Changes in the water quality of the Wilderness and Swartvlei lake systems, South Africa

I.A. RUSSELL

Russell, I.A. 1999. Changes in the water quality of the Wilderness and Swartvlei lake systems, South Africa. *Koedoe* 42(1): 57–72. Pretoria. ISSN 0075-6458.

Measurements of water temperature, salinity, total dissolved solids, pH, dissolved oxygen, secchi disk depth, turbidity and total suspended solids were undertaken monthly in the Wilderness and Swartvlei lake systems between 1991 and 1997. The range of most water quality variables is wider than recorded in earlier studies. Potential causes are discussed for each variable, and include both anthropogenic modification of the quantity and timing of water movements within the lakes, as well as higher sampling and longer duration studies resulting in more accurate recording of natural variability. Historical data on total dissolved solids (1978 to 1990) were combined with data collected in these surveys to assess the occurrence of trends in relation to freshwater inflows. Long-term (19-year) changes in total dissolved solids have occurred in all lakes, with decreases during high runoff periods and increases during low runoff periods. There is little evidence of unidirectional change in total dissolved solids despite increased water abstraction from influent rivers.

Keywords: water quality, temperature, salinity, pH, oxygen, clarity, Wilderness, Swartvlei, freshwater depravation.

I.A. Russell, South African National Parks, P.O. Box 176, Sedgefield, 6573 Republic of South Africa.

Introduction

The Wilderness and Swartvlei lake systems are situated on the Cape south coast and form the core conservation area of the Wilderness National Park. The park is unusual in South African in that it is partially located within populous urban areas. There are also several nodes of development adjacent to the park in rural areas. Development of the lake catchments, which fall largely outside of the park boundaries, is extensive, and includes both agricultural (20.7 % of catchment area) and silviculture (28.5 % of catchment area) practices (Hughes & Filmalter 1993). The extensive anthropogenic modifications of the lake catchments and residential developments adjacent to the waterbodies have the potential to substantially influence water quality in the lakes. For example, water levels in the lakes are managed to prevent inundation of adjacent low-lying residential properties. This entails periodic artificial breaching of estuary mouths with resultant modification of the exchange of waters between the lake and marine environments. Alteration of such exchanges could influence the salinity of the lake waters. Additional factors which could influence water quality include (i) reductions in freshwater inflows, (ii) increased input of suspended and dissolved compounds principally from runoff from agricultural areas, (iii) lack of reticulated sewage in most adjacent residential areas, and (iv) accelerated erosion of catchment due to disturbance of ground cover and consequent increased sediment inputs, particularly during high rainfall events.

South African National Parks (SANP) initiated a water quality monitoring program in the Wilderness and Swartvlei lake systems in 1991 to address concerns about possible declines in water quality. This program was undertaken to supplement monitoring actions already undertaken by the Department of

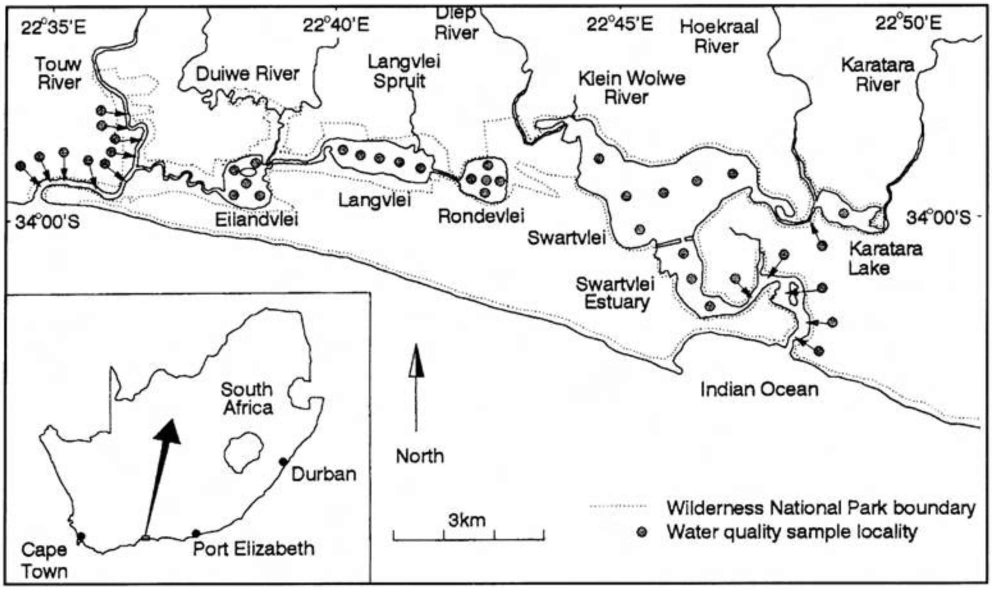

Fig. 1. Map of the Wilderness National Park indicating water sample localities.

Water Affairs and Forestry (DWAF), and entailed more detailed assessments of change in some water quality parameters (total dissolved solids (TDS), salinity) and the introduction of regular measurement of additional parameters (pH, dissolved oxygen, total suspended solids (TSS), and turbidity). The objectives of this program were (i) to establish if substantial, long-term (>10 years), changes have occurred in water quality, and in particular TDS, and (ii) investigate short-term changes in water quality parameters (particularly TSS, turbidity, salinity, pH and dissolved oxygen) in relation to runoff and breaching of the estuary mouths. This paper presents results from the first seven years of this program, with are compared to historical data to assess the occurrence and possible causes of changes in aspects of water quality.

Study Area

The Wilderness system comprises three lakes (Rondevlei, Langvlei, Eilandvlei) interconnected by shallow channels, and the Touw Estuary which connects with Eilandvlei via the sinuous Serpentine channel. The Swartvlei system comprises three waterbodies: Karatara Lake, Swartvlei Lake, and Swartvlei Estuary (Fig. 1).

Three rivers, the Touw River, Duiwe River and Langvlei Spruit, flow into the Wilderness system, whereas the Diep, Klein Wolwe, Hoëkraal and Karatara rivers flow into the Swartvlei system. All these rivers arise in forest and fynbos covered catchments in the Outeniqua Mountains. They flow predominantly over Table Mountain sandstone and are low in dissolved solids and stained with humates (Robarts & Allanson 1977). Mean annual rainfall in the catchments is between 900 and 1000 mm/y. (Adamson 1975) with little seasonal variation (Whitfield *et al.* 1983).

The estuaries are subject to wide variations in hydrology resulting from frequent mouth closure by south-westerly wave conditions and longshore sand transport (Whitfield *et al.* 1983) and erratic river inflow (Heydorn & Tinley 1980). Periodic heavy rains in the river catchments result in flooding of the estuaries and breaching of the sand bar across the estuary mouths.

Aquatic macrophytes are widespread in all of the waterbodies, and consist predominantly of pure and mixed stands of *Ruppia cirrhosa*, *Potamogeton pectinatus*, *Charophyta* and filamentous algae (Howard-Williams & Liptrot 1980; Weisser & Howard-Williams 1982; Whitfield *et al.* 1983). *Zostera capensis* is abundant in the lower reaches of the Swartvlei Estuary (Whitfield *et al.* 1983) and occurs sporadically in the Touw Estuary. Aquatic macrophytes do not generally occur in waters deeper than 3 m (Whitfield 1984). The lakes are fringed by a narrow margin of emergent aquatic plants (for example *Phragmites australis*, *Scirpus littoralis*, and *Typha latifolia*) with these species being sparsely distributed along Swartvlei Estuary. Abundant estuarine and marine fish (Hall *et al.* 1987, Whitfield 1984, Russell 1996) and waterbird (Boshoff *et al.* 1990a, 1990b, 1990c) populations inhabit the lake systems.

