The deteriorating nutrient status of the Berg River, South Africa

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Abstract

The upper catchment area of the Berg River in the Western Cape, South Africa, supplies most of Cape Town and its suburbs with freshwater, in addition to providing water for irrigation purposes along the middle and lower reaches of the river. This study investigates the nutrient status of the Berg River and long-term trends therein. It is shown that inorganic nitrogen and phosphorus levels increase downstream by a factor of more than 10, in response to anthropogenic inputs. Similarly, nutrient levels fluctuate seasonally by more than an order of magnitude, in response to input from diffuse and point sources of pollution. These changes of more than 1 000% far exceed the 15% maximum change stipulated by the South African water quality guidelines for aquatic ecosystems. Total phosphorus levels indicate that hypertrophic conditions prevail at least episodically at all of the Berg River monitoring stations and most of the time at some of them. Additionally, river water phosphate levels show a dramatic increase over the past 20 years. There is also strong evidence that the trophic status of the Berg River is very sensitive to reduced river runoff. The implication is that the construction of the new Berg River Dam in the upper catchment area of the Berg River will exacerbate the existing situation, threatening ecosystem services, human health and lucrative agricultural activities.

Keywords: Berg River, eutrophication, nutrients, nitrate, phosphate

Introduction

Eutrophication, excessive plant growth in response to nutrient enrichment, is considered to be one of the most serious problems facing freshwater ecosystems, globally (Vitousek et al., 1997; Carpenter et al., 1998; Galloway and Cowling, 2002; Camargo and Alonso, 2006; Mainstone and Parr, 2002). The major nutrients that contribute to eutrophication are phosphorus as phosphate ions (PO_4^{3-}) and nitrogen as nitrate (NO_3^-), nitrite (NO_2^-) and ammonium (NH_4^+) ions. Nutrient levels of many freshwater ecosystems have increased dramatically, by a factor of 4 at least, over the last couple of decades in response to widespread agricultural intensification and increased discharge of domestic wastes (Vitousek et al., 1997; Galloway and Cowling, 2002). A particular problem facing developing countries such as South Africa is the significant increase in urban runoff and increasingly so from overloaded or dysfunctional municipal water treatment plants and un-sewered human settlements (Barnes, 2003; Bere, 2007; Mtetwa and Schutte, 2003; Luger and Brown, 2003; Van Vuuren, 2005). All of these are potentially significant sources of nutrients and other pollutants to river and groundwater reservoirs

The South African water quality guidelines (DWAF, 1996a) stipulate Target Water Quality Range (TWQR) values for 7 different water-use sectors: domestic, recreational, industrial, irrigation, stock watering, aquaculture and aquatic ecosystems. TWQR is defined as 'the range of concentrations or levels at which the presence of the constituent would have no known adverse or anticipated effect on the fitness of the water assuming long-term continuous use, and for safeguarding the health of aquatic ecosystems.' Aquatic ecosystems are unique amongst the different types of water users, in that aquatic plant and animal species have very different water quality requirements and tolerances, depending on locality. As a result, there are no stipulated TWQR nutrient values for aquatic ecosystems, but rather a recommendation that 'a TWQR should be derived only after case- and site-specific studies' (DWAF, 1996b). Additionally, 'inorganic nitrogen (and phosphorus) concentrations should not be changed by more than 15% from that of the water body under local unimpacted conditions at any time of the year.' There is no documented evidence, however, that such 'case- and site-specific studies' have been carried out for any of South Africa's freshwater ecosystems. It is also not clear that the development of such site-specific TWQR values for nutrients is one of the objectives of the relatively new National Eutrophication Monitoring Programme, NEMP (DWAF, 2002). As a result, classification of the trophic status of South Africa's aquatic ecosystems is presently restricted to the use of 4 broad categories: oligotrophic, mesotrophic, eutrophic and hypertrophic (Table 1), with no allowances made for diverse ecosystem requirements.

