

Understanding and quantifying groundwater's contribution to baseflow

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ABSTRACT

Promulgation of the National Water Act (Act 36 of 1998) has resulted in greater attention being paid to the role of groundwater in sustaining baseflow during dry periods. It has subsequently emerged hydrologists and geohydrologists have different understandings of groundwater and groundwater discharge into rivers. Not all baseflow is derived from groundwater and not all groundwater abstraction has the potential to impact flow in rivers. Using the Thukela River as an example, this paper defines groundwater, provides a conceptual understanding of groundwater discharge into rivers and describes a simplistic method that can be used to provide a first approximation of the annual volume of groundwater discharged into rivers.

INTRODUCTION

More than ever before, understanding the interaction between surface and groundwater is required to facilitate appropriate decision-making and resource management. Historically, surface and groundwater were isolated in policy and regulation, partly as a result of the private status of groundwater under the old Water Act (Act 56 of 1956). This resulted in surface and groundwater practitioners working in isolation and seldom appreciating the interconnectivity between the two. Similarly, surface and groundwater resources were managed separately. Promulgation of the National Water Act (Act 36 of 1998) and other environmental legislation now requires water resources be managed in a holistic fashion.

PROBLEM STATEMENT

As a result of closer working relationships between hydrologists and geohydrologists, it has emerged that our understanding of surface – groundwater interaction is poor and many previous hydrological investigations have not addressed this issue adequately. It is well understood groundwater contributes to river flow, particularly in wetter areas that experience high rainfall. However, the concept of baseflow does not enjoy a common understanding between hydrologists and geohydrologists.

- Hydrologists usually define baseflow as that component of flow that varies relatively little, occurs frequently and has a low amplitude (as opposed to the less frequently occurring, high amplitude and rapidly changing flow associated with individual or seasonal rainfall events). It occurs during dry periods or periods of little or no precipitation and is sometimes referred to as sustained “fair weather flow” or “dry weather flow”. They distinguish between stormflow and baseflow using well established, but arbitrary baseflow separation techniques, with no distinction being made between the origins of the water and the mechanisms and processes by which it arrived in the river.
- Geohydrologists generally understand baseflow has its origin from groundwater discharged into streams and propose estimates of baseflow provide an indication of minimum levels of recharge. Vegter and Pitman (1996), for example, used this approach.

Baseflow separation techniques are used to analyse hydrographs and estimate the relative proportions of stormflow and baseflow (Figure 1). These techniques are described by Hughes and Munster (2000), Smakhtin (2001), Xu *et al.* (2002) and Hughes *et al.* (2003). Using graphical separation techniques, baseflow rating curves or recession-curve displacement methods, hydrologists attempt to calculate a baseflow index (BFI), which is the proportion of baseflow to total flow or runoff. It must be noted this is not an estimate of groundwater discharge to rivers, but rather a measure of slowly responding flows (Lerner, 1996). Traditionally, baseflow separation techniques have not attempted to differentiate the origins of baseflow nor the process by which it reaches a river. Workers such as Moore (1992), Xu *et al.* (2002) and Hannula *et al.* (2003), however, have attempted to quantify the groundwater component of baseflow.