The Wilderness system, with the exclusion of the Touw Estuary, is a designated Ramsar site.

Methods

Water quality parameters of surface waters in the lake systems were measured monthly from January 1991 to December 1997 at 40 localities (Fig. 1). Measurements undertaken in the field at 30 cm depth were: water temperature (°C) and salinity (g/kg) using a YSI Model 33 S-C-T meter; dissolved oxygen (mg/l) using a SG 867 digital O_2 meter; and pH with a Knick 751 pH meter. Measurement of dissolved oxygen was terminated in 1994 due to equipment failure.

Secchi disk readings were taken to the nearest 0.01 m. In the shallow estuaries and portions of Langvlei and Swartvlei Lake light penetration is frequently to the substratum. Consequently in these waterbodies secchi disk readings where obtainable only during turbid conditions. Despite this limitation, measures of secchi disk depth where retained to enable comparison with historic data. Measurement of turbidity was undertaken to provided a more accurately measure of water clarity. Water samples were collected at 30 cm depth and transported to a laboratory where, within three hours of sample collection, turbidity (NTU) was measured with a Hach 16800 turbidimeter.

Total suspended solids (mg/kg) was determined by filtering samples through Whattman GF/C or equivalent glass fibre filters. These filter papers were dried at 60 °C for more than three hours prior to filtering, and 24 hours after filtering, and weighed on a Sartorius A200S electronic balance to the nearest 0.0001 gram. Total dissolved solids (g/kg) was determined by evaporating the filtered water at a temperature < 70 °C and weighing the dry evaporate.

Mean pH values for waters in the Touw and Duiwe rivers for the period 1991–1997 were obtained by averaging the antilog of the reciprocals of recorded monthly pH values.

Results and Discussion

Water temperature

Water temperature in the lakes and estuaries varied between 8.0 °C and 28.2 °C (Table 1), with the largest range occurring in the Touw Estuary. Mean water temperature was similar in most waterbodies, though minimum temperatures were substantially lower (2.0–4.8 °C) in the Touw Estuary (Table 1). The similarity of recorded ranges in different lakes and estuaries suggests that water temperature is influenced primarily by ambient conditions rather than sea temperature. Upwelling of cold waters is reported to be a common event along the southern Cape coast (Smith 1949; Schumann *et al.* 1988) particularly during summer (Hanekom *et al.* 1989). Water temperatures in the lower portions of estuaries occasionally decline to below 13 °C during summer following the ingress of such waters (Schumann *et al.* 1988). These phenomena were not recorded influencing estuary water temperature during this study. The lowest temperature recorded in these surveys (8.0 °C; Table 1) occurred in mid-winter 1997 in the upper reaches of the estuary. Even though the estuary mouth was open during this period (Fig. 3d) ambient temperature rather than cold water upwelling is suggested as the primary cause, as salinity in the estuary remained below 3.8 g/kg indicating minimal seawater ingress.

Table 1
Summary statistics for eight water quality parameters in the Wilderness and Swartvlei lake systems between 1991 and 1997

		Touw Estuary	Eilandvlei	Langvlei	Rondevlei	Swartvlei Estuary	Swartvlei Lake	Karatara Lake
Temperature	max	28.2	28.0	27.0	27.5	28.0	27.2	27.0
(Celcius)	mean	19.2	20.0	19.9	20.0	19.9	20.1	19.6
	min	8.0	11.0	11.5	8.4	10.0	12.8	10.9
	n	680	400	395	399	663	480	158
Salinity	max	36.5	8.9	12.4	17.3	36.2	14.1	10.2
(g/kg)	mean	11.5	5.6	8.0	12.4	18.8	8.4	3.9
	min	0.0	1.4	3.9	8.4	2.2	0.5	0.0
	n	673	396	395	400	662	477	156
TDS	max	47.3	12.8	17.8	30.4	56.5	18.2	12.2
(g/kg)	mean	12.2	6.4	9.3	14.1	20.6	9.4	4.2
	min	0.1	2.4	3.7	8.6	2.8	1.1	0.2
	n	665	386	391	344	643	458	151
pH	max	10.2	9.1	9.3	9.7	10.1	10.4	8.5
	min	4.7	6.0	7.1	6.1	5.7	5.1	4.4
	n	595	251	220	349	582	424	140
Dissolved	max	17.9	18.2	14.2	15.3	22.1	14.5	11.0
oxygen	mean	6.9	7.8	7.8	7.8	7.4	7.1	6.7
(mg/l)	min	1.1	1.3	2.2	1.4	1.3	1.5	1.6
	n	328	195	198	199	320	240	80
Secchi	max	4.85	3.16	3.60	4.10	3.76	7.89	3.10
disk	mean	1.75	1.67	2.25	2.03	1.96	2.87	1.02
(m)	min	0.00	0.23	0.79	0.66	0.70	0.26	0.31
	n	201	383	292	380	75	425	134
Turbidity	max	34.0	88.0	20.0	30.1	37.0	78.0	78.0
(NTU)	mean	5.7	9.6	5.4	8.1	4.5	5.7	8.2
	min	0.7	2.1	1.5	0.6	0.7	0.8	1.2
	n	637	281	375	385	620	455	146
TSS	max	165.6	63.0	28.7	41.8	61.2	58.8	76.0
(mg/kg)	mean	15.7	12.5	12.0	18.1	20.6	13.3	8.9
	min	0.1	3.4	1.8	3.0	2.6	2.2	0.3
	n	663	400	388	389	648	479	156

Temperature ranges in Langvlei, Rondevlei, Swartvlei Lake and Swartvlei Estuary were within the bounds of ranges recorded during previous studies (Fig. 2a). Higher temperatures were recorded in both Eilandvlei (2.0 °C) and Touw Estuary (1.7 °C), presumably as result of higher ambient temperatures during study periods.

Salinity

A strong axial salinity gradient persisted in the Swartvlei system throughout the study period, with mean salinity highest in Swartvlei Estuary and lowest in Karatara Lake (Table 1). A salinity gradient also persisted in the lakes of the Wilderness system

