# How much streamflow is groundwater discharge? – A method for assessment

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The question of how much streamflow originates from groundwater is relevant to the issue of effects of land use on stream water quality. Whereas phosphorus from agricultural land is transported primarily by overland flow, nitrate is leached from the soil profile and moves to streams via saturated soil-water flow, installed drainage systems, and groundwater flow. The portion that is transported through groundwater is of particular interest because measurements of groundwater age show that average contaminant transport times, even in steep hillslopes (Mike Stewart, GNS Ltd), range from several to many years. This means that the response of nitrate concentration in streams to changes in land use in the catchment can be characterised by a time scale of years.

The proportion of streamflow derived from groundwater is also relevant to streamflow quantity. The associated problems of quantifying baseflow separation, low flow recession, and relationships between streamflow and groundwater storage, have been the subjects of mathematical theories for the past 130 years. The theoretical solution used as the basis for the groundwater component of the present method was suggested by Boussinesq a century ago, and has been applied in various forms more recently as improved computational methods became available.

The groundwater discharge concept shown in Figure 1 is described by a mathematical model that has only one parameter, although the associated equations appear to be quite complicated. This parameter $\alpha$ encapsulates the aquifer properties of hydraulic conductivity $k$, storativity $S$, as well as the dimensions of effective aquifer thickness $B$ and length of flow path $L$ from groundwater divide to surface waters. There is no requirement to know these physical quantities beforehand.
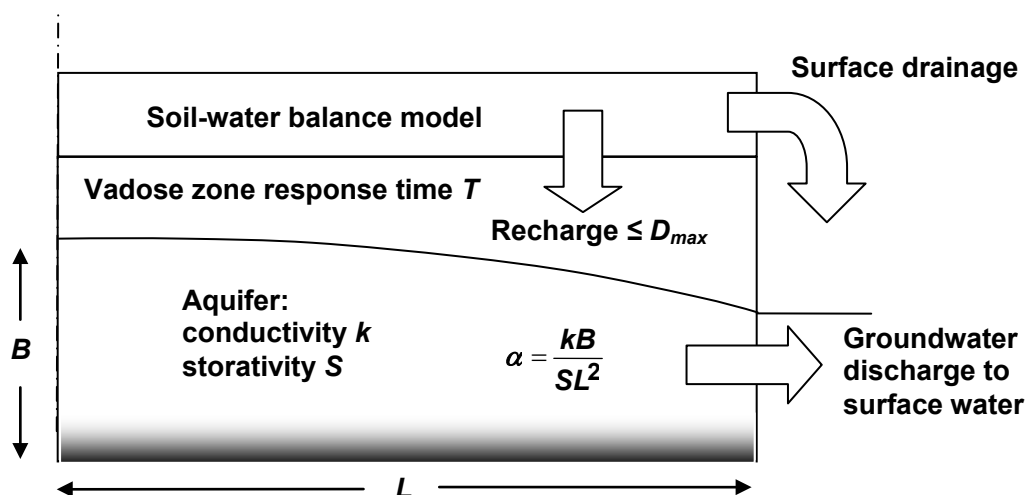


*Figure 1. Conceptual model of the response of groundwater discharge to recharge from soil-water drainage.*

Details of the soil-water balance model are not shown in Figure 1, because any suitable water balance model may be used as the "front end" for the groundwater component. Drainage through the vadose zone is limited by the rate parameter $D_{max}$. Drainage water that is surplus to this value is assumed to contribute to surface runoff, perched groundwater seepage, and other near-surface flow processes. The transit time of water displacement through the vadose zone is characterised by the average response time $T$.

The groundwater discharge model requires only three parameters ($D_{max}$, $T$, $\alpha$) to be calibrated, given concurrent time-series of soil-water drainage and streamflow for a catchment. Calibration can be done by use of the "solver" tool in an Excel spreadsheet of the model, for example. The fitting criterion for calibration can be restricted to streamflow below a selected flow level because the model does not assume that groundwater discharge would account for all high-flow events. Figure 2 shows the groundwater discharge model fitted to some hourly streamflow data for the 15 km$^2$ Toenepi catchment in Waikato.
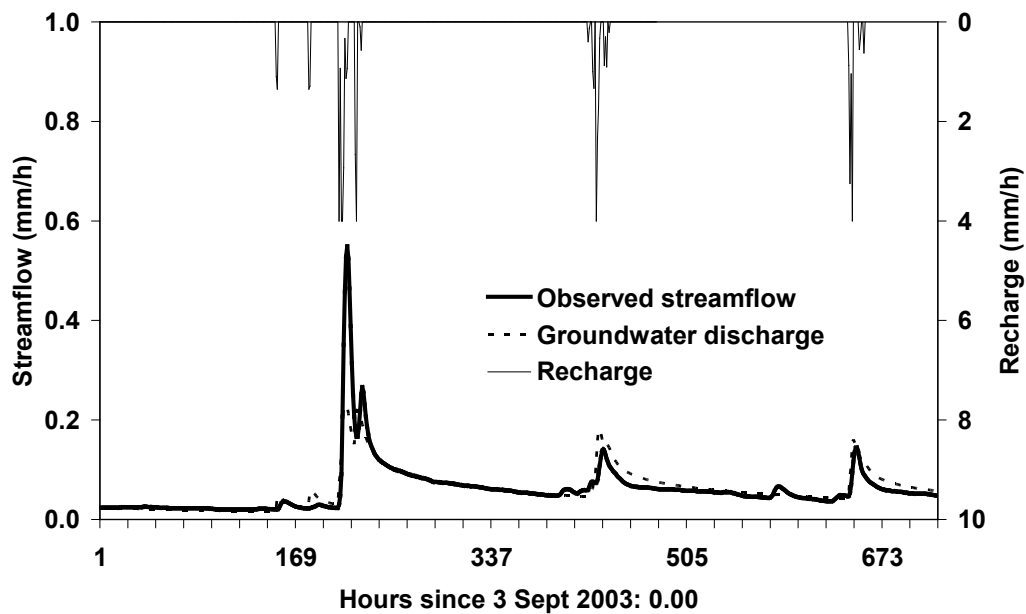


Figure 2. Comparison of observed streamflow and predicted groundwater discharge (hourly data per unit area) for the Toenepi catchment. ($D_{max}$ = 4 mm/h, T = 2.46 h, α = 0.00114 h$^{-1}$).

Figure 2 illustrates how groundwater discharge can respond rapidly to recharge from soil water drainage, and in this catchment it contributes more to streamflow during precipitation and drainage events than might be predicted by some "baseflow separation" methods. The one-parameter groundwater model is able to simulate typical time-variation in the rate of flow recession following a drainage event. The resulting value of the groundwater model parameter $\alpha$ can also be used to explore the ranges of likely values of $L$, $B$, $k$, $S$ that are consistent with other physical data such as age dating of groundwater.