Journal of Hydrology (NZ) 46 (2): 63-72 2007
© New Zealand Hydrological Society (2007)

Decreases in low flows in the lower Selwyn River?

A. I. McKerchar and J. Schmidt
NIWA, P.O. Box 8602, Christchurch
Corresponding author: a.mckerchar@niwa.co.nz

Abstract

A multiple linear regression equation is developed to predict seasonal low flows for 1984–2005 at Coes Ford on the Selwyn River in mid-Canterbury. It uses upstream low flows measured at Whitecliffs in the Canterbury foothills and annual recharge to groundwater calculated for the Hororata and Lincoln climate stations. Residual errors from this regression show a trend for the low flows to decrease with time. The inclusion of a time term to model the trend gives a multiple linear regression with three independent variables that explains more than 90% of the variance of the Coes Ford seasonal low flows.

The trend term implies the low flows at Coes Ford have decreased at a rate of about 32 L/s per year over the 22 years of recording. Since the influence of recent years with low rainfalls over the Canterbury Plains is accounted for by the recharge data, the decrease must be due to other causes. The decrease provides evidence to reject the null hypothesis that upstream flow and recharge are sufficient to explain variability in the Coes Ford low flows, and to support an alternative hypothesis that low flows have decreased over the last 22 years. The decrease is consistent with increased irrigation abstractions from groundwater.

Keywords

low flows, drought, Canterbury Plains, irrigation effects, land-use change.

Introduction

In recent years, the economics of agriculture in New Zealand have favoured a shift of land use on the Canterbury Plains from traditional dryland farming, typically a mix of cropping and sheep farming, to intensive dairy farming. This shift to dairy farming has been accompanied by a major increase in irrigation through spring, summer and autumn to maintain pasture growth and raise milk production.

Over the Canterbury Plains, much of the water for irrigation is provided by large-scale government-subsidized schemes constructed in previous decades that divert water from the major rivers. However, such schemes are largely absent in the Central Plains region between the Waimakariri and Rakaia Rivers, and instead, most of the irrigation water in this region is obtained from on-farm wells.

The rapid growth in the use of groundwater for irrigation has become a concern for the wider community. Large quantities of water are required over the summer season when flows in many of the smaller Canterbury streams are naturally low. Another concern is the impairment of water quality due to the more intensive land use.

Lowland spring-fed Canterbury streams are a particular concern because their low flows in recent years have been depleted. It has been claimed that the lower flows are caused by increased withdrawals from groundwater for irrigation. However, the evidence available has been inconclusive because recent low flows have coincided with a number of years with lower-than-normal winter rainfalls that recharge groundwater. Also, no consistent set of records of irrigation water-use are available for the region.

This study focuses on the Selwyn River, a main water-course in the Central Plains. Its flows at both upstream and downstream stations have been monitored since 1984.

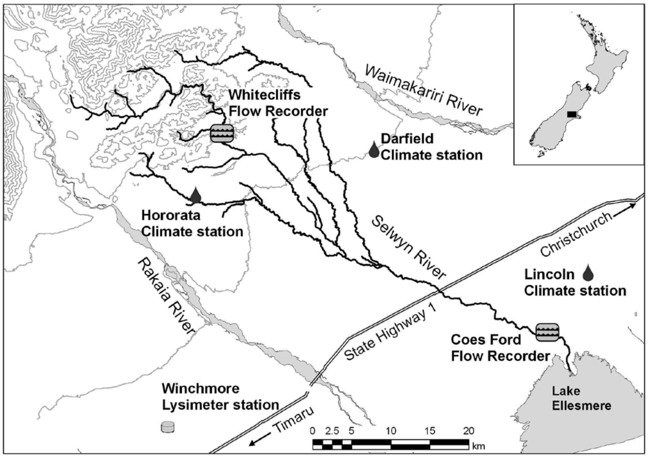

Figure 1 – The Selwyn River, showing locations of stream gauging and climate stations. Contours at 200 m intervals are shown as grey lines.

Selwyn River

The Selwyn River typifies a number of rivers draining the Canterbury foothills. It flows from mid-Canterbury foothills across the Canterbury Plains into Lake Ellesmere/ Te Waihora, a coastal lake that is near sea level (Fig. 1). The Selwyn River main channel occupies the intersection of outwash fans for the Rakaia and Waimakariri Rivers. The river is the focus of a NIWA hydrology-aquatic ecology research programme funded by the Foundation for Research, Science and Technology (Larned *et al.*, accepted).

