

Influence of Prescribed Burning on Nutrient Budgets of Mountain Fynbos Catchments in the S. W. Cape, Rep. of South Africa¹

D. B. Van Wyk²

The undisturbed mountain fynbos areas of the Western Cape characteristically produce sediment-free, high-quality water. Fire is a widely used tool in managing the vegetation here. Fire can have a beneficial effect by increasing the quantity of water flowing out of these catchment areas and also benefit the vegetation itself, but may have a negative effect on the mineral budgets and other facets of the fynbos ecosystems. Thus research was started in 1971 with the purpose of formulating suitable management prescriptions for the fynbos, which is inherently sensitive. Initially only the influence of prescribed burning on the chemical quality of the water was studied. Research was later expanded to include the study of mineral budgets in burnt, protected and afforested catchments.

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²Hydrologist, Department of Water Affairs, Forestry and Environmental Conservation, Jonkershoek Forestry Research Station, Private Bag X5011, Stellenbosch, 7600. Republic of South Africa.

Abstract: The nutrient budgets of the Western Cape Mountain fynbos areas of the Republic of South Africa have been the subject of investigations since 1971. The average nutrient input (120 kg/ha/yr) exceeds the output (96 kg/ha/yr) by 29 percent. Because in this case the main source of nutrients in precipitation is the sea, heavy loads of Na and Cl are deposited into the fynbos areas. The other constituents of precipitation are K, Ca, Mg, Cl. Traces of HCO₃ and SO₄ were found, while no traces of N and P were detected. The constituents in streamflow were present in the same ratio as in precipitation. The influence of prescribed burning in different seasons on stream water quality was also investigated. Results indicate that nutrient release as a result of prescribed burning does not persist beyond the first winter after burning. The month in which burning takes place has an influence in this respect. It was found that the net release of nutrients takes place during the first two floods after the burn. There is no marked increase in sediment loads of the streams after burning.

Results show that in these systems bulk nutrient input appears to exceed output. Furthermore it is clear that veld management can have a marked effect on stream water quality as well as on the intricate balance that exists between precipitation deposition and internal mineral cycles within the catchment.

This paper reports the influence of prescribed burning at different rotations (4 to 13 years) and seasons (Spring, Early Summer and Autumn) on mineral budgets, water quality and sediment loads of streams in the Jonkershoek, Zachariashoek and Jakkalsrivier research areas in the Western Cape mountain fynbos areas.

THE STUDY AREA

The study areas are in the mountain catchments of the South Western tip of Africa, a zone of mediterranean-type climate. Some information about the relevant areas is listed in Table 1. The research areas are shown in Figure 1, and their position is approximately 19°E and 34°S.

The underlying strata present in these areas are of Table Mountain sandstone, shale and granite. The geology of the areas is discussed by Wilson (1964), Van der Zel (1974), Kruger (1974) and Wicht *et al.* (1969).

Table 1--The research areas and management practices applied

Area	Name	Geology	Mean annual precipitation (mm)	Mean annual runoff (mm)	Management	Rotation (years)	Season
A	Zachariashoek	Quartzites and shales of Table Mountain Group	1 238	581	Burning	6 & 12	Early Summer
B	Jonkershoek	Quartzites of Table Mountain Group and Cape Granite	1 618	723	Burning	Variable 4 - 13	Variable Winter
C	Jakkalsrivier	Quartzites and shales of Table Mountain Group	961	367	Burning	5 & 10	Spring Autumn

