Precipitation chemistry of Roodeplaat Dam catchment

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Abstract

Precipitation quality over the Roodeplaat Dam catchment was measured at nine sampling sites during the 1979 and 1980 rain seasons. Both macro determinands and trace metals were measured in the bulk precipitation. At one sampling site bulk and wet-only precipitation quality was also determined. Parallel water quality determinations were made on the inflowing rivers into Roodeplaat Dam. Sulphate concentrations were observed in the range 2,9 mgℓ^{-1} to 5,7 mgℓ^{-1}. More than half of the sulphate load to the catchment is retained within the catchment. The retention is greater for particle associated trace metals, in excess of 90% of their load being intercepted within the catchment. The inflowing rivers are well buffered with a mean pH of 7,7 and the acidic rainfall with a mean pH of 4,0 had no observable effect on the pH of the surface water.

Introduction

The deleterious effect of long-term pollution of the atmosphere by oxides of sulphur and nitrogen, with consequent corrosion of man-made concrete and marble structures through acid rain has been well documented in overseas studies (Martin, 1982; Sharma and Sharma, 1982). The introduction of pollution via atmospheric precipitation plays an important role in reservoir water quality (Betson, 1978; Makhon'ko, 1980) and may contribute significantly to the sulphate concentration in impoundments (Brezonik *et al.*, 1980) as well as to the nutrient load as found for North American lakes (Dolske and Sievering, 1980). Acid rain, which may be defined as a rainfall with a pH value of less than 5,6 may cause further deterioration in a water body through detrimental effects on the aquatic ecology (Glass *et al.*, 1982).

The pH of rainfall is, however, influenced by natural sources of acidity in addition to the contribution from atmospheric carbon dioxide, such as nitrogen fixation during thunderstorms (Veimeister, 1960) and the possibility of release of volatile organic acids from vegetable matter to the atmosphere (Galloway *et al.*, 1982). Doubt therefore exists as to the question, "what is the background pH of rainfall?". Concern has been expressed as to the consequence of the introduction of anthropogenic sources of acidity into water bodies for instance, fish deaths may occur as a consequence of the increased solubility of aluminium at acidic pH-values (Howells *et al.*, 1983).

While the effects of fossil-fuel burning on atmospheric precipitation and reservoir water quality have been well documented in European and North American studies (Glass *et al.*, 1982; Lesinki, 1983; Likens *et al.*, 1979), the studies conducted in South Africa have been limited to particular aspects of the problem e.g., measurement of water quality of precipitation at point sites (Funke, 1981; Hemens *et al.*, 1977; Van Wyk, 1982) or analysis of dry deposition (Wells and Van As, undated).

To establish the significance of atmospheric deposition as a vehicle for pollutant input to the Roodeplaat Dam catchment, the pilot study described in this paper was undertaken over the 1979/80 period. Major-ion and trace metal constituents were measured in the rainfall, as well as in the inflowing rivers. Through use of precipitation and flow data, element loads to the catchment and the reservoir were estimated.

Description of the study area

The Roodeplaat Dam catchment lies north-east of the city of Pretoria. The study area includes suburbia e.g. Waverley, Villeria, Queenswood, Hatfield, Brooklyn, Lynnwood, Waterkloof, Ashlea Gardens, Monument Park, and Eersterus and Mamelodi townships, as well as industrial areas e.g., the South African Railways Workshop complex at Koedoespoort and the motor industry (Chrysler Park). The remainder of the study area consists of farms and small-holdings.

The catchment is therefore of mixed type, covering the range suburbia, industry and agriculture. (Figure 1).

Morphologically the catchment consists of undulating hills, with shallow valleys, and is characterised by streams of rapid drainage. From Klipkop in the south, to Roodeplaat Dam in the north, the topography drops by more than 300 m over a north-south distance of 35 km.