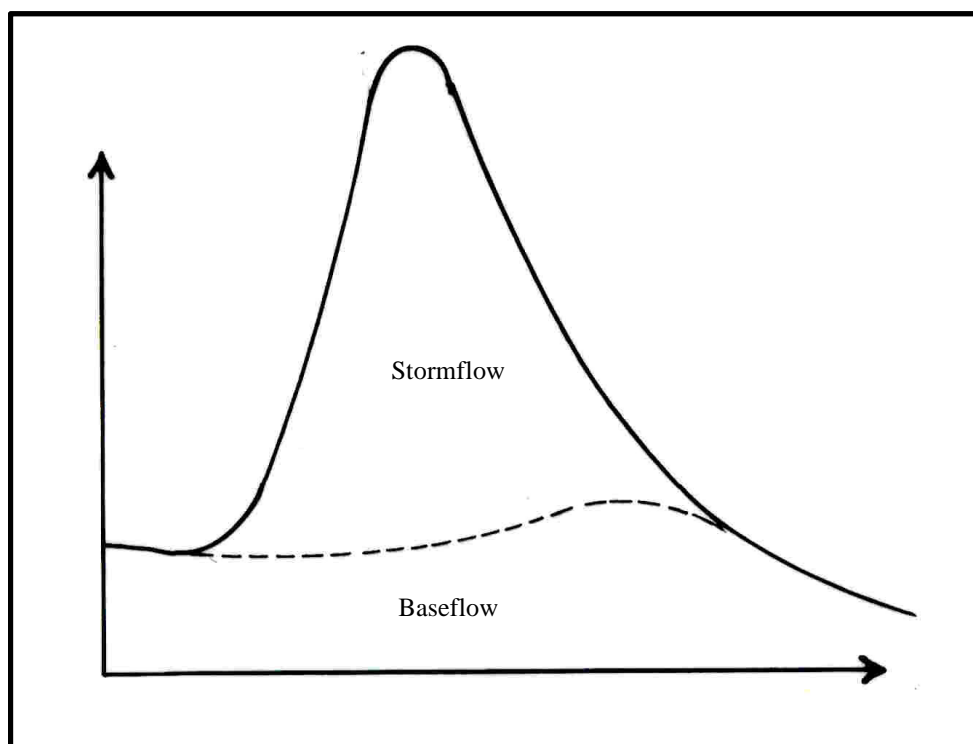


Figure 1: Components of stream flow, as recognised by traditional baseflow separation techniques.

Because of the wide belief that groundwater sustains low flows during dry periods, the geohydrological community has accepted baseflow represents the groundwater contribution to river flow. However, when comparing estimates of recharge to baseflow, it has emerged baseflow is usually significantly greater than estimates of recharge in wetter areas and underestimates recharge in drier climates. This is particularly true in the wetter eastern parts of South Africa where Hughes (2003), for example, observed estimates of baseflow are up to 10 times greater than expected recharge. In the drier parts of the country where baseflow is either very limited or absent, estimates of baseflow clearly under-estimate recharge.

The order of magnitude increase in groundwater discharge to streams predicted by most baseflow separation techniques does not match observed changes in groundwater levels. Accepting groundwater discharge to rivers is governed by Darcy's Law and transmissivity and aquifer width remain (relatively) constant, the only mechanism for increasing groundwater discharge to rivers during storm events is to significantly increase the hydraulic gradient. While groundwater levels may increase in response to recharge from rainfall (and seepage from the river), increases of a magnitude sufficient to explain the increase in groundwater discharge predicted by baseflow separation techniques are not observed in monitored groundwater level data.

ASSESSMENT OF PROBLEM

In trying to unravel the issues described above, two main problems emerged. Both relate to a fundamental understanding of the hydrological system. The first problem relates to understanding what groundwater is, while the second relates to hydrologists and geohydrologists not adopting a common and accepted terminology.

What is Groundwater?

A major source of interdisciplinary confusion arises from not appreciating the difference between groundwater and subsurface water (Figure 2). While the term *subsurface water* is a recognised geohydrological term (Davis and DeWiest, 1966; Driscoll, 1995), it is seldom used. Many non-groundwater specialists (and some groundwater specialists for that matter) confuse groundwater and subsurface water. By definition, groundwater is that water found in the zone of saturation and does not include water stored in soil horizons or the unsaturated (or vadose) zone (Figure 2). The upper limit of groundwater is the water table or piezometric surface.

The unsaturated zone has a unique position in that it integrates many of the components of the hydrological cycle. Unfortunately the role of water held in this zone is often ignored and generally under-appreciated. However, it plays a crucial role in sustaining terrestrial ecosystems as well as sustaining wetlands and stream flow. Water in this zone can move relatively quickly due to a combination of downward gravitational forces and macropore flow. Discharge from the unsaturated zone contributes to interflow, which is the rapid flow of water along essentially unsaturated flow paths, water that infiltrates the subsurface and moves both vertically and laterally before discharging into other water bodies. Interflow is hence transitional between relatively rapid overland flow and slower groundwater discharge to rivers (Figure 3).

