# Correlates of water colour in streams rising in Southern Cape catchments vegetated by fynbos and/or forest

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## Abstract

Both so-called "white" and "black" streams occur in the Southern Cape. We investigated 33 streams in the Southern Cape to determine which factors (catchment vegetation, altitude, geology/soil-type, slope and aspect) may be correlated with water colour. Most black streams rise in high elevations on steep south slopes, with catchments vegetated by fynbos and with pale-coloured soils. Exceptions such as permanently white fynbos streams and black indigenous forest rivers do occur. When black water was filtered through horizons of different soils in most cases, and especially in red/yellow soils, the water was decolored. Streams from catchments with red/yellow soils did not become darker during stormflow. The main correlate with dark stream colour is the paleness of catchment soil colour.

## Introduction

Streams with both clear ("white") and stained ("black") waters occur in areas of the Cape with nutrient-poor soils. This co-existence of both types of streams continues to be puzzling (Van Wyk, 1988). Rivers that are acid, black and foamy due to the presence of certain dissolved organic carbon (DOC) compounds (e.g. phenols, tannins, humic/fulvic acids and saponins) largely produced by plants, are well known to be typical of many areas of the world with nutrient-poor, sandy, bleached and podzolised soils and are usually associated with sclerophyllous evergreen vegetation (Janzen, 1974). They are also common in peaty areas (Mitchell, 1990). Biologically these DOC compounds are considered to deter herbivores (Janzen, 1974). These DOC are a dynamic group of humic compounds (Chesworth and Macias-Vasquez, 1985), once leached out of plant material they usually form organo-metal (iron/aluminium) complexes and are responsible for staining of the water (Moore, 1988; Mitchell, 1990). The formation and mobilisation of organo-metal complexes in the soil initiates podzolisation. Podzolisation is a complex soil process which eventually leads to bleached sandy upper horizons and the formation of impenetrable organo-metal hardpans further down the profile (Duchafour, 1982). Black waters are the active eluviating agents in the podzolisation process (Reeve and Fergus, 1982).

Very little work has been published on the aspects of the chemistry of Cape plants related to their defense from herbivores and which may also play a role in staining streams. Glyphis and Puttick (1988) recorded a mean phenol level of 7,55 % in 23 species in a Cape strandveld community. This value is close to the high level of 7,57 % recorded in a nutrient-poor African rain forest (McKey et al., 1978). Another study showed that phenolic compounds were widespread in all species from the Cape Proteaceae genera *Leucadendron* and *Leucospermum* (Perold, 1984). Despite the general lack of information on this aspect of the phytochemistry of Cape plants, they can be expected according to Janzen (1974), to be heavily chemically defended against herbivory. This is because the dominant mesic vegetation types of the Cape, both the shrublands ("fynbos") and forest, are sclerophyllous and evergreen because the soils are typically sandy and nutrient-poor (Kruger, 1979). Therefore all the rivers rising in catchments with these nutrient-poor soils should be stained, as are rivers in other similar areas. The question thus becomes: why are some of the rivers of this area of the Cape actually white?

River water colour may possibly relate to the fynbos/forest dichotomy. For example, Schloms et al. (1983) suggested that black streams rising on areas of the S. Cape plateau are black due to the presence of fynbos, rather than indigenous forest, in their catchments. To date there are no data to show whether the indigenous forest can, or does, give rise to black rivers.

Another possible factor is the effect of different soil types and horizons, within a nutrient-poor environment, on river colour. Reeve and Fergus (1982) investigated the occurrence of occasional white water streams in an area with predominantly black-water streams in S.E. Australia. In their situation white springs occurred where black water had passed through yellow-brown podzol C horizons before it formed a spring downslope. In the yellow-brown horizon the organic compounds are sorbed onto active clay minerals and thus removed from the system. Thus the adsorbtion of DOC by podzol horizons appears to be largely responsible for regulating its concentration in streams (McDowell and Wood 1984). Reeve and Fergus (1982) argued that white waters were "the residual liquid phase of the podzolisation process".

