Understanding flow paths of diffuse pollution by separating stream flow into groundwater and event water contributions

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New Zealand's pastoral agriculture is the primary source of diffuse nitrate pollution contributing to excessive nutrient levels in surface water. The grazing of sheep and beef on hill country pastures in New Zealand results in nitrate concentrations five-fold higher than from equivalent small forested catchments (Quinn et al., 2002). Under pastoral land use, nitrate is predominantly generated within the soil zone. Water draining through the soil zone can transport nitrate into the deeper vadose zone and subsequently into the underlying groundwater. This nitrate ultimately reaches surface waters through **groundwater discharge**. Additionally, nitrate can also be transported into surface waters by **event water** reaching surface waters quickly via 'near-surface' flow paths. These may be prevalent during rain events and comprise surface runoff, interflow, interflow re-emerging along a hill slope, and artificial drainage (where applicable). Understanding the contributions that groundwater and event water make to stream flow is of great relevance, as they differ significantly in their likely nutrient loading and temporal dynamics. Moreover, any potential for natural attenuation and mitigation options also differ substantially between these flow paths. The concentration of silica (SiO_2) in the stream flow can be used to differentiate between the contributing flow paths, as the silica concentration reflects the length of the time the water was in contact with silica bearing minerals in the subsurface. Event water that has reached the stream quickly via near-surface flow paths consequently has substantially lower silica concentrations than older groundwater.

To investigate the contributions of groundwater and event water to stream flow, a small (3 ha), steep headwater catchment (Pukemanga) grazed by sheep and beef cattle was instrumented. Stream flow was measured over a period of 28 months (mean annual flow 0.44 l s^{-1}) and water samples were collected episodically and analysed for SiO_2. A separation analysis was applied to 18 flow peak events with discharge ranging between 0.9 and 104 l s^{-1}.

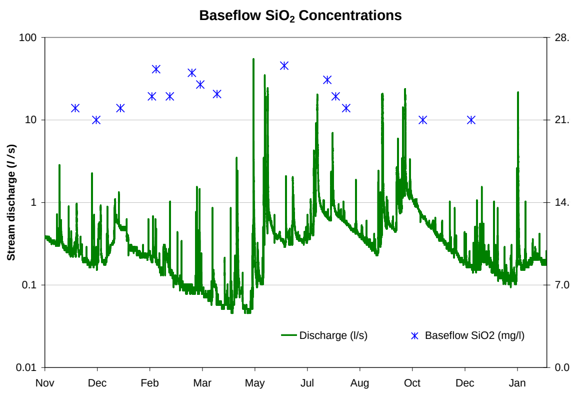

Figure 1.1 Pukemanga stream flow records and SiO_2 concentrations at sampling dates when only groundwater was contributing to stream flow.

SiO_2 concentration of groundwater discharge. On 15 occasions, stream flow was sampled after prolonged periods of dry weather (Fig. 1.1). The stream flow at these times varied between 0.06 to 0.74 l/s, and SiO_2 concentrations ranged between 21.0 to 25.6 mg/l with an average of 23.0 mg/l (stdev.1.6). In these 15 measurements the SiO_2 concentrations were not correlated to flow. A concentration of 23.0 mg/l in groundwater contribution to stream flow is consistent with the range of groundwater SiO_2 concentrations found in the catchment.

SiO_2 concentration of event water. The SiO_2 concentration of the event water was determined by plotting all SiO_2 concentrations sampled against measured flow (Fig 1.2). A power-law relationship was fitted to the data and the SiO_2 concentration for event water was estimated to be 2.8 mg/l. Measurements of SiO_2 concentration in runoff generated during high rainfall events ranged between 2.4 to 4.5 mg/l, which is consistent with this estimate of event water of 2.8 mg/l.

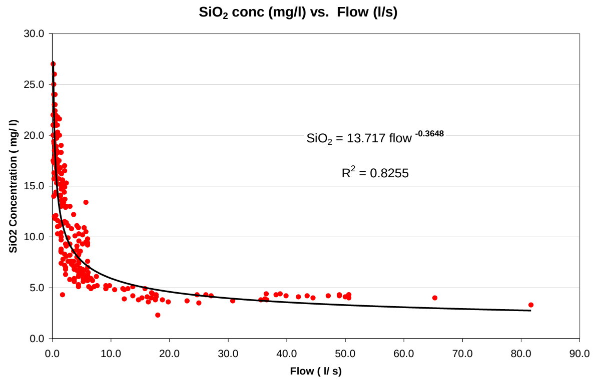

Figure 1.2 Relationship between concentration of SiO_2 and flow rate in the Pukemanga stream

Separation of stream flow Based on the analysis of SiO_2 concentrations measured during 18 flow peaks, with two examples shown in Figure 1.3, the following conclusions can be drawn; 1) The groundwater contribution to a flow peak shows a very strong and instantaneous response to rain, concurrent with the increase in stream flow. 2) The contribution from groundwater to stream flow is highest when the stream flow peaks. 3) The contribution of the event water can have a relatively long recession. 4) Depending on the size of the event, the groundwater contribution can dominate the increase in stream flow. 5) The fraction of groundwater contributing to a flow peak, decreases with the increasing peak discharge of the event.

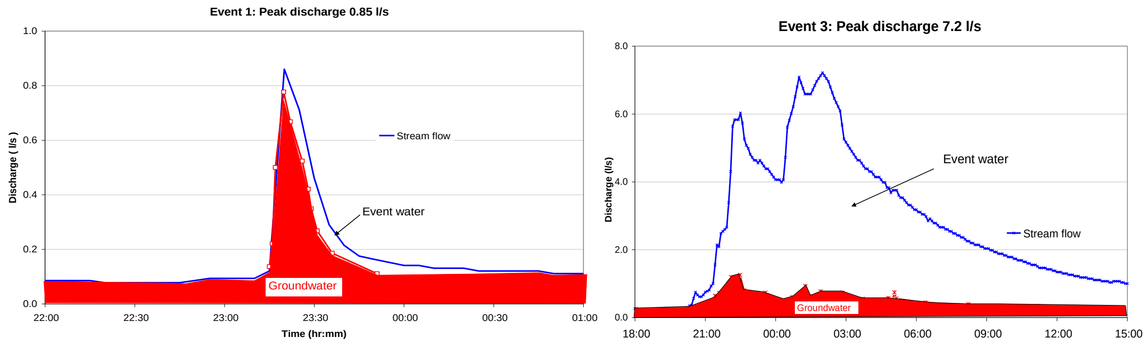

Figure 1.3 Two flow peak events with peak discharges of 0.85 and 7.2 l/s showing the groundwater and event water contribution to stream flow based on SiO_2 analysis.

Groundwater contribution to annual stream flow: Using the relationship between stream flow and SiO_2 concentration (Figure 1.2), the annual contribution to stream flow from groundwater is estimated to be 68%. This is consistent with the results of Bidwell et. al. (2008) who used a hydrometric analysis to estimate the groundwater contribution to stream flow in this catchment.

***Conclusions**:* 1) For small events, the dynamics of the groundwater and event water contribution to stream flow, as based on SiO_2 measurements, is significantly different from that considered in conventional flow separation methods i.e. constant discharge or slope, or concave separation methods. 2) For larger flow events, the groundwater contribution is smaller and the contribution dynamics are in better agreement with those using conventional methods. 3) In small flow events, an increase in the wetted area of the stream due to the groundwater contribution may result in transportation of near surface-associated pollutants i.e. bugs and particulate-associated nutrients, since no event water (i.e. run-off) contributes to stream flow.

References

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