This study provides a detailed investigation of the nutrient status of the Berg River, located in the Western Cape Province in South Africa (Fig. 1). The Berg River provides the bulk of the water for household and industrial use in the Cape Town metropole and greater Cape Peninsula area, in addition to irrigation water for extensive cultivation along the length of the river. A combination of recent dry spells, population growth and a fast growing local economy has put severe pressure on water resources within this system. The construction of an additional dam in the Groot Drakenstein Mountains near Franschhoek (Berg River Dam) will provide some relief for Cape Town's water supply problems, but has also raised serious concerns about the implications for water quality along the lower reaches of the river.

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TABLE 1

Trophic status classification of freshwater ecosystems according to (a) average summer levels of inorganic nitrogen ($NO_3^- + NO_2^- + NH_4^+ + NH_3$) and inorganic phosphorus (measured as PO_4^{3-}), from the South African Water Quality guidelines for Aquatic Ecosystems (DWAF, 1996a) and (b) mean annual chlorophyll *a* and mean annual total phosphorus levels, from the National Eutrophication Monitoring Programme guidelines (DWAF, 2002)

Parameter	Oligotrophic	Mesotrophic	Eutrophic	Hypertrophic
Inorganic Nitrogen (µg N/ℓ) – *SAWQ guidelines for Aquatic Ecosystems*	< 500	500 - 2 500	2 500 - 10 000	> 10 000
Inorganic Phosphorus (µg P/ℓ) – *SAWQ guidelines for Aquatic Ecosystems*	< 5	5 - 25	25 - 250	> 250
Mean annual total phosphorus (µg P/ℓ) – NEMP	< 15	15 - 47	47 - 130	> 130
Mean annual chlorophyll a (µg/ℓ) – NEMP	< 10	10 - 20	20 - 30	> 30

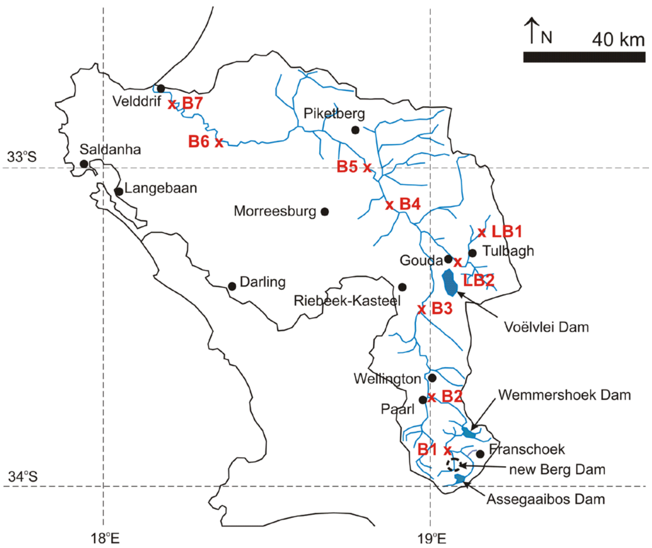

Figure 1
Berg River catchment and DWAF monitoring stations LB1, LB2 and B1 to B7 (station details are listed in Table 2)

The new NEMP 'has not been implemented' in the Berg Water Management Area (NEMP, 2003), despite the known eutrophic status of the Misverstand Dam (http://www.dwaf.gov.za/iwqs/eutrophication/NEMP/TrofieseStatus2003.pdf). Some of the manifestations of 'eutrophic' conditions along the Berg River are the increasingly problematic presence of water hyacinth along the middle and lower reaches of the Berg River and dramatic declines in fish catches. Additionally, bacterial counts indicative of sewage pollution (Barnes, 2003; Paulse et al., 2007) and heavy metal concentrations (Jackson et al., 2007) exceeding recommended DWAF guidelines have been reported for the Berg River.

The most recent sources of information on the nutrient water quality status of the Berg River (Görgens and De Clercq, 2005; Quibell, 1993) are based on DWAF water quality monitoring data prior to 1998. It has been noted (Görgens and De Clercq, 2005) that 'an increase in phosphate concentrations at all stations can be clearly seen', but these trends or more recent DWAF water quality data for the Berg River system have not been examined in great detail. This study examines DWAF water quality data up to 2005 at 9 monitoring stations on the Berg River to determine downstream, seasonal and long-term trends in the following nutrient parameters: nitrate and nitrite (NO_3^- and NO_2^-, or NO_x), ammonium (NH_4^+), total phosphorus (TP) and orthophosphate (PO_4^{3-}).

