Assessing groundwater nutrient discharge into Lennard Brook, Western Australia

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Abstract This paper describes the application of a technique for estimating the nutrient discharge into a stream from groundwater. The study basin of the Lennard Brook is one where a large proportion of the nutrients are expected to be contributed from this source. In addition to the measurement of streamflow quantity and quality, the technique involves direct measurement of fluxes of groundwater and its nutrient concentration. Recently developed seepage meters are employed to monitor the amount of groundwater seepage into the river continuously and automatically. Flux measurements were made on an hourly basis during January 1996. The flow of the Lennard Brook ranged from 10 300 to 11 500 m$^3$ day$^{-1}$ and the seepage rate into the brook ranged from $3.3 \times 10^{-6}$ m s$^{-1}$ (0.29 m day$^{-1}$) to $2.6 \times 10^{-6}$ m s$^{-1}$ (0.22 m day$^{-1}$). Using average river dimensions, the estimated seepage rate amounted to 9 100 to 11 300 m$^3$ day$^{-1}$. The average ratio of groundwater seepage to streamflow was 0.88. Concentration of PO$_4$-P, NO$_3$-N and Cl in streamflow ranged from 0.013 to 0.026 mg l$^{-1}$, 0.165 to 0.432 mg l$^{-1}$ and 238 to 243 mg l$^{-1}$, respectively. PO$_4$-P and NO$_3$-N concentrations measured in the seepage water were similar to those estimated previously for groundwaters at downstream locations.

INTRODUCTION

Evaluation of nutrient discharge into rivers is a key to understanding water quality issues such as eutrophication. It is important to evaluate not only the volume and concentration of water inputted from tributaries, but also the volume and nutrient discharge contributed from groundwater, because groundwater contribution to streamflows can often be large in many rivers.

Interactions between river water and groundwater have been studied using stable isotope tracers (Shimada et al., 1993), analysis of the thermal regime (Silliman & Booth, 1993; Constantz et al., 1994) and natural solutes. Recently, Taniguchi & Fukuo (1993) developed a new device to measure directly and automatically water fluxes at the interface between groundwater and surface water bodies. This automatic seepage meter has been used to evaluate the interaction between surface water and groundwater (Taniguchi, 1995; Taniguchi & Fukuo, 1995).

The objectives of the present study were to quantify the groundwater contribution to streamflow by direct measurements of seepage rate using the automatic seepage meter, and to evaluate nutrient discharge through groundwater seepage into the Lennard Brook, Western Australia.
METHODS

The study area of the Lennard Brook is located at the head of the Ellen Brook basin, Western Australia (Fig. 1), and a large part of its drainage area is being extensively developed for horticulture. The land use includes market gardening, orchards, fertilized pasture for grazing, and rural residential development, and the area has a producing abattoir. The basin has perennial flow in the brook.

Streamwater fluxes were measured by Ultrasound Doppler Instrumentation (UDI), in which stream velocities are determined using Doppler shifts in the frequency of an ultrasound beam projected into the flow, and stream depths are

![Fig. 1 Study area of the Lennard Brook within Ellen Brook, Western Australia.](image-url)
determined using a differential pressure transducer. UDIs were installed at the CSIRO gauging station (Fig. 2). Stream sampling for water quality was accomplished using automated sample storage collection devices (Gamets) near the CSIRO gauging station (Fig. 2). The gamets collect stream samples daily and can store 24 samples. Samples were analysed for NO$_3$-N, PO$_4$-P, Cl, pH and EC.

Automatic seepage meters based on a heat pulse method were used for measuring groundwater seepage rates continuously and automatically for short intervals. Details of these meters are given in Taniguchi & Fukuo (1993) but the instrumentation and measurement method can be summarized as follows. An iron funnel with a 40 X 40 cm square section was set into the river bed and the seepage water was introduced into a small acrylic tube for measuring the velocity. The seepage rates at the river bed were obtained from the velocity in the tube multiplied by the ratio of the cross-sectional area of the tube to that of the funnel. Heat pulses were applied as tracers to measure the water velocity in the tube. Since two thermistors upstream and downstream from the heat source are set in the tube, water fluxes from groundwater to river and from river to groundwater can both be detected. The heat pulses were applied for 1 s every 4 min by using a relay switch which consisted of a programmable crystal clock and preset binary counters.