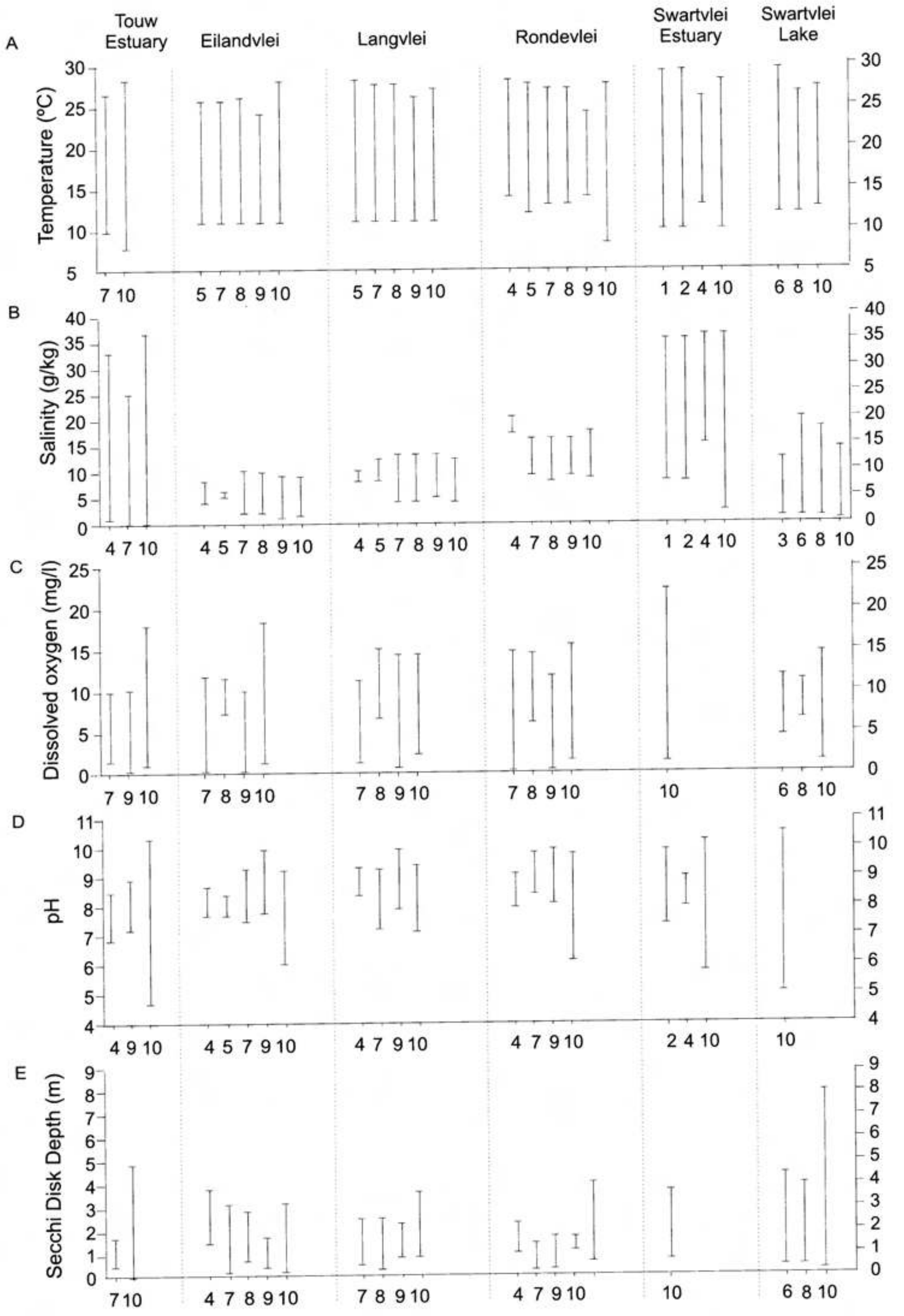

Fig. 2. Ranges in five water quality parameters recorded in the Wilderness and Swartvlei systems where author 1 = Liptrot (1978), 2 = Liptrot & Allanson (1978), 3 = Howard-Williams & Allanson (1978), 4 = Coetzee (1978), 5 = Coetzee & Palmer (1982), 6 = Whitfield (1982), 7 = Allanson & Whitfield (1983), 8 = Boshoff (1981 to 1984 unpublished data), 9 = Hall (1985b), and 10 = this study.

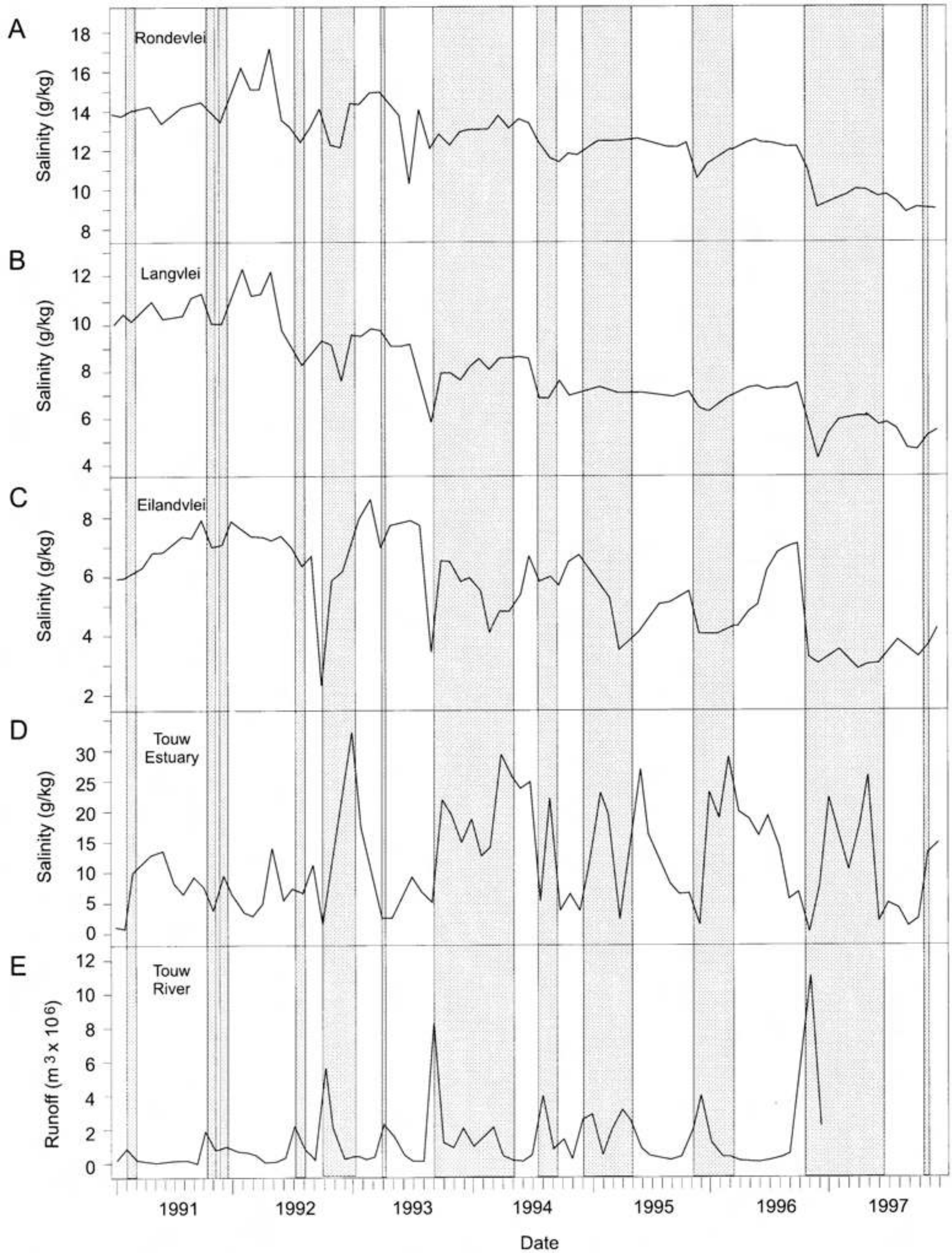

Fig. 3. Mean monthly salinity values for (A) Rondevlei, (B) Langvlei, (C) Eilandvlei and (D) Touw Estuary in the Wilderness system, and (E) monthly runoff from the Touw River catchment between 1991 and 1997. Shaded bars indicate periods when the mouth of Touw Estuary was open.

(Table 1), though differed from the Swartvlei system in that higher salinities occurred in Rondevlei, the lake furthest removed from the sea, and lower salinities in Eilandvlei, the lake closest to the sea. Allanson & Whitfield (1983) have also previously recorded this reversed salinity gradient in the Wilderness system.