Study area and database

The Berg River (300 km long) rises in the Groot Drakenstein Mountains near the town of Franschhoek, drains a catchment area of about 9 000 km^2, and enters the sea on the west coast at Velddrif (Fig. 1). The geology of the catchment area is dominated by sandstone and quartzites of the Cape Supergroup in the upper reaches, Cape granites in the middle reaches and recent sediments near the coast. The catchment is therefore characterised by nutrient-poor lithologies. Almost 50% of the catchment area is cultivated agricultural land, mainly vineyards, fruit trees and wheat fields. River flow peaks during the winter rainy season, from June to August. Although evaporation exceeds precipitation throughout the catchment, the river water budget is dominated by runoff.

DWAF water quality monitoring data is available at 9 sites along the Berg River: LB1, LB2 and B1 to B7 (Fig. 1, Table 2), from as early as 1967 at one of the stations and from the 1970s at most of the stations. With due consideration of differences in length and completeness of time series data between stations, only data from 1985 onwards were considered in this study. Sampling frequency also varies between sites, from almost weekly to monthly. Where more than one water quality data point was available in a given month, an average monthly value was calculated to provide time-series data at a monthly resolution. This also provides compatibility with DWAF's total monthly water flow records.

The DWAF database contains data for the dissolved inorganic nitrogen species [$NO_2^- + NO_3^-$] and [NH_4^+] (all expressed as µg N/ℓ, with 20 to 40 µg N/ℓ detection limits) and dissolved total phosphorus (TP) and soluble reactive phosphate (SRP measured as PO_4^{3-}, expressed as µg P/ℓ, with reported 3 to 5 µg P/ℓ detection) limits. Data for [NH_4^+] and total dissolved phosphorus (TP) were available at only some of the stations or sections of the record. As a result median, mean and maximum TP and [NH_4^+] values reported (Table 2) represent shorter data periods.

For data evaluation purposes nutrient levels in the Berg River are compared to both South African trophic status guideline values (Table 1) and more detailed international water quality guidelines. The latter, for the protection of aquatic animals, are 2 000 to 3 600 µg NO_3^--N/ℓ for the NO_2^--NO_3^- forms of inorganic nitrogen (Camargo et al., 2005; CCME, 2003) and between 20 and 100 µg P/ℓ for soluble reactive phosphorus (Mainstone and Parr, 2002). Un-ionised ammonia (NH_3) is the most toxic form of inorganic nitrogen to aquatic animals and water quality criteria ranging from 50 to 350 µg NH_3-N/ℓ for short-term exposures and 10 to 20 µg NH_3-N/ℓ for long-term exposures have been recommended (Camargo and Alonso, 2006; Constable et al.,

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TABLE 2
Berg River water quality monitoring station detail, time-series data median, mean and maximum dissolved [NO_3^- + NO_2^-], [NH_4^+], [TP] and [PO_4^{3-}] values. NA denotes stations for which no TP data is available

Sample – DWAF ID – Location	Lat (°S)	Long (°E)	Data period	[NO_x] µg N/ℓ			[NH_4^+] µg N/ℓ			[TP] µg P/ℓ			[PO_4^{3-}] µg P/ℓ		
				med	mean	max	med	mean	max	med	mean	max	med	mean	max
LB1 – G1H021 – Mountainview	33.185	19.155	1976-2004	65	67	450	5	22	120	NA	NA	NA	10	16	304
LB2 – G1H008 – Niewkloof	33.311	19.075	1977-2004	130	241	1216	23	32	235	57	63	210	15	19	572
B1 – G1H004 – Bergriviershoek	33.927	19.061	1985-2004	110	137	1410	68	80	405	62	70	182	19	25	244
B2 – G1H020 – Dal Josafat	33.708	18.911	1967-2004	564	598	2070	47	54	945	NA	NA	NA	18	24	110
B3 – G1H036 – Hermon	33.435	18.957	1982-2004	791	829	4334	47	58	307	255	271	740	72	91	785
B4 – G1H013 – Drieheuvels	33.133	18.862	1970-2004	328	472	1937	31	40	157	96	106	276	23	31	415
B5 – G1H031 – Misverstand	32.997	18.779	1974-2005	378	490	2434	40	50	570	98	111	487	24	29	487
B6 – G1H023 – Jantjiesfontein	32.925	18.329	1972-2004	150	440	6346	45	45	357	NA	NA	NA	20	30	495
B7 – G1H024 – Kliphoek	32.817	18.194	1983-2004	135	341	2172	76	92	717	NA	NA	NA	29	38	323

