Journal of the Royal Society of Western Australia, 79:155-160, 1996

The impact of vegetated buffer zones on water and nutrient flow into Lake Clifton, Western Australia

P M Davies[1] & J A K Lane[2]

[1] Department of Zoology, The University of Western Australia
Nedlands, WA 6907
[2] Department of Conservation and Land Management
Wildlife Research Centre, PO Box 51 Wanneroo, WA 6065

Manuscript received October 1995; accepted March 1996

Abstract

Lake Clifton, a saline lake situated on the Swan Coastal Plain, south of Perth, is recognised under the Ramsar Convention as a “Wetland of International Importance”. Intensification of rural and urban developments along the eastern catchment of the lake have been implicated in increased nutrient levels and consequent algal growth in the water. This has adversely affected a highly-restricted microbialite population which is the largest in the southern hemisphere. Existing buffer zones of native vegetation separate the cultural developments from the lake, and have the potential to reduce impacts both by the uptake of surface-water flow and the assimilation of nutrients. These buffer zones can be divided into three categories based on width; small (20-50 m), medium (100-150 m), and large (500-600 m).

Surface-water flow into Lake Clifton from the buffer zones was highly episodic, occurring predominantly during and immediately after rainfall events of >10 mm rainfall over a 48 hour period. During six substantial rainfall events (May to September 1993), surface flow into the lake (located using a low-flying aircraft) was measured for rates of instantaneous water discharge and water samples were taken for nutrient analyses. Surface water discharge from small buffer zones was about 100 times higher and total nitrogen content was significantly greater compared with the other buffer zones. Although not statistically different, mean levels of total phosphorus ranged from 0.16, 0.04 and 0.07 mg L^{-1} from the small, medium and large zones respectively.

Our results suggest that the existing buffer zones, particularly those classified as small, are inadequate to limit nutrient input into Lake Clifton. The inadequacy of these buffer zones is mitigated, in part, by the small volumes of water flowing into the lake via surface discharge. However, unless wide buffer zones are provided, further development in the catchment will increase the rate of eutrophication of Lake Clifton.

Introduction

Lake Clifton is part of the Peel-Yalgorup system on the western edge of the Swan Coastal Plain, approximately 100 km south of Perth. The environmental significance of this Ramsar-listed lake is based, in part, on an extensive (400 ha) living microbialite (thrombolite) community that is the largest known in the southern hemisphere (Moore *et al.* 1983; CALM 1990). The presence of microbialites along the eastern shore of the Lake has been attributed to constant discharge of low salinity, highly alkaline groundwater (Moore *et al.* 1983; Moore 1987; Moore & Turner 1988).

Lake Clifton lies within Yalgorup National Park, but only the lake basin and a very narrow margin of land are protected. Much of the land on the eastern catchment is privately owned and used for livestock and horticultural purposes (Moore & Turner 1988), and more recently for urban developments. There has been considerable concern expressed that survival of the microbialite community may be threatened by increasing nutrient inputs from these cultural developments, and that buffer zones may not be substantial enough to reduce nutrient movement into the lake. Excessive nutrient inputs have already been implicated in increased growth of a green alga (*Cladophora vagabunda)* which, along with epiphytic algae and plankton blooms, smothers and spatially competes with microbialites (Moore 1990).

There are a number of mechanisms whereby nutrients enter the lake, the two major ones being overland flow and groundwater discharge. Overland flow is episodic, occurring after substantial rainfall events, while groundwater input is relatively more constant. Preliminary results have shown that the groundwater typically has a lower total nitrogen concentration than Lake Clifton water (Moore & Turner 1988). However, surface water has not yet been monitored for rates of discharge and associated nutrient levels. Surface flow may be intercepted by vegetated buffer zones, reducing the impact of land practices on a wetland.

Buffer zones are generally described as areas of undeveloped, vegetated land extending from the banks or high water level of a wetland to some landward point (Palfrey & Bradley 1990); the function of a buffer zone is to protect a wetland from negative impacts of catchment land-uses (Carter 1992). Buffer zones around wetlands are valuable as biological filters of both sediment and nutrients. These zones can reduce the extent of channelised surface-flow into a lake and have an inher-

Figure 1. The study sites along the eastern edge of Lake Clifton. Sites as follows: 2,5,8 (large [L]), 1,3,7 (medium [M]) and 4,6,9 (small [S]).

ent capacity to assimilate nutrients and sediment (Davies & Lane 1995). Buffer zones of native vegetation, of varying widths, have been created along the eastern edge of Lake Clifton around rural land-use areas and, recently, urban sub-divisions. This presented an opportunity to compare the effectiveness of buffer zones of different widths in reducing both water discharge and nutrient inputs into Lake Clifton.