The character of the Selwyn River changes from perennial where it emerges from the foothills to ephemeral as river water is lost by drainage into the Canterbury Plains groundwater systems. It becomes perennial again in the lower river where low flows are sustained by discharge from groundwater. This leads to a complex pattern of river flow permanence along the Selwyn main channel, as described by Larned *et al.* (accepted) (Fig. 2). For the purpose of this study, this complex pattern of flow permanence – caused by variations of unconfined and confined aquifers along the Selwyn River – can be reduced to the facts that the Selwyn River is losing large proportions of its river flow to groundwater after it drains the foothills. River flows in the lower part of the Selwyn main channel close to Lake Ellesmere are controlled by flow gains out of groundwater-fed springs and the water left passing through the entire main channel. Groundwater levels are controlled by rainfall recharge, river losses in the upper Selwyn catchment and unknown sources and sinks such as contributions from the Waimakariri River system to the north and irrigation abstractions. For much of the time, when the river in its middle reaches is dry, the lower Selwyn can be classified as a lowland stream.

Flow in the Selwyn emerging from the foothills has been monitored with a stream gauge at Whitecliffs since 1964 and the lower river flow has been monitored at Coes Ford, 7 km upstream from Lake Ellesmere/Te Waihora, since 1984 (Fig. 1). The catchment area for the Whitecliffs recorder is 164 km^2 (Walter, 2000). For the recorder at Coes Ford, the topographic catchment area is 762 km^2, but because of the considerable groundwater contribution to flows in the lower catchment, the topographic area is not particularly relevant.

Climate stations with records of daily rainfalls are located are Darfield, Hororata, Lincoln and Winchmore (Fig. 1). Other climate data (temperatures, wind run, solar radiation, sunshine hours) are available for some of these stations.

Data used

Streamflow data for Whitecliffs from 1964 to April 2006 and Coes Ford data from 1984 to May 2006 were assembled for the study. Figures 2 and 3 show the hydrographs for both stations from 1984 until 2006.

A derivative of the climate station data, termed "recharge", can be obtained from NIWA's Climate Database for the Hororata climate station. The calculated recharge is the surplus water or "runoff" from the operation of a one-dimensional soil moisture storage model for the root zone. In this model, which uses a field capacity of 150 mm, water is added by rainfall and depleted by evapotranspiration (Porteous *et al.*, 1994). This model is applied routinely throughout New Zealand to assess soil moisture status (see: www.niwa.co.nz/ncc). As the 150 mm field capacity is regarded as too high for much of the plains part of the Selwyn catchment (White *et al.*, 2003), the Hororata recharge was recalculated using a field capacity of 50 mm.

Since the Canterbury Plains have generally free-draining soils overlying gravels, and overland flow is rarely, if ever, observed, it is assumed that the calculated "runoff" from the model is drainage or recharge to groundwater. Figures 2 and 3 also show soil moisture deficit and excess water (which is taken as recharge) as calculated from the model for the Hororata climate station.

To represent the lower part of the catchment, the annual recharge data for Lincoln as presented in Larsen (2005), and calculated with a capacity of 100 mm, were also used. To aggregate the mainly winter recharge, recharge was expressed as total recharge over calendar years. Averages of annual recharge totals for Hororata and Lincoln were used in subsequent calculations.

Separate estimates of annual groundwater recharge, as measured with two lysimeters at Hororata for 1999–2005, were provided by Environment Canterbury, the regional water resource management agency.

