the adsorption coefficient (K_d) for exchangeable phosphorus in lowland Australian rivers range from 0.95 to 4.0 m^3/kg (Webster *et al.*, 2001), while values of K_d for upland rivers are poorly known. ANNEX however, uses K_d to partition the total phosphorus load between the suspended sediment and the dissolved phase, hence values of K_d based on total sediment phosphorus rather than exchangeable sediment phosphorus are required. Data from Hancock (*pers. comm.*) indicate that the total phosphorus content of suspended sediment in the Namoi river is about 20 times higher than the exchangeable phosphorus content, suggesting values of K_d for total phosphorus in the range of 20 to 80. Because of the scarcity of data to evaluate K_d, K_d is used as a calibration factor in ANNEX. Adjusting K_d not only alters the balance between dissolved and particulate phosphorus, but because there is no loss pathway for dissolved phosphorus in ANNEX, adjusting K_d also alters the total phosphorus load exported from river basins. For higher proportions of dissolved phosphorus, the relative loss of phosphorus from transport is lower, and hence total exports are higher.

RIVER NUTRIENT MODEL CALIBRATION

The NLWRA implementation of ANNEX depended on modelled data for river sediment loads, runoff nutrient loads, and river hydrology. Each of these modelling exercises included their own calibrations, and the documentation cited in the report for these models should be sourced for details. To calibrate ANNEX, the predicted nutrient loads were compared to nutrient loads estimated from flow and water quality data for 93 stations across Australia (Figure 1, Appendix A). Because of time constraints the selection of calibration sites was limited to immediately available data. The heavy dependence on Victorian sites resulted in a strong geographic bias (Figure 1). Because only a limited data set was immediately available, only a single Australia-wide calibration of ANNEX was undertaken.

