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Dissolved Nutrients from Submarine Groundwater in Flic en Flac Lagoon, Mauritius

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Abstract—The aim of this study was to investigate dissolved nutrients in a submarine groundwater discharge (SGD) in Flic en Flac lagoon on the west coast of the volcanic island of Mauritius. The SGD enters Flic en Flac lagoon through a thin blanket of unconsolidated sediment through a fracture system and is concentrated along the irregular surface of the buried rock. The results show that the major inputs of dissolved nitrate and phosphate in Flic en Flac lagoon arise from agricultural and domestic sources during periods of heavy rain. Dissolved nitrate (150-470 μg/l) and phosphate (10-115 μg/l) concentrations in the SGD, lagoon and offshore in the Flic en Flac region fell within the range of seawater values in the Pacific region. Rainfall caused dissolved nitrate and phosphate transfer through groundwater conduits in the coralline basement of the lagoon, delivering a significant discharge during the cyclone season in summer. The lagoon is subjected to diffuse SGD flows which may contribute to its high dissolved nutrient values. This will lead to a reduction in the lagoon's assimilative capacity, exacerbating the problem of excessive nutrient input and associated eutrophication in the lagoon. The submarine groundwater discharge thus merits consideration in Mauritian coastal zone management and similar tropical volcanic lagoonal systems.

INTRODUCTION

Lagoons and estuaries in Mauritius are vulnerable areas with sensitive and ecologically important fauna and flora. The coastal zone of Mauritius (1850 km^2 at 20^oS; 57^oE) consists of terrestrial and marine interfaces impacted by industrial and urban activities. Baseline investigations on the west coast of Mauritius have highlighted the susceptibility of local estuaries and lagoons to metal and dissolved nutrient input from surface runoff and submarine groundwater discharge (Ramessur and Ramjeawon, 2002; Gustavsson, 2004; Anon., 2005; Burnett *et al*., 2006). Development in the coastal zone has evolved in response to sectorial interests

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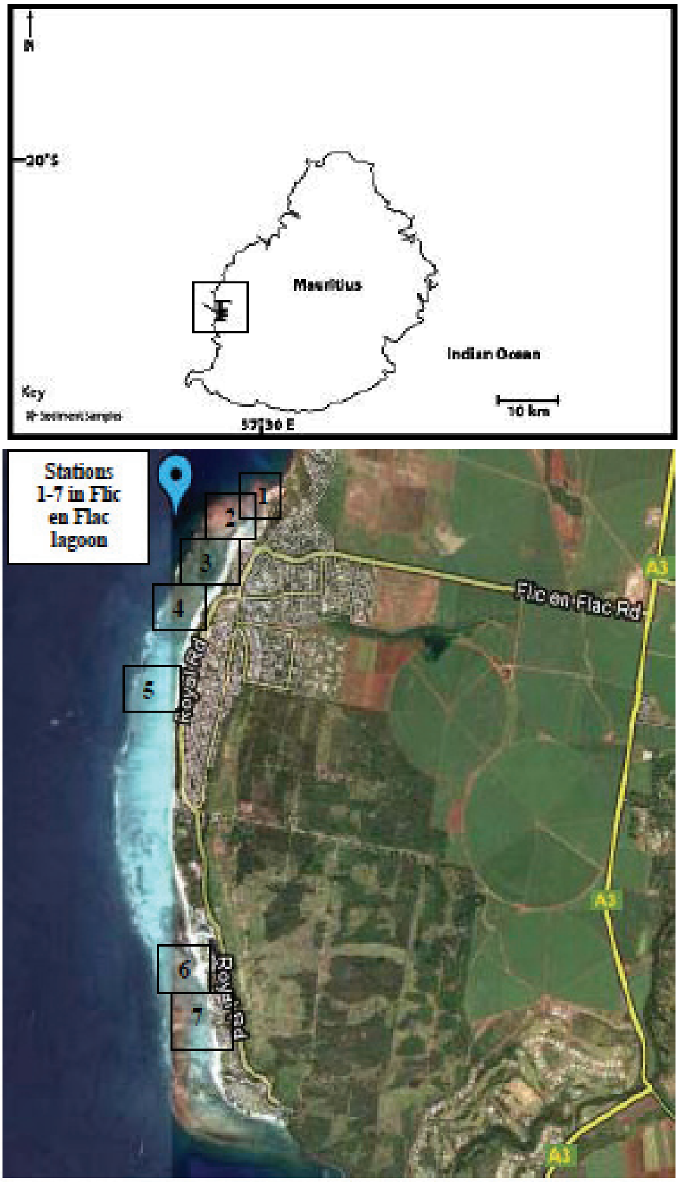