2003; Environment Canada, 2001; USPA, 1986). NH_3 concentrations are not directly measured in the Berg River, but measured levels of NH_4^+ combined with pH values of 6 to 8 predict very low to negligible levels of NH_3. Recommended dissolved inorganic nitrogen and phosphorus levels for the prevention of eutrophication are lower than those for aquatic animals. Levels higher than 30 µg TP/ℓ are generally considered conducive to eutrophication, provided that inorganic nitrogen or other nutrients are not limiting (Camargo and Alonso, 2006; Swedish EPA, 2000). Plants require nitrogen and phosphorus in a ratio of between 7 and 8 (weight/weight) and concomitant dissolved values of > 400 µg total N/ℓ and > 30 µg total P/ℓ are generally considered favourable for eutrophication in freshwater systems.

Annual nutrient fluxes at each of the monitoring stations were calculated for 2 time periods (1985-1994 and 1995-2004) as follows: for each 10-year period, monthly averaged river flow, [NO_x] and [PO_4^{3-}] values were calculated, an average monthly nutrient flux was then calculated from the product of the average flow and [NO_x] and [PO_4^{3-}] values for that month. The annual nutrient flux for each 10-year period was then calculated from the sum of the monthly average flux values.

Results

Downstream trends in river water nutrient levels

Long-term monthly median, mean and maximum Berg River nutrient values are listed in Table 2 and time-series data for monthly values are illustrated in Figs. 2 and 3. The long-term median values indicate an almost 10-fold downstream increase in [NO_3^- + NO_2^-] and [TP] levels, with these parameters as well as [PO_4^{3-}] peaking along the middle section of the river at B3, where values are 791, 255 and 72 µg/ℓ respectively. The long-term mean values for [NO_3^- + NO_2^-], [TP] and [PO_4^{3-}] levels at B3 are 829, 271 and 91 µg/ℓ respectively (Table 2). Towards the coast nutrient levels decrease again, to values approximating those observed in the upper reaches of the catchment, possibly indicating the consumption of nutrients by algal and macrophyte productivity within the river system. Ammonium levels are relatively constant downstream and represent a minor fraction of the total inorganic nitrogen pool, indicative of a well-aerated system (Table 2).

According to the NEMP trophic status classification scheme (DWAF, 2002), based on long-term mean [TP] levels, all of the stations for which TP monitoring data are available are eutrophic with the exception of B3, which is hypertrophic. Along almost the entire length of the Berg River, from B2 to B6 (Dal Josafat in Paarl to Hermon; Fig. 1) long-term mean [NO_3^- + NO_2^-] values exceed the 400 µg/ℓ recommended international guideline for aquatic plant life. Additionally, at all the stations where TP data are available, the long-term mean value exceeds the 30 µg TP/ℓ recommended international guideline for aquatic plant life, by a factor of 2 to almost 10 (Table 2). It is instructive to note that nutrient levels at the Misverstand Dam (B5), earmarked as the NEMP monitoring site on the Berg River, are more than a factor of two lower than further upstream (B3 at Hermon).