Methods

Site description

Lake Clifton is an elongate (approximately 28 km x 1 km), shallow and saline lake about 100 km south of Perth on the Swan Coastal Plain (Fig 1). The extensive shoreline means there is considerable potential for nutrient enrichment from adjacent land practises.

Sampling program

There are no major drains flowing into Lake Clifton (Moore *et al.* 1983). However, previous observations revealed that surface water becomes channelised and flows into the lake after substantial rainfall events. Substantial rainfall events were defined by analysing historical rainfall records for Mandurah (Bureau of Meteorology, Perth). On the basis of this analysis, events of >10 mm rainfall over a 48 hour period were determined to be "substantial". Sampling was then conducted on six of these events (Table 1), which accounted for almost 20% of the 1993 total rainfall.

During each sampling occasion, the eastern edge of the lake was observed from a low-flying aircraft to determine areas where surface water was channelised and flowed into the lake. Channelised surface flow was defined as stream-flow originating within each buffer zone and flowing into the lake. Channelised flow did not originate from outside the boundary of any buffer zone. Existing buffer zones along the eastern edge of the lake, from the airstrip in the north (site 1) to Location 52 in the south (site 9) (approximately 10 km), were placed into three width categories (Fig 1); small, 20-50 m; medium, 100-150 m; and large, 500-600 m wide.

A total of nine buffer zones were investigated, with three from each of the above categories. The zones were approximately the same length (see Fig 1). These buffer zones were interspersed, minimising the effects of spatial arrangement confounding the subsequent statistical comparisons. Additionally, there were no land-use areas associated with only a single buffer category, which could also have confounded the results. Flow from these zones accounted for the total visible surface flow into the lake. The extreme south-east corner was inaccessible to sampling; however, surface water flow from this area into the lake appeared to be minimal.

Instantaneous channelised discharge from each site was estimated from the rate of water flow and its width and depth. The rate of flow was measured by a Marsh-McBirney 201M model field water-flow meter. Where the water was not of sufficient depth for the meter to operate, discharge was estimated by the time taken to fill a plastic 1 litre measuring cylinder.

Water samples were collected from each site for the analyses of total nitrogen, ammonia, nitrite and nitrate, and total phosphorus and orthophosphate. Unfiltered water samples were collected into sterile 250 ml plastic bottles for measurement of total nitrogen and total phosphorus. Water samples filtered through a 0.22 µm millipore filter into a 100 ml sterile plastic bottle were collected for the measurement of ammonium, nitrate and orthophosphate. Due to costs of each analyses, ammonium, nitrate and orthophosphate were not measured from all sites, with analysis restricted to one sample from each buffer-width category on each occasion. Within each buffer zone where channelised flow was evident from more than one area, nutrient sampling was conducted from a randomly-determined location. However, total discharge was estimated by measuring flow from all channelised flow within each buffer zone. Samples of lake water for nutrient analyses were taken adjacent to one of the large buffer zones (site 8). All samples were kept on ice prior to delivery to the Chemistry Centre of Western Australia for analyses.

Data analyses

All data were plotted prior to parametric analyses to check for normality, and bivariate plots were examined to determine possible non-linear relationships between variables. Statistical comparisons between means were made by Analysis of Variance (ANOVA); Cochran's C was used to test for homogeneity of variances and appropriate transformations were made for biased data, *e.g.* log(x), or log(x+1) if data contained zero values. After ANOVA, if there was a significant difference, a Tukey's test was used to find which factors or sites were different. Tukey's tests have been recommended for *post hoc* significance testing as a method using the correct experiment-wise error rate (Day & Quinn 1989).

Table 1

Sampling dates and associated 48 hour rainfall data for Yalgorup National Park during 1993.