Figure 1. Study area at Flic en Flac (F) on the west coast of Mauritius.

without adequate consideration of the effects of one form of development upon another. Consequently, many of the coastal resources have become susceptible to negative impacts. Previous studies have shown that Mauritian lagoons are particularly vulnerable to eutrophication (Ramessur *et al*., 1998; Ramessur *et al*., 2001; Ramessur, 2002; Ramessur, 2004; Ramessur *et al*., 2010, Ramessur, 2010), highlighting the need to monitor such pollution. Considering the increasing population growth in Mauritius and the extensive use of pesticides and fertilizers, dissolved nutrients may thus pose the greatest present and future threat to the marine environment from the species to the community level.

This study was thus carried out to determine the dissolved nitrate and phosphate levels in coastal waters and in a submarine groundwater discharge in Flic en Flac lagoon. It was undertaken in a rural area to assess eutrophication from dissolved nutrients in coastal waters along the western coast of Mauritius during winter and summer, from August 2008 to February 2009.

The objectives were to establish if:

- Submarine groundwater discharge introduces significant levels of dissolved nitrate and phosphate to Flic en Flac lagoon.
- There are seasonal differences in dissolved nitrate and phosphate during winter (dry) and summer (wet) periods in the lagoon.
- Denitrification occurs in the lagoon and the ratio of dissolved N:P lies between the global levels of 2-15 found in coastal waters.

MATERIALS and METHODS

Flic en Flac

Flic en Flac (20°16'S; 57°22'E) is an urban area with 2000 inhabitants found in the district of Black River on the western coast of the island of Mauritius (Fig. 1). It has a coastline of 0.5 × 13 km with nine large hotels extending from Flic en Flac to Wolmar, the beach being visited by 0.5 million bathers p.a. Flic en Flac covers an area of about 13 km^2, 4 km^2 being under plantation, particularly sugar cane. The maximum air temperature at Flic en Flac is 31.6ºC in February and 28.4ºC in August. The mean monthly rainfall during the period of August 2008 – February 2009 was in the range of 9.7 – 167.1 mm. Water in the minor aquifer in Curepipe tends to move towards the west, flowing to Flic en Flac and the La Ferme Reservoir through the Pierrefond Tunnel. In addition to the surface flow in the River Rempart (West), groundwater flows through its aquifer producing marshes in the Flic en Flac coastal region and a freshwater spring in the lagoon. Seven stations were assessed at Flic en Flac for contamination by anthropogenic activities.

Dissolved nutrient analysis

Duplicate samples of water were collected in 200 ml plastic bottles (dissolved nitrate) and glass bottles (reactive phosphate) in the coastal area of Flic en Flac. Samples were collected from the lagoon, wells in the Flic en Flac area, from seepage chambers placed along transects in the Flic en Flac lagoon and in the open sea at a distance 5 km offshore. Nine seepage meters were placed in the lagoons. Seepage chambers of the Lee (1977) type (an up-ended 200 l steel drum, fitted with a sample port and a plastic collection bag sunk into the sediment) were deployed in three shore-normal transects (one adjacent to the large submarine spring, one in a cove 1 km north of the spring, and one about 500 m south of the spring), as well as in a 1500 m shore-parallel transect. A total of 18 seepage chambers were located along this transect for a period of 10 h to 5 days. Not all measurements along this transect were recorded simultaneously; however, at least six of the devices along this transect measured the submarine groundwater discharge (SGD) throughout the sampling period. Water was collected from the seepage chambers for dissolved nutrient analysis. Samples were also collected from beach boreholes drilled 4 m deep on the public beach. Samples were stored at 4^{o}C and analysed within 24 h. The concentrations of dissolved nitrate and phosphate were determined using standard spectrophotometric methods (Parsons *et al*., 1984) at 543 nm and 882 nm respectively using a PU 8710 spectrophotometer and a UNICAM 8700 Series UV/VIS spectrometer following calibration using reference solutions. Quality control was achieved against an internal reference independently prepared from the standard and standard curves were verified after ten successive runs of one standard solution within the linear range of each nutrient. The precision of nitrate determinations was to 1 µmol l^{-1}, whereas that of phosphate determinations was to 0.1 µmol l^{-1}.