In the S. Cape, as a result of varied geology and topography, a wide variety of soil forms occurs. Although the soils vary in physical nature they are generally acid and podzolised. According to Schloms et al. (1983) and Schafer (1992) the dominant soils (using the system of MacVicar et al., 1977) are: Lamotte (dunes), Estcourt and Glenrosa (coastal plateau), Oakleaf, Clovelly, Kroonstad and Lamotte (mountain foothills), Houwhoek, Mispah, Cartref and Champagne (mountains). For the fynbos biome as a whole, Campbell (1983) noted that Mispah, Cartref, Glenrosa and Champagne accounted for more than 65% of the soil profiles. True podzols (Houwhoek, Lamotte), are neither common nor well developed (i.e. with impenetratable horizons) in the Cape (Campbell, 1983; Schloms et al., 1983). The lack of strongly developed podzols suggests that sorption sites for soluble organic compounds produced by the plants should still be present on clay minerals in most soil profiles. Thus most of the Cape rivers should apparently be white.

A further confounding factor is the common observation that many rivers become darker during winter. Van der Zel et al.

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**TABLE 1**
**DETAILS OF THE CATCHMENTS AND WATER QUALITY OF SOME S. CAPE STREAMS (SEE FIG. 1 ALSO)**

| River | Altitude PT sampled | Altitude Catchment maximum | Slope categories | Dominant aspects | Geology | Range of soil depths | Podzol frequency |
|---|---|---|---|---|---|---|---|
| 1 Kranshoek | 178 | 276 | 2 | S | Dunes | D | A |
| 2 Klein Eiland | 180 | 290 | 2 | S | Dunes | D | A |
| 3 Witrivier | 200 | 290 | 2 | S | Dunes | D | A |
| 4 Witels Hill F. | 200 | 280 | 2 | S | Dunes | D | A |
| 5 Damon se Plek | 200 | 260 | 2 | S | Dunes | D | A |
| 6 Klein (small) | 280 | 320 | 2 | E | Sandstone | M-D | R |
| 7 Kleineiland (large) | 180 | 380 | 2 | E | Sandstone | M-D | R |
| 8 Petrusbrand | 300 | 380 | 2 | E | Sandstone/SH | M-D | R |
| 9 Klaas | 360 | 638 (P) | 3 | S | Sandstone | M-D | C |
| 10 Kruisbos | 360 | 522 | 3 | W | Sandstone | M-D | C |
| 11 Ou Witels 1 | 440 | 884 (P) | 2-3 | S | Sandstone | S-D | C |
| 12 Ou Witels 2 | 460 | 760 (P) | 2-3 | S | Sandstone | S-D | C |
| 13 Gouna-Browns | 250 | 360 | 2 | SW | Sandstone | M-D | C |
| 14 Groenkloof 1 | 300 | 950 | 3 | W | Sandstone | M-D | R |
| 15 Groenkloof 2 | 300 | 920 | 3 | N-S | Sandstone | M-D | R |
| 16 Kleinplaat R1 | 340 | 1 122 | 3 | S | Sandstone | S-M | R |
| 17 Kleinplaat R2 | 500 | 900 | 3 | S | Sandstone | S-M | R |
| 18 Karmenaadjieskraal | 500 | 720 | 2 | SW | Sandstone | M-D | R |
| 19 Touw | 120 | 1 100 (P) | 3 | N-S-W | QZ/SS/PH | S-M | R |
| 20 Silver | 100 | 1 300 (P) | 3 | S | QZ/SS/PH | S-M | C |
| 21 Kaaimans | 90 | 1 255 (P) | 3 | S | QZ/SS/PH | S-M | C |
| 22 Platbos 1 | 550 | 900 (P) | 4 | S | SS/QZ | S | C |
| 23 Platbos 2 | 580 | 900 (P) | 4 | S | SS/QZ | S | C |
| 24 Duiwe | 20 | 320 | 1-3 | S | Phyllites | S-M | R |
| 25 Powerline 1 | 720 | 950 (P) | 3 | N | QZ/SS | S-M | C |
| 26 Powerline 2 | 700 | 1 130 (P) | 3 | N | QZ/SS | S-M | C |
| 27 Grootdoring | 620 | 1 222 | 4 | N-S | SS/QZ | S-M | R |
| 28 Kleindoring | 640 | 1 400 | 4 | NW | SS/QZ | S-M | R |
| 29 Moord 1 | 420 | 980 (P) | 4 | S | SS/QZ | S-M | C |
| 30 Moord 2 | 440 | 850 | 4 | W | SS/QZ | S-M | C |
| 31 Moord 3 | 400 | 828 | 4 | N | SS/QZ | S-M | C |
| 32 Swart | 200 | 1 570 (P) | 4 | S | SS/QZ | S | C |
| 33 Perdekraal | 200 | 300 | 3 | S | SS/PH | M | C |
| 34 Saasveld Spring | 300 | | 3 | S | | | |
| 35 Witfontein Spring | 230 | | 3 | S | | | |
| | | P = PEATY | 1 = 0-8%<br>2 = 9-29%<br>3 = 30-55%<br>4 = >55% | | SS = SANDSTONE<br>QZ = QUARTZITE<br>PH = PHYLLITES<br>SH = SHALES | S= SHALLOW<br>M = MODERATE<br>D = DEEP | R = RARE<br>C = COMMON<br>A = ABUNDANT |