The catchment is drained by three main rivers, viz., the Hartbeesspruit, with its major tributary the Morrelettaspruit; the Pienaars River; and the Edendalespruit. The area drained by each river is 357 km², 161 km² and 129 km² for the Pienaars River, Hartbeesspruit and Edendalespruit respectively; these areas being the catchment areas above the weirs A2M27 (Pienaars River), A2M28 (Hartbeesspruit) and A2M29 (Edendalespruit) (Figure1). The area below the weirs, constituting 5,4% of the total catchment area, is occupied by Roodeplaat Dam and its immediate environs. The full supply surface area of the reservoir itself is 3,9 km². The reservoir full supply capacity is 41,9 × 10^6m³ (Division of Hydrology, 1977).

Of the three rivers, the Edendalespruit drains the predominantly agricultural area on the east side of the catchment. The Pienaars River drains the central part of the catchment, which receives run-off from the Mamelodi township, as well as biologically treated sewage effluent from the Baviaanspoort sewage works. The Hartbeesspruit drains the suburban west part of the catchment, as well as the industrial area through the Morrelettaspruit.

The water quality of the urban run-off is influenced not only by pollution occurring within the catchment, but also by the quality of the water received across the catchment divide, as the major domestic source of water is obtained from the Vaal System (Rand Water Board).

Materials and methods

Collection of precipitation samples

Precipitation samplers were installed at 6 sites in the Roodeplaat Dam catchment in February 1979. A further three sampling sites were added in September 1979 (Figure 1).

The bulk precipitation samplers used in 1979/80 consisted of a 260 mm deep, 310 mm diameter plastic funnel mounted 1,2 m above ground level, on a mild steel tube. The stem of the funnel fits tightly into a 1 ℓ polyethylene bottle placed on a shelf

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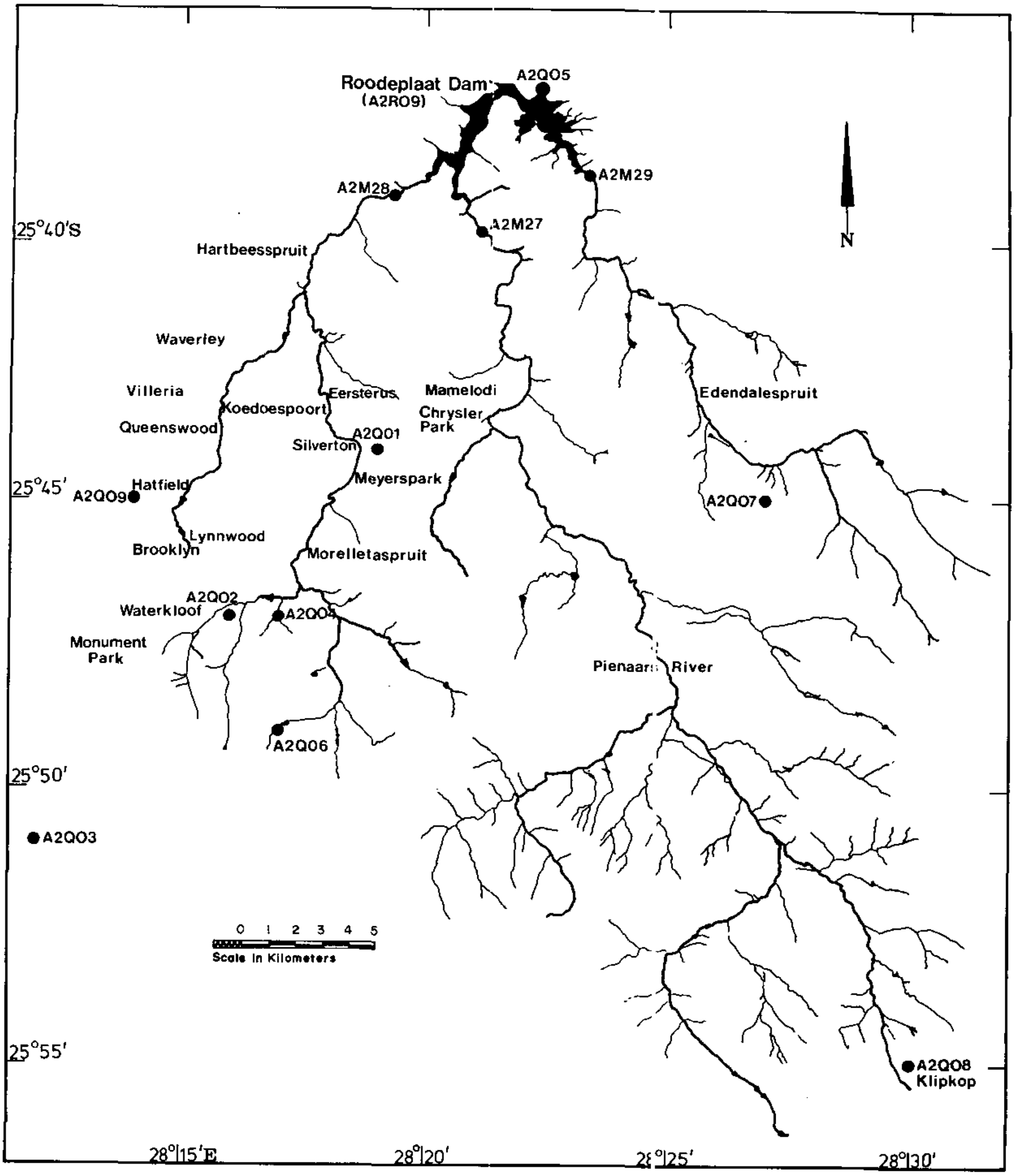

