The use of stable isotopes of water (D and ^{18}O) in hydrological studies in the Jonkershoek Valley*

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Abstract

We used stable isotopes of water in rainfall and streams in the Jonkershoek Valley to determine the relative contribution of new water (i.e. rain) during stormflow conditions. We found significant differences between rain and stream isotopic signatures which facilitated the use of a mass balance equation to calculate the components of stormflow. Analyses indicated that < 5% of the stormflow comprised direct runoff. This suggests that the rapid response of these streams to rainfall is mainly due to displaced groundwater.

Introduction

Stable isotopes of hydrogen (^2H or D) and oxygen (^{18}O) in water are excellent tracers of the origin and movement of water for use in studies of catchment hydrology. When a storm in a catchment produces rain with a significantly different isotopic signature to that of streams, it provides the opportunity to study the application of tracers on an enormous scale. By this approach isotopes have been used to determine the relative contribution of "new" (i.e. from a rain event) water to streamflow. To date such studies in catchments in Australia (Turner et al., 1987) and New Zealand (Pearce et al., 1986) have generally shown the somewhat surprising result that new water (i.e. direct contribution from a particular rain event) contributes less than 10% of the stormflow. In this paper we report on the use of this technology to analyse aspects of catchment hydrology in the Jonkershoek Valley of the SW Cape.

Here streams are quick to respond to rain events and within an hour of the beginning of a rain event, significant increases in the streamflow occur. On an annual basis, between 36% and 71% of rainfall (mean for 6 catchments is 51.1 %) leaves the Jonkershoek catchments as streamflow (Van Wyk, 1987); however, the bulk of this runoff is as baseflow. This is reflected in low mean storm response ratios (quickflow as a proportion of stormflow) of between 1.9 and 18% (Scott, 1993). On the basis of an analysis of rainfall intensity and stormflow, Hewlett and Bosch (1984) argued that overland flow plays a minor role in flood production in streams from this area.

The stable isotope signature of particular rain events is largely determined by a "temperature-effect" (the colder the more negative) and to a lesser degree an "amount effect" (heavy storms result in greater depletion of heavier isotopes and thus a more negative isotopic signature) (e.g. Datta et al., 1991). The isotopic content of streams is an approximate long-term average of isotope concentration of precipitation in source catchments as well as reflecting a component of evaporative enrichment. Evaporative enrichment can be detected by comparisons with the local meteoric water line (MWL) (e.g Datta et al., 1991; Turner et al., 1987), the MWL merely being an empirical relationship between D and ^{18}O in the precipitation of an area.

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Study area

Many streams in the Jonkershoek Valley (see map in Van Wyk, 1987) have been gauged and there is an extensive network of stations that monitor the climate of the valley (Hewlett and Bosch 1984; Van Wyk, 1987). We mainly studied the Bosboukloof and Lambrechtsbos B catchments, where mean rainfall is 1 296 and 1 472 mm respectively (Van Wyk, 1987). Most of the natural fynbos (macchia) vegetation has been replaced in both catchments by pine plantations. The geology of the catchments is mainly Table Mountain Sandstone (TMS), although the soils in both catchments are generally a talus TMS sandstone accumulation over a weathered granite mantle. They are usually structureless, deep and rocky. In places road cuttings indicate that soils are several metres deep. This suggests that the water holding capacity of the catchment is large, given that 1 m of soil can store 300 to 500 mm of water (Pearce et al., 1986). Also, soil characteristics are such that infiltration capacities are well in excess of normal rainfall intensities (Versfeld, 1981). In terms of the South African binomial system (MacVicar et al., 1977), Oakleaf and Glenrosa forms predominate in the lower reaches of these catchments, with Hutton and Clovelly forms also becoming important at upper elevations (Versfeld, 1993).

Methods

An initial study of isotopic composition of rainfall and streamflow was made at Bosboukloof in July 1988. Thereafter a more detailed sampling programme was conducted in several catchments, but mainly Lambrechtsbos-B, in the period February to September 1992.

Rain was collected from rain gauges equipped with Nipher shields and stream water was collected in well-mixed sections of the streams above stilling ponds. After collection, samples were immediately placed in sealed bottles. Stable isotope analyses were performed by CSIR-Ematek in Pretoria on a VG SIRA24 mass spectrometer using an ISOPREP line. Equilibration was with CO_2 and for D the exchange reaction was catalysed with platinum. Values are given relative to standard mean ocean water (SMOW).

We calculated a local MWL using the isotope data for rainfall (Fig. 1) and we used a mass balance equation (Pearce et al., 1986) to determine the relative roles of old (stored) and new (current rain) water respectively. As integration period we used the full period for which stream isotopic values were collected (see Figs. 2 and 3).