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Uncertainty in Great Barrier Reef Catchment soil nutrient data - implications for land use management

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Abstract: The reduction of particulate nutrient loads (nitrogen and phosphorus) has been an important objective for managers of Great Barrier Reef Lagoon (GBRL) catchments. These loads are believed to be dominated by non-point sources, but end-of-catchment load measurements provide little insight into the distribution and relative magnitude of pollutant sources within the catchment. This has led to a reliance on computer modelling to identify probable pollutant sources and to devise and compare management strategies to deal with them. The most common modelling approach used in the GBRL region is to compute spatially-distributed budgets of nutrient sources and sinks. The largest source is usually hillslope erosion which is calculated using a form of the revised universal soil loss equation (RUSLE) and then assigned nitrogen and phosphorus contents to the soil based on values held in the Australian Soil Resource Information System (ASRIS). To this is added subsoil erosion from river banks and gullies where subsoil has traditionally been assumed to have spatially uniform phosphorus and nitrogen contents.

We assessed the uncertainty in the most recently updated ASRIS GBRL soil nutrient data and the implications of using these data for modelling and management of particulate nutrient loads at spatial scales ranging from individual farms to subcatchments with areas > 1000 sq. km. Bias in the assumed subsoil nutrient content suggests that particulate loads of subsoil phosphorus may be underestimated by 14% whereas subsoil nitrogen loads are likely to be overestimated by a factor of three. Variability (expressed as std dev/mean) of surface soil nutrient content at a single sampling site was 34% for nitrogen and 21% for phosphorus. When considering variability within the smallest resolved spatial units (unique mapping area, UMA) in ASRIS encompassing four or more sample sites the results were 38% and 48% for N and P, respectively. This level of intrinsic variability in the observed data in combination with the relatively large size of a UMA makes it very difficult to discriminate differences in nutrient fluxes at scales much less than 25 sq. km with confidence.

Keywords: catchment modelling; uncertainty; erosion; nutrients; ASRIS; Great Barrier Reef

1. INTRODUCTION

The reduction of sediment, nutrient (nitrogen and phosphorus), and pesticide loads is an important objective for managers of Great Barrier Reef Lagoon (GBRL) catchments (Brodie et al. 2003; Cogle et al. 2006; Williams 2001; Environment Australia 2002). Measurements of particulate nutrient loads at the mouths of some of the catchments have
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suggested a very large increase in pollutant loads entering the Great Barrier Reef Lagoon following European settlement and the commencement of large scale mining, agricultural and pastoral industries in the area (Furnas 2003; McCulloch et al. 2003). With > 95% of the land area subject to grazing, agricultural, or forestry uses and < 2% of the land area urbanised the pollutant loads are believed to be dominated by non-point sources. Cogle et al. 2006 used the catchment model SedNet/ANNEX to estimate nutrient loads for the GBRL catchments and found point sources to contribute 16% of dissolved nitrogen and 44% of dissolved phosphorus loads but just 4% of and total nitrogen and 3% of total phosphorus loads.

End-of-catchment load measurements have, however, provided little insight into the distribution and relative magnitude of pollutant sources within the catchment. This has led to a reliance on computer modelling to identify probable pollutant sources and to devise and compare management strategies to deal with them. The most common modelling approach used in the GBRL region is to use the model SedNet/ANNEX to compute sediment supply due to river bank, gully and hillslope erosion processes and then assign nitrogen and phosphorus contents to the sediment based on values held in the Australian Soil Resource Information System (ASRIS) (Bormans et al. 2004; McKergow et al. 2005; Cogle et al. 2006). Subsoil sediment (defined here as B-horizon and below) has traditionally been assumed to have a constant (non-spatially varying) nutrient content (due to a lack of sufficient spatial data) whereas hillslope sediments have a spatially varying nutrient content. Sediment supplied by hillslope erosion is calculated using a form of the revised universal soil loss equation (RUSLE) (Wilkinson et al. 2004).

Catchment models require, as input data, spatially distributed estimates of a range of parameters such as rainfall, potential evapotranspiration, slope, vegetation, land use, etc. Much, if not most, of the apparent spatial resolution of these data sets is based either on interpolation or extrapolation of much sparser measurement data sets (e.g. rainfall, gully density, soil nutrient content) and/or may rely on associations between directly observed parameters (e.g. satellite remote sensing of the electromagnetic spectrum) and the parameters of interest (e.g. various landscape attributes) (Jeffrey et al. 2001; Henderson et al. 2001). These input data sets will contain uncertainty arising from intrinsic natural variability of the directly measured data as well as from the inaccuracies in the procedures used to map the source data points into a spatial grid.