RESULTS AND DISCUSSION

Figure 3 shows daily streamflow and rainfall from January 1992 to December 1993 at the WAWA gauging station (Fig. 2). Typical flows for summer and winter are $15 \times 10^3$ m$^3$ day$^{-1}$ and $30 \times 10^3$ m$^3$ day$^{-1}$, respectively. There are very sharp short-term flow peaks in fast response to rainfall events. The perennial nature of the stream indicates a very strong groundwater contribution. The flow is exclusively from groundwater during summer, and contribution from groundwater is still very significant during winter. Sharma et al. (1996) estimated that, on a yearly basis, groundwater contribution to the stream is about 80% based on an approximate hydrograph separation analysis.

Groundwater seepage rates were measured by automatic seepage meters from 11-25 January 1996 at a site 20 m upstream from the CSIRO gauging station. Despite some periodical changes, hourly groundwater seepage rates showed an overall decrease in the period 11-18 January (Fig. 4). Streamflow measured at the CSIRO gauging station showed a similar pattern of variation (Fig. 5). During January 1996, the flow volume of the Lennard Brook ranged from 10 300 to 11500 m$^3$ day$^{-1}$, and the seepage rate into the river ranged from $3.3 \times 10^{-6}$ m s$^{-1}$ (0.29 m day$^{-1}$) to $2.6 \times 10^{-6}$ m s$^{-1}$ (0.22 m day$^{-1}$). Based on an average river width of 2 m and a channel length of 20 km, the estimated seepage rate volume ranged from 9100 to 11 300 m$^3$ day$^{-1}$ during the study period. The ratio of groundwater seepage to streamflow was calculated to vary from 0.82 to 0.99, with an average of 0.88. These results are encouraging, because during the rainless summer month of January 1996, groundwater was the sole contributor of streamflow.

The concentration of PO$_4$-P, NO$_3$-N and Cl in streamflow ranged from 0.013 to 0.026 mg l$^{-1}$, 0.165 to 0.432 mg l$^{-1}$ and 238 to 243 mg l$^{-1}$, respectively. On the other hand, concentrations of PO$_4$-P and NO$_3$-N in groundwater ranged from 0.024 to
Fig. 2 Location of seepage meter and gauging stations.
Fig. 3 Daily streamflow and rainfall in Lennard Brook at the WAWA gauging station during a 2-year period (after Sharma et al., 1996).
0.071 mg l$^{-1}$ and 1.28 to 5.59 mg l$^{-1}$, respectively, which were higher than those of streamflow. Because water quality data is lacking for upstream locations, it is not possible to compare the quality of stream water and the corresponding groundwater. However, PO$_4$-P and NO$_3$-N concentrations measured in the seepage water were similar to those in groundwaters at downstream locations and higher than those of streamflow. The reason for this is that groundwater at the seepage meter site is derived predominantly from horticultural areas, while groundwater at upstream locations comes mainly from pasture areas and therefore is expected to have lower nutrient concentrations. As shown by Sharma $et~al.$ (1996), NO$_3$-N and PO$_4$-P concentrations of streamflow were two to three times higher at the exit of the Lennard Brook catchment compared with those measured at the CSIRO gauging station. This increase is caused by enhanced discharge of nutrients primarily through groundwater from predominantly horticultural areas between the two locations, as was also confirmed by process modelling (Sharma $et~al.$, 1996).
CONCLUSIONS

Direct measurements of groundwater seepage rate using an automatic seepage meter and of streamflow have been made to evaluate nutrient discharge into the Lennard Brook, Western Australia. The groundwater seepage rate measured by automatic seepage meter agreed well with the rate estimated by an approximate hydrograph separation analysis. An automatic seepage meter can thus be a useful tool in quantifying the proportion of groundwater to surface water and the nutrient load derived from groundwater.

REFERENCES