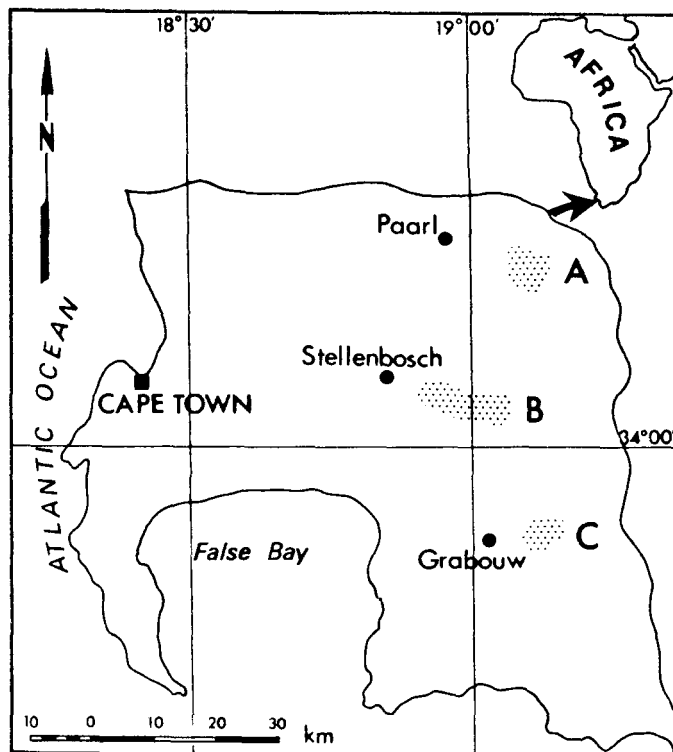


Figure 1--Location of the study area. A Zachariashoek, B Jonkershoek, and C Jakkalsrivier. (See Table 1).

CLIMATE AND HYDROLOGY

The climate of all the research areas is mediterranean. The summer seasons are dry, and the average temperature of the warmest months varies between 18°C and 22°C. Summer temperatures above 38°C are occasionally recorded. Cool to mild conditions prevail during winter.

The prevailing winds are north-westerly

in the winter and south-easterly in the summer.

Over 90 percent of the annual rainfall occurs during the winter. The average rainfall in these areas ranges from 1 000 mm to 2 200 mm per year. The streams in all these catchments are perennial. Streamflow amounts to 40 to 60 percent of rainfall. See Table 1 for the mean annual precipitation and runoff.

VEGETATION

The natural vegetation of the research areas is discussed by Van Wilgen and Kruger (1981), Kruger (1974) and Wicht *et al.* (1969). Most of the area is covered with xerophytic, sclerophyllous scrub of a type characteristic of the mediterranean climate and which has ecological affinities with vegetation of other Mediterranean ecosystems. In the Republic of South Africa it is known as Fynbos.

EXPERIMENTAL METHODS

The experimental methods applied were adapted from the studies of Likens, Bormann, Johnson, Fisher and Pierce (1969).

Meteorological, rainfall and streamflow data are collected at all of the research areas on a routine basis (Wicht 1967). Manual water sampling of streams was carried out weekly from 1971 and precipitation samples were collected over the same period by means of a sterile apparatus that opens only when it rains (Van der Zel 1974). Dry input of the area was measured over a short period.

Table 2--The minimum detection levels and the nutrient concentrations in precipitation and streamwater of A Zachariashoek, B Jonkershoek and C Jakkalsrivier experimental catchments.

Ion	Concentrations mg/ℓ					Minimum detection level, mg/ℓ
	Precipitation Area		Streamflow Area			
	A	B	A	B	C	
Na	2,067	2,722	4,412	4,02	9,375	0,1
K	0,220	0,725	0,163	0,398	0,513	0,1
Ca	0,436	0,422	0,495	0,430	0,800	0,1
Mg	0,359	0,268	0,733	0,537	1,850	0,1
Cl	4,519	5,000	9,011	6,377	18,375	5,0
SO ₄	<5,0	<5,0	<5,0	<5,0	6,25	5,0
HCO ₃	<5,0	<5,0	<5,0	<5,0	<5,0	5,0
PO ₄	<0,1	<0,1	<0,1	<0,1	<0,1	0,1
NO ₃ -N	<1,0	<1,0	<1,0	<1,0	<1,0	1,0
NO ₂ -N	<0,5	<0,5	<0,5	<0,5	<0,5	0,5

These measurements were obtained during weeks with no rain.