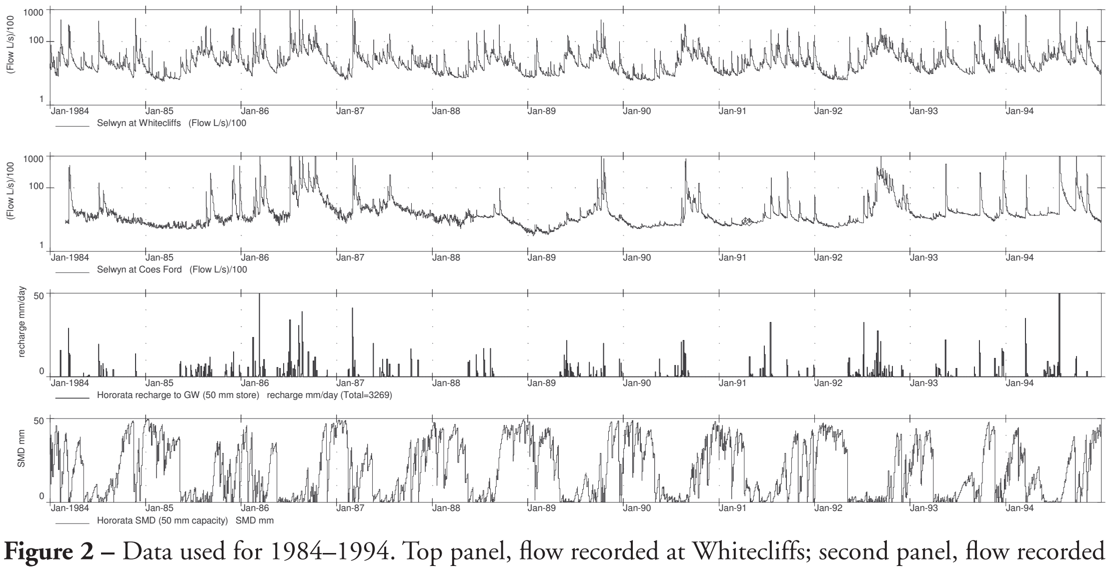

Figure 2 – Data used for 1984–1994. Top panel, flow recorded at Whitecliffs; second panel, flow recorded at Coes Ford; third panel, daily recharge estimates; fourth panel, daily soil moisture deficits (SMD).

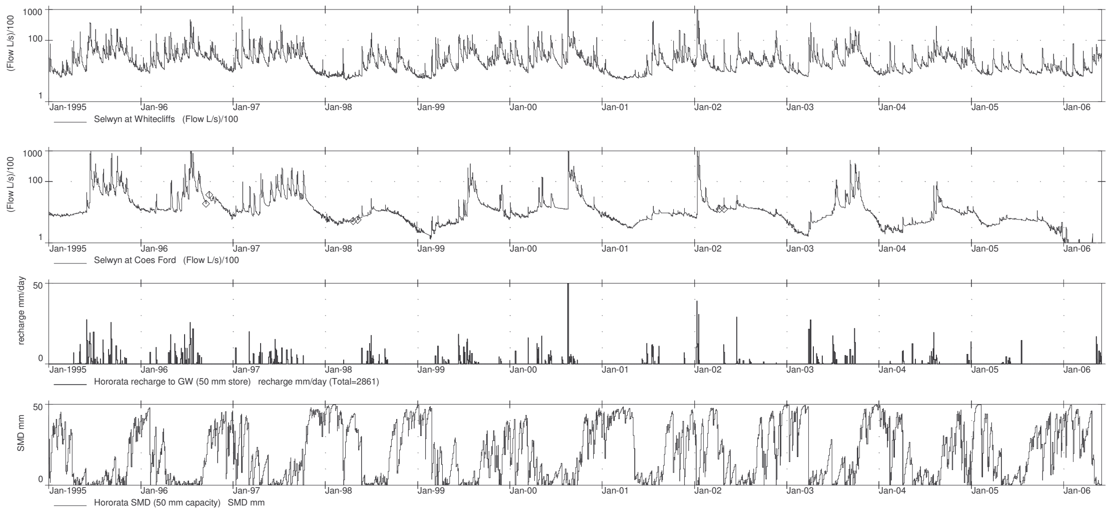

Figure 3 – Data used for January 1995 to May 2006. Top panel, flow recorded at Whitecliffs; second panel, flow recorded at Coes Ford; third panel, daily recharge estimates; fourth panel, daily soil moisture deficits (SMD). Note that the Coes Ford flows for January-May 2006 fall below the log scale minimum of 100 L/s.