(1979) suggested that this was due to a greater volume of water being available for leaching of organic compounds from the vegetation and for flushing stained ground water into streams.

The complexity of the situation regarding water colour in the Cape and the lack of data on the topic, led Van der Zel et al. (1979) to consider the following as a research priority: "to determine the relationship between pH, colour and humic acids and the ways in which geological formation, soil, vegetation and aspect influence these variables". Recently, research has taken place on the physico-chemical properties of some of the small lakes (vleis) of the S.W. Cape (Gardiner, 1988). However, as Van Wyk (1988) noted, "there still seems to be no literature concerning the reasons for the differences in acidity and brownness of the streams across the biome". Our goals were to document broad patterns in the S. Cape and to consider the above relationships.

We asked:

- what landscape-level attributes (e.g. soils, slope, vegetation) are correlated with intensity of river colour;
- if the dominant species of both fynbos and forest stain water;
- if horizons from the dominant soils decolour water to different degrees, and;
- if all rivers become darker during stormflow ?

## Materials and methods

### Landscape-level correlates

In total we sampled 33 streams and two springs (Fig. 1) from catchments which covered the whole spectrum of factors considered to control water colour; fynbos versus forest, podzols and non-podzols, sandstone and non-sandstone, peaty versus non-peaty, and a range of dominant catchment slopes and maximum altitudes. Peaty soils are those with over 12 % organic

**TABLE 1 (CONTINUED)**

| Dominant soil texture | Dominant subsoil colours | Vegetation | River pH | Water colour | Sample conductivity (mS·m⁻¹) | Latitude | Longitude |
|---|---|---|---|---|---|---|---|
| L | Yellow | I | 6,85 | 0,029 | 43,0 | 34°05' | 23°14' |
| L | Yellow | I | 5,82 | 0,016 | 43,0 | 34°05' | 23°14' |
| L | Yellow | I | 5,47 | 0,022 | 37,0 | 34°04' | 23°13' |
| L-H | Yellow | I + P | 6,45 | 0,013 | 31,8 | 34°03' | 23°10' |
| L | Yellow | I | 6,5 | 0,022 | 31,8 | 34°03' | 23°11' |
| M-H | Yellow/Grey | I | 6,42 | 0,015 | 28,0 | 33°59' | 23°12' |
| M-H | Grey/Yellow | I | 7,05 | 0,017 | 47,5 | 33°59' | 23°12' |
| M-H | Grey/Yellow | I | 5,55 | 0,007 | 16,8 | 33°58' | 23°11' |
| L-H | Grey/Yellow | I | 4,4 | 0,148* | 13,8 | 33°57' | 23°08' |
| L-H | Grey/Yellow | I | 4,55 | 0,239* | 15,3 | 33°57' | 23°08' |
| L-H | Grey/Yellow | I, F | 4,71 | 0,070* | 14,2 | 33°57' | 23°06' |
| L-H | Grey/Yellow | I, P+F | 4,71 | 0,070* | 14,2 | 33°57' | 23°06' |
| M-H | Grey/Yellow | I | 4,95 | 0,009 | 67,6 | 33°57' | 23°02' |
| L-M | Red | F, P | 6,01 | 0,006 | 18,3 | 33°53' | 23°41' |
| L-M | Red | P | 6,5 | 0,004 | 17,9 | 33°52' | 22°41' |
| L-M | Red | F | 5,7 | 0,027 | 16,1 | 33°52' | 22°41' |
| L-M | Red | F | 6,62 | 0,005 | 17,1 | 33°51' | 22°40' |
| L-M | Red | P | 6,72 | 0,008 | 51,9 | 33°52' | 22°38' |
| L-M | Grey | F | 5,15 | 0,063* | 16,4 | 33°57' | 22°36' |
| L | Grey | F, P, I | 4,3 | 0,266* | 17,6 | 33°58' | 22°34' |
| L | Grey | F, P, I | 4,7 | 0,164* | 14,6 | 33°58' | 22°23' |
| L | Black | I | 3,75 | 0,390* | 18,3 | 33°54' | 22°20' |
| L | Black | I, F | 4,02 | 0,222* | 13,4 | 33°54' | 22°20' |
| M-H | Yellow | I, F | 7,1 | 0,010 | 168,2 | 33°59' | 22°39' |
| L | Grey/Black | F | 4,5 | 0,176* | 12,3 | 33°54' | 22°20' |
| L | Grey/Black | F | 4,4 | 0,198* | 10,8 | 33°54' | 22°20' |
| L | Grey/Red | F | 6,8 | 0,007 | 10,5 | 33°52' | 22°17' |
| L | Grey/Red | F | 6,0 | 0,021 | 12,0 | 33°52' | 22°13' |
| L | Grey/Black | F, I | 5,9 | 0,013 | 1,0 | 33°54' | 22°07' |
| L | Grey | F | 6,7 | 0,002 | 8,6 | 33°54' | 22°07' |
| L | Grey | F | 6,1 | 0,005 | 9,0 | 33°54' | 22°07' |
| L-M | Grey/Black | F, I, P | 4,55 | 0,242* | 9,7 | 33°56' | 22°31' |
| M | Grey/Yellow | I | 4,75 | 0,012 | 21,5 | 33°56' | 22°33' |
| | | | 4,55 | 0,002 | 25,4 | 33°56' | 22°31' |
| | | | 5,55 | 0,001 | 30,0 | 33°56' | 22°27' |