Apparatus for the sampling of floods was also developed at the Jonkershoek Forest Research Station. This sampler functions in stages on the rising and falling limbs of floods. The apparatus was used to sample the first floods after an experimental burn. Before the development of the sampler first floods after prescribed burns were sampled manually during the rising and the falling stages.

Conductance and pH of the samples is measured weekly, whilst a full chemical analysis of the water is done monthly by the C.S.I.R. (Council for Scientific Industrial Research). Samples are analysed for Na, K, Ca, Mg, Cl, SO₄, HCO₃, and P. The precision of the analyses is indicated in Table 2.

A factor (0,54) to convert conductance to total dissolved solids was calculated based on eight years' data for the Western Cape mountain streams.

The samples are vacuum filtered and sediment loads are determined.

PRECIPITATION CHEMISTRY

This was the first attempt at investigating precipitation chemistry in this region. The addition of nutrients by way of precipitation can certainly be of significance in areas of low natural fertility such as the fynbos mountain catchments.

The main input of nutrients into any catchment is through wet or dry deposition (Dethier, 1979). The location of the research areas in relation to the sea and industrial areas makes it probable that these two sources are significant for nutrient input in these fynbos areas.

The major chemical constituents of precipitation are K, Na, Ca, Mg and Cl. HCO₃ and SO₄ were undetectable in most samples, while no traces of P or N could be found during the study period. Data for inputs and outputs are summarised in Tables 2 and 3.

Bulk annual input of nutrients into Zachariashoek research area through precipitation varies from 66 kg/ha to 196 kg/ha; the eight-year average is 120 kg/ha/year (Table 4). Ion concentrations of precipitation range from 2 mg/ℓ to 60 mg/ℓ, and the relationship between rain-storm depth and ion concentration was negatively curvilinear, namely

$$\begin{aligned} \text{Sampler RK:} & \quad Y = 20,4875 - 3,0153 \ln X \\ \text{Sampler RZ:} & \quad Y = 23,9000 - 3,8700 \ln X \end{aligned}$$

RK and RZ are precipitation samplers in the Zachariashoek research area, Y is ion concentration of precipitation (mg/ℓ) while X is the rainstorm depth (mm) that was sampled. In both cases r^2 was 0,24.

Precipitation dividers, developed at the Jonkershoek Forest Research Station, were installed and samples of precipitation at progressive stages during storms were collected. The results obtained did not show a trend as the rainstorms progressed.

Table 3--Average ion in- and output in the S. W. Cape mountain catchments by precipitation and stream discharge in Kg/Ha/Yr.

Average ION budgets/Kg/Ha/Yr		
Ion	Input	Output
Na	27,011	23,929
K	2,335	0,753
Ca	5,755	3,304
Mg	5,238	3,740
Cl	56,514	42,105
SO ₄	TR	TR
HCO ₃	TR	TR
P	TR	TR
N	TR	TR

In some cases there was a decrease in concentration, in other cases there was a rise and in some cases the concentrations were variable. Cole and Johnson (1977) found in a study near Washington U.S.A. that there was a variable increase in TDS over a 12 h rainstorm. This is comparable with the results obtained in this study.

Dry deposition in these areas is minimal and depends to a large extent on presence of fall-out from industrial areas, prevailing winds, traffic and cultivation. It constitutes 10,4 kg/ha/yr (8,4 percent of the bulk input) in the Zachariashoek area. In the case of Jonkershoek the dry input is probably more and in the case of Jakkalsrivier less - depending on the factors mentioned above. Brasell and Gilmour (1980) found that dry inputs can be regarded as minimal in Queensland, Australia. Low levels were also found in the U.S.A., but depended on the prevailing humidity (Cole & Johnson 1977).

Chemical analysis of dry deposition indicated that anthropogenic and continental aerosols were not the main dry input sources: low levels of Ca, Mg and SO₄ were found.

The ranges of concentrations of the constituents of precipitation in these areas appear in Table 2. These values show that the ionic concentrations in precipitation are lower than those in streams. The concentrations of SO₄ and HCO₃ are very low, and these ions cannot be regarded as regular constituents of precipitation input.