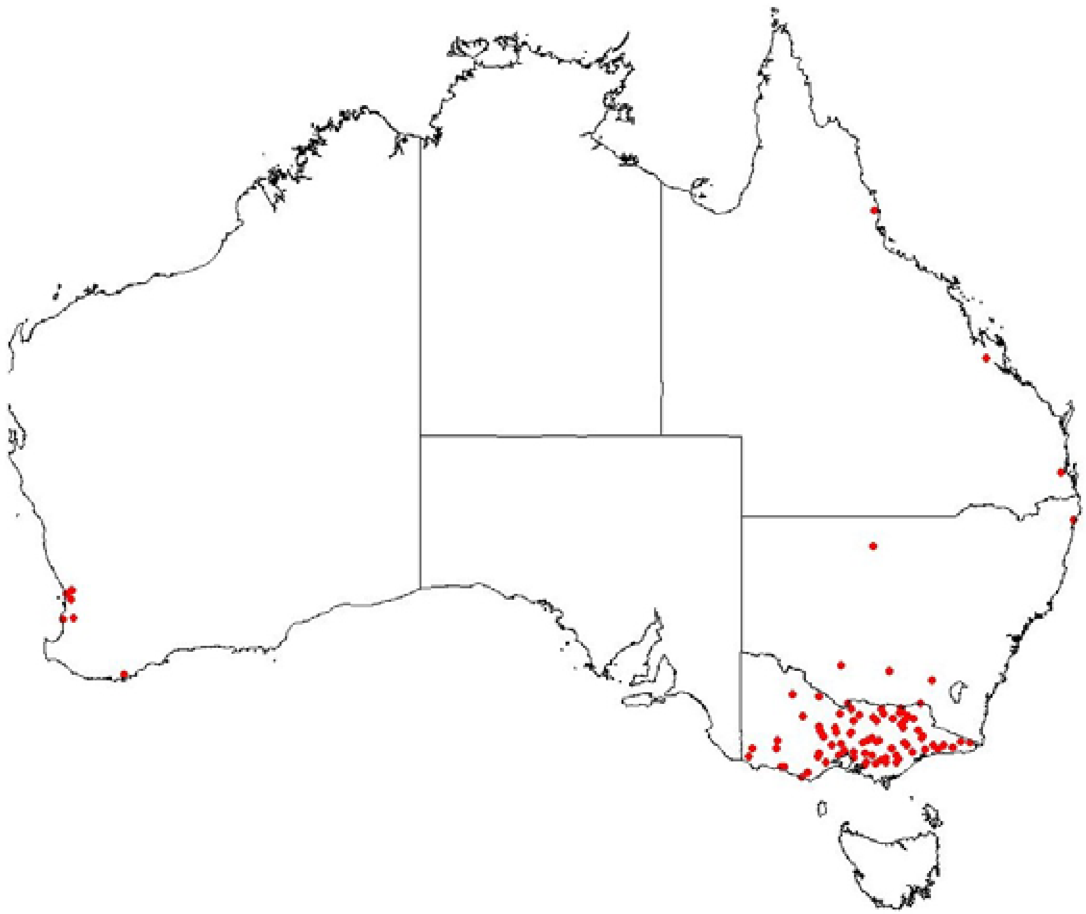

Figure 1: Geographic distribution of ANNEX calibration sites.

The majority of the estimated ('measured') loads at calibration sites were calculated as the product of the mean of the measured nutrient concentrations and the gauged mean annual flow. At a small number of sites paired flow and nutrient concentration data at either monthly or annual times scales were used to first calculate historic monthly or annual loads, and from these calculate mean annual load. Because nutrient sampling at the calibration sites was infrequent, the concentration data are strongly biased towards low flow conditions, and insufficient data were available to construct reliable rating curves to predict concentration as a function of flow. Because the nutrient sampling at most calibration sites are biased towards low flow conditions, it is likely that they substantially under-estimate the true loads. The calibration of ANNEX therefore did not seek to minimise the differences between the model predictions and gauge estimates. Rather, ANNEX parameters were adjusted so that the predicted loads were higher than the estimated loads to an extent determined largely by professional judgement. Two other predicted measures were considered in the calibration process: firstly, the ratio of dissolved phosphorus to total phosphorus, and secondly, the ratio of total nitrogen to total phosphorus. ANNEX parameters were adjusted to give as good as possible match between the predicted and the 'measured' values of these ratios. For the proportion of dissolved phosphorus, data were available for only 69 of the 93 calibrations sites. The calibration data sets did not contain data for the partitioning of total nitrogen into dissolved and sediment-attached fractions.

Three parameters in ANNEX were adjusted in the calibration process: the dissolved phosphorus delivery ratio and the dissolved nitrogen delivery ratio which determined the proportion of the BIOS-predicted water-borne nutrient loads that reach the river network, and the adsorption coefficient (K_d) that determined the partitioning between dissolved and sediment-bound phosphorus in the river network. Because SedNet was calibrated separately, no calibration of the nutrient loads entering the river with sediment was undertaken in ANNEX. Adjustment of the dissolved nutrient delivery ratios was used to obtain the correct magnitude of total load. Adjustment of K_d served two purposes, it directly allowed calibration of the ratio of dissolved to sediment-bound phosphorus, and in addition, because the only loss pathways for phosphorus in ANNEX are for sediment-attached phosphorus, adjustment of K_d altered the proportion loss of phosphorus from the river network and thus affected the calibration of phosphorus exports from the river network to receiving waters. Because of the lack of dissolved nitrogen data for the calibration sites, the ratio of dissolved nitrogen to total nitrogen is uncalibrated. Furthermore, no data were available to calibrate the denitrification loss within ANNEX. Any errors in the predicted denitrification rates are likely to have been compensated for in the calibration process by adjustment of the dissolved nitrogen delivery ratio. Any such compensation will have lead to errors in the uncalibrated ratio of dissolved to total nitrogen. This aspect of ANNEX calibration is one that requires further work and better calibration data sets.