L = LIGHT
M = MEDIUM
H = HEAVY

I = INDIGENOUS FOREST
P = PINE PLANTATION
F = FYNBOS

* = BLACK STREAMS

carbon (i.e. Champagne soil form) (Tate, 1987). Information on the soils of each catchment was derived from a classification of the land-types of the S. Cape (Schafer, 1992) which provides an inventory of soil types and their relationship to soils and climate and also from Schloms et al. (1983). Our sampling was not, and was not intended to be, random and this precludes the use of inferential statistics at this stage.

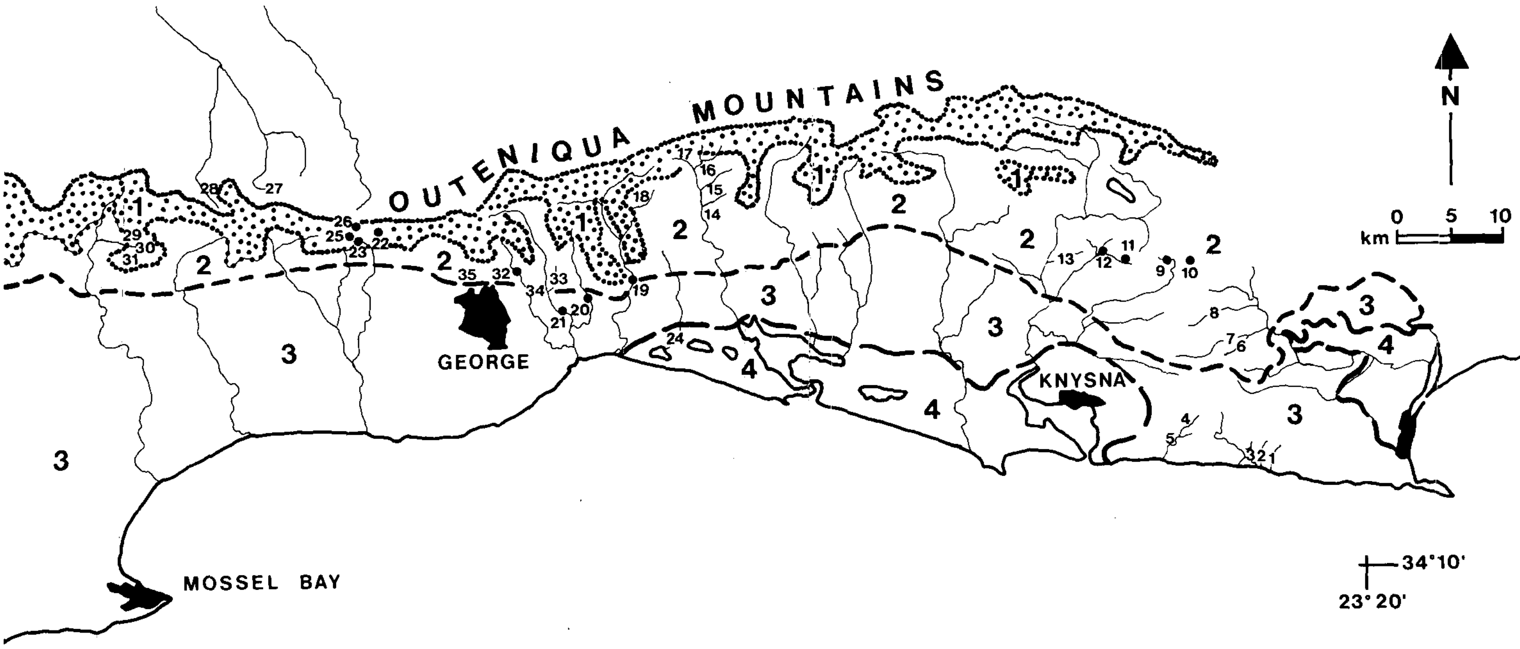
### Decoloration of black water by soils