RESULTS and DISCUSSION

Water entering the SGD in Flic en Flac does so through a thin blanket of unconsolidated sediment via a fracture system and concentrates along the irregular surface of the buried rock. The major inputs of dissolved nitrate in Flic en Flac originate from terrestrial sources during periods of heavy rain, whereas the phosphate may originate from domestic effluents. Meteorological phenomena thus influenced dissolved nitrate and phosphate transfer in the coastal area. Dissolved nitrate and phosphate concentrations in the wells, SGD, the lagoon and offshore in the Flic en Flac region (Tables 1-4) fell within the range of values in seawater cited by Naidu *et al*. (1991) in the Pacific region. This can

Table 1. Concentration of dissolved nitrate in Flic en Flac lagoon during August 2008-Feb 2009.

Stations	Dissolved Nitrate, µg/l
Wells	4663.4 ± 2817.2
Seepage Chambers	910 ± 1394.4
Lagoon	159.3 ± 136.8
Offshore (5 km)	160.7 ± 71.2

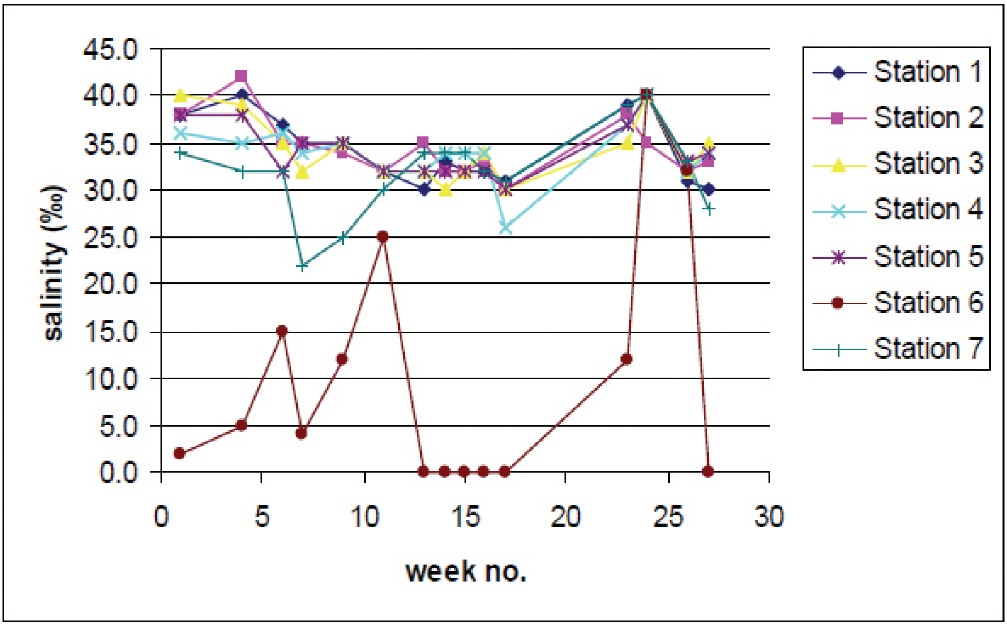

Figure 2. Weekly variation in salinity in Flic en Flac lagoon from August 2008 - February 2009.

Table 2. Concentration of dissolved phosphate in Flic en Flac lagoon during August 2008-Feb 2009.

Stations	Dissolved Phosphate, μg/l	Range
Wells	42.5±29.6	
SGD in Seepage Chambers	47.0 ±33.6	2.5 ±1μmol/l [b]
Lagoon	<10	2.5 ±1μmol/l [b]
Offshore (5 km)	<10	1.5± 1μmol/l [a]

[a] Open University, 1989
[b] Balls *et al*., 1995

lead to a lowering of the lagoon's assimilative capacity, exacerbating nutrient input and associated eutrophication.

Seasonal variations in dissolved nitrate and phosphate in the Flic en Flac lagoon in winter 2008 and summer 2009 are presented in Figures 2 and 3. The mean values for dissolved phosphate were 161.3 ± 58.9 μg/l during winter and 273.0 ± 60.0 μg/l during summer at Flic en Flac. These seasonal differences were not significant at the 5% significance level (t-test), neither were the differences between the stations. The mean concentration of dissolved phosphate was higher during the wet period due to heavy rainfall. Much of the dissolved phosphate washed into the water may be attributable to agricultural runoff.

Mean values for dissolved nitrate were 731.9 ± 683.4 μg/l during winter and 727.6 ± 310.2 μg/l during summer. While the seasonal differences in nitrate were not

Table 3. Mean and standard deviation of phosphate (μg/L) levels in Flic en Flac lagoon during August 2008-Feb 2009.