SAMPLING DATES	ACRONYM	RAINFALL (mm over 48 h)
28 May 1993	MAY	28
29 June 1993	JUN	19
28 July 1993	JUL	34
25 August 1993	AUG	12
7 September 1993	SEP	17
30 September 1993	OCT	12

Results

Lake Clifton is within a region of Western Australia typified by a mediterranean climate (Seddon 1972) where rainfall occurs predominantly from late autumn to early spring. Rainfall in 1993 for Yalgorup National Park (Fig 2) followed this pattern although storms during early autumn and late spring delivered substantial rainfall. The total rainfall in 1993 was 688 mm, which is substantially less than the average 1982-1992 annual rainfall of 780 mm.

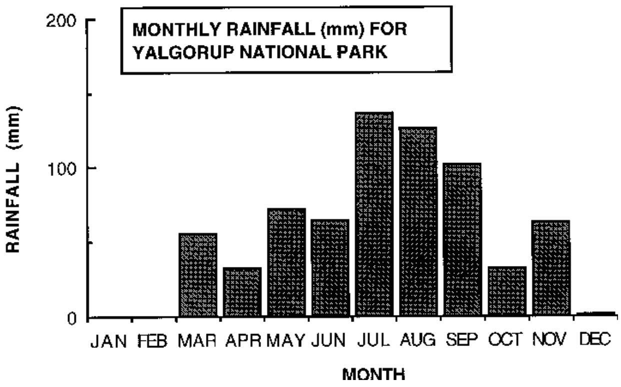

Figure 2. Monthly rainfall for Yalgorup National Park (which incorporates Lake Clifton) during 1993.

Table 2

Mean (SEM) levels of total nitrogen (mg L^{-1}) from the three different buffer sizes and from Lake Clifton during the six sampling periods. Sampling size for the small and medium buffers, n = 3 on each occasion. One sample was collected from the lake and from a large buffer zone (site 8) on each occasion.

MONTH	SMALL	MEDIUM	LARGE	LAKE
MAY	31.56 (26.67)	4.17 (1.24)	11.00	1.7
JUN	4.50 (0.40)	4.43 (1.58)	20.00	1.1
JUL	5.90 (1.10)	5.53 (1.01)	0.48	1.3
AUG	13.50 (7.99)	3.80 (1.45)	0.27	1.1
SEP	13.43 (9.76)	0.90 (0.15)	1.50	1.0
OCT	3.17 (0.91)	1.28 (0.44)	4.80	1.5

Surface runoff

Rates of discharge from the small buffer zones were about four times those of the medium-sized buffer zones and about 100 times those of the large buffer zones (Fig 3). Runoff from the large buffer zones was negligible, with the exception of site 8 (see Fig 1) which was subsequently the only large buffer zone sampled. This area had been burnt prior to the May sampling period, removing the majority of the understorey. This may have contributed to the extent of the measured surface runoff.

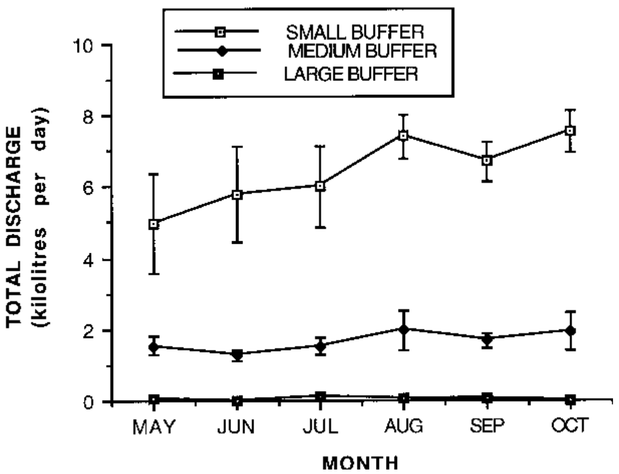

Figure 3. Mean (±SEM) surface runoff (in kilolitres per day) from the three different-sized buffer zones during each sampling occasion. Sampling sizes for the small and medium buffers, n = 3 on each occasion. A single sample was taken from the large buffer zones (site 8).

The measured surface water runoff contributed little to the total lake water levels. Determining the area of Lake Clifton from aerial photographs, and assuming an annual mean depth of 1 m, enabled the estimation of the mean water volume of the lake. Assuming that the mean surface flow measured during the substantial rainfall events was constant for six months of the year, this flow would contribute only about 0.005% to the total lake volume. This emphasises the importance of sources of water inputs other than surface flow for the maintenance of lake water levels.