Figure 1
Distribution of precipitation quality sampling stations in the Roodeplaat Dam catchment. In the text sample sites are referred to by the last digit in the station number for brevity.

inside the steel tube, the sample bottle being accessible through a cut-out (Figure 2). Similar bulk precipitation samplers to those constructed for this study were subsequently described by Elejalde *et al.* (1981). Sampling was initiated in March 1979 at sampling sites 1 to 6; and in October 1979 at sites 7 to 9. Sampling was terminated in December 1979 at site 4, and in February 1980 at sites 1, 2, 3, 4 and 6. Sampling at the sites 7, 8 and 9 which were added after the beginning of the project, and 1, was continued until December 1980. In addition to the bulk sampling (rain and dust) at point No. 5, an effort was made to collect rain only samples on a storm-event basis by placing a pre-cleaned glass bowl of approximately 200 mm diameter out above the lawn at 1,2 m at the onset of a precipitation event. The bowl was retrieved immediately after the end of a precipitation event. The rain only samples are referred to hereafter as wet-only, in accordance with the literature (Hendry and Brezonik, 1980; Madsen, 1982).

For the bulk samples, the sampling personnel were requested to retrieve the collected sample daily or as soon as practically feasible after the end of a precipitation event. On each occasion the 1 ℓ sampling bottle was shaken, and the sample divided into two aliquots, viz. one aliquot of 20 ml for trace metal analysis and a second aliquot of 300 ml for macro element analysis. Where insufficient rain had fallen, it was not always possible to analyse for all determinands.

The aliquot for trace metal analysis was transferred to a

20 ml polyethylene bottle to which a pre-weighed amount of the disodium salt of the preservative ethylenediamine-tetra-acetic acid (EDTA), had previously been added to ensure a concentration of 1gℓ^{-1} EDTA in the sample. The sample for macro element analysis was placed in a prewashed 300 ml polyethylene bottle without preservative. Samples were frozen immediately after collection, and were thawed just before analysis. Each sampler was supplied with a container of deionized water with which to rinse out the 1 ℓ polyethylene sampling bottle after each sample collection. Samplers were also supplied with rain gauges (Weather Bureau, 1973), with which to record the quantity of precipitation. The wet-only sample at point No. 5 was treated after collection in the same way as the bulk sample prior to analysis. Table 1 shows the total number of macro and trace element samples collected at each sampling point, together with the latitude and longitude of each location.