	Winter 2008	Summer 2009	Mean
Station 1	128.3 ± 101.2	222.9 ± 243.4	185.1 ± 199.5
Station 2	165.6 ± 153.3	259.5 ± 347.1	222.0 ± 282.0
Station 3	125.3 ± 96.9	257.9 ± 338.6	204.9 ± 270.9
Station 4	119.8 ± 69.7	273.4 ± 358.6	211.9 ± 285.1
Station 5	121.0 ± 65.3	207.0 ± 240.0	172.6 ± 190.7
Station 6	281.1 ± 176.6	389.1 ± 418.7	345.9 ± 338.1
Station 7	187.9 ± 95.6	301.5 ± 335.9	266.5 ± 283.7
Mean	161.3 ± 58.9	273.0 ± 60.0	229.8 ± 59.3

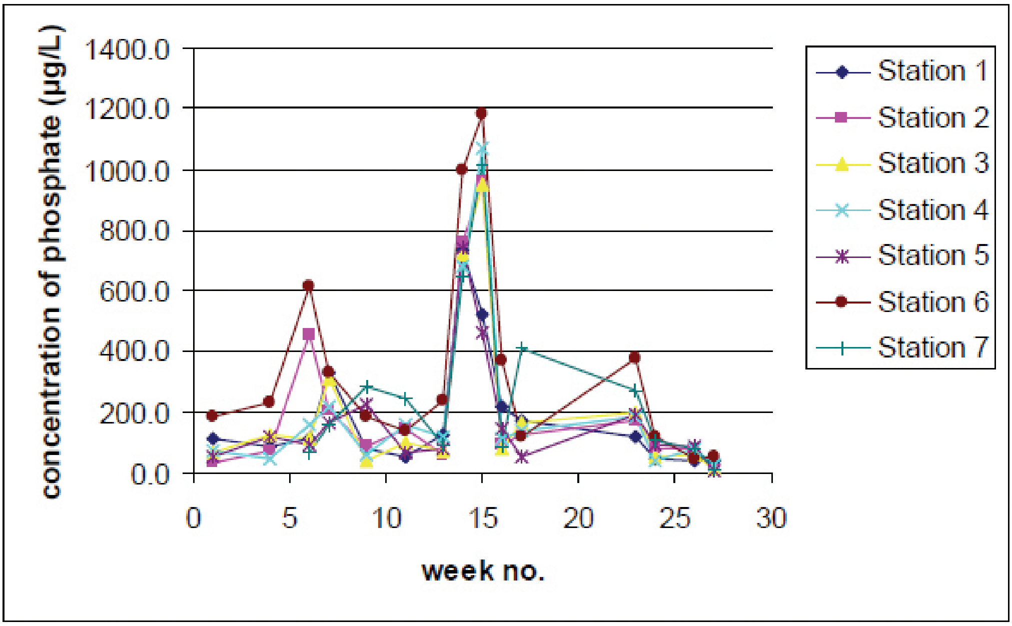

Figure 3. Weekly variation in dissolved phosphate in Flic en Flac lagoon from August 2008 - February 2009.

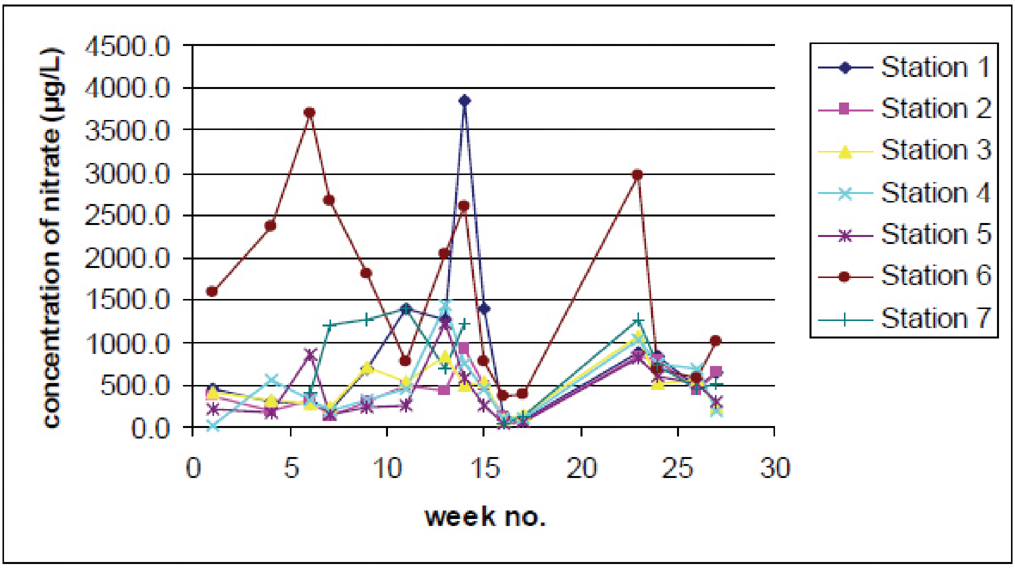

Figure 4. Weekly variation of dissolved nitrate in Flic en Flac lagoon from August 2008 - February 2009.