Low concentrations of nutrients are found during winter (2 mg/l) and high values during summer (60 mg/l). The high summer concentrations have a relatively minor effect on the total input of nutrients; more than 77 percent of the

Table 4--The total average yearly nutrient budgets (Kg/Ha/Yr) of a mountain fynbos catchment at Zachariashoek in the Western Cape.

Total nutrient budgets			
Year	Kg/Ha/Yr		Average percent of output provided by input
	Average Input	Average Output	
72	73	55	133
73	98	65	151
74	114	110	104
75	121	98	123
76	173	119	145
77	174	169	103
78	90	61	147
Average	120	96	129

total yearly nutrient input is deposited during the period April to September (winter).

The average pH for precipitation in this area ranges from 4,7 to 5,0. This is higher than that of polluted rain from industrial discharge.

STREAMFLOW CHEMISTRY

Samples were taken from perennial streams in sixteen fynbos catchments in the three experimental areas. This sampling clearly indicates the range in quality of the streams in this region.

The concentration of solids in streams ranges from 10 - 60 mg/l. There is a clear seasonal variation. During winter there is a drop in the concentration levels due to an increase in discharge. The reverse takes place during summer.

The main outflow of nutrients from these catchments comprises Na and Cl (see Table 3) with lower levels of K, Ca and Mg. No traces of P and N were found. As regards HCO₃ and SO₄ the results were not constant for the different research areas. Only traces of HCO₃ were observed at Zachariashoek and Jonkershoek (<5 mg/l) while levels at Jakkalsrivier were constant at 6 mg/l. The same trend was observed in the case of SO₄.

The budget in Table 4 shows a net gain of nutrients through precipitation to the Zachariashoek area by an annual average of 29 percent (24,5 kg/ha/yr). These results show that the areas are nutrient poor and that the loss of nutrients from the catchment is partly due to mineralization by ion exchange accelerated by heavy loads of ions in the precipitation.

Table 5-- First spates after prescribed burning. Average ion concentrations in the Zachariashoek (early summer burn) and Jakkalsrivier (autumn burn) catchments.

	Concentrations Mg/t				
	Early summer burn		Autumn burn		
	Output		Input	Output	
	Spate		Precipitation	Spate	
	Pro- tected	Burned		Pro- tected	Burned
Na	4,645	6,70	2,155	9,46	18,48
K	0,115	2,29	0,255	1,86	7,135
Ca	0,375	1,125	0,330	1,06	3,85
Mg	0,655	1,355	0,380	1,83	5,73
Cl	8,365	15,20	5,425	18,38	35,58
SO ₄	5,000	10,60	2,500	5,83	27,57
HCO ₃	1,225	3,690	1,000	2,958	6,687

The pH levels of the streams vary from 3,2 to 6,5, this variation correlates partly with substrate, the highest pH in the granites at Jonkershoek and the lowest value for the "black waters" of Jakkalsrivier.

BURNING AND STREAM CHEMISTRY

Experimental burns were applied to several catchments in September (spring) 1974 and 1979, November (summer) 1971 and 1977 and March (autumn) 1975 and 1980. The ion concentration values obtained during the first spate after these burns are presented in table 5, together with the results from the unburnt catchments. The two November burns were unfortunately followed by years of below average rainfall. This may have had a marked influence on the results obtained.

The total monthly outflow of nutrients rose by 1 kg/ha after an early summer burn at Zachariashoek. This effect lasted for only 10 months after the burn. The first two winter months after the burn produced the greater part of the post-burn nutrient outflow.

Six months after a spring burn at Jakkalsrivier the initial increase in nutrient levels in streamflow had returned to pre-burn levels. In these six months there were fourteen rainstorms with only four of more than 10 mm.

Twelve weeks after the autumn burn at Jakkalsrivier the total nutrient output returned to pre-burn levels.