River water samples

Daily samples of river water were collected between March 1979 and December 1980 at stations A2M27 (Pienaars), A2M28 (Hartbeesspruit) and A2M29 (Edendalespruit) as well as at Roodeplaat Dam itself (station A2R09 at the wall). The samples for trace metal analysis were preserved with nitric acid (10 ml.ℓ^{-1}) and the samples for macro analysis were preserved with mercury(II)-chloride (20 mgℓ^{-1}). The samples were analysed using the same methods as for the precipitation samples.

Figure 2
Rainfall sampler
A Polyethylene collection bottle (1 ℓ) on shelf.
B Mildsteel tube, 1,2 m x 312 mm diameter. 1,2 m above ground level. C Anti-bird perch (PVC material).
D Wet-only precipitation, collected in glass bowl, being transferred into 300 ml polyethylene bottle for macro-chemical analysis. E Standard raingauge 1,2 m above ground level.
F Plastic funnel 310 mm diameter used in sampler. G Polyethylene collection bottle (1 ℓ)
H Polythylene bottle (300 ml) for macro-analysis. I Polyethelene bottles (25 ml) with EDTA preservative added prior to sampling, for trace metal determination.

TABLE 1
STATION AND SAMPLING INFORMATION

Station	Name	Orientation		Number of samples	
		Lat °S	Long °E	Macro	Micro
A2Q01*	Meyers Park	25°44'	28°19'	58	62
A2Q02	Ashlea Gardens	25°47'	28°16'	33	35
A2Q03	Verwoerdburg	25°51'	28°12'	23	23
A2Q04	Garsfontein	25°47'	28°17'	20	21
A2Q05 A	Roodeplaat Dam	25°37'	28°22'	98	89
A2Q05 B	Roodeplaat Dam	25°37'	28°22'	78	77
A2Q06	Constantia Park	25°49'	28°17'	19	16
A2Q07	Pienaarspoort	25°44'	28°25'	53	39
A2Q08	Klipkop	25°55'	28°30'	44	13
A2Q09	Hatfield DSG**	25°45'	28°15'	46	39
513/405 A	IGY-WB	25°45'	28°14'	?	—

*A: Drainage region.
2: Sub-region two.
Q: Precipitation quality designation.
01: Sequence of station designation (sampling site number).
A2Q05 A: Bulk precipitation samples.
A2Q05 B: Wet-only precipitation samples.
**: St. Mary's Diocesan School for Girls.
IGY-WB: International Geophysical Year initiated in 1957 sampling period, 1957-1966, by Weather Bureau.

TABLE 2
METHODS USED FOR MACRO DETERMINAND ANALYSIS

Determinand	Method
Calcium	AAS[a]
Magnesium	AAS[a]
Sodium	FP[b]
Potassium	FP[b]
Sulphate	AA[c]
Chloride	AA[d]
Fluoride	Ion selective electrode
Silica	Molybdosilicate method
Nitrate + nitrite	Cadmium reduction and diazotization
Ammonia nitrogen	Phenate method
Orthophosphate	Molybdenum blue method
Total phosphorus	Acid digestion, molybdenum blue
DOC[e]	Persulphate/U.V oxidation[f]

[a] Atomic absorption spectrometry (AAS) with an air-acetylene flame with use of caesium and lanthanum as interference suppressants.
[b] Flame photometry (FP) using lithium as internal standard.
[c] Autoanalyzer (AA) method based on barium sulphate turbidimetry.
[d] Autonalyzer (AA) method using mercury (II) thiocyanate and iron (III) nitrate.
[e] Dissolved organic carbon (DOC).
[f] Gravelet-Blondin *et al.* (1980).

Analysis of samples for macro determinands

Samples were analysed immediately after thawing for pH and electrical conductivity (EC) using a combination glass electrode and a platinum conductivity cell respectively (Verhoef and Engelbrecht, 1977). Samples were thereafter analysed for macro determinands with automated analytical equipment using the methods as shown in Table 2.

Analysis of samples for trace metals

Trace metal samples were analysed by inductively coupled plasma (ICP) emission spectroscopy using an ARL 34000 ICP emission spectrometer. Standards were prepared in an EDTA or nitric acid matrix, to match that of the samples, and results corrected for spectral interferences using correction coefficients (Kempster *et al.*, 1983).