Even very brief episodes of nutrient enrichment can be exceedingly detrimental to aquatic plant and animal life, there-

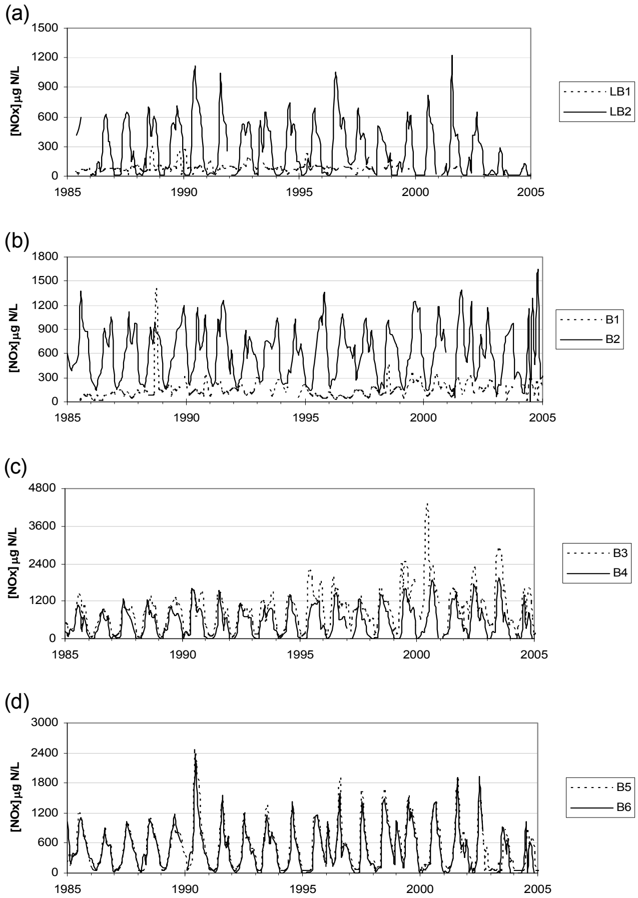

Figure 2
Temporal trends in dissolved [NO_3^- + NO_2^-] along the (a) Little Berg River and (b-d) along the Berg River mainstream

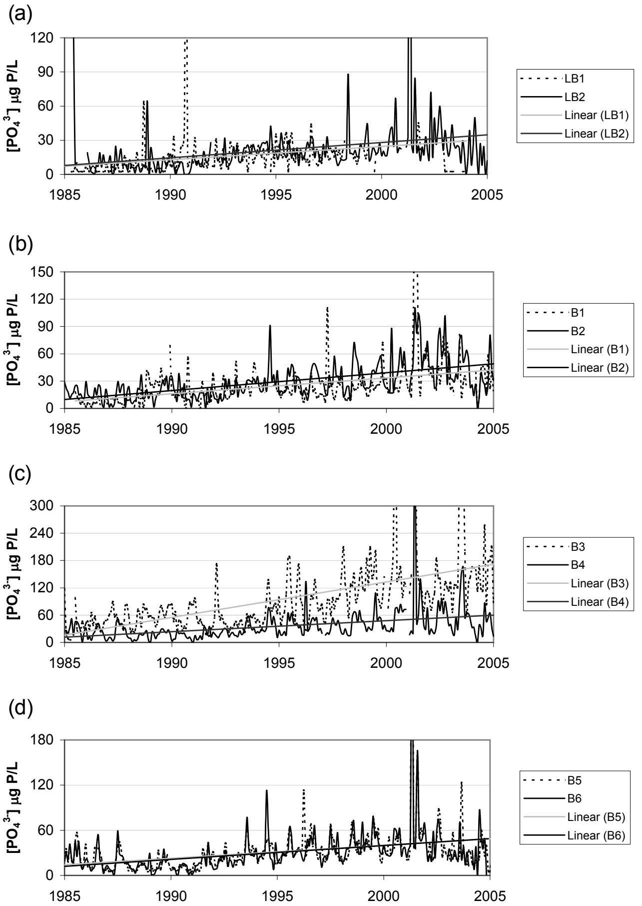

Figure 3
Temporal trends in dissolved [PO_4^{3-}] along the (a) Little Berg River and (b-d) Berg River mainstem. Lines indicate linear regression fits through the data.