To test the ability of different soils to remove the stain from black water, we poured 300 mℓ of black water from the Swart River (stream 32 of Table 1) through an equal volume (a Buchner funnel sealed with filter paper) of a representative sample of soil from the dominant soil types of the S. Cape. Each horizon was tested separately and the filtered water was analysed as for the other samples.

### Effect of vegetation on water colour

There are no published data to show if undecomposed fynbos or indigenous forest plants can stain water or whether the stain is only released from decomposed organic material in peats.

To indicate the possible staining effect of undecomposed components of the two main indigenous catchment vegetation types of S. Cape, fresh (i.e. green) samples of equal mass of a typical proteoid, ericoid and restioid from S. Cape fynbos (*Leucadendron eucalyptifolium, Erica versicolor* and *Restio triticeus*) and typical forest species (*Olea capensis macrocarpa, Podocarpus latifolius* and *Ocotea bullata*) were collected near Saasveld. They were dried in paper bags at room temperature for a month. Three samples of dried but unmilled leaves and twigs, each of 30 9, were separately soaked in 250 mℓ of distilled water for 2, 12 and 18 h and then analysed for pH and colour.




PHYSIOGRAPHIC REGIONS

| | | | |
|---|---|---|---|
| 1 | Steep mountains | - | Over 800 m |
| 2 | Mountain foothills | - | 250 - 800 m |
| 3 | Coastal plateau | - | 200 - 250 m |
| 4 | Knysna-lakes embayment | - | < 200 m |

• Black rivers

*Figure 1*

*Map of the S. Cape showing the sampling points. Small numbers refer to sampling sites on Table 1 (see legend for large numerals)*

**Effect of stormflow on water colour**

Rivers were initially sampled on 16/17 May 1989. No rain had fallen for a few days prior to our sampling. Overall conditions were dry with only about 56% of the average rainfall for the first five months of the year having fallen. Since it is well known that rivers tend to be more darkly stained when they are in spate (Van der Zel et al., 1979), our sampling can be considered to indicate which streams are always darkly stained. During October and November 1989 more than double the expected monthly rain fell. To determine the effect of storm conditions a selected subset of streams was sampled at approximately the same time on 16 November during the rain event. Almost continuous rainfall had occurred for more than 24 h prior to sampling.

**Chemical analyses**

Water was collected and frozen within three hours of collection. Prior to analyses samples were defrosted and thereafter filtered through Whatman No 2 paper. Black water filtered through some soils produced extremely turbid water, which was filtered through Millex (0,00045 mm). Conductivity ($mS \cdot m^{-1}$) and pH were measured with glass electrodes on (unbuffered) samples.

Colour of water is usually a good measure of the amount of dissolved organic compounds (like humic and fulvic acids), which are often difficult to separate and measure directly. Gardiner (1988) found that absorbance values within the range of 250 to 400 nm were highly correlated with each other. We therefore measured colour spectrophotometrically (on a Beckman 700) as absorbance at 400 nm (also in Hazen units for a sub-sample) relative to a distilled water blank. Initial results indicated a good correlation between colour measured in Hazen units and absorbance at 400 nm ($n=30$, $r^2=0{,}93$, $p< 0{,}001$). We subsequently measured absorbance only. No attempt was made to quantify the different organic components of the water from black streams.