Results

Inspection of data

The data for 1984-2006 are presented as sets of plots in Figures 2 and 3. These show the flows at Whitecliffs and Coes Ford, the estimated daily Hororata recharge and, for completeness, the estimated soil moisture deficit. The following features are apparent from study of these plots:

- Seasonal low flows typically occur in the first few months of the calendar year and higher flows typically occur in winter and early spring. Also, some correlation is apparent between the seasonal low flows for the two sites.
- While the Whitecliffs record shows many freshes, only the higher flows continue down the main channel of the river to be recorded at Coes Ford.
- Recharge varies considerably from year to year and mostly occurs in winter months. Recharge was particularly low over 2001-2005.
- The soil moisture deficit data have a strong seasonal pattern and are at the minimum of 0 mm when recharge occurs.
- Exceptionally low summer flows at Coes Ford tend to follow winters with relatively low recharge. In particular, record low flows at Coes Ford early in 2006 followed the winter of 2005 when recharge was particularly low.

From these observations, it appeared that seasonal low flows for Coes Ford might be partially caused by seasonal low flows at Whitecliffs and partially by the quantity of recharge in the preceding winter. Seasonal low flows for July to June water years for both flow recorders were characterised by taking average flows over a 90-day window and selecting the least value for each year. Dates of occurrence of the Coes Ford lows, typically between December and April, were noted and the constraint was imposed that Whitecliffs lows should occur before the Coes Ford lows. This adjustment was necessary in five of 22 years.

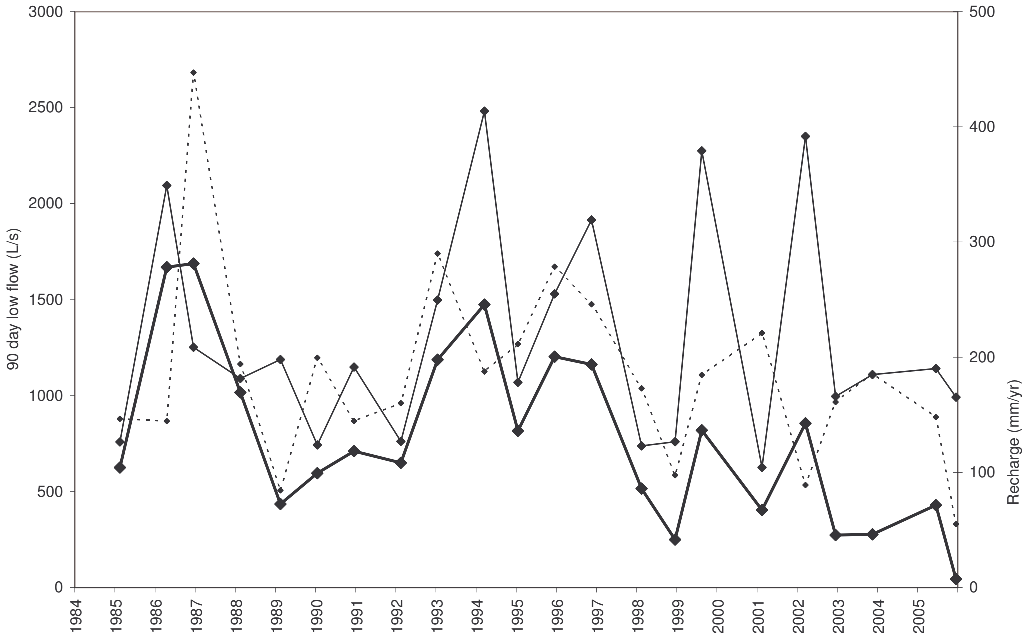

Figure 4 – Observed 90-day annual minimum flows for Whitecliffs (light line) and Coes Ford (heavy line), and average of annual Hororata and Lincoln recharge (dashed line, scale on right).

The estimates of low flows and annual values for recharge are displayed in Figure 4.

Analysis

A multiple linear regression fitted to the data in Figure 4 gave Equation 1, where CF and WC are respectively the Coes Ford and Whitecliffs 90-day minima (L/s), and RC (mm) is the calendar year average recharge for Hororata and Lincoln.

$$CF = 3.29*RC + 0.479*WC - 448 \quad (R^2 = 0.737, se = \pm 250) \qquad (1)$$

Predictions from this equation are compared with observed values in Figure 5. However, residual errors from this regression (i.e., observed minus predicted Coes Ford flows) were not random as required by linear regression theory, but showed a clear, approximately linear, decrease (Fig. 6). Since climate variation is accounted for by the recharge data and the Whitecliffs low flows, this trend is attributed to other factors.