Variation in salinity was highest in the estuaries, and followed the predictable pattern of substantial decreases during periods of high freshwater inflows, and increases during low freshwater inflow periods and when the estuary mouths were open (Figs. 3d and 4c). Substantial short-term declines in salinity occurred in the Wilderness lakes during high runoff periods (Figs. 3a–3c). Periodic increases in salinity when the estuary mouth was open were apparent in Eilandvlei (see October 1992 to January 1993: Fig. 3c). The inflow of marine water following the breaching of Touw Estuary appeared to have little influence on salinity of Langvlei and Rondevlei, indicating only minor exchange of water between the upper lakes and the marine environment. The trend of short-term changes in salinity in Swartvlei Lake and Swartvlei Estuary were similar (Figs. 4b & 4c) suggesting extensive exchange of both marine and fresh water between these waterbodies.

Mean TDS was higher than salinity in all waterbodies (Table 1), suggesting periodic high organic salt concentrations. Prolific algal growth which have been noted during this study, particularly in Eilandvlei and Rondevlei which, together with faecal deposition by abundant waterbirds (Boshoff *et al.* 1990a, 1990b, 1990c), possibly contribute to periodic high organic salt concentrations. The small deviation of recent (1995–1997) salinity:TDS ratios from unity (Table 2) suggests that measures of TDS and salinity are frequently comparable.

Long-term (19-year) changes in TDS have occurred in all waterbodies (Figs. 5a–5d, 5f) though there is little evidence of unidirectional change. The direction of change in TDS in the lakes is strongly influenced by freshwater inflows, with increases in TDS coinciding with reduced inflow periods (1984–1990), and decreases in TDS occurring predominantly during comparatively high inflow periods (1978–1983; 1991–1996) (Figs. 5a–5g). The frequency of directional change in TDS concentrations is highest in the waterbodies with substantial freshwater inflows, namely Eilandvlei (Fig. 5c), Touw Estuary (Fig. 5d) and Swartvlei Lake (Fig. 5f). Alternatively, a low frequency of directional change in TDS concentration was recorded in Rondevlei and Langvlei where freshwater inflows are relatively small.

Salinity ranges in the lakes were similar to those recorded in previous studies, whereas larger ranges were recorded in the estuaries (Fig. 2b). Maximum salinity in Touw Estuary was higher than those recorded by Coetzee (1978) (difference between past and present measurements = 3.5 g/kg) and Allanson & Whitfield (1983) (difference between measurements = 11.5 g/kg), whereas the lowest previous recordings of salinity in Swartvlei Estuary are substantially higher (5.8 g/kg) than recorded in this study (Fig. 2b). Larger ranges in salinity in the estuaries are likely the consequence of dilution during high intensity rainfall events (e.g. September 1993 where rainfall was 142mm in 72hours) (SANP unpublished data), and extended tidal conditions following periods

Table 2
Ratio of salinity to TDS for water samples collected in the Wilderness and Swartvlei lake systems from 1995 to 1997

Waterbody	Salinity:TDS	*n*
Rondevlei	1:1.008	159
Langvlei	1:0.988	157
Eilandvlei	1:0.993	159
Touw Estuary	1:0.989	225
Swartvlei Lake	1:1.007	189
Swartvlei Estuary	1:1.015	220
Karatara Lake	1:1.011	40

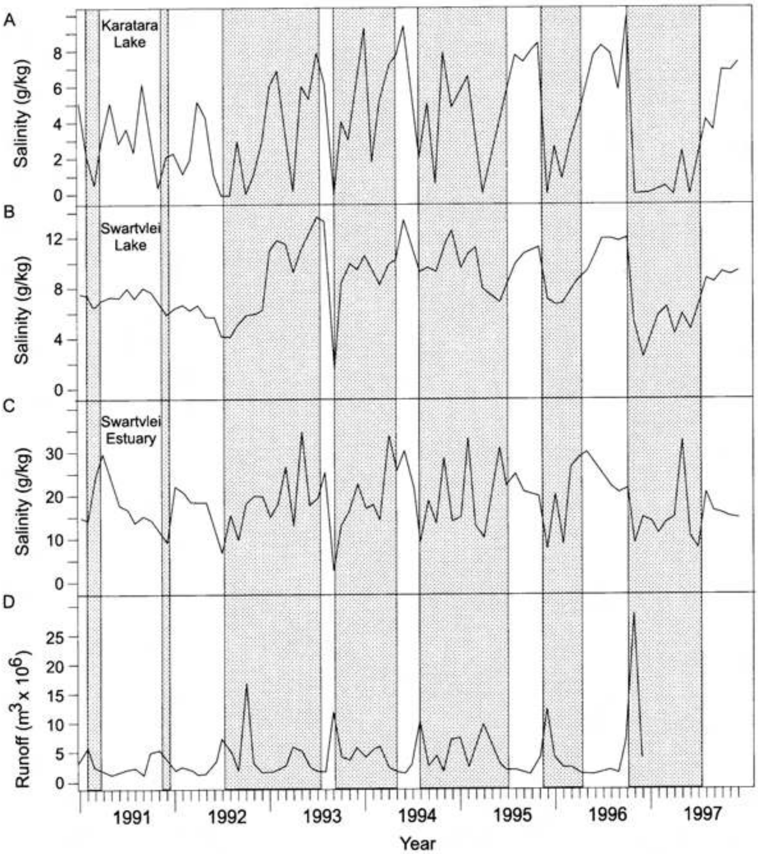

Fig. 4. Mean monthly salinity values for (A) Karatara Lake, (B) Swartvlei Lake and (C) Swartvlei Estuary in the Swartvlei system, and (E) combined monthly runoff from the Diep, Hoëkraal and Karatara river catchments into the Swartvlei system between 1991 and 1997. Shaded bars indicate periods when the mouth of Swartvlei Estuary was open.

of high runoff which enable salinity to approximate that of seawater.

Dissolved oxygen

Wide variations in dissolved oxygen concentration were recorded in waterbodies in both the Wilderness (1.1 mg/l to 18.2 mg/l) and Swartvlei (1.3 mg/l to 22.1 mg/l) systems (Table 1). The periodic recording of high dissolved oxygen concentrations in Swartvlei Estuary is similar to the findings of Liptrot & Allanson (1978) where saturation levels exceeding 200 % were occasionally recorded in Enteromorpha mats. The range in dissolved oxygen concentrations in Touw Estuary, Eilandvlei and Swartvlei Lake, however, were substantially larger than ranges recorded in earlier studies (Fig. 2c).

Dissolved oxygen in the lake systems has been found to vary in response to biological activity, with higher concentrations frequently being associated with the presence of aquatic plants (Kok & Whitfield 1986). Periods of comparatively high biomass of submerged aquatic plants have been recorded during this study in both Eilandvlei

(1978–1983 maximum = 1100 g/m² (Hall 1985a); 1991–1994 maximum = 3466 g/m²) (SANP unpublished data) and Touw Estuary (1979 = 265 g/m² (Howard-Williams 1980); 1991–1994 maximum = 458 g/m²) (SANP unpublished data) which may have contributed to increased oxygen concentrations in these waterbodies. Similarly, historical data on dissolved oxygen concentrations in Swartvlei Lake (Fig. 2c) were collected predominantly during a period of submerged macrophyte senescence (1979–1981) (Whitfield 1982) and subsequent early recovery phase (1982–1983) (Weisser *et al.* 1992). Thus higher dissolved oxygen concentrations recorded in this study may be a consequence of increased photosynthetic activity resulting from an increase in the biomass of aquatic plants.