Results

The mean precipitation water quality found in the rain samples is given in Table 3 (macro determinands) and Table 4 (trace metals). *For sample site A2Q05, at the Hydrological Research Institute (HRI),* where both bulk and wet-only samples were collected, the mean concentrations which were found over the sampling period, are given in Tables 5 and 6 for macro and trace metal determinands respectively.

A comparison of the mean water quality found in this study for one of the sampling sites in Pretoria (Diocesan School for Girls *(DSG), Harfield, Pretoria) A2Q09 as compared to values ac*quired in the International Geophysical Year (IGY) initiated in 1957 (for the period 1957/66) for the Weather Bureau, Roper Street, Pretoria, is given in Table 7.

In Table 8 the mean electrical conductivity and pH in the bulk precipitation and in the surface run-off to Roodeplaat reservoir is given.

The estimated element loads to the catchment of Roodeplaat Dam, as compared to the load to the reservoir itself from the inflowing rivers is shown in Tables 9 and 10 for macro and trace metal determinands respectively. Element loads for the catchment were calculated from the bulk precipitation quality data and the mean depth of rain recorded over the catchment. Run-off loads into Roodeplaat Dam were calculated by the water balance method (Chow, 1964). Mean pH was calculated by converting pH values into hydrogen ion concentrations, taking the arithmetic mean and expressing as the negative logarithm:

$$\text{mean pH} = -\log_{10}\left[\frac{1}{n}\sum 10^{-\text{pH}}\right]$$

where n = number of measurements.

Discussion

pH

The pH of rainfall is naturally acidic due to the carbonic acid equilibrium, and a pH value of 5,6 is generally accepted as the equilibrium pH value (Galloway *et al.*, 1982; Glass *et al.*, 1982). Other natural sources of acidity exist however, such as nitrogen fixation during thunderstorms (Veimeister, 1960), as well as volatilization of organic acids from vegetation (Galloway *et al.*, *1982). It is therefore postulated that the natural background pH* of rainfall may be considerably lower than the carbonic acid equilibrium value of 5,6 or at least ≧ pH 5 if contributions from human activities were removed, to quote Galloway *et al.* (1982).

The mean pH value of the bulk precipitation for the sampling points in the Roodeplaat Dam catchment lay in the range 3,9 to 4,4 (Table 3). The rainfall over the sampling period could therefore be described as acidic. *Comparing the pH values* found in this study with that reported by Victor (1966) for the In-

TABLE 3
MEAN VALUES FOR BULK PRECIPITATION QUALITY OVER THE SAMPLING PERIOD: MARCH 1979 TO DECEMBER 1980

Determinand		Station A2Q.. 01	02	03	04	05	06	07	08	09
EC ($mS\,m^{-1}$,25°C)		2,8	3,0	2,6	3,6	2,5	3,0	2,2	3,1	2,7
pH (pH units)		4,2	4,4	3,9	4,1	4,0	4,3	4,0	4,1	4,2
Ca	$mg\,\ell^{-1}$	1,6	2,3	1,6	2,3	0,7	2,3	1,1	1,5	1,8
Mg	,,	0,5	0,6	0,6	0,6	0,2	0,6	0,3	0,4	0,6
Na	,,	0,7	0,8	0,5	1,5	0,7	0,4	0,4	2,0	0,9
K	,,	0,5	0,6	0,5	0,7	0,3	1,0	0,2	<0,1	0,5
SO_4	,,	3,7	3,6	2,9	3,9	5,1	4,4	5,3	3,9	5,7
Cl	,,	1,1	0,8	0,9	1,5	0,8	0,9	1,5	1,8	1,3
F	,,	0,3	0,2	0,2	0,2	<0,1	0,3	0,2	0,2	0,1
Si	,,	0,2	0,2	0,2	0,5	0,1	0,3	0,1	0,2	0,2
$N_{2\&3}$-N[a]	,,	0,7	0,7	0,6	0,5	0,4	0,5	0,1	0,6	0,5
NH_4-N[b]	,,	0,5	0,5	0,5	0,4	0,6	0,4	0,3	0,4	0,6
P[c]	,,	0,07	0,08	0,08	0,04	0,11	0,04	0,05	0,06	0,10
TP[d]	,,	0,11	0,10	0,11	0,07	0,27	0,06	0,04	0,05	0,15
DOC[e]	,,	3,9	3,5	2,8	4,7	1,9	3,7	2,9	11,1	4,0