## Results

For the 33 rivers we sampled, dark colour and low pH were strongly correlated ($r^2 = 0{,}68$, $p <0{,}01$). Conductivity and colour were not correlated.

**Environmental effects on water colour**

Black waters (arbitrarily taken as absorbance greater than 0,060) tended to come from streams which rise in high elevations (600+ m) on steep south-facing slopes in catchments dominated by sandstone/quartzite geological formations, except those with yellow/red soils (e.g. streams 14, 15, 16, 17 in Table 1). Black streams are common in high altitude (> 900 m) catchments which are peaty.

Rivers rising on north slopes in the lee of the mountains are usually white, as are most rivers on the inland mountains (personal observation). Exceptions occur where upper catchments have peaty topsoils overlying saprolite with little soil development (streams 25, 26).

**Vegetation effects**

Undecomposed fynbos and forest plants rapidly stain and acidify distilled water (Table 2). Fynbos plants appear to lower pH more

TABLE 2
THE EFFECT OF SOAKING DRIED VEGETATION FROM FYNBOS AND THE INDIGENOUS FOREST ON THE COLOUR (ABSORBANCE AT 400 nm) AND pH OF DISTILLED WATER. VALUES ARE MEANS OF THREE SAMPLES

| | pH | Colour | Conductivity |
|---|---|---|---|
| Control | 6,1 | 0,000 | 0,7 |
| **Indigenous forest** | | | |
| 2 h | 5,75 | 0,978 | 16,7 |
| 12 h | 5,70 | 1,13 | - |
| 18 h | 5,58 | 1,48 | - |
| **Fynbos** | | | |
| 2 h | 4,27 | 0,757 | 30,9 |
| 12 h | 4,31 | 2,256 | - |
| 18 h | 4,25 | - | - |

rapidly than forest plants.

Thus both vegetation types have the potential to stain water, although most streams rising in forest are only lightly stained. The exceptions are black forest rivers rising high up the mountains (streams 9,22) and some white fynbos rivers on north slopes (streams 27, 28, 31) or from catchments with yellow/red soils (streams 17, 16).

### Soil effects

Most soil horizons and thus most profiles, increase the pH and decolorise the black water poured through them (Table 3). Not one of the soil types (Mispah, Champagne and to a lesser degree Oakleaf) which did not strongly decolour the water, can be considered to be a podzol.

### Storm-flow effects

The only consistently dark streams (Table 4), tended to be peaty or to have pale coloured soils. The catchments which consistently yielded white streams (streams 17,16 on Table 1) had red soils.

## Discussion

### Effect of indigenous vegetation on water colour

We have shown that typical fynbos and forest species of the S. Cape can both stain river water. Further data support this contention. Both vegetation types and especially the forest include indigenous conifers, a group of plants well known for containing high amounts of secondary phytochemicals (Janzen,1974). Stem flow and throughfall collected from the six most common indigenous forest species is also often exceptionally darkly stained (personal observation). Surface pools resulting from rain events, in both fynbos and forest, may also be darkly stained even though rivers rising in both these areas may be white. Incidentally, *L. eucalyptifolium* communities are often found on deep red soils and thus often in catchments with white streams. Yet we have shown experimentally (Table 2) that elements from this community can stain water. Therefore differences in the intensity of colour amongst streams in various catchments are not mainly due to differences in ability to stain water of different fynbos plant species.

Similarly, the great extent and degree of podzol formation under indigenous forest in the old dune sands of the S. Cape (Schloms et al., 1983) indicates a significant phenolic output of the indigenous forest. However, streams rising in this area are not darkly stained. The point is that both fynbos and forest species have the capacity to stain water and therefore that landscape-level (or even biome-level) reasons for lack of stained rivers are probably mainly due to other factors.

The established view that black waters arise on peaty catchments is borne out by the S. Cape. However, this has little directly to do with the peat (since undecomposed plants produce water staining compounds), but has to do with the type of situations where organic matter does accumulate and the negative consequences of peaty soils on infiltration. Also, in some cases peat formation is the final consequence of podzolisation (Cresser and Edwards, 1988).

### Effect of soils on decoloring black water

There is considerable variation within a single soil type as defined by MacVicar et al. (1977), not only in physical properties of horizons but also in the genesis of the soil. Our survey of about 30 soil horizons is thus very preliminary.