Here, we present an assessment of the uncertainty in GBRL soil nutrient data found in the ASRIS database and the implications for modelling and management of particulate nutrient loads at spatial scales ranging from individual farms to subcatchments with areas > 1000 sq. km. This is done by assessing the variability of the original measurement data stored in the Queensland Soil and Land Information (SALI) database system from which the ASRIS values were derived.

2. METHODS

2.1 The ASRIS database

The ASRIS data set contains the up-to-date soil-related information for all of Australia. The structure of the data set is described in detail by (McKenzie et al. 2005). ASRIS is a repository for data and allows for 7 ranges of spatial resolution ranging from 10 m to 30 km. The resolution of any particular data set accessed through ASRIS reflects the resolution of the data supplied by the contributing agency. The resolution of soil nutrient data varies across GBRL catchments depending on the nature of the original surveys (e.g. soil survey, land system survey, land resource area survey) for which the data were collected (Brough et al. 2006). The soil nutrient data described here was originally sourced from the Queensland Soil and Land Information (SALI) database system and contributed by Queensland Department of Natural Resources, Mines and Water to the ASRIS database.
The ASRIS database was revised in late 2007 for Queensland and now provides soil attribute data that are based on direct measurements, where available, and by extrapolation based on a range of landscape attributes where no measurement data are available. ASRIS provides a single value of an attribute (e.g. total phosphorus content) for each unique mapping area (UMA). The size of UMAs varies because of the different survey methods used in different parts of the catchments with map scales ranging typically from 1:25 000 to 1:1 million. UMAs are generally discriminated using attributes such as slope, regolith material, climate, lithology and soil suborder (McKenzie et al. 2005). Within the GBRL catchments, UMAs have a wide range of sizes from 5 hectares to more than 7000 sq. km with an average size of roughly 35 sq km. This imposes a fundamental constraint on our ability to resolve spatially the particulate nutrient fluxes at the paddock and farm scales typically considered for the prioritisation of land use management interventions.

2.2 The SALI database

A detailed description of the SALI data and how it was processed prior to being provided to ASRIS is given by Brough et al. (2006). Total phosphorus values were determined using XRF and total nitrogen content was measured using an automated Kjeldahl method. For most measurement sites a number of samples from various depths in the soil profile are available and were analysed for nitrogen and/or phosphorus depending on landuse and the motivation for a particular soil survey. Soil horizon information is provided as well. A measurement performed on a single soil sample is referred to here as a 'spot' measurement. In addition to spot measurements, some sites also have 'bulk' measurements. Bulk samples are a composite of a number of surface soil samples collected in the vicinity of the sample site coordinates. The collection of samples is mixed together and then subsampled for analysis. The bulk sampling method is typically undertaken as part of soil fertility analyses and represents an average nutrient content for soil within some distance of the site coordinates. Bulk samples are flagged in the SALI database.

In this work, subsoil is defined as belonging to the B horizon or lower and where the top of the sample was located at least 0.3 m below the soil surface. Some sample locations had more than one subsoil sample. For total phosphorus (TP) there were 3298 discrete sample locations with a total of 9661 individual samples. Total nitrogen was less frequently measured with a total of 197 discrete locations and 445 individual samples.

A surface soil sample is defined as any sample having an upper sample depth of 0 m and may be either a spot or a bulk sample. The sample thickness was typically 0.1 m. Total phosphorus was determined for a total of 1413 sites with bulk samples (total of 1545 determinations) and for 3901 sites with spot samples (total of 4286 determinations). Both spot and bulk samples were available for P at 347 sites and for N at 547 sites.

2.3 Calculations

Two methods were used to compute mean subsoil nutrient concentrations: simple averaging of all individual samples; and calculation of a weighted mean subsoil concentration for each discrete location. For the weighted mean concentration, each concentration value was multiplied by the thickness of the sample strata, the results summed, and then divided by the sum of the sample thicknesses.

The surface concentrations were determined by averaging all values at a discrete location (latitude, longitude) where the top of the sample had a depth of 0 m. Bulk and spot samples were considered separately.

Basic statistical characteristics of the data (average, minimum, maximum, standard deviation, standard error) were computed for each site with at least four samples of a particular type.