fore evaluation of maximum values observed is critical. Maximum TP values (Table 2) indicate that all of the Berg River monitoring stations experience episodic hypertrophic conditions, i.e. TP values exceeding 130 µg P/ℓ according to the NEMP classification scheme (DWAF, 2002). Maximum values for [NO_3^- + NO_2^-], TP and [PO_4^{3-}] (Table 2) indicate that the international recommended values for aquatic plant life are exceeded at least episodically at all the monitoring stations on the Berg River. The 400 µg N/ℓ recommended [NO_3^- + NO_2^-] value for aquatic plant life is exceeded during at least half the seasonal cycle at all the stations except the most upstream stations along the Little Berg and Berg rivers, LB1 and B1 (Figs. 2a and b). The highest values and most pronounced trend in [PO_4^{3-}] levels are observed at B3 (Fig. 3c), where baseline values have more than doubled, from below 60 to more than 120 µg P/ℓ over the past 20 years. The middle reaches of the Berg River, therefore, are approaching a state of permanent hypertrophic conditions. At all the monitoring stations baseline [PO_4^{3-}] is either already exceeding the 30 µg TP/ ℓ recommended value for aquatic plant life, or approaching it. Additionally, the international water quality guidelines for aquatic animal life (~ 4 000 µg N/ℓ for [NO_3^- + NO_2^-] and 20 to 100 µg P/ℓ for soluble reactive phosphorus (Mainstone and Parr, 2002) are exceeded at least episodically for [NO_3^- + NO_2^-] at B3 and B6, and at all the monitoring stations in the case of phosphorus.

Seasonal fluctuations and long-term trends in river water nutrient levels and fluxes

Evaluation of long-term nutrient levels (Figs. 2 and 3) demonstrates well-defined seasonal changes in [NO_3^- + NO_2^-] and that the amplitude of this seasonal cycle has remained fairly constant since the 1980s at all stations except B3, where it has increased by a factor of ~ 2, and B4, where it has increased by ~ 50% (Fig. 2c). Even at the stations where the seasonal amplitude of change in [NO_3^- + NO_2^-] levels has remained fairly constant, however, the magnitude of seasonal variability is at least an order of magnitude (Fig. 2). This translates into a seasonal change resulting from anthropogenic factors of at least 1 000%, compared to the less than 15% change stipulated by the South African water quality guidelines for aquatic ecosystems (DWAF, 1996b). The long-term [PO_4^{3-}] records demonstrate less well-defined seasonal cycles compared to [NO_x], but a dramatic increase in levels and the magnitude of intra-annual variability over time (Fig. 3). During the 1985-1994 period [PO_4^{3-}] levels were relatively constant throughout the year at all stations in the catchment area. During the past 10 years, however, concentration levels have almost doubled throughout the year at all stations and a more pronounced seasonal cycle has emerged.

Representative seasonal runoff and nutrient concentration profiles were constructed for the periods 1985-1994 and 1995-2004, to yield insight into changing nutrient dynamics and the relative roles of diffuse and point sources of nutrients. Typical Berg River seasonal profiles are illustrated for B3 (Fig. 4) and the total annual fluxes derived from the combined run-