Black waters in the S. Cape appear to be linked to cool steep catchments with peaty, shallow and pale soils. Organic matter accumulations that result in peat formation may occur because of high soil acidity, oxygen depletion, low redox potentials and low temperatures and high amounts of phenols (Tate, 1987). All of these factors are present to a lesser or greater degree on the high steep south slopes of the S. Cape. Although black waters are typical of temperate and saturated conditions they can occur in warm freely drained environments so long as the soil is low in sorption sites (i.e. low in bases and clay minerals). Many areas of the S. Cape either have soils with horizons that are red/yellow soils (e.g. Oakleaf, Clovelly, Hutton forms) or have a high percentage clay content (e.g. Estcourt form). In both these types of soil sufficient iron-clay sorption sites will occur so that the organic compounds moving through the soil will be removed and resultant streams will be white, at least during baseflow. The coastal black-water vleis of the S.W.Cape have low-lying shallow catchments (Gardiner, 1988). In this case we predict that these waters are black because their catchments have soils with bleached sand-grains. Whether these soils are podzols or not should be relatively unimportant.

We suspect that in many areas in the mountains of the S. Cape the ground water will be white. Evidence for this is the whiteness of the spring waters (Table 1) and the observation that some rivers stay clear even during storms (Table 4). This indicates that when plant-produced DOC are adsorbed in well drained red/yellow soils (i.e. resulting in white streams) they may not subsequently be desorbed by spate conditions or that the ground water is black.

Rivers rising in freely-drained old dune sands are usually darkly stained (Janzen, 1974; Reeve and Fergus, 1982). Surprisingly, the rivers rising in dunes in our sample tended to be white (Table 1). This appears to be due to the decoloring ability of the podzol b horizon or the deep red palaeo-horizon in younger dunes (Table 3). This in part may explain why Groenvlei is a white lake (Van der Zel et al., 1979), despite having a dune catchment which is vegetated by sclerophyllous

**TABLE 3**
**THE EFFECT OF DIFFERENT SOIL HORIZONS ON DECOLORING BLACK WATER. SOIL FORMS FOLLOW SYSTEM OF MACVICAR et al. (1979). AN EQUAL VOLUME OF EACH HORIZON WAS USED. THE NAMES OF SOME SOIL FORMS WILL SOON BE CHANGED AND THESE ARE INDICATED WITH A SUBSCRIPT AND THEIR NEW NAMES ARE INDICATED BELOW. PRESENCE OF PODZOL HORIZONS IS ALSO INDICATED. COLOUR WAS MEASURED AS ABSORBANCE AT 400 nm (IN ONE CASE THE FILTERED WATER WAS TOO TURBID FOR COLOUR DETERMINATION)**

| Soil forms | Podzol | Horizon | pH | Colour | Conductivity ($mS \cdot m^{-1}$) |
|---|---|---|---|---|---|
| Glenrosa | no | A | 5,32 | 0,259 | 24,3 |
| (yellow/brown) | | B | 5,39 | 0,179 | 35,9 |
| | | C | 6,18 | 0,053 | 43,0 |
| Mispah | no | A | 4,6 | 0,278 | 15,3 |
| (grey) | | E | 5,45 | 0,262 | 13,5 |
| Lamotte[1] | yes | Bh | 5,58 | 0,155 | 29,9 |
| (red) | | Bt[2] | 6,15 | 0,008 | 171,6 |
| | | C | 5,85 | 0,204 | 50,1 |
| Houwhoek[3] | yes | E | 4,52 | 0,321 | 4,0 |
| (grey) | | Bh | 5,17 | 0,021 | 3,3 |
| Griffin | no | A | 5,90 | 0,126 | 12,3 |
| (red) | | $B_{21}$ | 6,05 | 0,002 | 10,8 |
| | | $B_{22}$ | 6,1 | 0,005 | 10,8 |
| Avalon (yellow) | no | B | 5,3 | 0,001 | 12,3 |
| Clovelly (yellow) | no | B | 6,2 | 0,006 | 19,1 |
| Champagne (peat) | no | - | 4,85 | 0,293 | 13,5 |
| Estcourt | no | AE | 5,7 | 0,173 | 12,3 |
| (grey) | | B | 6,15 | ?[4] | 17,6 |
| Oakleaf | no | A | 5,8 | 0,220 | 10,1 |
| (red/yellow) | | B | 5,02 | 0,125 | 15,7 |
| | | C | 4,92 | 0,089 | 16,8 |
| Cartref | no | A | 5,25 | 0,180 | 13,5 |
| (grey) | | E | 5,45 | 0,175 | 11,2 |
| | | B | 5,6 | 0,039 | 12,9 |
| Lamotte | yes | A | 4,6 | 0,051 | 37,0 |
| (brown) | | Bh | 5,45 | 0,186 | 10,8 |
| | | C | 5,17 | 0,198 | 11,2 |
| Houwhoek[5] | yes | A | 5,32 | 0,173 | 10,1 |
| (yellow) | | Bh | 6,0 | 0,044 | 15,0 |
| | | C | 6,5 | 0,004 | 10,8 |