Incorporation of time as a third independent variable into the regression equation yielded Equation 2, where MTH is the number of months since 1 January 1900.

$$CF = 2.51*RC + 0.489*WC - 2.66*MTH + 2729 \quad (R^2 = 0.916, se = \pm 146) \qquad (2)$$

Predictions from this equation are compared with observed values in Figure 7. These predictions provide very good estimates of the 90-day low flows at Coes Ford and the residual errors for the regression (Fig. 8) show no trend. The linear regression with three independent variables (Whitecliffs low flow, recharge, time) accounts for more than 90% of the variance of the 90-day low flows at Coes Ford.

Discussion

The trend evident in Figure 5 and included in Equation 2 implies the low flows at Coes Ford have decreased at a rate of about

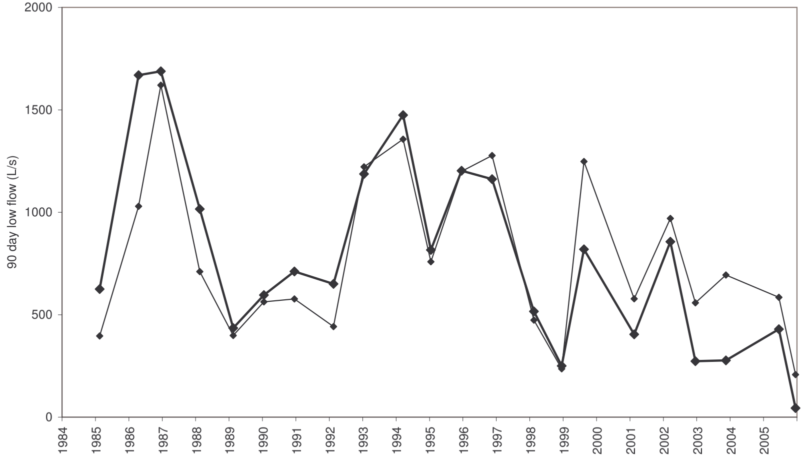

Figure 5 – Observed (heavy line) and predicted (light line, using Equation 1) 90-day annual minimum flows for Coes Ford.

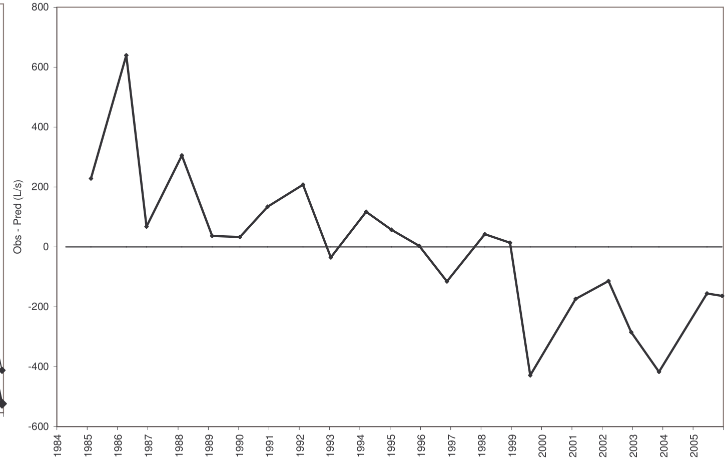

Figure 6 – Differences between the observed and predicted values for 90-day annual minimum flows for Coes Ford (see Fig. 5).

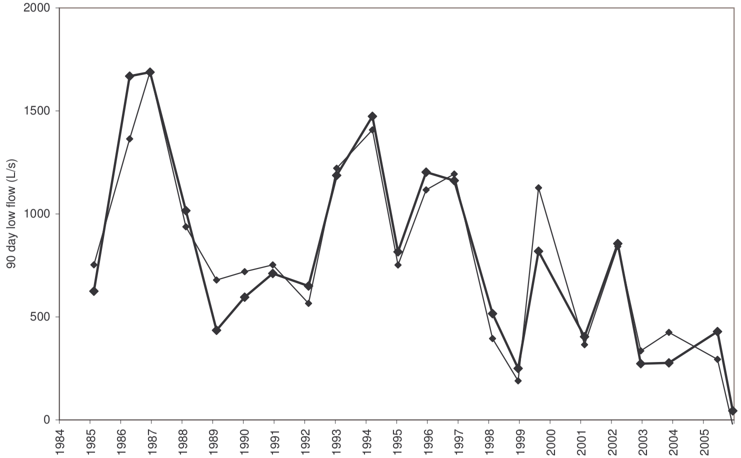

Figure 7 – Observed (heavy line) and predicted (light line, using Equation 2) 90-day minima for Coes Ford.

