A hydrogeomorphological approach to quantification of groundwater discharge to streams in South Africa

Y Xu[1]*, R Titus[1], SD Holness[1], J Zhang[2] and GJ van Tonder[3]

[1] Department of Earth Sciences, University of the Western Cape, Private Bag X17, Bellville 7535, South Africa
[2] Environmentek, CSIR, Stellenbosch, South Africa
[3] Institute for Groundwater Studies, University of the Free State, Bloemfontein, South Africa

Abstract

In South Africa, the flow requirements for maintaining the normal functioning of aquatic ecosystems is termed the "ecological reserve", and these should be determined when a licence application for water allocation is processed. Determination of the ecological reserve entails investigation of the relationship between the major interactive components of the hydrologic cycle, namely groundwater and surface water bodies including rivers, lakes and estuaries. Information on groundwater discharge towards surface water bodies is critical for the water resource manager to make a decision regarding the amount of groundwater allocation that can be licensed without causing a negative impact on aquatic ecosystems. Existing techniques of hydrograph-separation are too subjective either due to the fact that assumptions of the techniques cannot be met in reality or that the parameters used in models do not have physical meanings. This paper presents a geomorphologic framework under which the quantification of groundwater from a hydrograph is discussed. A focus is placed on hydrogeomorphological typing that can be used to guide a process of separating groundwater discharge time series from hydrographs where a monthly groundwater discharge time series is required for comparison with instream flow requirements. For generating monthly groundwater discharge time series, a generic procedure is proposed, which is applied in a case study.

Introduction

The South African National Water Act of 1998 places emphasis on the protection of water resources for their sustainable utilisation. Officially, from the 1st of October 1999, a preliminary or comprehensive Reserve evaluation of a water management area should be determined when a licence application for water allocation is processed. The ecological reserve is a generic term representing flow requirements for aquatic ecosystems. In the case of rivers, it is referred to as the instream flow requirement (IFR). The fundamental assumption for the derivation of the IFRs is that rivers with a high degree of hydrological variability will require a lower proportion of their natural mean annual runoff, because they are accustomed to experiencing such conditions. In addition, the higher the desired conservation status is, the more instream flow is required.

Annual IFRs for high, low and drought flows are further assigned by hydrological and ecological specialists into 12 monthly values of the hydrological year from October to the following September. The 12 monthly values, often expressed in terms of various confidence levels, are based on generated instream flow time series (Hughes and Münster, 1999). The low flow component of the IFRs may be fed or maintained by groundwater discharge if there is hydraulic connection between aquifer and stream. Hence, groundwater allocation must take into account the possible impact of over abstraction of water on the low flow component of IFR.

The general approach to the quantification of the groundwater contribution to surface water is numerical simulation. However the numerical results often suffer from lack of measured groundwater flow data for calibration. Alternatively, hydrograph-separation techniques are used in South Africa. It is commonly accepted that a hydrograph consists of baseflow (groundwater), interflow and direct runoff. The hydrograph-separation techniques are used to separate baseflow from a hydrograph by removing quick (or high) flow from slow (or low) flow (Smakhtin, 2001). Many researchers have focused on hydrograph-separation for short period events such as a single flood (Linsley et al., 1958; Farvolden, 1964; Rorabaugh, 1964; Halford and Mayer, 2000). Automation of hydrograph-separation methods has made their techniques easier to apply for larger time scales (Rutledge, 1993; Mayer and Jones, 1996). However, as Halford and Mayer (2000) point out, all hydrograph-separation techniques, when used alone, are poor tools for estimating groundwater discharge because the major assumptions of the techniques are not easily met. In South Africa, Herold (1980) suggests that the current groundwater component results from the combined effect of decay of previous groundwater discharge and previous streamflow increase. This method was adopted in the Water Resources 1990 project in South Africa, in which a time series of monthly flows could be separated into surface and groundwater components for each of the approximately 2000 Quaternary catchments of the study area (South Africa, Lesotho and Swaziland) (Vegter and Pitman, 1996). Even though the Herold method is an improvement on earlier hydrograph-separation techniques, it is still very subjective and does not take hydrogeological settings into account. Existing hydrograph-separation methods used in South Africa are summarised in Table 1.

These methods often seem to be unable to differentiate the origins of the low flow component that may contain groundwater discharge as well as interflow. Questions like; what portion of low flow is groundwater and to what degree groundwater contributes to instream flow requirements (IFRs) remain unresolved.

The understanding of the mechanism of baseflow generation in rivers is a prerequisite for the estimation of any realistic time series

* To whom all correspondence should be addressed.
☎ 021 959-3882; fax 021 959-2438; e-mail: yxu@uwc.ac.za
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