[a] Nitrate plus nitrite nitrogen
[b] Ammonia nitrogen
[c] Orthophosphate as P
[d] Total phosphorus
[e] Dissolved organic carbon

TABLE 4
ARITHMETIC MEAN CONCENTRATIONS ($\mu g\,\ell^{-1}$) FOR TRACE METALS IN THE BULK PRECIPITATION SAMPLES: MARCH 1979 TO DECEMBER 1980

Trace metals	Sampling Station A2Q.. 01	02	03	04	05	06	07	08	09
Al	218	175	34	740	58	38	195	267	190
Cr	8	8	7	8	<2	13	5	7	8
Cu	10	12	8	10	7	7	28	27	248
Fe	110	220	78	452	34	79	196	199	146
Mn	59	58	57	21	27	38	64	46	77
Mo	12	2	5	6	2	<2	11	20	7
Ni	477	40	61	45	7	29	46	65	34
Pb	33	57	29	47	26	16	18	34	49
Zn	11	<1	<1	70	<1	<1	10	<1	21

TABLE 5
COMPARISON OF MEAN VALUES FOR MACRO DETERMINANDS BETWEEN BULK AND WET-ONLY PRECIPITATION SAMPLES AT THE HRI (A2Q05)

Determinand*		Macro analysis Wet-only	Bulk	Wet/Bulk
EC ($mS\,m^{-1}$, 25°C)		1,7	2,5	0,68
pH (pH units)		3,9	4,0	0,98
Ca	$mg\,\ell^{-1}$	0,4	0,7	0,57
Mg	,,	0,2	0,2	1,00
Na	,,	0,6	0,7	0,86
K	,,	0,3	0,3	1,00
SO_4	,,	3,7	5,1	0,73
Cl	,,	0,7	0,8	0,88
F	,,	<1	<1	—
Si	,,	0,1	0,1	1,00
$N_{2\&3}$-N	,,	0,2	0,4	0,50
NH_4-N	,,	0,3	0,6	0,50
K-N	,,	1,16	4,8	0,24
P	,,	0,05	0,11	0,45
TP	,,	0,10	0,27	0,37
DOC	,,	1,2	1,9	0,63

*See footnotes in Table 3.

TABLE 6
COMPARISON OF MEAN CONCENTRATION FOR TRACE METALS IN BULK AND WET-ONLY PRECIPITATION SAMPLES AT SITE A2Q05 (HRI, AT ROODEPLAAT DAM)

Determinand	Trace metal concentrations $\mu g\,\ell^{-1}$ Wet-only	Bulk	Wet/bulk
Al	34	58	0,59
Cr	<2	<2	—
Cu	1	7	0,14
Fe	15	34	0,44
Mn	11	27	0,41
Mo	<5	<5	—
Ni	<5	7	—
Pb	<6	6	—
Zn	<1	<1	—

ternational Geophysical Year (IGY) study, it appears as if a marked decrease in the pH-value of rainfall over Pretoria has occurred over the past two decades.

This is, however, probably an erroneous conclusion, as it is doubtful that the pH-value of 6,7 reported by Victor (1966) is representative of the actual rainfall. The samples for the IGY study were integrated over monthly periods and no mention is made of any precautions taken to avoid changes in pH on standing. The NH_4-N to NO_3-N ratio of 0,6 found by Victor (1966) is considerably lower than a ratio of 1,1 found in this study, which indicates that NH_4-N may have been lost on standing in the

TABLE 7
THE MEANS FOR BULK PRECIPITATION AS REPORTED FOR IGY (1957/66)* COMPARED WITH THE VALUES FOUND IN THE STUDY FOR DSG (A2Q09) DURING THE PERIOD 1979/80

