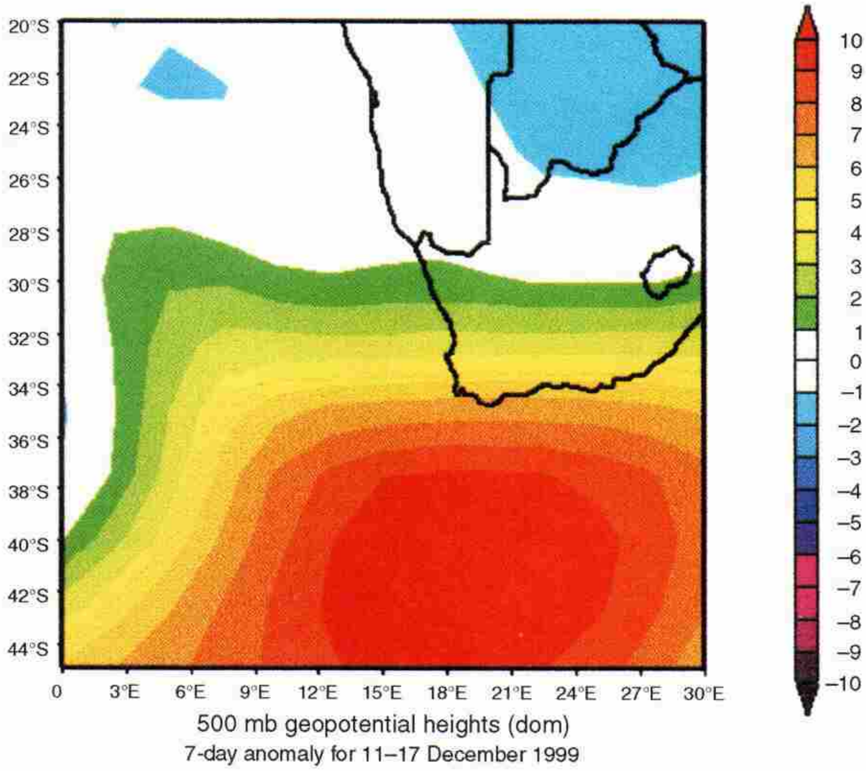

NCEP Operational Dataset
NOAA-DIRES/Climate Diagnostics Center

Fig. 4. Large-scale weather map averaged for the period 11–17 December 1999, illustrating the presence of a blocking high in upper level geopotential height anomalies (in red) analysed from NCEP data via the website: http://www.cdc.noaa.gov/HistData/.

Composite satellite imagery was kindly provided by Scarla Weeks of OceanSpace, University of Cape Town. Surface weather data were collected at Koeberg power station and provided by F. Potgieter. Large-scale weather maps and data were analysed from the NCEP reanalysis website of the NOAA Climate Diagnostic Center in Washington, D.C.

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How do we know how much groundwater is stored in southwestern Cape mountains?

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WE USED ISOTOPES OF WATER (D, ^{18}O) IN rain and streams to obtain an estimate of the amount of groundwater in the southwestern Cape mountains. We assumed that the groundwater reservoir is well-mixed and that the water isotope signals in local streams are the same as those of groundwater. Our analysis suggests that reservoir volume can be several times that of local rainfall minus local streamflow and up to 2–3 times that of local rainfall. This in turn suggests considerable residence times of water to allow this quantity of water to accumulate. This has implications for hydrology as well as for understanding the influence of vegetation on streamflow.

Although southwestern Cape rivers, in the vicinity of Cape Town and Stellenbosch, respond with increased flow within minutes to a rain event, Midgley and Scott,[1] on the basis of isotopic (^{18}O and D) evidence, suggested that this is not directly due to rain from the particular event. They showed that less than 5% of the rain directly enters a stream during and immediately after rainfall. The rapid response presumably implies that rain rapidly reaches the groundwater reservoir and then displaces some of it into the stream. Apart from increased flow during storms, groundwater is gradually released as baseflow, such as during the relatively rainless summers of the area. Here, we speculate about the magnitude of the groundwater reservoir.