In samples taken on a weekly basis, concentrations of Na and Cl showed a

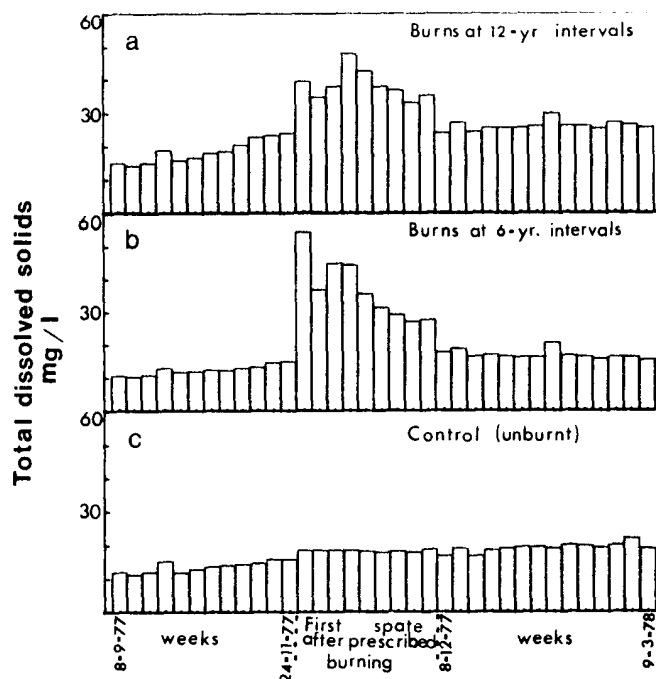


Figure 2--The influence of prescribed burning at different rotations at Zachariashoek on the total dissolved solid content of the first spate, on 30/11/77 and 1/12/77, after the burning.

(a) Zachariashoek catchment (b) Kasteelkloof catchment (c) Bakkerskloof catchment.

noticeable increase after burning but changes in the concentrations of Mg, Ca, and K could not be detected. However, there was an increase of SO₄ and HCO₃, which had been at very low levels before the burn.

Thus, Na and Cl comprised the bulk of the increase in total dissolved solids following fire.

Analysis of samples during the first four spates after an early summer burn shows an increase in total nutrient output during the first two spates only. Figure 2, a & b shows the influence of the burn during the first spate after fire. No increase in nutrients was found in the control catchment during this spate (see figure 2c). Furthermore a previous spring burn of two catchments at Jakkalsrivier had no influence on the chemical content of streamflow during a spate six months after the burn. The bulk outflow of nutrients occurred during a few spates after late spring rains. Only occasional rains were recorded in the summer. This is the normal rainfall pattern.

Analysis of the rainfall pattern shows that 13 rain storms occurred in the period

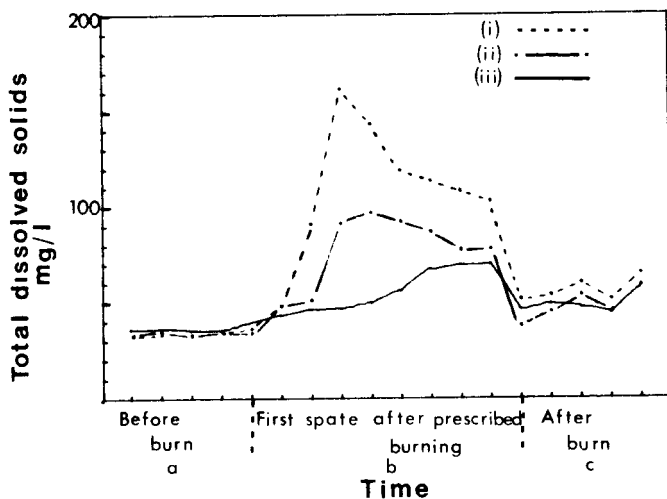


Figure 3--The response in total dissolved solids as they are influenced by source area at Jakkalsrivier. The trace mark represents the total dissolved solids in streamwater of a catchment that was (i) 100 percent burned (ii) 62 percent burned and (iii) 27 percent burned. Period (a) is a calibration period from 1978 to 1979 with irregular sampling; (b) sampling during spate over 24 hours based on stage; (c) irregular sampling after spate during 1980.

between the spring burn (October) and the autumn burn (March). Two were high intensity storms (27 - 35 mm) and the rest were of a minor nature. During these two storms the release of all nutrients which became available from the catchment after the burn probably took place.