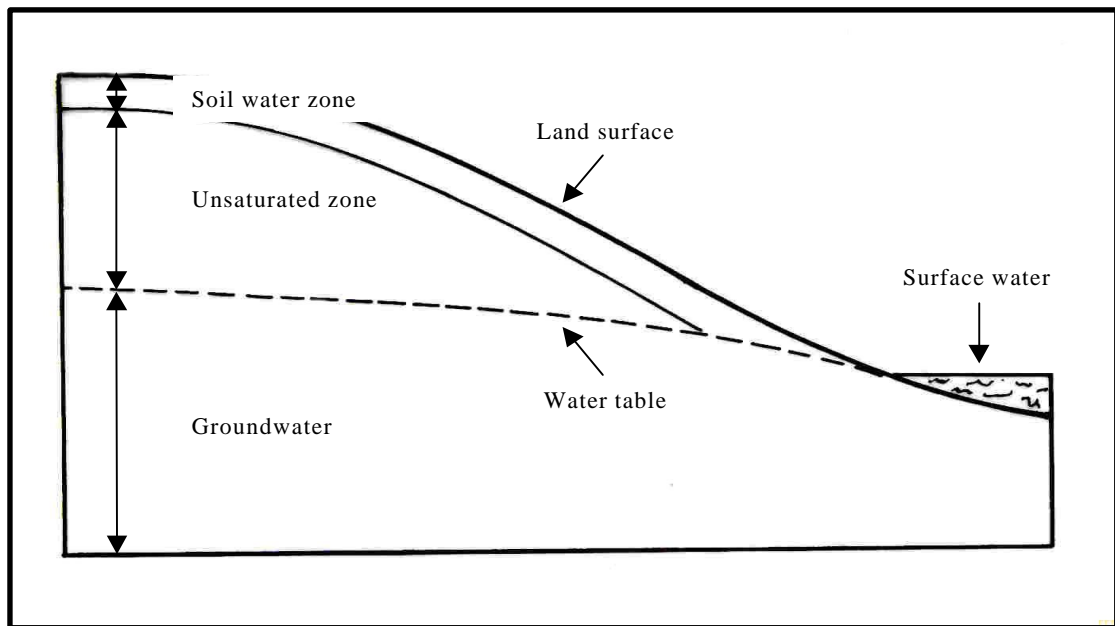


Figure 2: Distinction between groundwater and other subsurface waters.

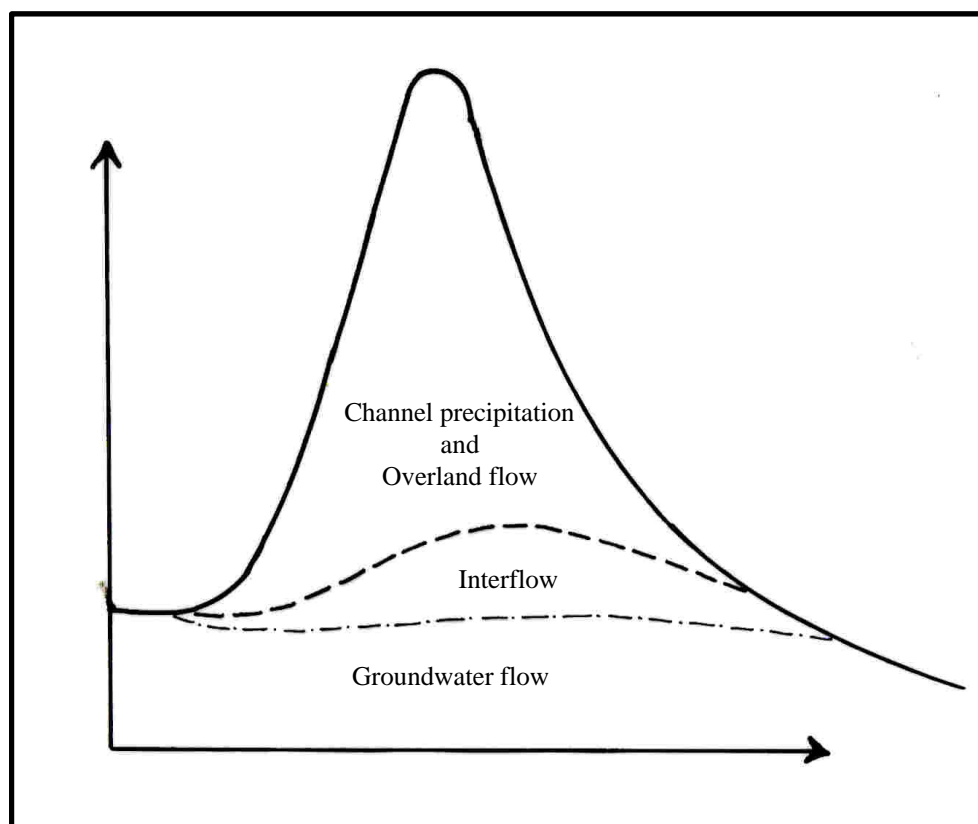


Figure 3: Components of stream flow, based on the processes by which water is discharged into a stream.