Nitrogen concentration in surface runoff

In surface runoff, total nitrogen concentration ranged from low values of 0.59 mg L^{-1} from site 3 (a medium-sized buffer) during September to a high value of 85.0 mg L^{-1} from site 9 (a small-sized buffer) during May (Table 2). Total nitrogen values of 11.0 and 20.0 mg L^{-1} were recorded in May and June from site 8 (a large-sized buffer) which was burnt in May. Concentrations at site 8 were lower in subsequent months, presumably because the regenerating understorey was taking up water and nutrients and the release of nutrients due to the fire had diminished.

Mean values of total nitrogen from the three different-sized buffer zones and the lake are shown in Table 2. On most occasions, total nitrogen concentration was substantially greater in the flow from the buffer zones compared with the lake water. Statistical analysis showed the total nitrogen concentration measured in water from the small buffer zones was significantly greater (ANOVA, $P<0.05$) than the medium and large buffer zones (Table 3).

Total phosphorus level was low, with highest concentrations measured from small buffer zones during September. The concentration of total phosphorus in the lake was 0.01 mg L^{-1} on all occasions with the exception of August and September, when the values were less than detection limits (Table 4). The mean values of total phosphorus from the small buffer zones were about three to four times levels measured in the other buffer zones. There were no statistically significant differences (Table 5).

Table 3

One-way ANOVA for total nitrogen concentrations for water originating from the three different-sized buffer zones. Data were transformed by a log function, which was the closest approximation (*cf* untransformed, square-root) to homoscedasticity, Cochran's C=0.606.

Source	df	MS	F	P
Buffer size	2	4.54	3.73	<0.05
Residual	39	1.22		

Results of Tukey's tests on transformed data. Untransformed means (total [N] in mg L^{-1}) are presented in parentheses.

Buffer Size	Small	>	Medium	=	Large
	(12.07)		(3.18)		(6.34)

Table 4

Mean (SEM) levels of total phosphorus (in mg L^{-1}) from the three different buffer sizes and from Lake Clifton during the six sampling periods. Sampling size for the small and medium buffers, n = 3 on each occasion. One sample was collected from the lake and from a large buffer zone (site 8) on each occasion.

MONTH	SMALL	MEDIUM	LARGE	LAKE
MAY	0.03 (0.01)	0.02 (0.00)	0.02	0.01
JUN	0.06 (0.02)	0.02 (0.01)	0.16	0.01
JUL	0.06 (0.04)	0.11 (0.05)	0.04	0.01
AUG	0.22 (0.10)	0.06 (0.02)	0.01	<0.01
SEP	0.52 (0.44)	0.02 (0.01)	0.06	<0.01
OCT	0.07 (0.05)	0.03 (0.01)	0.15	0.01

Table 5

One-way ANOVA for total phosphorus concentrations for water originating from the three different-sized buffer zones. Data were transformed by a log function, which was the closest approximation (*cf* untransformed, square-root) to homoscedasticity, Cochran's C=0.436.

Source	df	MS	F	P
Buffer size	2	2.46	2.27	NS
Residual	39	1.08		

Extractable nutrient components

Analyses of extractable nutrients showed nitrate and ammonia concentrations were always a small component of total nitrogen concentrations (Table 6). In all measurements, orthophosphate was below detection limits. Concentrations of each nutrient in the lake and in surface flows were similar except for nitrate in July and October when values in the surface flows were 5.5 and 7.5 times those of the lake water respectively.

Table 6

Levels of extractable nutrients (in mg L^{-1}) from the lake and from surface flows during each sampling occasion. Note, values for surface flows are means (SEM), n = 3 and lake values are from single samples taken on each occasion.