Analysis for the ions Na, K, Ca, Mg, Cl, SO₄, HCO₃ also shows an increase in concentration during the first floods after the burns. The same trends were observed in all the burned catchments. It is interesting to note that SO₄ and HCO₃ concentrations which had been at more or less untraceable levels before, peaked during the flood. (See Table 5). In every case only traces of P and N in its various forms were found. Concentrations of all the measured ions declined on the recession of the spate. There was no increase in concentration of any of the ions in the control catchments during the spate.

The dilution effect of contribution of streamflow from protected catchments is shown by Figure 3. Samples taken from immediately below the burnt catchment showed an increase in nutrient outflow during the first spate after an autumn burn, while the sample point further downstream showed a delay in recording the increase of

nutrients. The level of increase also drops markedly due to the influence of water inflow from the protected fynbos areas.

At Jakkalsrivier there was an increase in pH during the first spate after the autumn burning. The pH of the burnt catchments was 1,5 to 2,0 pH units higher than the pH of the control streams in the same area before burning took place. This was the case only in areas with black waters (humic stained) and where the normal pH is between 3,2 and 4,0. In the other catchments, where the pH is normally about 5,0, no response to fire was recorded.

EFFECTS OF FIRE ON SUSPENDED SEDIMENT

Results obtained by means of stage sampling for suspended sediment during spates show that the sediment loads from the fynbos-vegetated catchments at Zachariashoek are very low, the maximum average release of suspended sediment from a 350 ha fynbos catchment being 0,0291 kg/ha. This fynbos catchment yielded a total of 0,04 kg/ha of suspended sediment over the four spates that followed burning.

The sediment loss after prescribed burning in early summer at the Zachariashoek area was 0,20 kg/ha (287 ha catchment) and 0,97 kg/ha (324 ha catchment). The total suspended sediment release for the first three spates after prescribed burning was 224 kg and 748 kg from these burnt catchments. During the same period only 10 kg was released from the protected catchment, mentioned in the previous paragraph. If it is taken into account that sediment release occurred during three spates over a period of four months, and that the catchments cover an area of roughly 300 hectares, sediment loss may be regarded as minimal.

After an autumn burn at Jakkalsrivier the quantity of suspended sediment released was found to be even smaller. During the first spates after this burn, the protected catchments released less than 0,01 kg/ha, while the burned catchment released 0,04 kg/ha.

Loss of soil from fynbos catchments occurs in stages. The soil is brought down the slopes by soilcreep and is released from the catchment as bed load. This is the principal way in which soil is lost from most of the fynbos catchments of the Western Cape. Bedload release has been measured for the past ten years.

Results of bedload measurements from fynbos catchments show that the protected catchment releases more soil in this form

than the burnt catchments. Soil slips also appeared in the protected catchments, but were not observed in the burnt catchments. Higher rainfall infiltration due to the higher vegetal cover may have an influence in the latter case. The results here show the weighted average yearly mass of bed-load from the regularly burned catchments was 6,26 kg/ha against 7,72 kg/ha from the control catchment with 10 years old fynbos.

Turbidity was not measured, field observation shows that it is very high during the rise of any spate, but lessens during the recession of the spate and the water soon becomes as clear as it had been before.

According to the results of measurement of suspended sediment from burnt and protected fynbos catchments obtained so far, it seems obvious that suspended sediment from the table mountain sandstone catchments is very low, and that burning does not have a significant effect on sediment loads.

Because sediment release is difficult to monitor, more data are required for the fynbos areas before a full understanding of sediment loss and the erosion of burnt and protected areas may be reached.

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