All data were kept in a mySQL database and all calculations performed using the SQL language.
3. RESULTS

3.1 Subsoil nutrient content

Subsoil (B-horizon and below) nutrient contents averaged 0.028% P and 0.036% N. These measured values compare with the assumed values of 0.025% P and 0.10% N used in all modelling of GBR catchment nutrient loads up to and including 2006. Clearly, in regions with substantial gully and stream bank erosion the particulate nitrogen load is likely to be over-estimated by nearly a factor of 3 whereas the error in subsoil phosphorus load is just 14%.

3.2 Surface soil small scale variability

The small scale natural variability of soil N and P content within a sampling site was assessed by comparing composite bulk samples with spot samples where both methods were used at a site. After linearly regressing spot sample against bulk sample data and eliminating a few conspicuous outliers (Figure 1) the P data fit closely to a 1:1 slope ($r^2 = 0.91$) whereas the N data exhibited a bias in slope (spot:bulk = 0.93) and were slightly more variable ($r^2 = 0.81$).

![Figure 1. Comparison of surface soil nutrient content measured using spot and bulk sample collection methods for phosphorus a) and nitrogen b). Outliers omitted from curve fit are shown as grey circles.](image)

3.3 Surface soil measurement precision

It is important to understand how accurately a single measurement represents the true soil nutrient concentration at a particular location. An estimate of the precision of the mean value for a specific site and sampling method (bulk or spot) was computed by calculating the means, ranges and standard deviations for each site where there were four or more determinations made using the same technique. Results averaged over the 37 qualifying sites with N measurements and 56 sites with P measurements are given in Table 1. Soil N content was less precisely determined than was soil P with the average standard deviation / mean being 0.34 ($n = 37$) and 0.21 ($n = 56$), respectively.
Table 1. Precision of multiple soil nutrient measurements at a single site where each site has at least four values for a specific measurement type (spot or bulk). Average values considering all sample sites for: mean, minimum, maximum P and N concentrations; standard deviation/mean; range and standard error.

<table>
<thead>
<tr>
<th></th>
<th>Average mean conc (%)</th>
<th>Average minimum conc (%)</th>
<th>Average maximum conc (%)</th>
<th>Average std dev/ mean</th>
<th>Average Range (%)</th>
<th>Average Std err of mean</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>0.078</td>
<td>0.049</td>
<td>0.13</td>
<td>0.34</td>
<td>0.077</td>
<td>0.01</td>
<td>37</td>
</tr>
<tr>
<td>P</td>
<td>0.029</td>
<td>0.022</td>
<td>0.038</td>
<td>0.21</td>
<td>0.016</td>
<td>0.003</td>
<td>56</td>
</tr>
</tbody>
</table>

3.4 Variability of soil properties within unique mapping areas

Having established how well we know the soil nutrient content at a single site we now wish to estimate how much the soil nutrient content varies within a unique mapping area - the smallest scale at which soil nutrient content is typically resolved for catchment modelling in the GBRL catchments. Variability of soil nutrient content within a UMA was assessed by calculating the mean, range and standard deviation of values for all sites within each UMA containing at least 4 sampling sites. For sample sites with more than one value, the site average of the observed values was used in determining the UMA average, i.e. only one value per site was used. No consideration was given to the spatial distribution of sample sites within a UMA - possible biases in true UMA mean concentrations arising from distribution of vegetation, soil types, etc and how well they were represented in the selection of sample sites are not considered here.

Results are given in Table 2 for the 298 qualifying UMAs with N data and 245 UMAs with P data. In contrast to the measurement precision at a single sample site (Table 1), the average UMA soil nutrient content is less precisely determined (i.e. std dev/mean is greater). Not surprisingly, there is a much greater range of concentrations within a UMA and this has relevance for decisions focusing on sub-UMA scale areas. Whereas soil P content is relatively more precisely determined than soil N content at the scale of an individual sample site, P content is more variable than N content at the scale of a UMA.