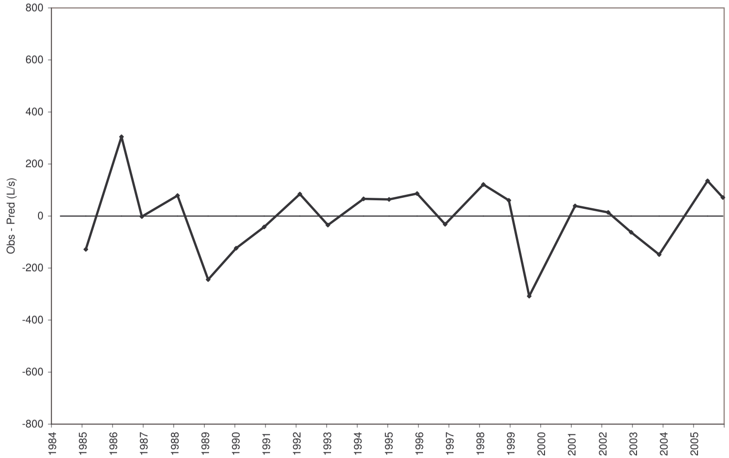

Figure 8 – Differences between the observed and predicted values for 90-day minima for Coes Ford (see Fig. 7).

32 (i.e., 2.66*12) L/s per year over the 22 years of recording, after the effect of recent low-rainfall years is accounted for.

Since low rainfalls in recent years are accounted for by the recharge data, the decrease must be due to other causes. The decrease provides strong evidence to reject a null hypothesis that upstream flow and recharge are sufficient to explain variability in the Coes Ford low flows, and to support an alternative hypothesis that a decrease in low flows over the last 22 years has occurred over and above the effect of recent dry years.

One reason for the decrease is increases in irrigation abstractions from groundwater. Environment Canterbury resource consent data show that increases in permitted takes of water increased progressively from 1991. The trend term in the equation is consistent with increasing abstractions from groundwater for irrigation, but the analysis is not sufficiently sensitive to identify a low rate of increase in irrigation said to have occurred in the first few years, from 1984–1989.

A possible alternative explanation is that the trend observed in low flows is a consequence of long-term depletion of groundwater from naturally occurring high levels of the 1950s. An indication is given by the levels recorded by an Environment Canterbury monitoring well located at Charing Cross, 12 km southeast of Darfield (Fig. 1). These levels do show relatively high levels in the 1950s (Fig. 9). The annual recharge data for Hororata (50 mm soil moisture storage) and Darfield (for 150 mm soil moisture storage), and Lincoln (Larsen, 2005; 100 mm soil moisture storage) are also plotted on Figure 9. A moderate level of correlation is evident between the groundwater levels and the annual recharge values. Relatively high levels of recharge occurred in the 1950s. Also, the records of recharge suggest that the recent dry period is not exceptional. In particular, the annual recharge data for 2001–2005 are comparable with the data for 1968–1972, but the well levels were much lower in 2005–2006. Unfortunately, no Coes Ford flow data are available for 1968–1972. The linkage between computed recharge and variation of groundwater levels is clearly worth further investigation.

The recharge data for Hororata and Lincoln are computed using a model that assumes respective field capacities of 50 mm and 100 mm for the soil moisture root zone. To check the representativeness of the recharge data, the Hororata and Lincoln annual recharge totals for 1999 to 2005 are compared with average annual totals of recharge measured at two lysimeters at Hororata. The comparison (Fig. 10) shows that while the magnitudes differ, the year-to-year variability is consistent between the estimates. For example the least value for each series occurs in 2005 and the largest value occurs in 2000.

The Hororata climate station was selected to provide recharge data because it is centrally located in the plains part of the Selwyn catchment and has had relatively few site changes (Larsen, 2005). Use of only Hororata, or Lincoln, or Darfield, recharge data (without averaging between sites) and alternative assumed soil moisture capacities all yielded comparable results and the conclusions were unchanged.

This study used minima flow data averaged over 90 days: similar results applied for 28 day minima.