The periodic occurrence of low dissolved oxygen concentrations in all waterbodies is similar to the findings of previous studies (Fig. 2c). De-oxygenated conditions, as observed by Liptrot (1978), occurred most frequently in deeper water or along the channel edges amongst decomposing organic matter. Widespread de-oxygenation throughout a waterbody has however previously been recorded in Rondevlei (Russell 1994), and is thought to have resulted from the senescence of a dinoflagelate/algal bloom. Periodic low oxygen concentrations are a natural phenomenon in the Wilderness and Swartvlei systems, though it is unknown to what extent the input of pollutants from the catchments is a contributing factor.

pH

The pH in all waterbodies (Table 1) deviated substantially from the 7.8 to 8.3 range expected for seawater (Day 1981), and varied widely within the typical range of 4 to 11 expected for most surface freshwater systems on South Africa (Dallas *et al.* 1998). Although geological, atmospheric, biological and anthropogenic influences may all affect the proportion of major ions in waterbodies, and hence pH (Wetzel 1983), the following three processes are possibly dominant in the lake systems: (i) the inflow of poorly buffered waters draining fynbos covered catchments, the pH of which may be low (e.g., Touw River pH 3.6–5.4–6.6 min-mean-max; $n = 63$; 1991–1997; Duiwe River pH 4.8–6.5–7.4 min-mean-max; $n=55$; 1991–1997) (SANP unpublished data) owing to the influence of organic (humic) acids; (ii) the inflow of well buffered, slightly alkaline seawater following the breaching of estuary mouths, and (iii) biological activity and in particular the consumption of CO_2 (resulting in an increase in pH) during photosynthesis by abundant aquatic plants, and release of CO_2 (resulting in a decrease in pH) during respiration and decomposition (Wetzel 1983).

Periodic reductions in pH following increases in freshwater inflows are most evident in Touw Estuary, and to a lesser extent Eilandvlei, as well as Karatara Lake (for example, see large inflow periods in October 1992, September 1993, December 1995 and November 1996) (Figs. 6c, 6d and 7a). Increases in pH following the ingress of seawater after breaching of the sandbar at the estuary mouth are evident in both the Touw Estuary (October 1992–January 1993; November 1995–March 1996; October 1996–June 1997) (Fig. 6d) and Eilandvlei (October 1992–January 1993) (Fig. 6c). Increases in pH are also evident during some tidal phases in the Swartvlei system (for example, September 1993–May 1994) (Figs. 7a–7c) where seawater inflows are indicated by increases in salinity (Figs. 4a–4c). This phenomenon, however, is not evident during all tidal phases (for example, July 1992–July 1993) (Fig. 7a–7c). During these periods, as well as when freshwater inflows are low and the estuary mouths closed, it is assumed that biological activity would be the primary determinant of pH.

Trends of change in pH in Rondevlei, Langvlei and Eilandvlei are similar (Figs. 6a–6c). Poor correlation between pH and both high freshwater inflow and tidal periods in Rondevlei and Langvlei (Figs. 6a and 6b) suggests that biological activity is the primary determinant of pH in these waterbodies,

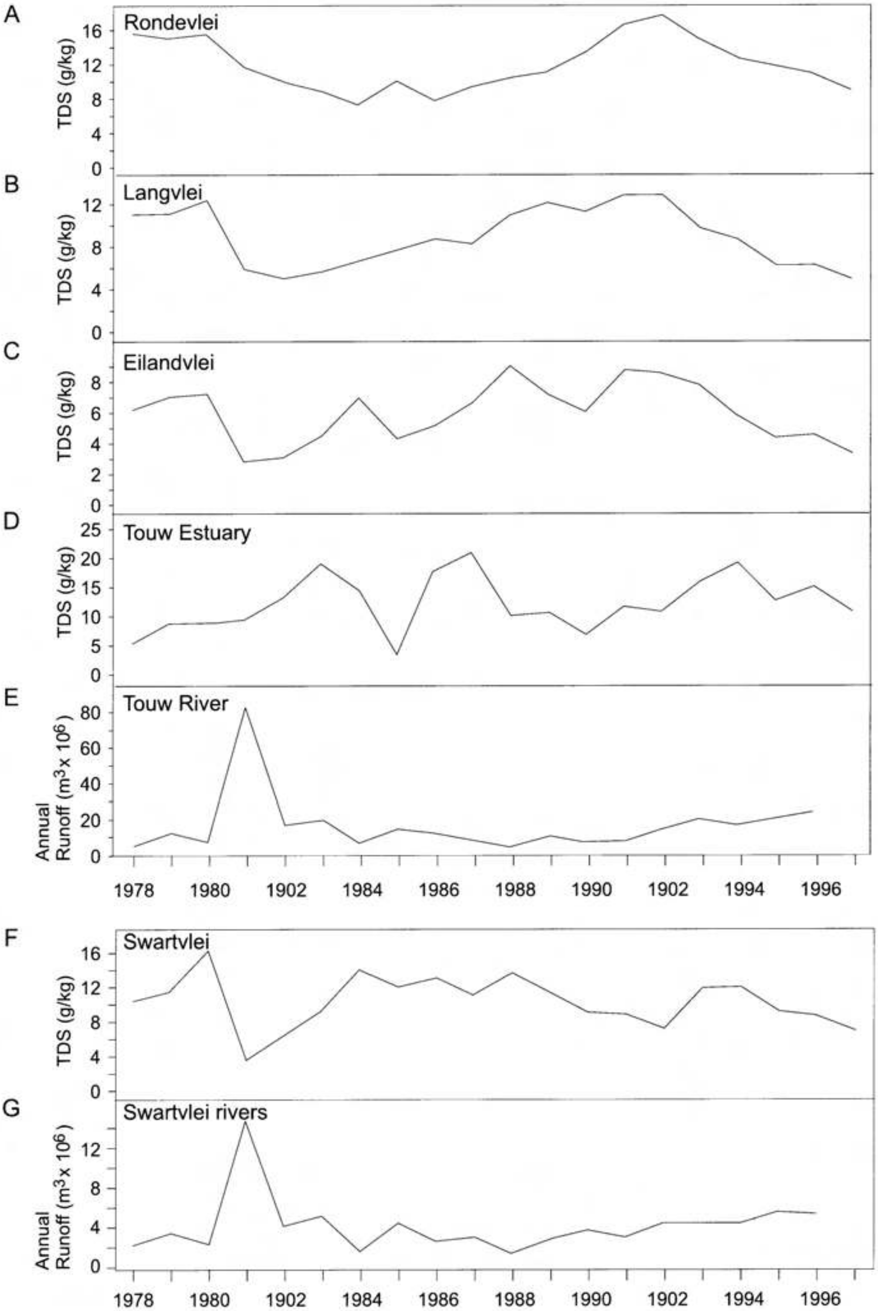

Fig. 5. Mean annual concentrations of total dissolved solids in (A) Rondevlei, (B) Langvlei, (C) Eilandvlei and (D) Touw Estuary in the Wilderness system, (F) Swartvlei Lake in the Swartvlei system, and annual runoff from (E) the Touw River catchment in the Wilderness system, and (G) combined annual runoff from the Diep, Hoëkraal and Karatara river catchments into the Swartvlei system between 1978 and 1996. All runoff data, and dissolved solid values prior to 1990, obtained from Department of Water Affairs and Forestry unpublished records.

and to a lesser extent, Eilandvlei. Large changes in pH during extended closed phases in Swartvlei Estuary during 1991 and 1992 coincided with comparatively large changes in the biomass of submerged aquatic plants (principally *Ruppia cirrhosa*). Increases in pH occurred when plant biomass was high in 1991 (134.7 g/m²) and early 1992 (614.2 g/m²), and decreased following the senescence of aquatic plants in 1993 (3.1 g/m²) (Fig. 7c), suggesting that biological activity may, at times, significantly effect pH in this waterbody.