By comparing Figures 1 and 3, the root of confusion becomes apparent. While hydrologists considered stormflow and baseflow on the basis of non-process related flow characteristics (as manifested by the shape of the hydrograph), geohydrologists considered stream flow on the basis of how water got into a stream. While baseflow may be equivalent to groundwater discharge into a stream long after a storm event, this is not true during and immediately after a storm when interflow contributes significantly to baseflow.

Examination of baseflow after prolonged periods without rain may provide an indication of the groundwater contribution to river flow. This approach was used in the Thukela River catchment where it was found that the BFI ranged between 32 and 40 % of the mean annual runoff (MAR), but the groundwater contribution to flow ranged between 3 and 18% (Parsons, 2003). The groundwater contribution to flow was estimated by using the lowest daily flows as an indication of the groundwater contribution to baseflow and converting the low flows to an annual groundwater discharge. Groundwater contribution for the three gauging stations in Figure 4 were set at 0.1 m³/s, 0.3 m³/s and 5 m³/s. Verification of the groundwater contribution to flow using a coarse Darcian modeling approach indicated a degree in similarity of the results, thereby supporting the contention that analysis of low flows during dry periods can provide an indication of the groundwater contribution to stream flow.

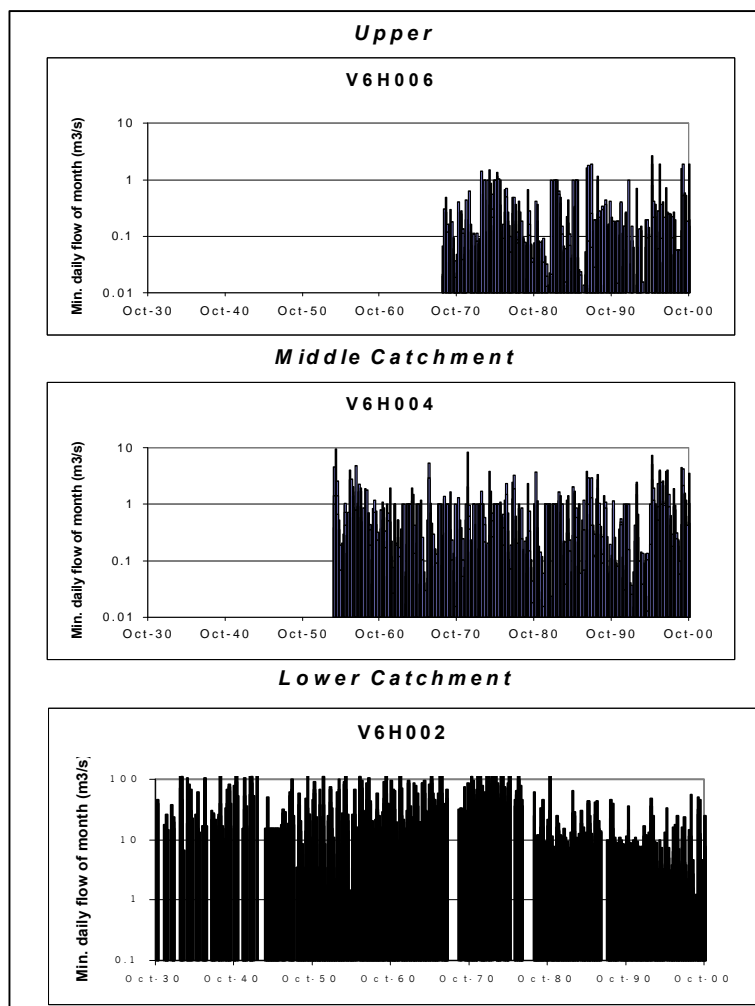


Figure 4: Lowest daily flow recorded in a particular month at three gauging stations on the Sundays River, Thukela River catchment.