The Selwyn River data are important for the region because the records of flows for both upstream and downstream sites for more than two decades cover a period of substantial change in land use. No other lowland Canterbury stream has such long records and it is anticipated that the findings of this study will be applicable for other streams in the region.

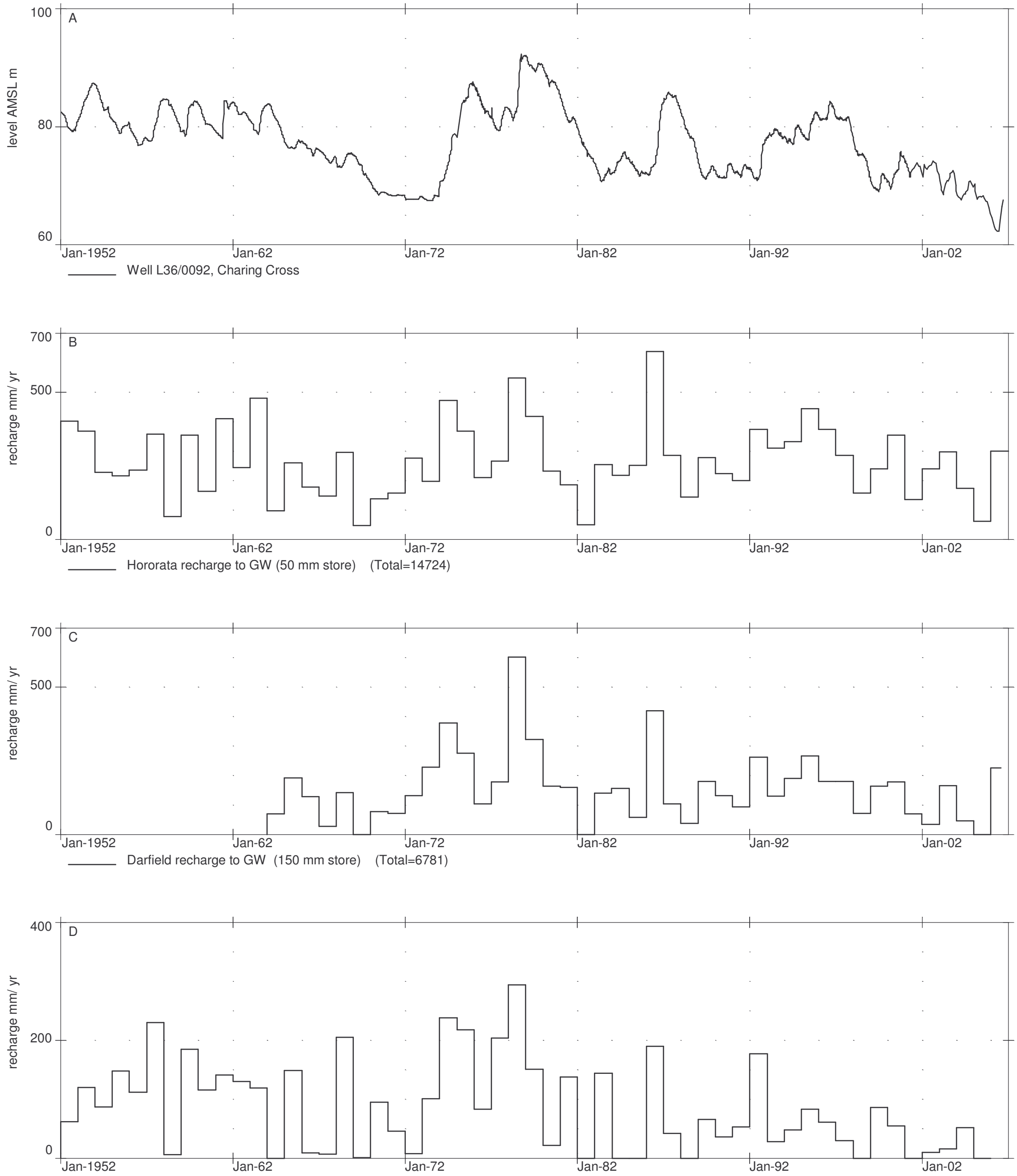

Figure 9 – Plot A, levels recorded in Environment Canterbury's monitoring well at Charing Cross; Plots B, C and D are annual estimates of recharge for Hororata, Darfield and Lincoln respectively. Soil moisture storage capacities of 50 mm, 150 mm and 100 mm are assumed for Hororata, Darfield and Lincoln respectively. The Lincoln data are from Larsen (2005).