The pH ranges in the Touw Estuary, Eilandvlei, Rondevlei and Swartvlei Estuary were found to be wider than those recorded in earlier studies (Fig. 2d). pH range in Langvlei, however, corresponds closely to those given by Coetzee (1978), Allanson & Whitfield (1983) and Hall (1985b). Increases in pH range could have resulted from anthropogenic influences on the spatial and temporal movement of water through and within the lake systems, as well as the quantity and quality of such inputs. It is also possible that the longer duration of this study compared to earlier studies has enabled more accurate recording of natural variability in pH thus contributing to larger ranges.

Clarity

Clarity of water was highest in Langvlei and the Touw and Swartvlei estuaries, indicated by low means and comparatively small ranges in turbidity readings (Table 1). Mean turbidity in Swartvlei Lake was similar to those recorded in Langvlei and the estuaries, indicating frequent occurrence of clear water conditions. High maximum values in Swartvlei Lake, however, indicate periodic occurrence of highly turbid conditions that frequently occurred during periods of high freshwater inflow. Mean turbidity was highest in Eilandvlei, Rondevlei and Karatara Lake (Table 1), with high maximum values in Eilandvlei and Karatara Lake indicating the periodic occurrence of highly turbid conditions.

Mean TSS concentrations did not mirror mean turbidity, with TSS being highest in Rondevlei and Swartvlei Estuary, whereas TSS in the frequently turbid Eilandvlei was not substantially higher than the less turbid Touw Estuary, Langvlei and Swartvlei Lake (Table 1). Alternatively, mean TSS was lowest in Karatara Lake where mean turbidity was comparatively high (Table 1). Differences between mean TSS and turbidity values suggest that the nature of suspended solids differ between waterbodies. High concentrations of planktonic organisms in Swartvlei Estuary, which is frequently tidal (Fig. 4d), and Rondevlei where algal/dinoflagellate blooms occurred during the study period (Russell 1994), possibly resulted in higher TSS values though did not contribute to decreased clarity as much as inorganic particulate matter of fluvial origin. Alternatively, the waters of Karatara Lake are frequently stained with humic particles which, although contributing relatively little to TSS values, substantially decreased clarity. Periodic high TSS concentrations in Touw Estuary, Eilandvlei, and Swartvlei Lake, coincided with rainfall events, indicating high input of particulate matter from river catchments.

A natural background of 10 to 20 mg/l of suspensoids, consisting of planktonic organisms, organic matter and clay particles, is present in most northern hemisphere estuaries (Dyer 1972). This compares well with both Wilderness and Swartvlei systems where, only in Swartvlei Estuary, did mean TSS marginally exceed 20 mg/kg (Table 1). Thus, despite periodic inputs of substantial volumes of fluvial sediments that decrease water clarity, both Wilderness and Swartvlei remain clear water systems.

Historical data on the clarity of waters exists only as measures of secchi disk depth. Greater ranges in secchi disk depth were recorded in all waterbodies with comparable datasets, with the exception of Eilandvlei (Fig. 2e). Increased input of fluvial sediments is suggested by decreased minima in both Touw Estuary and Swartvlei Lake – waterbodies into which major rivers flow

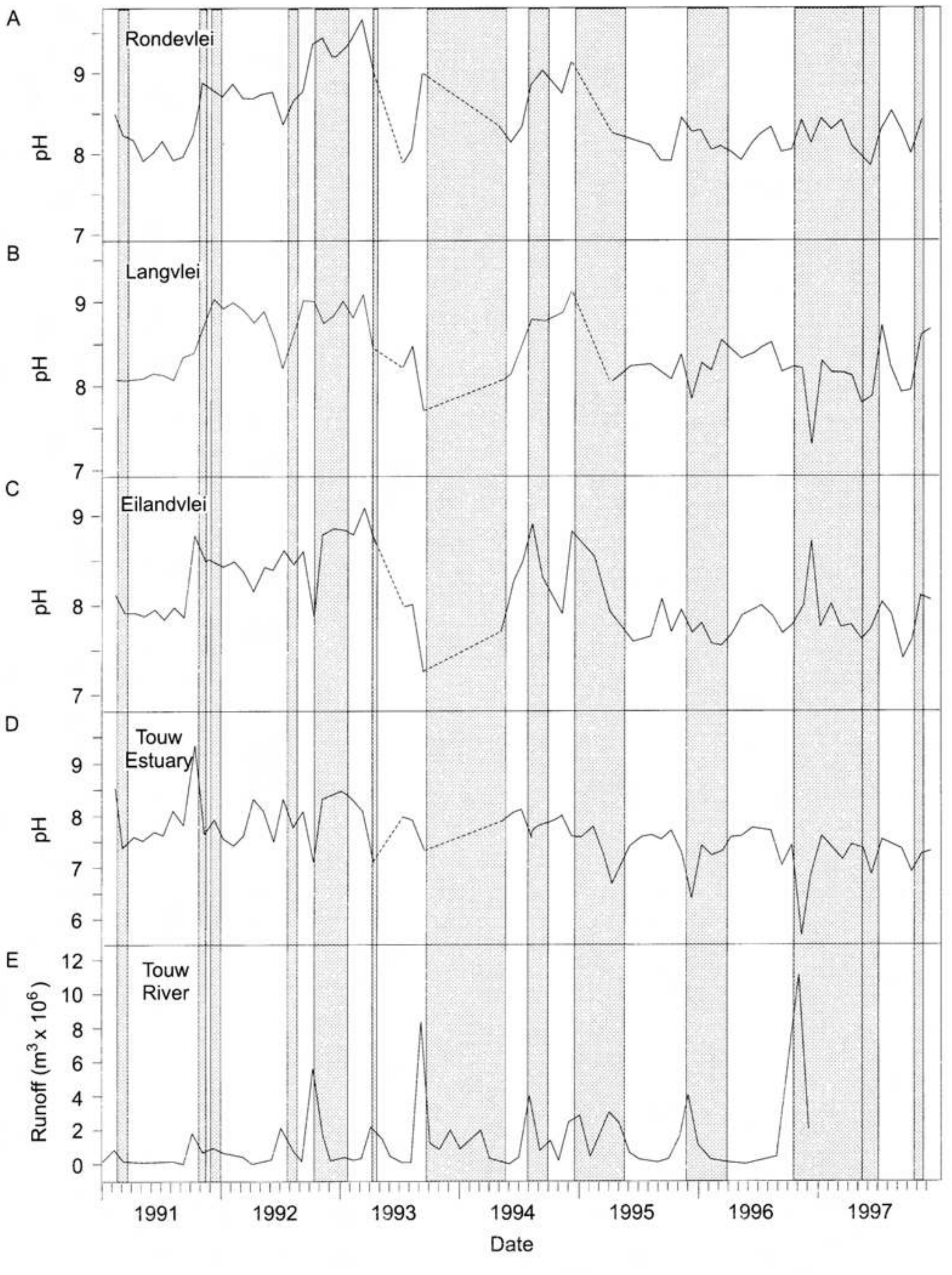

Fig. 6. Mean monthly pH values for (A) Rondevlei, (B) Langvlei, (C) Eilandvlei and (D) Touw Estuary in the Wilderness system, and (E) monthly runoff from the Touw River catchment between 1991 and 1997. Stippled lines indicate periods when pH was measured at intervals of greater than one month. Shaded bars indicate periods when the mouth of Touw Estuary was open.