In the NLWRA implementation of ANNEX the calibration parameters were not optimised to obtain a best fit of predictions to measurements across the measures described above, but rather, trial and error refinements of model parameters over multiple models runs were made to obtain reasonable model performance. The final values of the calibration parameters for the NWLRA implementation of ANNEX were: a dissolved nitrogen delivery ratio of 0.08, a dissolved phosphorus delivery ratio of 0.02, and a K_d value of 40.

Nutrient Loads and Export Rates

For the NLWRA implementation of ANNEX the calibration of nutrient loads, as noted above, did not aim to minimise the difference between the model predictions and the estimates based on water quality data. The final parameter set "over-predicts" total phosphorus loads by 1.8 times on average, and "over-predicts" total nitrogen loads by 2.4 times on average. While it is very likely that the loads estimated using water quality data under-estimate the true loads, the extent of this under-estimation is unquantified, and hence the calibration should be considered an 'order of magnitude' calibration. The different phosphorus and nitrogen load calibrations are a result of seeking a reasonable match between predicted and measured nitrogen to phosphorus ratios.

A measure of model error (E) was used to assess model performance. E is the mean percentage of the ratio of the root-mean-square difference between the predicted and observed value to the observed value (Equation 10).

$$E = \frac{1}{n}\sum_{i=1}^{n}\frac{\sqrt{\left(PRED_i - OBS_i\right)^2}}{OBS_i} \times \frac{100}{1} \qquad 10$$

For the total phosphorus loads the model error was *E*=117.3% and for total nitrogen loads the model error was *E*=156.7%. Plots of predicted loads vs observed loads indicate the scatter across calibration sites (Figure 2). Figure 2 shows reasonable agreement between the predictions and observations over four orders of magnitude. However, at any scale there is considerable scatter, particularly in the nitrogen loads.

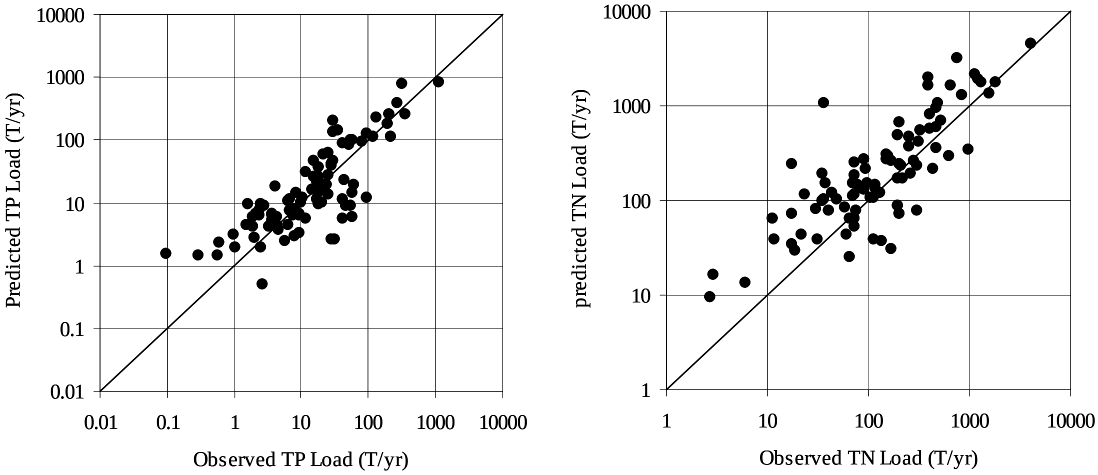

Figure 2: Comparison of predicted and observed average annual nutrient loads.

Figure 2 suggests less scatter (better predictions) at higher loads. However, because the highest loads are often associated with the highest flow volumes (hence largest drainage area), a comparison of areal nutrient export rates (kg/ha/yr) is also useful (Figure 3). Figure 3 indicates a similar degree of scatter across all magnitudes of export rates. The model errors (*E*) for export rates are of course the same as for loads as both the predicted and observed values are scaled by the same drainage areas.