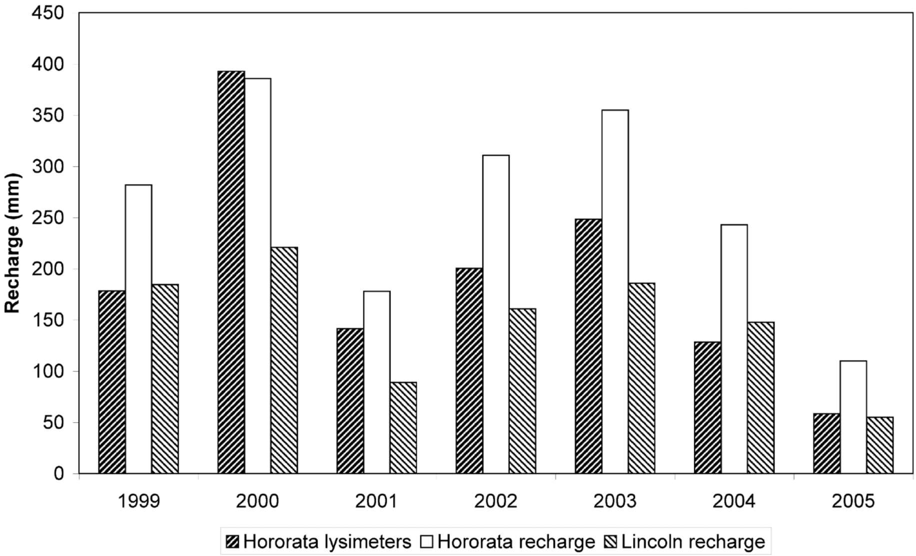

Figure 10 – Comparison of recharge measured for a lysimeter at Winchmore and calculated for Hororata (50 mm soil moisture capacity) and Lincoln (Larsen, 2005, 100 mm soil moisture capacity).

Conclusions

More than 90% of the variance of the seasonal low flows at Coes Ford is explained by a multiple linear regression that uses three independent variables. The three independent variables are upstream low flow, annual recharge and time.

The time trend implies that the low flows at Coes Ford have decreased at a rate of about 32 L/s per year over the 22 years of recording after the effect of recent low-rainfall years is accounted for.

Since low rainfalls in recent years are quantified by the recharge data, the decrease observed is likely to be due to other causes. The analysis provides evidence to doubt an hypothesis that upstream flow and recharge are sufficient to explain variability of Coes Ford flows. Instead, the results support the alternative hypothesis that a trend is required to explain the variability in Coes Ford low flows. This trend is consistent with increased use of groundwater for irrigation.

Acknowledgement

This project is funded through the Foundation of Research Science and Technology Water Allocation Programme (Contract C01X0308). Environment Canterbury is thanked for provision of the Coes Ford streamflow data, Charing Cross groundwater levels and the lysimeter data.

References

Larned, S.T.; Hicks, D.M.; Schmidt, J.; Davey, A.J.H.; Dey, K.; Scarsbrook, M.; Arscott, D.B.; Woods, R.A. (accepted): The Selwyn River of New Zealand: a benchmark system for alluvial river plain rivers. *River Research and Applications.*

Larsen, S.H. 2005: Evaluation of drought at Lincoln, Canterbury. Environment Canterbury Report R05/29.

Porteous A.S.; Basher, R.E.; Salinger, M.J. 1994: Calibration and performance of the single-layer water balance model for pasture sites. *New Zealand Journal of Agricultural Research 37:* 107-118.

Walter, K. 2000: Index to hydrological recording sites in New Zealand. NIWA Technical Report 73. NIWA, Wellington.
White, P.A.; Hong, Y-S.; Murray, D.L.; Scott, D.M.; Thorpe, H.R. 2003: Evaluation of regional models of rainfall recharge to groundwater by comparison with lysimeter measurements, Canterbury, New Zealand. *Journal of Hydrology (NZ) 42(1)*: 39-64.

Manuscript received 16 March 2007; accepted for publication 4 September 2007