Table 2. Unique mapping area averages for: mean, minimum, maximum P and N concentrations; standard deviation/mean; range and standard error. Only UMAs with 4 or more sample sites are included. Results are shown for all Queensland data (QLD) and GBRL region only (GBR).

|       | Average mean conc (%) | Average minimum conc (%) | Average maximum conc (%) | Average std dev/ mean | Average Range (%) | Average Std err |
|-------|-----------------------|--------------------------|--------------------------|-----------------------|-------------------|-----------------|-----|
| N (QLD)| 0.13                 | 0.065                    | 0.23                     | 0.38                  | 0.16              | 0.02            | 298 |
| N (GBR)| 0.13                 | 0.066                    | 0.23                     | 0.39                  | 0.17              | 0.02            | 227 |
| P (QLD)| 0.055                | 0.024                    | 0.112                    | 0.48                  | 0.09              | 0.01            | 245 |
| P (GBR)| 0.048                | 0.021                    | 0.099                    | 0.51                  | 0.08              | 0.01            | 173 |

Ultimately, the utility of the ASRIS data set will depend on the spatial scale at which it is used and this can be assessed in terms of how well the ASRIS values correlate with individual site measurements and with UMA averages. A comparison between ASRIS and individual SALI site values is shown in Figure 2. A trend line is evident, but there is a significant spread of values about it ($r^2 = 0.46$ TN, 0.40 TP). The mean concentration values considering all data are for TP (0.056% SALI, 0.054% ASRIS) and for TN (0.12% SALI, 0.12% ASRIS).
Figure 2. ASRIS soil TP a) and TN b) concentrations compared to SALI measured values at each SALI site in the GBRL catchments.

Figure 3. ASRIS surface soil nutrient content compared with corresponding mean SALI nutrient content for each unique mapping area. Soil total phosphorus for all UMAs a); total phosphorus for UMAs containing > 3 SALI sites b); total nitrogen for all UMAs c); total nitrogen for UMAs with > 3 SALI sites d).

The comparison improves at the UMA scale (Figure 3) if one considers the mean SALI concentration within a UMA. For UMAs containing > 3 SALI measurement sites the linear fit to the data is reasonable ($r^2 = 0.65$ TP, 0.67 TN) but decreases when all UMAs
containing a SALI measurement site are considered ($r^2 = 0.41$ TN, 0.49 TP). There appears to be a bias towards higher TN values in the ASRIS data (Figure 3c).

### 3.5 ASRIS area coverage of GBRL catchments

The ASRIS database has 14327 UMAs that are fully or partially within the GBRL catchments covering an area of 465,669 km$^2$. Roughly 4% of UMAs contain at least one sample site. This includes 867 UMAs with phosphorus data covering a total area of 107371 km$^2$ (23% of GBRL catchments) and 1015 UMAs with nitrogen data covering 128480 km$^2$ (28% of GBRL catchments). The mean and median areas of UMAs containing SALI measurement sites are 137 km$^2$ and 45 km$^2$, respectively. There is no correlation between UMA area and soil nutrient content and similarly the relative error (defined as (SALI - ASRIS)/SALI) does not correlate with UMA area although the range of relative errors is greater as UMA area decreases.

### 4. CONCLUSIONS

Surface soil nutrient content is not very sensitive to the sampling method. Both spot and bulk (composite) sample techniques yield very similar results. In other words, the spot measurements represent concentrations within the bulk sampling radius with acceptable accuracy.

The intrinsic natural variability in soil nutrient content coupled with the variability of nutrient content between sites within a UMA constrains our ability to predict differences between UMAs. UMA surface soil nitrogen and phosphorus content in the GBR catchments should be assumed to have relative uncertainties of at least ± 35% and ± 45% (std dev/mean), respectively. When considering individual sites within a UMA the uncertainty increases to approximately ± 75% for both TN and TP.

Both ASRIS and SALI datasets have the same mean values for TN and TP when averaged over all of the available data. This confirms that the mapping of SALI values into the ASRIS data set is sound. Care should be taken when interpreting catchment model predictions of particulate nutrient loads based on the ASRIS data set to ensure the appropriate level of uncertainty is applied.

The model used most frequently in GBRL catchments is Sednet/ANNEX. This model has a variable spatial resolution based on the size of subcatchments that drain into first order streams. As these subcatchments range in size from very small to 45 km$^2$ or larger the relative uncertainty of the predicted particulate nutrient loads can be expected to decrease from ± 75% to about ± 40%. Sednet/ANNEX typically is used to predict changes in nutrient fluxes arising from different management scenarios and to identify nutrient supply 'hot spots' within a catchment. The scale dependence of soil nutrient content uncertainty means that differences in nutrient loads from subcatchments > 45 km$^2$ will be more confidently discriminated than those for smaller subcatchments.

### REFERENCES


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