Terminology

Inconsistent use of terminology, misuse of terminology and over-simplification of hydrological processes have all played a role in the current misunderstanding of baseflow. As a result of knowledge gained in implementing the National Water Act (Act 36 of 1998) and attempting to quantify the role of groundwater in sustaining aquatic ecosystems, it would be unwise to accept that all baseflow is derived from groundwater and that baseflow provides a measure of recharge. While these premises may be true for more humid climates, sufficient evidence exists to suggest they do not necessarily hold true for arid and semi-arid environments.

Using terminology presented by Ward (1975) as a guide, it is proposed the terms *stormflow* and *baseflow* be retained in their traditional hydrological sense i.e. non-process terms relating to the frequency and amplitude of flow characteristics of a river (Figure 5). Baseflow separation techniques such as those described by Hughes and Munster (2000) and Smakhtin (2001) would be used to quantify the baseflow component of runoff.

It is further proposed the terms *channel precipitation*, *overland flow*, *interflow* and *groundwater contribution to river flow* (or simply groundwater flow) be used to describe time-dependent processes and mechanisms that result in water discharging into a river or stream. Overland flow would include essentially surface mechanisms such as direct run-off and overland flow that result in precipitation discharging into rivers during and relatively soon after a precipitation event (say seconds to hours after the event). Interflow includes those essentially near-surface mechanisms in the unsaturated zone that result in water discharging into rivers days to weeks after a storm event. Because of the range of time interflow may take to reach a river, rapid interflow and delayed interflow can be distinguished (Figure 5). The groundwater contribution to river flow is that steady on-going contribution to flow from groundwater.

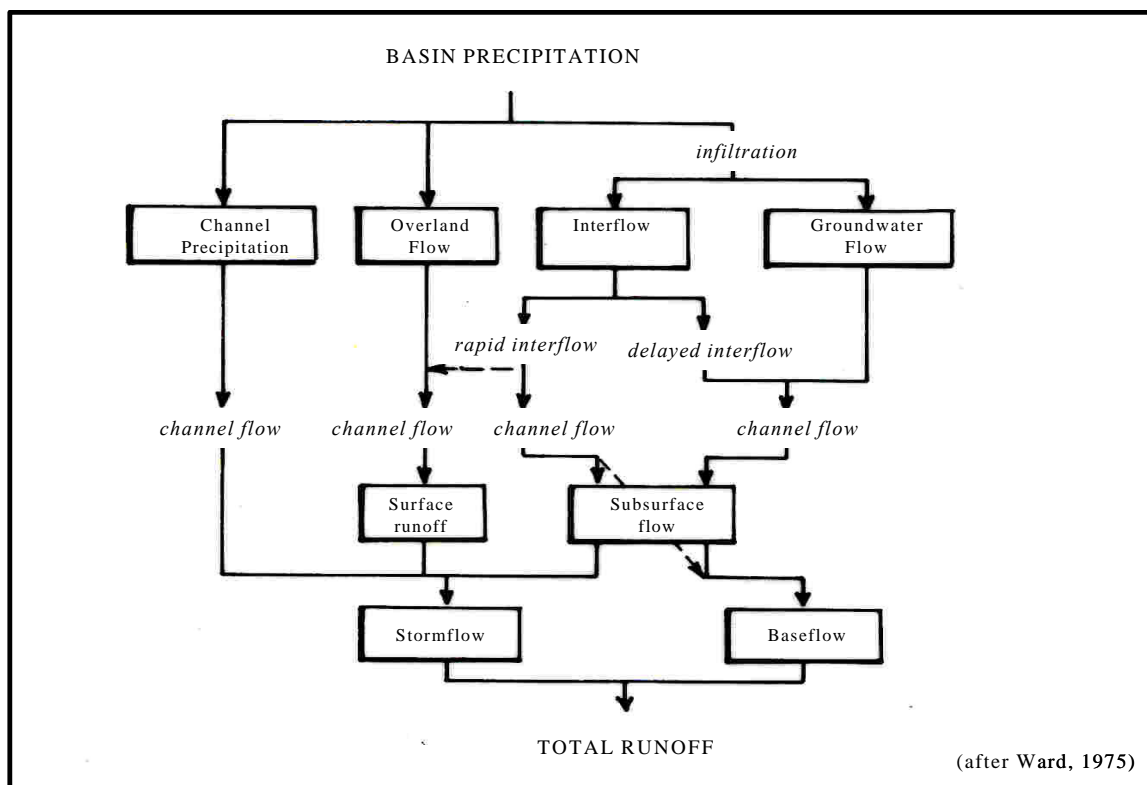


Figure 5: Diagrammatic representation of the runoff process.