To do this we make two assumptions. First, that the stream water isotope signal is the same as that of the groundwater reservoir, and second that the groundwater is well-mixed. The high responsiveness of streams suggests that time taken for precipitation to reach the reservoir is relatively short and thus the stream signal reliably reflects the groundwater signal. Also, variations in the isotopic content of the stream are dampened both during and after storms (Figs 1, 2). We interpret these points to suggest that the reservoir is thus not composed of different volumes of water kept apart by the slow percolation periods en route to the reservoir. We determined the effect of rain events of known magnitude and isotope concentration on stream-isotope concentration before and after rainfall by solving the following simple mass balance equation:

Reservoir depth R (unknown, mm) × stream isotope concentration immediately before a rain event + amount of rain during an event (mm) × rain isotope concentration = (R+ amount of rain) × stream isotope concentration after the rain event.

Four storms were studied and in all cases rainfall was more depleted in water isotopes than were local streams. This difference in isotope concentration of rain and pre-rain stream water often had little or no effect on post-rain stream isotope concentration. We interpret this to mean that the reservoir was deep enough to be well-buffered.

The first two analyses use data from Stellenbosch catchments studied by Midgley and Scott.[1] At LambrechtsbosB, the study took place from 21–23 September 1992. The final stream sample was taken about 26 hours after the last rain and thus well after stormflow had receded (see Fig. 2 in ref. 1). At Bosboukloof, the study took place from 8–10 July 1988. At this site, despite a period of more than 6 hours after the last rain and the virtual

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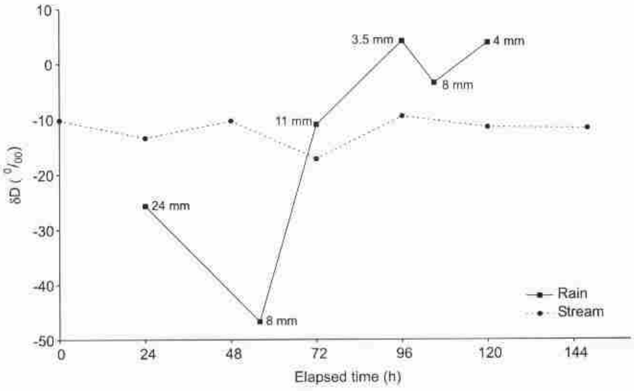

Fig. 1. Storm and rain isotope concentrations for storm 3 (see Table 1).

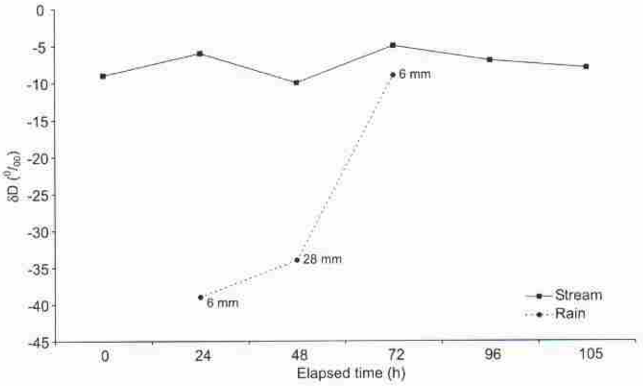

Fig. 2. Storm and rain isotope concentrations for storm 4 (see Table 1).