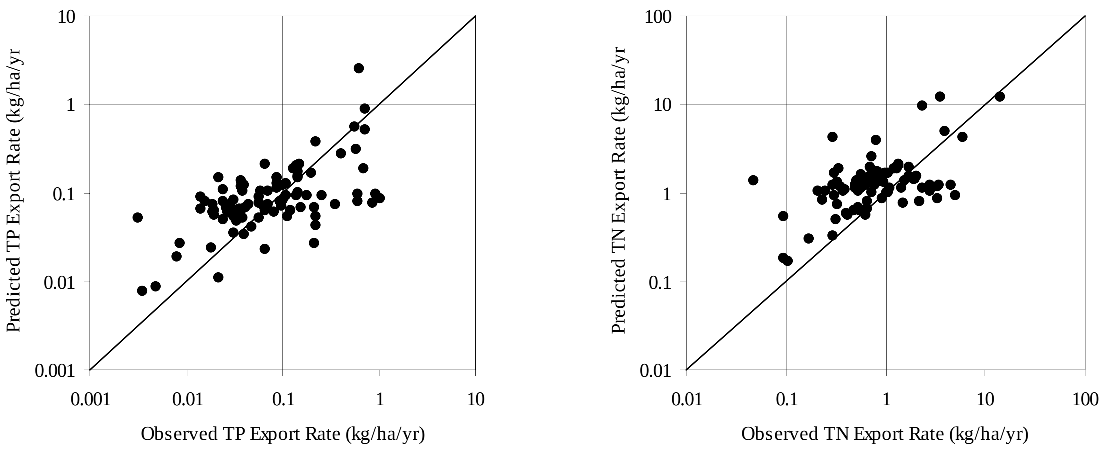

Figure 3: Comparisons of predicted and observed average annual nutrient export rates (kg/ha/yr).

Nutrient Ratios

Comparisons of the predicted and observed values of the ratio of dissolved to total phosphorus show a reasonable calibration was achieved at the national scale, with an average observed ratio 0.25 and an average predicted ratio of 0.30. However, the model error (*E*) for this ratio is high (178.9%) reflecting the large amount of scatter across the calibration sites (Figure 4). There are several possible reasons for the poor matching of dissolved to total phosphorus loads across calibration sites. Given that *MAF* and the suspended sediment load are both reasonably calibrated, the above results may be due to the assumption of a spatially constant K_d value. The few data available for K_d do show significant variation between sites (see Webster *et al.*, 2001), however, the reasons for these variations are unclear and so do not provide a basis for estimating spatial variations in K_d. The poor matching of dissolved phosphorus to total phosphorus ratios may also be due to the assumption of a spatially constant dissolved phosphorus delivery ratio. Further work is required to determine the processes that control this delivery, and their variability across the drainage network. Finally there may be considerable error in the measured dissolved and total phosphorus loads. Inspection of the data reveal large changes in the ratio of dissolved to total phosphorus over short distances (<10 km) in some Victorian rivers for no obvious reason. The reliability of the measurements is unknown.

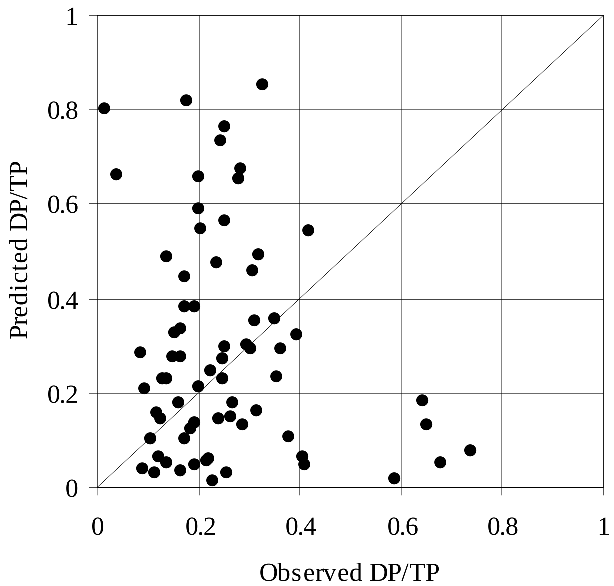

Figure 4: Comparison of predicted and observed ratios of dissolved to total phosphorus.