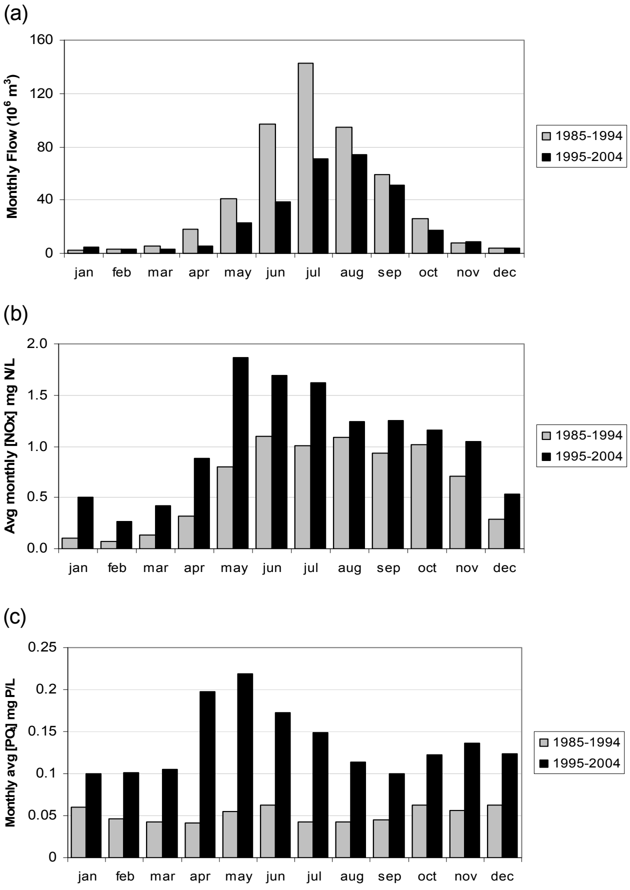

Figure 4
Comparative river flow, [NO_3^- + NO_2^-] and [PO_4^{3-}] monthly averaged data for the periods 1985-1994 and 1995-2004, at monitoring station B3

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TABLE 3 Runoff and nutrient fluxes at the Berg River monitoring stations, calculated as described in the text										
ID	Location	Area	Average runoff 10^6 m³/a		Average NO_x flux kg N/a		Average PO_4^{3-} flux kg P/a		NO_x flux kg N/a/ km²	PO_4^{3-} flux kg P/a/ km²
		km²	1985-1994	1995-2005	1985-1994	1995-2005	1985-1994	1995-2005	1995-2005	1995-2005
LB1	Little Berg @ MountainView	30	17	14	1319	1094	284	281	36	9
LB2	Little Berg @ Niewkloof	383	84	58	43321	23125	1189	1508	60	4
B1	Berg @ Bergriviershoek	75	169	133	20668	18726	2765	4165	250	56
B2	Berg @ Dal Josafat	592	396	304	308373	251568	9194	14336	425	24
B3	Berg @ Hermon	1444	500	304	480510	419626	24508	41653	291	29
B4	Berg @ Drieheuvels	3554	717	492	584880	455980	22113	30112	128	8
B5	Berg @ Misverstand	4772	523	379	452949	337278	15127	19734	71	4

off and concentration profiles tabulated for all the stations (Table 3). Runoff (Fig. 4a) peaks during the winter, consistent with the winter rainfall location of the Berg River catchment area. An important observation is that the 1995-2005 period was drier than 1985-1994, with average runoff for the month of June reduced by as much as 60% at Station B3 (Table 4).

Seasonal [NO_x] profiles peak during high runoff conditions, consistent with a diffuse source such as agricultural runoff (Fig. 4b). The 1995-2004 [NO_x] profile also indicates increased levels compared to 1985-1994, throughout the year (Table 4). Increased values during drier conditions are indicative of a concentration effect, i.e. reduced dilution of anthropogenic inputs. The most pronounced impact of this concentration effect during reduced runoff conditions is an increase of almost 400% in NO_x values during the summer and 54 to 60% during the winter at monitoring station B3 (Table 4).

Seasonal [PO_4^{3-}] profiles demonstrate a dramatic change in seasonality over time (Fig. 4c), in addition to 67 to 373% increases in average monthly concentrations over time (Table 4). An absence of seasonality in [PO_4^{3-}] during the 1985-1994 period has been replaced by a seasonal profile that exhibits a peak in [PO_4^{3-}] values coinciding with the onset of increased river flow during late spring/early winter (Fig. 4c).

Evaluation of the average annual NO_x flux during 1995-2004 compared to the 1985-1994 period reveals a flux reduction of only 13%, compared to an almost 40% reduction in runoff (Table 3). PO_4^{3-} fluxes, in contrast to NO_x, have increased during the 1995-2004 period by as much as 50%, despite the reduced runoff (Fig. 4c). NO_x fluxes/catchment area values peak in the middle section of the Berg River at station B2, coincident with peak concentration levels (Table 3). PO_4^{3-} fluxes/catchment area values however, peak in the upper Berg River catchment at station B1 (Table 3).