[1] Kruisfontein
[2] Red/yellow palaeo horizon
[3] Benekop
[4] Too turbid, even after filtering through 0,00045 mm
[5] Jonkersberg

**TABLE 4**
**CHANGE IN RIVER-WATER QUALITY BEFORE AND AFTER INTENSE STORMFLOW. COLOUR IS ABSORBANCE AT 400 nm. NUMBERS IN BRACKETS REFER TO RIVER NUMBERS ON TABLE 1**

| | | During drought | | During stormflow | |
|---|---|---|---|---|---|
| | | pH | Colour | pH | Colour |
| Groenkloof 1 | (14) | 6,01 | 0,006 | 5,9 | 0,020 |
| Groenkloof 2 | (15) | 6,5 | 0,004 | 6,0 | 0,008 |
| Kleinplaat 1 | (16) | 5,7 | 0,027 | 4,8 | 0,126 |
| Kleinplaat 2 | (17) | 6,62 | 0,005 | 6,3 | 0,054 |
| Kaaimans | (21) | 4,7 | 0,164 | 4,4 | 0,206 |
| Perdekraal | (33) | 4,75 | 0,012 | 3,9 | 0,137 |
| Moordkuils 1 | (29) | 5,9 | 0,013 | 5,0 | 0,155 |
| Swart | (32) | 4,55 | 0,242 | 4,4 | 0,320 |

fynbos and forest communities.

Reeve and Fergus (1982) found that when they poured black water through podzol A horizons, the water became even more acidic. In contrast, not one of the horizons we tested resulted in a lowering of the pH. Podzols can form at the rate of decades or centuries (e.g. Duchafour, 1982). Given the abundance of very dark and acid waters in the S. Cape, the sandy low-base status of the soils and the millenia that sclerophyllous vegetation has been in the area, the relative lack of well developed podzols in the S. Cape is thus surprising. We suggest that in part this may be due to the relatively high iron (1 to 2 %) content of the soil (Schloms et al., 1983).

### Synthesis

We suggest that the two major factors which are correlated with increased intensity of colour of streams in the Cape are the low contact period water has with a soil profile and/or the paleness of the soil horizons. Paleness of the soil may be due to many factors such as waterlogged conditions causing reducing conditions, intense eluviation of clay minerals or a lack of iron/clay minerals in the parent material. Whether the soil is podzolised or not is fairly irrelevant because impenetratable podzols are rare in the Cape. A deep podzol will decolour black water far more than a shallow pale nonpodzolised soil.

The S. Cape differs from many other regions with black-water systems in being areas of high relief. Our results indicate that the high altitude and steep relief is strongly linked to stained water because the soils formed in these areas may be bleached and the short contact period between soil and water, the steep relief will cause. We envisage that during spates, the degree of overland flow and interflow increases and thus the colour of the stream intensifies. Catchments with shallow, pale and/or peaty soils should experience greater colour changes than those with deep red and freely drained soils. Other factors which influence the degree of overland flow (e.g. rock dominance, peatiness and soil hydrophobia) should therefore also be correlated to a darkening of river water colour.

Lambrechts (1983) considered it difficult to determine the evolutionary stage of podzolic soils in the Fynbos Biome. He noted for example that podzolic features of deep acid sands of the S.W. Cape were associated with low rainfall and white waters and thus he wondered whether they were palaeosols. The plants which Glyphis and Puttick (1988) analysed come from such an area as Lambrechts (1983) discussed. The mean level of phenols they determined (7,55 %) is fairly high. We suggest that these plants produce black waters which are removed with contact with the soil. Therefore this aspect of the podzolization process should still presently be active in this area. We predict that black streams in other areas of the Cape will not be associated with catchments with yellow/red or brown soils, irrespective of whether vegetated by fynbos or forest.

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