	LAKE			*SURFACE FLOWS*		
	NO_3^-	NH_4^+	PO_4^{3-}	NO_3^-	NH_4^+	PO_4^{3-}
MAY	0.10	0.18	<0.01	0.11 (0.03)	0.53 (0.34)	<0.01
JUN	0.02	0.10	<0.01	0.01 (0.01)	0.02 (0.02)	<0.01
JUL	0.02	0.02	<0.01	0.11 (0.01)	0.05 (0.03)	<0.01
AUG	0.04	0.05	<0.01	0.04 (0.00)	0.05 (0.00)	<0.01
SEP	0.07	0.02	<0.01	0.05 (0.02)	0.03 (0.01)	<0.01
OCT	0.04	0.03	<0.01	0.29 (0.14)	0.02 (0.00)	<0.01

Discussion

Our results showed the inadequacy of the existing small buffer zones on the eastern catchment of Lake Clifton to control nutrient inputs. Both surface water discharge and the nutrient concentration of the water from the small buffer zones were substantially greater than from the other zones measured. The inadequacy of the small zones and the impact of surface flow into the lake is mitigated, in part, by the low volumes of water flowing from the buffer zones. Measured surface discharge from all nine buffer zone sites accounts for a small amount of the total volume of Lake Clifton. However, total rainfall in Yalgorup National Park during 1993 was significantly less than average. During wetter years, surface flow is expected to make a greater contribution to the water level of the lake.

A previous fire in a large buffer zone probably resulted in substantial nutrient inputs into the lake. This declined over the next few months, presumably as revegetation of the understorey buffer zone increased, reducing both water and associated nutrient levels. The concentrations of phosphorus and nitrogen in streams in northwestern United States increased after a wildfire from 5 to 60 fold over background levels (Spencer & Hauer 1991). Fortunately, fires are probably relatively infrequent in buffer zones around most wetlands of the Swan Coastal Plain, although management practices need to recognise the effects of nutrient release after fires around both lakes and streams.

The total nitrogen content of surface runoff from the small buffer zones was significantly greater than for the other buffer zones. Similarly, total phosphorus concentration in the smaller buffers was about 4 times the concentration from the other buffers. Nutrient concentrations in surface water were high compared with groundwater levels (*e.g.* Moore & Turner 1988). The mean nutrient concentrations in pore water were: total phosphorus 0.03 mg L^{-1}; total nitrogen 0.05 mg L^{-1}; ammonium 0.05 mg L^{-1} and nitrate 0.02 mg L^{-1} (Moore & Turner 1988). Concentrations of total phosphorus and nitrate in pore water were similar to the lowest values recorded in surface water while total nitrogen was two orders of magnitude lower in groundwater than surface water.

Many of the wetlands of the Swan Coastal Plain receive high levels of nutrients from their surrounding catchments and are becoming increasingly eutrophic. The following factors contribute to the increased rates of eutrophication (Birch 1984; Yeates *et al.* 1985; Schofield *et al.* 1985; Sanders *et al.* 1988; Humphries & Bott 1988): limited nutrient-holding capacity of the sandy Coastal Plain soils; a high and seasonal rainfall; the shallow water-table; extensive drainage of waterlogged soils; the over-use of fertilisers; inadequate treatment of effluent and inappropriate drains into wetlands.

Nutrient enrichment of wetlands may be reduced by adequate buffer zones; however, in the absence of scientific information, arguments for larger buffer zones have had little influence (Lane 1991). This study provides the first empirical data on the capacity of buffer zones to reduce nutrient input into wetlands of the Swan Coastal Plain and complements research elsewhere (*e.g.* Doyle *et al.* 1977; Overcash *et al.* 1981). Based on the results from nutrient enrichment of Lake Clifton, an adequate buffer zone would be considered to be greater than the "medium" buffer width (100-150 m) category of this study. Davies & Lane (1995) recommend a buffer zone of at least 200 m to minimise nutrient enrichment of wetlands on sandy soils. That recommended width is supported by the results of this study.

Many pools formed in depressions on the shoreline became continuous with the main body of the lake water during late winter. Some of these pools, particularly those adjacent to the rural lots with small buffer zones, would result in the input of nutrients into the lake. Future research should measure the nutrient levels in these pools and determine the contribution they make to the total lake nutrient concentrations.

At this stage, Lake Clifton could be classified, on the basis of trophic status (*sensu* Wetzel 1975), as meso-eutrophic. As the surface run-off from the small buffer regions was eutrophic to hyper-eutrophic, future developments need to provide wider buffers to reduce the rate of eutrophication of the lake.

Acknowledgments: We thank the Water Authority of Western Australia (J Kite and L Moore); the Department of Conservation and Land Management (S Dutton); the Royal Aero Club of Western Australia; the Chemistry Centre of Western Australia (R Schulz); and particularly for field assistance, I Craig. Financial support from the Land and Water Resources Research and Development Corporation through the National Riparian Program is acknowledged.