A reduction in the annual NO_x flux between B4 and B5 and in the annual PO_4^{3-} flux between B3 and B5 suggests *in situ* consumption of nutrients, most probably assimilation by plants and algae and adsorption by sediments (Table 3). There is a reduction in runoff at B5 compared to B4, however, attributable to water extraction just upstream of the B5 monitoring station, that contribute to the nutrient flux reductions observed between B4 and B5 (Table 3).

Discussion

The two most likely anthropogenic sources of nutrients along the Berg River are agricultural runoff and effluent from overloaded municipal sewage works and un-sewered communities. Both sources are expected to peak in magnitude along the middle section of the Berg River, between Paarl and Hermon (B3 to B4), the most heavily cultivated and most populated area along the river. This includes informal human settlements that have developed along the banks of the river.

TABLE 4 Long-term percentage change in average monthly flow, [NO_x] and [PO_4^{3-}] levels at monitoring station B3, calculated as follows: 100*([monthly average]$_{1995\text{-}2005}$ - [monthly average]$_{1985\text{-}1994}$)/ [monthly average]$_{1985\text{-}1994}$			
Month	Flow %	Average NO_x %	Average PO_4^{3-} %
January	72	380	67
February	5	251	119
March	-40	223	146
April	-69	182	373
May	-45	133	293
June	-60	54	177
July	-51	60	253
August	-21	14	169
September	-12	35	120
October	-32	15	99
November	15	47	140
December	-3	84	98

Diffuse nutrient sources, such as agricultural runoff, produce seasonal concentration profiles coincident with river runoff, i.e. concentrations that peak during high runoff conditions. In contrast, point sources such as sewage effluent from municipal water treatment plants generally result in seasonal concentration profiles that have no relation to runoff, i.e. relatively constant input throughout the year, or an inverse relation to river runoff.

The positive relationship between NO_x levels and fluxes with runoff, i.e. peaks during the rainy winter season, is consistent with a diffuse source such as agricultural runoff being the most likely source of NO_x enrichment (Fig. 4b). Additionally, the smaller NO_x flux reduction during the past 10 years, compared to the 40% reduction in runoff, implies one of two scenarios or a combination thereof:

- Increased fertiliser application during the latter 10 years
- An increase in a different source, such as sewage effluent.

Evidence for increased NO_x levels during low runoff conditions supports an increased point-source scenario. It is also suggested that overloading of water treatment plants during high runoff conditions or flooding of informal human settlements during winter storm events may result in nutrient enrichment during high runoff, related to these 'point sources'.

Seasonal [PO_4^{3-}] and TP flux profiles suggest that the P budget of the river is dominated by point sources, most likely domestic waste and sewage effluent. It is not clear at this stage whether the late summer/early winter PO_4^{3-} concentration peak originates from agricultural runoff during early winter rains, i.e. increased P-fertiliser application, or whether it is related to increased loads associated with sewage and/or wastewater effluent.

A worst-case future scenario for the nutrient status of the Berg River would be a combination of increasing agricultural loading and point source pollution, and decreased streamflow in response to damming in the upper catchment or increased extraction. This is the scenario that the Berg River is faced with in the light of the almost completed construction of the Berg River Dam in the upper catchment. If the downstream flushing effect of runoff originating in the upper catchment is reduced, it can be confidently predicted that nutrient levels in the Berg River will significantly increase above their already unacceptably high levels. Reduced flow conditions in combination with higher nutrient levels will produce conditions even more favourable for the development of eutrophic and hypertrophic conditions than is already the case. There is, therefore, an urgent need for the implementation of the NEMP in the Berg River water management area, including monitoring strategies that incorporate measurement of algal biomass (i.e. chlorophyll *a*). There is also a strong argument to be made for NEMP activities on the Berg River to be carried out further upstream from the Misverstand Dam, closer to monitoring Station B3. Urgent remedies, such as the identification of point sources and source reduction, coupled with immediate intervention strategies such as the construction of artificial wetlands (Morse et al., 1998; Reed et al., 1988; Kovacic et al., 2000; Hammer, 1992; Comin et al., 1997; Fink and Mitch, 2004), need to be put in place.

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