Determinand**		Sampling station		IGY/DSG
		IGY	DSG	
pH		6,70	4,22	—
Ca	mgℓ^{-1}	1,75	1,82	0,96
Mg	,,	0,71	0,57	1,25
Na	,,	0,53	0,86	0,62
K	,,	0,36	0,53	0,68
SO_4	,,	3,96	5,71	0,69
Cl	,,	1,12	1,31	0,85
$N_{2\&3}$-N	,,	0,41	0,48	0,85
NH_4-N	,,	0,23	0,55	0,42

*VICTOR, A.H. (1966)
**See footnotes to Table 3.

TABLE 8
MEAN ANNUAL RUNOFF ELECTRICAL CONDUCTIVITY (EC) AND pH VALUES COMPARED WITH THE MEANS FOUND FOR BULK PRECIPITATION OVER THE ROODEPLAAT CATCHMENT (1979/80)

Determinand	Runoff	Bulk precipitation
EC (mSm^{-1}, 25°C)	51,0	2,5
pH (pH units)	7,7	4,0

TABLE 9
MEAN ANNUAL RUNOFF LOADS OF MACRO DETERMINANDS TO ROODEPLAAT RESERVOIR COMPARED WITH BULK PRECIPITATION LOADS FOR THE WHOLE CATCHMENT (1979/80)

Determinand*	Load (t a^{-1})***		
	Runoff**	Bulk Precipitation	Runoff/ Precipitation
Ca	240	710	0,34
Mg	680	210	3,2
Na	950	280	3,4
K	110	220	0,5
SO_4	1 040	2 200	0,47
Cl	1 100	560	2,0
F	13	83	0,16
Si	260	89	2,9
$N_{2\&3}$-N	71	240	0,3
NH_4-N	12	240	0,05
P	32	39	0,82
TP	34	72	0,47
DOC	200	2 000	0,10

*See footnotes to Table 3.
**Determined by water balance method.
***Metric tons per year.

TABLE 10
MEAN ANNUAL RUNOFF LOADS OF TRACE METALS TO ROODEPLAAT RESERVOIR AS COMPARED TO BULK PRECIPITATION LOADS FOR THE WHOLE CATCHMENT (1979/80)

Determinand	Load (t a^{-1})*		
	Runoff	Bulk Precipitation	Runoff/ Precipitation
Al	1,8	89	0,02
Cu	0,22	20	0,01
Fe	2,4	68	0,04
Mn	1,6	22	0,07
Ni	0,99	17	0,06
Pb	0,28	16	0,02

*Metric tons per year

samples of the IGY study. It is quite possible that the pH-value of freshly fallen rain during the period of the IGY was considerably lower than the value of 6,7 reported by Victor (1966).

Despite the marked acidity of the bulk precipitation over Roodeplaat reservoir, the average pH of the runoff actually flowing into the reservoir over the present sampling period was 7,7 which is alkaline (Table 8). It would thus appear that, despite the low pH of the rainfall itself, the acidity is rapidly neutralized once the rain reaches the surface. Attempts to correlate indicators of potential acidification of the reservoir, such as decrease in pH or alkalinity with increased inflow into the reservoir did not reveal simple relationships. Undesirable effects of acidic rainfall on the reservoir are not readily detectable due to confounding variables such as change in the character and degree of surface pollution and change in quality of imported water.

Undesirable effects of the acidic rainfall will not easily be noticed in Roodeplaat reservoir itself. An area of concern, however, would be the interception of falling rain by the leaves of vegetation, where the effects of acidic precipitation may occur before neutralization of acidity on contact with the soil. (Bubenick *et al.*, 1983; Lesinski, 1983).

Sulphate

Mean sulphate concentrations found in this study in the bulk precipitation were in the range 2,9 mgℓ^{-1} to 5,7 mgℓ^{-1} (Table 3). A comparison of the sulphate concentrations found at the Weather Bureau for the period 1957/66 and the sulphate found at DSG (A2Q09) in this study, indicates a 30% increase in sulphate concentration in Pretoria rainfall since the IGY measurements (Table 7), thus showing that sulphate pollution by rain may be an area of potential concern (Likens, *et al.*, 1979). A 30% increase in sulphate since the IGY study may not be significant.