References

Birch P B 1984 Catchment management to reduce phosphorus discharge into the estuary- setting the scene. In: Potential for Management of the Peel-Harvey Estuary. Department of Conservation and Environment, Perth. Bulletin 160, 33-42.

CALM 1990 Wetlands nominated by the Government of Western Australia for inclusion on the list of Wetlands of International Importance (Ramsar Convention). Department of Conservation and Land Management, Perth.

Carter R 1992 Management and policy perspectives. In: The Role of Buffer Strips in the Management of Waterway Pollution from Diffuse Urban and Rural Sources (eds Woodfull J, Finlayson B & McMahon T). Proceedings of a Workshop, University of Melbourne. Land and Water Resources Research Development Corporation and Centre for Environmental Applied Hydrology, Melbourne, 103-106.

Day R W & Quinn G P 1989 Comparisons of treatments after an analysis of variance in ecology. Ecological Monographs 59: 433-463.

Davies P M & Lane J A K 1995 Effective buffers for wetlands. Wetlands Australia 2: 9-10.

Doyle R C, Stanton G C & Wolf D C 1977 Effectiveness of forest and grass buffer filters in improving the water quality of manure polluted runoff. ASAE Paper 77-2501.

Humphries R & Bott G 1988 Intensive animal industries on the Swan Coastal Plain and their associated pollution problems. In: The Swan Coastal Plain in Crisis: Agriculture and the Environment. The Australian Institute of Agriculture Science, Perth. Occasional Publication 10:59-66.

Lane J 1991 The wise use of wetlands-managing wildlife habitat. In: Educating and Managing for Wetlands Conservation (eds Donohue R & Phillips B). Proceedings of the Wetland Conservation and Management Workshop, Newcastle, NSW. Australian National Parks and Wildlife Service, Canberra, 151-155.

Moore L S 1987 Water chemistry of the coastal saline lakes of the Clifton-Preston lakeland system, South-western Australia, and its influence on stromatolite formation. Australian Journal of Marine and Freshwater Research 38: 647-660.

Moore L 1990 Lake Clifton - an internationally significant wetland in need of management. Land and Water Research News 8: 37-41.

Moore L S & Turner J V 1988 Stable isotopic, hydrogeochemical and nutrient aspects of lake-groundwater relations at Lake Clifton. In: Proceedings of the Swan Coastal Plain Groundwater Management Conference (ed G Lowe). Western Australian Water Resources Council Publication 1/89, Perth, 201-213.

Moore L, Knott B & Stanley N 1983 The stromatolites of Lake Clifton, Western Australia. Search 14:309-314.

Overcash M R, Bingham S C & Westerman P W 1981 Predicting runoff pollutant in buffer zones adjacent to land treatment sites. Transactions of the American Society of Agricultural Engineers Volume 14:430-435.

Palfrey R & Bradley E 1990 The Buffer Area Study. Maryland Department of Natural Resources, Tidewater Administration, Maryland, USA.

Sanders C, Robinson S, McAlpine K & Bott G 1988 Environmental objectives: what are the criteria and how can we achieve change? In: The Swan Coastal Plain in Crisis: Agriculture and the Environment. The Australian Institute of Agriculture Science. Occasional Publication 10: 95-105.

Schofield N J, Bettenay E, McAlpine K W, Height M I, Ritchie G S P & Birch P B 1985 Water and phosphorus transport processes in permeable grey sands at Talbot's Site near Harvey, Western Australia. Department of Conservation and Environment, Perth. Bulletin 209.

Seddon G 1972 Sense of Place. University of Western Australia Press, Perth.

Spencer C N & Hauer F R 1991 Phosphorus and nitrogen dynamics in streams during a wildfire. Journal of the North American Benthological Society 10:24-30.

Wetzel R G 1975 Limnology. Saunders, Philadelphia.

Yeates J S, Arkell P T, Russell W K, Deeley D M, Peek C & Allen D 1985 Management of agricultural losses from the soils of the Peel-Harvey catchment. In: Peel-Harvey Estuarine System Study Management of the Estuary. Proceedings of a symposium at The University of Western Australia, February 19–20, 1985. Department of Conservation and Environment, Perth, Bulletin 195: 59-76.