return of baseflow conditions, there was no difference in stream isotope content after the storm compared to pre-storm values. To model this situation, we conservatively assumed a –0.1 per mil ^{18}O (= analytical precision) decrease in the post-storm values compared to pre-storm content. The third and fourth samples were taken from Blinkwater stream, a perennial watercourse on the western side of Table Mountain, during the periods 13–17 July 2000 and 1–7 August 1999 (Figs 1, 2). No precise rainfall data are available for the Blinkwater catchment. According to Weather Bureau records, mean rainfall at the top of the catchment (Cable Way station, 1067 m, 1933–1958) is 1407.3 mm, whereas at the base of the catchment (Camps Bay, 15 m, 1957–1974) it is 619 mm and at nearby Woodhead Tunnel (520 m, 1906–1999) it is 1278 mm. At Blinkwater Catchment, samples of rain and stream water were taken at an altitude of 190 m adjacent to the stream. We estimate the mean catchment height to be 500 m (max. altitude about 1100 m). Here too there was no difference in stream isotope concentrations of sample 3 before and after rainfall, despite the final sample being taken 40 hours after the rain stopped. We used –1 per mil D change in the post-storm signal to model minimum size of the reservoir. Final stream samples for storm 4 were taken 50 hours after it had rained.

Our analysis suggests that minimum groundwater depth ranges from 0.3–5 m (Table 1). These estimates are conservative for many reasons. First, the mean rainfall for the entire catchment is likely to be considerably greater, and mean rain isotope concentration considerably lower, than measured in our rain gauges situated near the base of the catchment. For example, 59 mm was measured at 190 m in Blinkwater, whereas 157.5 mm fell at the rain gauge at an elevation of 750 mm on the back table of Table Mountain during storm 4. Rainfall amount and isotope concentration in relation to variation in altitude (–0.3‰ ^{18}O per 100 m) is known for the Stellenbosch catchments,[1] allowing a realistic estimate of mean values for the whole catchments. The maximum value in the last column in Table 1 is based on these adjustments for altitude effects on rainfall amount.

Table 1. Isotope content in two Cape streams before and after rain events.

Catchment	Stream isotope (‰)	Rainfall (mm)	Rain isotope (‰)	Stream isotope after rainfall (‰)	Reservoir depth (m)
Storm 1					
LambrechtsB	–19.8 (D)	70.5	–41.5	–20.1	5–6
LambrechtsB	–4.44 (^{18}O)	70.5	–6.95	–4.48	4–8
Storm 2					
Bosboukloof	–3.96 (^{18}O)	65.5	–5.6	–3.96	1–?
Storm 3					
Blinkwater	–9.0 (D)	40.0	–31.0	–8.0	0.84–2.10
Storm 4					
Blinkwater	–10.2 (D)	59.0	–18.8	–11.7	0.28–2.60

Furthermore, the proportion of each catchment that is composed of cliffs and shallow soil needs to be considered. For example, we estimate that in the Blinkwater catchment only 50% of the surface comprises soil, the rest consisting of rock and protruding basement geology. Our estimate of groundwater depth assumes that it is equally spread over the whole catchment, clearly an erroneous assumption for rocky catchments.

Mean annual rainfall input and stream outflow in the two Stellenbosch catchments are 1297 mm and 593 mm at Bosboukloof and 1472 mm and 531.3 mm at LambrechtsbosB, respectively[2]. The difference between rainfall and streamflow provides the basis for estimating the effect of vegetation, such as exotic plants in catchments, on water delivery[2]. Thus, the 55–64% of the remaining rainfall at the two catchments is presumed to be lost by evapo-transpiration. Our analysis suggests that some rain reaches the groundwater reservoir and is retained there for periods long enough to allow a considerable reservoir to accumulate and therefore streamflow is not necessarily in short-term equilibrium with rainfall and evapo-transpiration.

The presence of a substantial groundwater reservoir raises other issues, such as the age and the residence time of the water in the reservoir. How deep down in the ground is this water and how do these factors vary with other factors such as depth of soil or fractures in the rock? Can deep-rooted exotic trees access this groundwater reservoir? Finally, van Wyk[2] noted that the relationship between annual input (precipitation) and outflow (streamflow) within a single catchment was poor, percentage catchment yield being relatively unpredictable. Is this because the groundwater reservoir is large enough to act as a buffer that prevents short-term equilibrium?

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