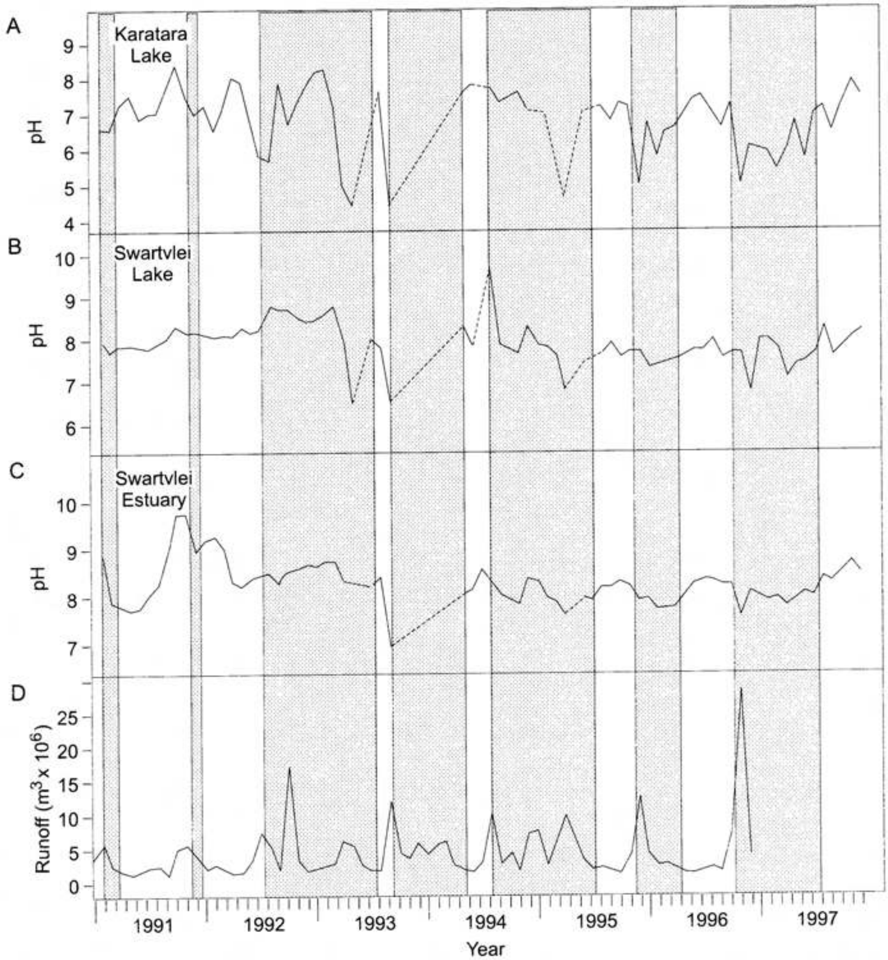

Fig. 7. Mean monthly pH values for (A) Karatara Lake, (B) Swartvlei Lake and (C) Swartvlei Estuary in the Swartvlei system, and (D) combined annual runoff from the Diep, Hoëkraal and Karatara river catchments into the Swartvlei system between 1991 and 1997. Stippled lines indicate periods when pH was measured at intervals of greater than one month. Shaded bars indicate periods when the mouth of Swartvlei Estuary was open.

(Fig. 1). Alternatively, substantially increased maxima in all waterbodies, with the exception of Eilandvlei, indicate periodic increases in water clarity and hence depth of light penetration. Wider ranges in secchi disk depth in most waterbodies can possibly be attributed to a higher sampling intensity resulting in more accurate recording of natural variability rather than an inherent change in water clarity.

Conclusions

Sufficient data for the establishment of long-term (>10 year) changes exists only for TDS. Although largely unidirectional changes in TDS have occurred in several waterbodies since 1991 (notably Rondevlei, Langvlei and Eilandvlei), there is as yet no evidence of this signifying a long-term trend. The strong influence of freshwater inflows on the direction of change in TDS, however, suggests that freshwater depravation through impoundment and abstraction of water from influent rivers could significantly alter the amplitude and temporal scale of TDS fluctuations in the lake systems.

Several short-term changes in water quality parameters (particularly TSS, turbidity, salinity and pH) in relation to runoff and breaching of the estuary mouths were evident. Freshwater inflows and the status of the estuary mouth are linked, in that reduced river inflows will lead to prolonged estuary mouth closure (Whitfield & Wooldridge 1994). Freshwater depravation resulting from further development of lake catchments could thus have significant direct and indirect effects on water quality within the lake systems. Altered water chemistry could, in turn, contribute to changes in distribution, abundance, and productivity of aquatic biota, and functioning of environmental processes. Increases in the recorded range of several water quality variables suggest anthropogenic influences on the water quality status of the Wilderness and Swartvlei Lake systems. It is important that all catchment management authorities afford high priority to the freshwater quantity and quality requirements of the lake systems when managing scarce freshwater resources, to ensure that these waterbodies function as viable, dynamic ecosystems that justify their current high national and international conservation standing.

Several changes in water quality in the Wilderness and Swartvlei systems have been linked to the movement of surface water within the lakes. The potential influence of groundwater movement on water quality in the lakes was, however, not addressed in this study. Preliminary estimates of seepage of water from the Wilderness (3×10^6 m^3/y) and Swartvlei systems (12×10^6 m^3/y) suggest the nett loss of large volumes of water to porous sediments (Fijen 1995a, 1995b). Modelling of water movements in the adjacent Groenvlei (Fig. 1), however, indicate that seepage losses are "very small" (0.11×10^6 m^3/y), whereas groundwater movements into the lake are comparatively large (c. 0.24×10^6 m^3/y) (Fijen 1995c). Thus estimates of the extent and direction of groundwater movement differ widely for adjacent waterbodies. In reality little is known about the movement of groundwater either into or from the lake systems, or its potential effect on water quality in the lakes and estuaries. Assessment of the extent of groundwater movement should receive priority in future research actions to facilitate identification of causes for water quality changes in the Wilderness and Swartvlei systems.

Acknowledgements

The funding of this work by the South African National Parks is gratefully acknowledged. The Department of Water Affairs and Forestry are thanked for providing data on streamflow and TDS used in this study. I and also grateful to Phillip Fisher, Lucas James, Julian Glynn and Eddie Kivett for assistance with the collection and processing of water samples.

References

ADAMSON, P.T. 1975. *Extension of monthly runoff records in the catchments of the Wit Els, Diep and Karatara rivers.* Pretoria: Department of Water Affairs.

ALLANSON, B.R. & A.K. WHITFIELD. 1983. *The Limnology of the Touw River Floodplain.* Pretoria: Council for Scientific and Industrial Research, National Scientific Programmes Unit. (South African National Scientific Programmes report; no. 79.)

BOSHOFF, A.F., N.G. PALMER & S.E. PIPER. 1990a. Spatial and temporal abundance of waterbirds in the southern Cape Province. Part 1: Diving and surface predators. *Ostrich* 62: 156–177.

