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A simple and rapid method to relate land cover and river flow rate to river nutrient concentration

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ABSTRACT

The quantification of diffuse input loads of nutrients to rivers is a challenge due to limited observed data. This study aimed to develop a simple model that can relate in-stream nutrient concentrations due to diffuse sources with land cover categories within a catchment affecting a river reach. A previously developed point-diffuse model was used to distinguish the diffuse nutrient signature within South African Department of Water Affairs historical monitoring flow and water quality data for selected river gauges. The diffuse signature was related to land cover categories within respective catchments using Principal Component Analysis (PCA), and influential land cover categories were used to construct land cover models relating land cover categories with in-stream nutrient concentrations. Generally, the land cover categories affecting diffuse signatures of nutrients as indicated by PCA were expected. Using land cover information, the developed land cover models performed well in re-creating the diffuse in-stream nutrient signature as determined by the point-diffuse model.

1. Introduction

Southern Africa, like many other parts of the world, is facing the problem of water quality deterioration of fresh water resources. Of the various types of problematic pollutants, nutrients, introduced through point and diffuse sources, are arguably the most damaging to fresh water systems, causing environmental damage, social and health problems, and increasing costs of treatment for human and industrial use (Withers and Jarvie, 2008).

Within the management of water resources for maintaining favourable water quality, water quality models can be useful for exploring management scenarios as well as investigating possible future water quality impacts in the absence of observed data (Rouch et al., 1998), such as changes in water quality due to future development and climate change. Complex deterministic models simulate real processes and therefore, can give useful indications of pollutant sources and possible ameliorative management action. However, in reality, practical considerations such as availability of observed data and limited resources such as time, finances, and lack of management capacity usually preclude the use of complex models within water resources management. In fact, many authors have argued for the use of simpler models that include some estimate of uncertainty (e.g. Beck, 1987; McIntyre et al., 2003; Reckhow, 1994; Young et al., 1996). In regards to management of nutrient inputs into water resources, useful models from a management perspective would be required to simulate in-stream nutrient concentrations using available historical monitoring data, as resource constraints usually preclude the collection of additional data.

It is relatively simple to simulate the in-stream nutrient loads due to point source input as compared to diffuse source inputs. Usually, there is some monitoring of the load originating from major point sources such as waste water treatment works. Most existing water quality models however, struggle to simulate the nutrient inputs of diffuse sources. In most cases, this is more an issue of a lack of data, rather than shortcomings of the models. Diffuse inputs of nutrients are highly variable on a temporal and spatial scale, therefore, it is difficult to collect accurate data to quantify diffuse nutrient input.

Bowes et al. (2008) introduced a model that explored the relationship of in-stream total phosphorus (TP) with flow, demonstrating that TP concentrations that showed an inverse relationship with flow are associated with point source input, while TP concentrations that showed a positive relationship with flow are associated with diffuse sources of nutrients, and developed a model to separately quantify point source and diffuse source phosphorus loading. The model was subsequently used to predict instream phosphorus concentrations resulting from improved sewage treatment (Bowes et al., 2010) as well as to quantify the changes in phosphorus inputs to the River Frome from point and diffuse sources (Bowes et al., 2009). The model presented by Bowes et al. (2008) was applied to historical flow and phosphate monitoring data for South African rivers collected by the South African Department of Water Affairs (DWA), but did not fit the data well

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Table 1
South Africa Department of Water Affairs historical monitoring data, as well as diffuse nutrient signatures as determined by a point-diffuse nutrient model (Slaughter and Hughes, 2013), used to construct a land cover nutrient model.

Gauge	River name	Lat.	Long.	Data availability		Nutrient	Diffuse signature	
				From	To		A	B
B1H005	Olifants River	26°0′23.00″	29°15′14.00″	1990	2007	PO_4-P	0.01	0.31
B1H010	Olifants River	25°53′30.01″	29°18′15.01″	1990	2008	PO_4-P	0.01	0.28
B1H012	Little Olifants River	25°48′29.01″	29°35′12.01″	1990	2007	PO_4-P	0.01	0.27
B1H020	Koringspruit River	26°6′20.98″	29°19′50.98″	1990	2006	PO_4-P	0.02	0.17
B2H003	Bronkhorstspruit	25°47′56.00″	28°44′8.987″	1991	2008	PO_4-P	0.01	0.29
B2H014	Wilgerivier	25°49′36.01″	28°52′50.98″	1991	2008	PO_4-P	0.01	0.38
B3H021	Elands River	24°55′31.00″	29°19′27.98″	1994	1998	PO_4-P	0.03	0.28
X1H016	Buffel Spruit	25°56′49.99″	30°34′6.995″	1990	2007	NO_3-N + NO_2-N	0.08	0.44
X2H005	Nels River	25°25′50.01″	30°58′0.012″	1990	2007	NO_3-N + NO_2-N	0.14	0.23
X2H006	Crocodile River	25°28′9.983″	31°6′5.115″	1990	2007	NO_3-N + NO_2-N	0.19	0.12
X2H022	Kaap River	25°32′31.99″	31°19′1.991″	1990	2007	NO_3-N + NO_2-N	0.18	0.27
X2H031	South Kaap River	25°43′45.01″	30°58′44.00″	1990	2007	NO_3-N + NO_2-N	0.14	0.34
X2H032	Crocodile River	25°30′50.00″	31°13′27.98″	1990	2007	NO_3-N + NO_2-N	0.14	0.19
X3H004	North Sand River	25°4′31.00″	31°7′53.00″	1990	2007	NO_3-N + NO_2-N	0.33	0.24
X3H006	Sabie River	25°1′48.00″	31°7′36.01″	1990	2000	NO_3-N + NO_2-N	0.12	0.31
X3H008	Sand River	24°46′8.003″	31°23′24.00″	1991	2007	NO_3-N + NO_2-N	0.05	0.27