significant, concentrations in the south of the lagoon were significantly higher at the 5% level compared to mid-lagoonal waters because of the freshwater and nutrient input from the rivulet in the south which passes through the coastal grazing lands. The slightly higher concentration of nitrate in winter may be attributable to winter-time additions of fertilizers to sugarcane in the watershed and irrigation of the latter during the winter season. Nitrates from fertilisation of inland sugarcane plantations and from urbanization will also leach into groundwater and eventually into the rivulet. The salinity in Flic en Flac estuary (Fig.

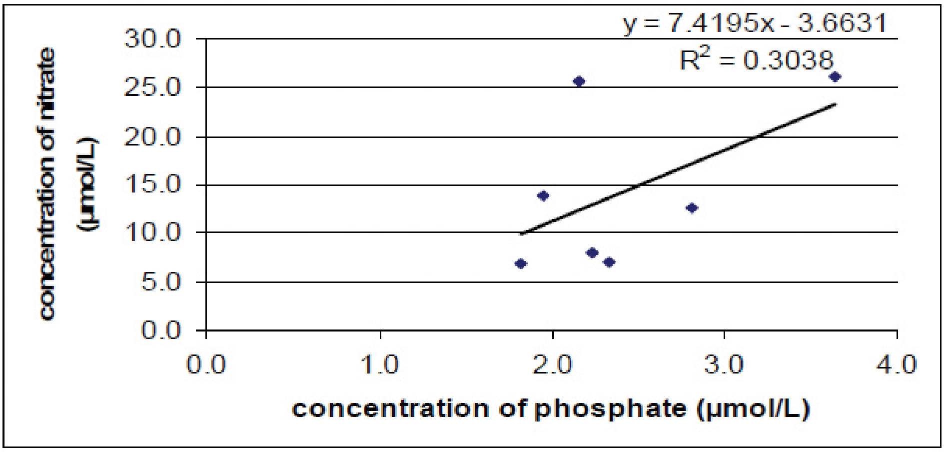

Figure 5. Correlation of dissolved nitrate and dissolved phosphate in Flic en Flac lagoon during August 2008-Feb 2009.

Table 4. Means and standard deviations of nitrate (µg/L) levels in Flic en Flac lagoon during August 2008-Feb 2009.

	Winter 2008	Summer 2009	Mean
Station 1	556.2 ± 449.1	1063.0 ± 1141.8	860.3 ± 939.7
Station 2	299.9 ± 126.6	526.1 ± 302.1	435.6 ± 266.5
Station 3	413.4 ± 179.4	500.6 ± 319.2	465.7 ± 267.7
Station 4	314.2 ± 186.1	612.3 ± 452.5	493.0 ± 390.2
Station 5	315.3 ± 269.0	491.0 ± 382.2	420.7 ± 342.4
Station 6	2153.3 ± 1009.1	1269.7 ± 1000.2	1623.1 ± 1065.9
Station 7	1071.0 ± 454.0	630.2 ± 447.6	777.2 ± 480.4
Mean	731.9 ± 683.4	727.6 ± 310.2	725.1 ± 433.0

4) fell below 5 in October 2009 due to flooding around weeks 12-15 and the Flic en Flac lagoon received higher dissolved nitrate and dissolved phosphate input from land runoff.

A low dissolved N:P ratio of 7 (Fig. 5, Table 5) was measured in the Flic en Flac lagoon, situated in a rural area, which fell between the values of 2 to 15 usually found in coastal waters (Tyrell & Law, 1997), suggesting that denitrification is occurring. However, a high dissolved N:P ratio in the wells and seepage chambers indicated a high input of nitrate to the Flic en Flac coastal area which may be derived from agriculture and fertilizers.

It can be argued that agricultural, urbanization and tourism activities have contributed to an increase in anthropogenic pollution, increasing sewage effluent and urban runoff in this area. Further investigation and modelling of the biogeochemical fluxes of nutrients is thus needed for effective integrated coastal management of such parameters in such small island states.

Table 5. Ratios of N:P in Flic en Flac lagoon during August 2008-Feb 2009

Stations	N: P
Wells	165
Seepage chambers	29.5
Lagoon	7.4
Beach borehole	17.4

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