BOSHOFF, A.F., N.G. PALMER & S.E. PIPER. 1990b. Spatial and temporal abundance of waterbirds in the southern Cape Province. Part 2: Waterfowl. *Ostrich* 62: 178–196.

BOSHOFF, A.F., N.G. PALMER & S.E. PIPER. 1990c. Spatial and temporal abundance of waterbirds in the southern Cape Province. Part 3: Wading birds. *Ostrich* 62: 197–214.

COETZEE, D.J. 1978. A contribution to the ecology of the zooplankton of the Wilderness Lakes. Ph.D. thesis, University of Stellenbosch, Stellenbosch.

COETZEE, D.J. & N.G. PALMER. 1982. Algemene fiesiese en chemiese toestande in Eilandvlei, Langvlei en Rondevlei gedurende 1978. *Bontebok* 2: 9–12.

DALLAS, H.F., J.A. DAY, D.E. MUSIBONO & E.G. DAY. 1998. *Water quality for aquatic ecosystems: tools for evaluating regional guidelines.* Pretoria: Water Research Commission. (Water Research Commission report; no. 626/1/98.)

DAY, J.H. 1981. The chemistry and fertility of estuaries. Pp. 57–75. *In:* DAY, J.H. (ed.). *Estuarine ecology with particular reference to southern Africa.* Cape Town: Balkema.

DYER, K.R. 1972. Sedimentation in estuaries. Pp. 397–407. *In:* BARNES, R.S.K. & J. GREEN (eds.). *The estuarine environment.* London: Applied Science Publishers.

FIJEN, A.P.M. 1995a. *Wilderness Lakes catchment. Touw and Duiwe rivers, water management strategy. Volume 2: Water resources.* Pretoria: Department of Water Affairs and Forestry.

FIJEN, A.P.M. 1995b. *Swartvlei Lake catchment, Diep-, Klein-Wolwe-, Hoëkraal- and Karatara rivers, water management strategy. Volume 2: Water resources.* Pretoria: Department of Water Affairs and Forestry.

FIJEN, A.P.M. 1995c. Groenvlei Lake catchment, water management strategy. Main report. Department of Water Affairs and Forestry, Pretoria.

HALL, C.M. 1985a Some aspects of the ecological structure of a submerged barrier lagoon system with particular reference to the distribution of fishes. MSc. thesis, Rhodes University, Grahamstown.

HALL, C.M. 1985b. *The Limnology of the Touw River Floodplain, Part II. Aspects of the ecological structure subject to floods, Drought and human interference.* Grahamstown: Rhodes University. (Institute for Freshwater Studies investigational report; no. 85/1.)

HALL, C.M., A.K. WHITFIELD & B.R. ALLANSON. 1987. Recruitment, diversity and the influence of constrictions on the distribution of fishes in the Wilderness lakes system, South Africa. *South African Journal of Zoology* 22: 163–169.

HANEKOM, N., L. HUTCHINGS, P.A. JOUBERT & C.N. VAN DER BYL. 1989. Sea temperature variations in the Tsitsikamma coastal park, South Africa, with notes on the effect of cold conditions on some fish populations. *South African Journal of Marine Science* 8: 145–153.

HEYDORN, A.E.F. & K.L. TINLEY. 1980. *Estuaries of the Cape. Part 1. Synopsis of the Cape coast – Natural features, dynamics and utilization.* Stellenbosch: Council for Scientific and Industrial Research. (Research report; no. 380.)

HOWARD-WILLIAMS, C. 1980. Aquatic macrophyte communities of the Wilderness Lakes: community structure and associated environmental conditions. *Journal of the Limnological Society of Southern Africa* 6(2): 85–92.

HOWARD-WILLIAMS, C. & B.R. ALLANSON. 1978. *Swartvlei Project Report Part 1. Introduction, research summary, management proposals for Swartvlei and recommendations on the use of aquatic macrophytes as nutrient filters.* Grahamstown: Rhodes University. (Institute for Freshwater Studies special report; no. 78/2.)

HOWARD-WILLIAMS, C. & M.R.M. LIPTROT. 1980. Submerged macrophyte communities in a brackish South African estuarine-lake system. *Aquatic Botany* 9: 101–116.

HUGHES, D. & E. FILMALTER. 1993. *Water quality management strategy for Wilderness, Swartvlei and Groenvlei lake areas. Hydrological assessment.* Grahamstown: Rhodes University. (Institute for Water Research report to GFJ Inc.)

KOK, H.M. & A.K. WHITFIELD. 1986. The influence of open and closed mouth phases on the marine fish fauna of the Swartvlei estuary. *South African Journal of Zoology* 21: 309–315.

LIPTROT, M.R. 1978. Community metabolism and phosphorous dynamics in a seasonally closed South African estuary. M.Sc. thesis, Rhodes University, Grahamstown.

LIPTROT, M.R. & B.R. ALLANSON. 1978. Swartvlei Project Report Part II. *Community metabolism and phosphorus dynamics in the Swartvlei estuary.* Grahamstown: Rhodes University. (Institute for Freshwater Studies special report; no. 78/4.)

ROBARTS, R.D. & B.R. ALLANSON. 1977. Meromixus in the lake-like upper reaches of a South African estuary. *Archiv für Hydrobiologie* 80: 531–540.

RUSSELL, I.A. 1994. Mass mortality of marine and estuarine fish in the Swartvlei and Wilderness lake systems, southern Cape. *South African Journal of Aquatic Science* 20(1/2): 93–96.

RUSSELL, I.A. 1996. Fish abundance in the Wilderness and Swartvlei lake systems: changes relative to environmental factors. *South African Journal of Zoology* 31(1): 1–9.

SCHUMANN, E.H., G.J.B. ROSS & W.S. GOSCHEN. 1988. Cold water events in Algoa Bay and along the Cape south coast, South Africa, in March/April 1987. *South African Journal of Science* 84: 579–584.

SMITH, J.L.B. 1949. *The sea fishes of southern Africa.* South Africa: Central News Agency.

WEISSER, P.J. & C. HOWARD-WILLIAMS. 1982. The vegetation of the Wilderness lakes system and the macrophyte encroachment problem. *Bontebok* 2: 19–40.

WEISSER, P.J., A.K. WHITFIELD & C.M. HALL. 1992. The recovery and dynamics of submerged aquatic macrophyte vegetation in the Wilderness lakes, southern Africa. *Bothalia* 22(2): 283–288.

WETZEL, R.G. 1983. *Limnology.* New York: Saunders.

WHITFIELD, A.K. 1982. Trophic relationships and resource utilization within the fish communities of the Mhlanga and Swartvlei estuarine systems. Ph.D. thesis, University of Natal, Pietermaritzburg.

WHITFIELD, A.K. 1984. The effects of prolonged aquatic macrophyte senescence on the biology of the dominant fish species in a southern African coastal lake. *Estuarine, Coastal and Shelf Science* 18: 315–329.

WHITFIELD, A.K., B.R. ALLANSON & T.J.E. HEINECKEN. 1983. *Estuaries of the Cape. Part II. Synopses of available information on individual systems.* Report No. 22 Swartvlei (CMS 11). Stellenbosch: Council for Scientific and Industrial Research. (Research report; no. 421.)

WHITFIELD, A.K. & T.H. WOOLDRIDGE. 1994. Changes in freshwater supplies to southern African estuaries: some theoretical and practical considerations. Pp. 41–50. *In:* DYER, K.R. & R.J. ORTH (eds.) *Changes in Fluxes in Estuaries.* Fredensborg: Olsen.