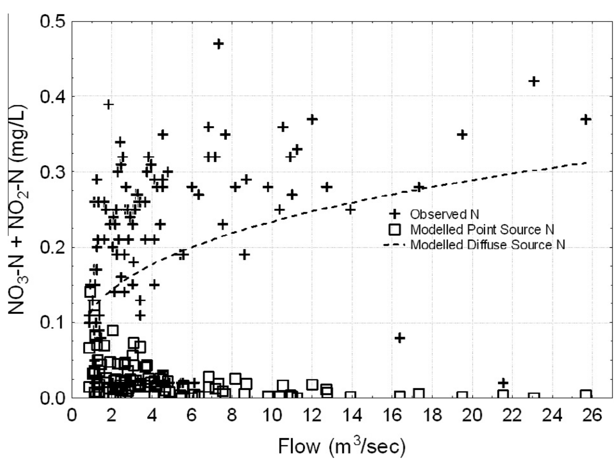

Fig. 1. Example of the simple point-diffuse model (Slaughter and Hughes, 2013) applied to flow and nitrate + nitrite data for the gauging site X3H006. The model allows the separate quantification of the point and diffuse contribution to total instream nutrient concentration by the relationship of instream nutrient concentrations to flow. In this case, the diffuse signature was quantified to follow the following power regression curve: $NO_3\text{-N} + NO_2\text{-N}_{(diffuse)} = 0.12 \times \text{flow}^{0.31}$.

Table 2
Land cover types represented in the catchments investigated.

Code	Description
L1	Rain-fed croplands
L2	Mosaic vegetation (grassland/shrub-land/forest) (50–70%)/cropland (20–50%)
L3	Closed to open (>15%) broadleaved evergreen or semi-deciduous forest (>5 m)
L4	Closed (>40%) broadleaved deciduous forest (>5 m)
L5	Open (15–40%) broadleaved deciduous forest/woodland (>5 m)
L6	Open (15–40%) needle-leaved deciduous or evergreen forest (>5 m)
L7	Closed to open (>15%) mixed broadleaved and needle-leaved forest (>5 m)
L8	Mosaic forest or shrub-land (50–70%)/grassland (20–50%)
L9	Mosaic grassland (50–70%)/forest or shrub-land (20–50%)
L10	Closed to open (>15%) (broadleaved or needle-leaved, evergreen or deciduous) shrub-land (<5 m)
L11	Closed to open (>15%) herbaceous vegetation (grassland, savannahs or lichens/mosses)
L12	Sparse (<15%) vegetation
L13	Artificial surfaces and associated areas (Urban areas > 50%)
L14	Bare areas
L15	Water bodies

as phosphate concentrations at low flows showed a high and apparently random variability. Slaughter and Hughes (2013) used the conceptual understanding of the Bowes et al. (2008) study to separate diffuse and point source signatures of nutrients (PO_4-P and NO_2-N + NO_3-N) by their relationship with flow from within DWA historical monitoring data, and developed a point-diffuse nutrient model to quantify the signatures.

This study aimed to investigate the relationship between the diffuse signatures in historical monitoring data identified by the point-diffuse model (Slaughter and Hughes, 2013) for various water quality monitoring points, and the land cover in the catchment of the monitoring points influencing these data. The objective of the study was to develop a model that can predict the diffuse nutrient signature for a stretch of river, given that land cover data and flow data are available for the catchment.

2. Data and model development

2.1. Data

A simple model (point-diffuse nutrient model) to separate point and diffuse signatures of nutrients by the relationship of in-stream nutrient concentrations with flow (Slaughter and Hughes, 2013), was applied to historical monitoring data collected by the South African Department of Water Affairs (DWA, 2013). While DWA gauging sites measuring flow and water quality exist across the entire coverage of South Africa, a subset of gauges were chosen for this study that showed strong diffuse signatures in order to demonstrate the method. These would be gauging sites where nutrient concentrations very evidently increased with increasing flow, indicating the influence of diffuse sources. Nutrient signatures investigated were those of PO_4-P and NO_3-N + NO_2-N. Table 1 lists the details of the data sets used as well as the nutrient signatures evident within the data as determined by the point-diffuse nutrient model. Fig. 1 gives an example of the simple point-diffuse model (Slaughter and Hughes, 2013) application to gauging site flow and nutrient data, where the relationship of intream nutrient data with flow allows the respective contribution of point and diffuse sources of nutrients to be separately quantified.

Land cover data used were derived from the Globcover regional (Africa) archive generated in 2009, and has a resolution of 300 m. The land cover types represented in the catchments investigated are shown in Table 2. The catchment area was delineated for each monitoring point using ArcMap 9.3 (ESRI, Inc.) using 1:50,000 river and relief coverages. The land cover coverage was then clipped by