A comparison between wet-only and bulk precipitation as measured at sampling site A2Q05 (HRI) showed that most of the sulphate is present in the wet-only fraction, the ratio of wet/bulk concentration of sulphate being 0,73 (Table 5).

Comparison of the sulphate loads over the catchment with the load in the inflowing rivers (Table 9) showed that while 2 200 t a^{-1} sulphate falls on the catchment, only 1 040 t a^{-1} is carried by runoff into Roodeplaat reservoir. As the sulphate loads to the catchment, from surface sources of pollution and via the importation of water already containing sulphate, into the catchment, have not been considered, it is apparent that only a fraction of the sulphate deposited on the catchment actually reached the reservoir. At least half of the sulphate deposited on the catchment was retained.

Nutrients

Nitrogen species

The mean concentrations of nitrate and nitrite nitrogen in the bulk precipitation were in the range 0,1 to 0,7 mgℓ^{-1}N (Table 3). The ammonia nitrogen concentrations covered a similar range of 0,3 to 0,6 mgℓ^{-1}N.

Phosphate species

The mean concentrations of orthophosphate in the bulk precipitation were in the range 0,04 to 0,11 mgℓ^{-1}P, while total phosphorus averages in the range 0,04 to 0,27 mgℓ^{-1}P were recorded (Table 3).

In the case of both nutrients, the runoff loads were less than the bulk precipitation loads for the whole catchment, indicating retention of the nutrients in the catchment (Table 9).

Other major ions

For magnesium, sodium and chloride the input loads to Roodeplaat reservoir via the inflowing rivers exceeded the total load to the catchment from precipitation (Table 9), indicating that surface sources of pollution or importation across the catchment divide predominate. Calcium, in contrast to magnesium, shows retention within the catchment, as indicated by the runoff to precipitation ratios in Table 9. This may have a bearing on the retention of sulphate within the catchment as the relatively insoluble calcium sulphate.

Metals

The bulk precipitation at the sampling sites in the Roodeplaat reservoir catchment showed the presence of significant concentrations of aluminium, iron and manganese, which is to be expected from the contribution of soil derived dust fall-out to the bulk precipitation (Table 6).

The trace metal loads to the catchment were largely retained within the catchment and the runoff loads were only a very small fraction of the loads from bulk fall-out (Table 10). This is consistent with the known association of metals with solid material (Table 6).

In the case of lead, the bulk precipitation load over the catchment was estimated at 16 t a^{-1}. Of this 0,28 t a^{-1} flows into Roodeplaat reservoir. Direct rainfall onto the area of the reservoir itself is of significance, however. The estimated input of lead into Roodeplaat reservoir from direct precipitation onto the surface of the reservoir was 0,048 t a^{-1}, which is 17% of the value found for the lead input from the inflowing rivers. This study confirmed the general finding of others that atmospheric transport is of importance in the dissemination of lead (Dethier, 1979).

Conclusions

The present study of the quality of the precipitation over the Roodeplaat Dam catchment revealed the following:

- 'Acid' rain is occurring over the catchment with mean pH values lying in the range 3,9 to 4,4. The acidic precipitation is neutralised, however, on contact with the ground and does not appear to have significantly influenced the mean pH of the Roodeplaat reservoir as yet. The significance of the acidic rainfall is debatable, as the natural background pH value of rainfall may be considerably lower than the pH value of 5,6 based on the carbonic acid equilibrium at the low partial pressure of atmospheric carbon dioxide.
- The sulphate content of the rainfall has only increased slightly since the IGY measurements approximately two decades ago. More than half of the sulphate is retained within the catchment. This raises the possibility of washout of large loads with flood events.
- The precipitation contained substantial concentrations of both the nitrogen and phosphorus based nutrients.
- The heavy metals showed considerable retention within the catchment.

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