Comparisons of the predicted and observed values of the total nitrogen to total phosphorus ratio also indicate a reasonable calibration was achieved at the national scale, with an average observed value of 13.3 and an average predicted value of 15.6. The general spread of total nitrogen to total phosphorus ratios is similar for the predicted and observed values (Figure 5), although the observations show more scatter, and more observations plotting below the 'Redfield ratio' of TN:TP=6.8 by weight (Redfield, 1958). The Redfield ratio is the ratio in which algae use nitrogen and phosphorus.

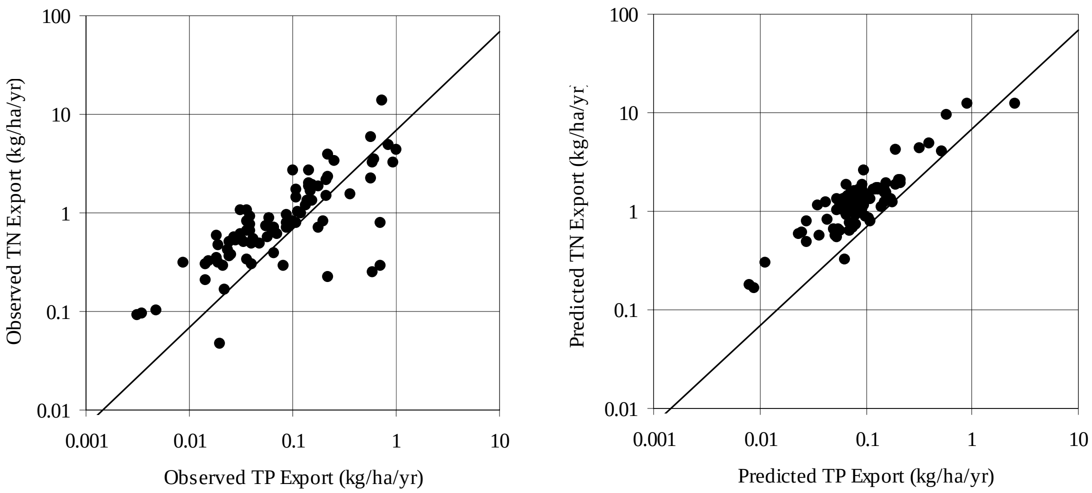

Figure 5: Total nitrogen vs total phosphorus for the observed data and predicted data at calibrations sites. The lines represent the Redfield ratio of TN:TP = 6.8 by weight.

In spite of the reasonable national calibration for nitrogen to phosphorus ratios, the model error (*E*) for this ratio is high (199.2%) reflecting the large amount of scatter across the calibration sites (Figure 6). As for the proportion of dissolved phosphorus, it is likely that calibration of ANNEX at a finer spatial scale is required to improve the matching of this ratio.

