

# Use of natural isotopes and groundwater quality for improved recharge and flow estimates in dolomitic aquifers

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## Abstract

The application of a model to several dolomitic aquifers in the RSA is presented and has successfully simulated the reappearance of  $^{14}\text{C}$  injected from nuclear tests in the discharge from springs. This is based on a new conceptual model, which accounts for the large variations of  $^{14}\text{C}$  in the groundwater still representing recently recharged water. The input of  $^{14}\text{C}$  is related to the recharge mechanism to yield low concentrations if the infiltration is direct; and higher concentrations if the recharge water interacts with biogenic  $\text{CO}_2$  generated in the soil zone. The model has produced estimates of the recharge parameters and their controls but requires an independent estimate of the average recharge e.g. the chloride mass balance method. A close match has been obtained with  $^{14}\text{C}$  measurements over the past three decades. A shallow component of the recharge mixes with a larger and older deep-water component. The model has provided the turn-over times of water in the system, which represent the storage capacity as multiples of the mean annual recharge. Quantitative estimates of the recharge of dolomitic aquifers could be derived from the bicarbonate concentrations of the spring waters.

The model has also been used to simulate the response of the limited temporal tritium measurements and single determinations of CFC for some springs. This has revealed significant differences that are related to additional dilution of the tritium tracer in the unsaturated zone, in comparison to  $^{14}\text{C}$  and CFC.

**Keywords:** dolomite, karst, carbonate, aquifers, groundwater, model, carbon 14,  $^{14}\text{C}$ , tritium,  $^3\text{H}$ , CFC, recharge estimation, turnover time

## Introduction

### Background to the study

In view of their importance as significant groundwater resources the dolomitic aquifers of South Africa have been the focus of studies over many years (Enslin and Kriel, 1967; Fleisher, 1981; Taylor, 1983; Bredenkamp et al., (1985); Foster, 1988; Vegter and Foster, 1990; Simonic, 1993; Bredenkamp et al., 1994; Veltman, 2003; Stephens et al., 2004) A variety of methods have been applied to improve the assessment of the recharge and flow characteristics of these aquifers. The latest contribution involves the simulation of the  $^{14}\text{C}$  pulse that had been injected into the atmosphere from thermonuclear tests and its reappearance in the spring discharge after a period of time. The  $^{14}\text{C}$  content of several dolomitic springs has been measured at irregular intervals over more than 30 years. Previous attempts (Talma and Weaver, 2003) to simulate the breakthrough of the bomb  $^{14}\text{C}$  have only been partially successful in view of:

- The difficulty to determine the initial  $^{14}\text{C}$  concentration and account for the large variations in  $^{14}\text{C}$  content of the recharge entering the aquifer
- Finding an acceptable mixing model for the water emanating from the spring.

According to the model the recharge comprises two components of different  $^{14}\text{C}$  contents that are determined by a low- and a high-threshold rainfall value. Good simulations of  $^{14}\text{C}$  have been achieved (Bredenkamp and Van Wyk, 2004).

The model has been further investigated to

- Determine the sensitivity of the model parameters
- Match the average recharge obtained from the model to the average recharge derived from the chloride mass balance method (CMB)
- Apply the model to simulate the response of the environmental tritium and CFC in groundwater
- Derive the age and turnover time of water in the aquifer, the latter representing the storage of groundwater as multiples of the average annual recharge. (Vogel, 1970; Bredenkamp and Vogel, 1970).

A WRC contract (K8/618) has been granted to further investigate the application of the method to dolomitic springs all over the country – see Fig. 1.

### Rationale of the $^{14}\text{C}$ model

The new simulation model conforms to the lumped parameter approach (Maloszewski and Zuber, 1996) but incorporates a bi-modal recharge that could yield both low and high  $^{14}\text{C}$  values, which still represent recent recharge (see Fig. 2). A two-box model has provided good results of the mixing occurring within these aquifers, without having to incorporate complex factors such as matrix flow, fracture flow, and dispersion of the tracer.

In the present  $^{14}\text{C}$  simulation model the recharge of the dolomite comprises two components according to the conceptual model shown in Fig. 2 with differential uptake of  $^{14}\text{C}$ . This yields both high and low  $^{14}\text{C}$  content for recent recharge, which admixes with water flowing in the aquifer. Recharge in closer proximity to the spring mixes with the deeper flowing water, representing recharge that has occurred at greater distances from the spring outlet, which represents recharge from an earlier period. The  $^{14}\text{C}$  content of the final mix therefore

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Received 21 July 2006; accepted in revised form 5 October 2006.