While it is recognised the diagrammatic representation of the runoff process and proposed terminology are simplifications of very complex processes which are site, scale and time dependent, they do provide a consistent framework from which various disciplines can work. The broader hydrological community in South Africa must be encouraged to adopt consistent, but internationally recognised terminology and nomenclature. Preparation of a Southern African dictionary of hydrological terms could facilitate this. To avoid confusion, and until such time a consistent terminology is adopted, the hydrological community should define terms used when writing policy, reports and other scientific publications. Further, senior scientists must take an active role in promoting proper use of terminology by managers, practitioners and researchers.

CONCLUSIONS

Promulgation of the National Water Act (Act 36 of 1998) and other environmental legislation resulted in closer working relationships between hydrologists and geohydrologists. From this, it emerged that our understanding of surface – groundwater interaction is poor and hydrologists and geohydrologists did not have a common understanding of the term *baseflow*. A lack of clarity on what constitutes groundwater and the misuse of terminology appear to be key contributors to this confusion. Over-simplification of the hydrological systems also played a role, with failure to consider water in the unsaturated zone and interflow being of relevance. It needs to be recognised that not all baseflow is derived from groundwater and that the terms *stormflow* and *baseflow* are non-process related terms used to describe flow in a river, irrespective of its origin and the processes and mechanisms by which it got there. However, the groundwater contribution to river flow can be estimated using that component of hydrographs not influenced by storm events and thus needs to exclude that component of flow contributed by interflow.

ACKNOWLEDGEMENTS

This paper was based on a project currently being undertaken on behalf of the Water Research Commission and experiences from a range of Department of Water Affairs and Forestry-sponsored Reserve determination projects. The support of these two organisations and a number of co-workers, in particular Prof. Denis Hughes, is gratefully acknowledged.

REFERENCES

- Davis, SN and DeWeist, RJ (1966) Hydrogeology; Wiley and Sons, New York.
- Driscoll, FG (1995) Groundwater and wells; Second edition, Johnson Screens, Minnesota.
- Government Gazette (1998) National Water Act (Act No. 36 of 1998); 26 August 1998, Government Printer, Pretoria.
- Hannula, SR, Esposito, KJ, Chermak, JA, Runnels, DD, Keith, DC and Hall, LE (2003) Estimating groundwater discharge by hydrograph separation; Ground Water Vol. 41 No. 3, pp 368 - 375.

- Hughes, DA and Munster, F (2000) Hydrological information and techniques to support the determination of the water quality component of the ecological Reserve for rivers; Report TT 137/00, Water Research Commission, Pretoria.
- Hughes, DA (2003) Incorporating ground water recharge and discharge functions into an existing monthly rainfall – runoff model; *in press*
- Lerner, DN (1996) Surface water – groundwater interactions in the context of groundwater resources; WRC and IAH (South Africa) workshop on groundwater – surface water issues in arid and semi-arid areas, Pretoria, October 1996.
- Moore, GK (1992) Hydrograph analysis in a fractured rock terrane; *Ground Water*, Vol. 30 No. 2 pp 291 – 304.
- Parsons, RP (2003) Thukela water decision support phase: Reserve determination phase – groundwater scoping report; Report No. PBV000-00-10304 prepared for the Department of Water Affairs and Forestry; Parsons and Associates, Somerset West.
- Smakhtin, VU (2001) Estimating continuous monthly baseflow time series and their possible applications in the context of the ecological reserve; *Water SA*, 27(2) 213 – 217.
- Vegter, JR and Pitman, WV (1996) Recharge and stream flow; Position paper presented at WRC-sponsored workshop on “Groundwater – surface water issues in arid and semi-arid areas”, Warmbaths, October 1996.
- Ward, RC (1975) Principles of hydrology; McGraw-Hill, London.
- Xu, Y, Titus, R, Holness, SD, Zhang, J and van Tonder, GJ (2002) A hydrogeomorphological approach to quantification of groundwater discharge to streams in South Africa; *Water SA* Vol. 28 No. 4, pp 375 – 380.