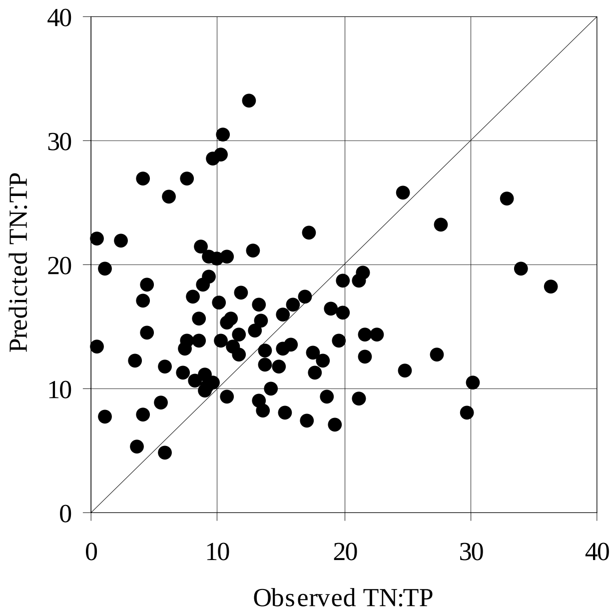

Figure 6: Predicted vs observed values of the ratio of total nitrogen to total phosphorus.

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APPENDIX A

Gauging stations used as ANNEX calibration sites indicating original data source. The loads for the Victorian stations were calculated by Bormans (*pers. comm.)* from the original water quality data and gauged mean annual flow values. Further information on gauging stations (including location) can be obtained from http://www.bom.gov.au/hydro/wr/sgc/index.shtml.

Gauge	River	N/P	Source
112000	South Johnstone	N,P	Furnas *et al.* (1995)
130002	Fitzroy	N,P	5 years QPEA data from Bormans (*pers. comm.*)
142000	South Pine	P	Cosser (1989)
203000	Richmond	N,P	McKee *et al.* (2000)
221201	Cann	N,P	(http://www.vicwaterdata.net)
221210	Genoa	N,P	(http://www.vicwaterdata.net)
221212	Bemm	N,P	(http://www.vicwaterdata.net)
222200	Snowy	N,P	(http://www.vicwaterdata.net)
222202	Brodribb	N,P	(http://www.vicwaterdata.net)
222206	Buchan	N,P	(http://www.vicwaterdata.net)
223202	Tambo	N,P	(http://www.vicwaterdata.net)
223205	Tambo	N,P	(http://www.vicwaterdata.net)
223208	Tambo	N,P	(http://www.vicwaterdata.net)
224201	Wonangatta	N,P	(http://www.vicwaterdata.net)
224203	Mitchell	N,P	(http://www.vicwaterdata.net)
224206	Wonangatta	N,P	(http://www.vicwaterdata.net)
225204	Macalister	N,P	(http://www.vicwaterdata.net)
225208	Thomson	N,P	(http://www.vicwaterdata.net)
225209	Macalister	N,P	(http://www.vicwaterdata.net)
225212	Thomson	N,P	(http://www.vicwaterdata.net)
226005	Latrobe	N,P	(http://www.vicwaterdata.net)
226209	Moe	N,P	(http://www.vicwaterdata.net)
226216	Tanjil	N,P	(http://www.vicwaterdata.net)
226222	Latrobe	N,P	(http://www.vicwaterdata.net)
226228	Latrobe	N,P	(http://www.vicwaterdata.net)
228204	Dandenong	N,P	(http://www.vicwaterdata.net)
228209	Lang Lang	N,P	(http://www.vicwaterdata.net)
228213	Bunyip	N,P	(http://www.vicwaterdata.net)
229200	Yarra	N,P	(http://www.vicwaterdata.net)
229214	Little Yarra	N,P	(http://www.vicwaterdata.net)
230200	Maribyrnong	N,P	(http://www.vicwaterdata.net)
230211	Emu	N,P	(http://www.vicwaterdata.net)
231204	Werribee	N,P	(http://www.vicwaterdata.net)
231213	Lerderderg	N,P	(http://www.vicwaterdata.net)
233200	Barwon	N,P	(http://www.vicwaterdata.net)
233215	Leigh	N,P	(http://www.vicwaterdata.net)
233223	Warrambine	N,P	(http://www.vicwaterdata.net)
235224	Gellibrand	N,P	(http://www.vicwaterdata.net)
235227	Gellibrand	N,P	(http://www.vicwaterdata.net)

236205	Merri	N,P	(http://www.vicwaterdata.net)
236209	Hopkins	N,P	(http://www.vicwaterdata.net)
238202	Glenelg	N,P	(http://www.vicwaterdata.net)
238204	Wannon	N,P	(http://www.vicwaterdata.net)
238206	Glenelg	N,P	(http://www.vicwaterdata.net)
238231	Glenelg	N,P	(http://www.vicwaterdata.net)
401201	Murray	N,P	(http://www.vicwaterdata.net)
401203	Mitta Mitta	N,P	(http://www.vicwaterdata.net)
401204	Mitta Mitta	N,P	(http://www.vicwaterdata.net)
401211	Mitta Mitta	N,P	(http://www.vicwaterdata.net)
402203	Kiewa	N,P	(http://www.vicwaterdata.net)
402204	Yackandandah	N,P	(http://www.vicwaterdata.net)
402205	Kiewa	N,P	(http://www.vicwaterdata.net)
402222	Kiewa	N,P	(http://www.vicwaterdata.net)
403200	Ovens	N,P	(http://www.vicwaterdata.net)
403205	Ovens	N,P	(http://www.vicwaterdata.net)
403230	Ovens	N,P	(http://www.vicwaterdata.net)
403241	Ovens	N,P	(http://www.vicwaterdata.net)
403244	Ovens	N,P	(http://www.vicwaterdata.net)
404200	Broken	N,P	(http://www.vicwaterdata.net)
404207	Holland	N,P	(http://www.vicwaterdata.net)
404210	Broken	N,P	(http://www.vicwaterdata.net)
404216	Broken	N,P	(http://www.vicwaterdata.net)
405200	Goulburn	N,P	(http://www.vicwaterdata.net)
405202	Goulburn	N,P	(http://www.vicwaterdata.net)
405203	Goulburn	N,P	(http://www.vicwaterdata.net)
405204	Goulburn	N,P	(http://www.vicwaterdata.net)
405205	Murrindindi	N,P	(http://www.vicwaterdata.net)
405209	Acheron	N,P	(http://www.vicwaterdata.net)
405219	Goulburn	N,P	(http://www.vicwaterdata.net)
405227	Big	N,P	(http://www.vicwaterdata.net)
405232	Goulburn	N,P	(http://www.vicwaterdata.net)
405240	Sugarloaf	N,P	(http://www.vicwaterdata.net)
406202	Campaspe	N,P	(http://www.vicwaterdata.net)
406207	Campaspe	N,P	(http://www.vicwaterdata.net)
406213	Campaspe	N,P	(http://www.vicwaterdata.net)
407202	Loddon	N,P	(http://www.vicwaterdata.net)
407203	Loddon	N,P	(http://www.vicwaterdata.net)
407210	Loddon	N,P	(http://www.vicwaterdata.net)
407215	Loddon	N,P	(http://www.vicwaterdata.net)
407221	Jim Crow	N,P	(http://www.vicwaterdata.net)
408200	Avoca	N,P	(http://www.vicwaterdata.net)
410004	Murrumbidgee	P	1 year DLWC data from Bormans (*pers. comm.*)
410005	Murrumbidgee	P	1 year DLWC data from Bormans (*pers. comm.*)
410136	Murrumbidgee	P	1 year DLWC data from Bormans (*pers. comm.*)
425000	Darling	P	GHD (1992)

602000	Kalgan	P	Bott (1993)
613000	Harvey	P	Birch (1982)
614000	Murray	P	Birch (1982)
614001	Serpentine	P	Birch (1982)
616004	Swan River	P	10 years of 2-weekly WQ data Bormans (*pers. comm.*)
616011	Avon River	P	Bormans (*pers. comm.*)
616027	Canning River	P	Bormans (*pers. comm.*)
616189	Ellen Brook	P	Bormans (*pers. comm.*)