BEFORE CANTERBURY REGIONAL COUNCIL

IN THE MATTER of the Resource Management Act 1991

AND

IN THE MATTER of the Proposed Land and Water Plan (Variation 1)

EVIDENCE OF ALISTAIR IAN MCKERCHAR
FOR TE RŪNANGA O NGĀI TAHU

DATED 29 AUGUST 2014

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Executive summary

1. This evidence discusses an effort to predict low flows in the lower Selwyn River/Waikirikiri which is one of the larger sources of freshwater inflow to Lake Ellesmere/Te Waihora.

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

3. The increased abstractions from groundwater for irrigation over the study period are consistent with the decrease observed in the low flows even after the effect of limited annual recharge in the latter part of the period was accounted for.

4. It is possible that if enhanced recharge to groundwater occurs due to irrigation with water from the proposed Central Plains Irrigation Scheme, low flows in the lower Selwyn/Waikirikiri may be enhanced.

Introduction

5. My name is Alistair Ian McKerchar. I hold the qualifications of Bachelor of Engineering (Honours – Civil) and Doctor of Philosophy (Civil Engineering) from Canterbury University. I have worked as a hydrologist with NIWA since its formation in 1992. Prior to that, I was with the Hydrology Centre of the Ministry of Works and Development and then the Department of Scientific and Industrial Research. I had a post-doctoral in Civil Engineering at Purdue University in the United States of America during 1971-1972 and I worked at the British Institute of Hydrology at Wallingford in the United Kingdom for 1973-1975. During my career I have worked on many aspects of surface water hydrology in New Zealand.

6. I have been commissioned by Te Rununga o Ngai Tahu to provide evidence about groundwater levels and low flows in the catchment of the Selwyn River/Waikirikiri and Lake Ellesmere/Te Waihora. This evidence summarises work that I have done at NIWA and published in the peer reviewed paper in the New Zealand Journal of Hydrology V46(2) in 2007.

7. Across the Canterbury Plains, much of the water for irrigation is provided by large-scale schemes that divert water from the main rivers. Such schemes are absent in the Central Plains region at present between the Waimakariri and Rakaia Rivers, and instead, most of the irrigation water in this region is sourced from on-farm wells.

8. The rapid growth in the use of groundwater for irrigation has become an issue 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.

9. Lowland spring-fed Canterbury streams are a particular concern because their low flows in the years leading up to 2007 have been depleted when this work was undertaken. It has been claimed (for example by the Water Rights Trust) that the lower flows are caused by increased withdrawals from groundwater for irrigation. However, the evidence available has been inconclusive because the low flows before 2006 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 from groundwater was available for the region.

10. This evidence focuses on the Selwyn River/Waikirikiri, a main water-course in the Central Plains. Its flows at both upstream and downstream stations have been monitored since 1984. The monitoring locations are indicated in Figure 1.

Selwyn River/Waikirikiri

11. The Selwyn River/Waikirikiri drains from mid-Canterbury foothills across the Canterbury Plains into Lake Ellesmere/Te Waihora (Figure 1). The Selwyn River mainstem occupies the intersection of outwash fans for the Rakaia and Waimakariri Rivers.

12. The character of the Selwyn River/Waikirikiri 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/Waikirikiri mainstem. This complex pattern of flow permanence – caused by variations of unconfined and confined aquifers along the Selwyn River – means the Selwyn River loses a large proportion of its river flow to groundwater after it emerges from the foothills. River flows in the lower part of the Selwyn mainstem close to Lake Ellesmere/Te Waihora comprise flow gains out of groundwater-fed springs and the water left passing through the entire mainstem. Groundwater levels are determined 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 River/Waikirikiri can be classified as a lowland stream.

13. The foothills-emergent flow in the Selwyn River/Waikirikiri has been monitored with a streamgauge 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 (Figure 1). The catchment area for the Whitecliffs recorder is 164 km^2. 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.

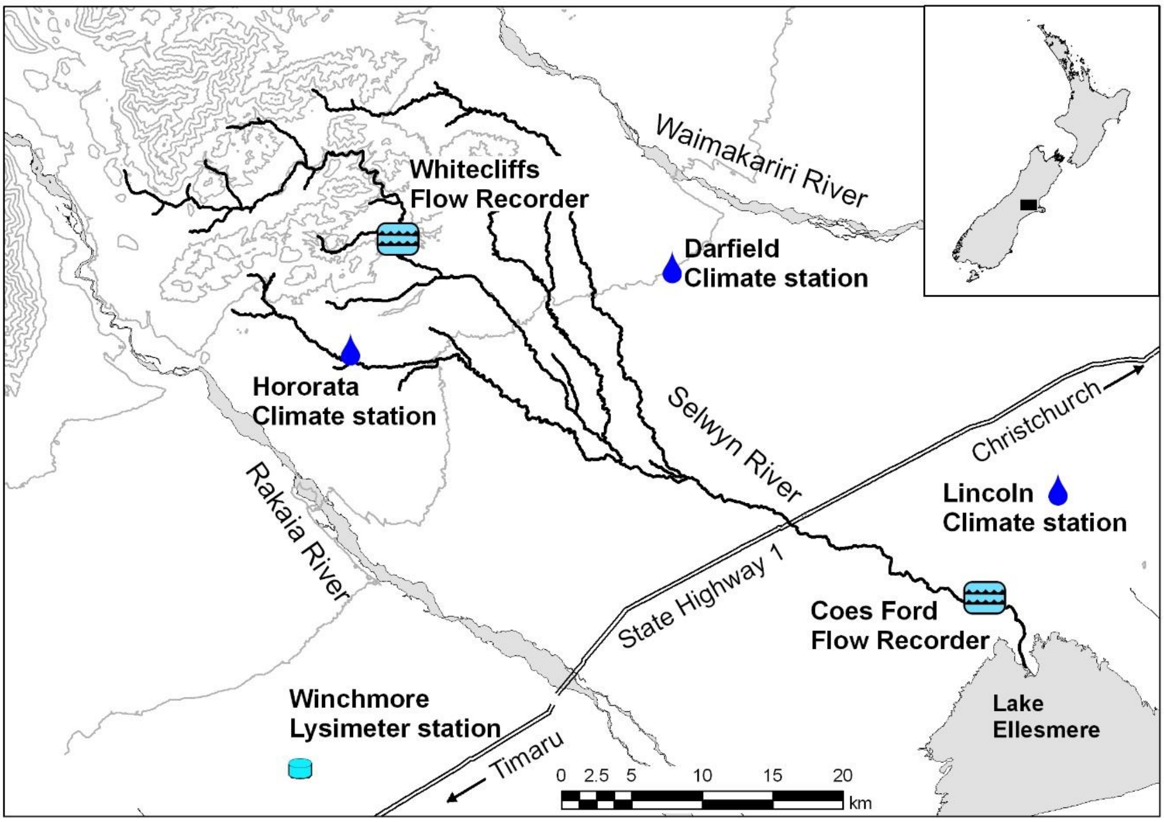

Figure 1: **The Selwyn River/Waikirikiri showing locations of streamgauging and climate stations**. Contours at 200 m intervals are shown as grey lines.

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

Data used

15. 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.

16. A derivative of the climate station data termed "recharge" can be obtained from NIWA's Climate Database. The calculated recharge is the surplus water or "runoff" derived from the operation of a one-dimensional soil moisture storage model for the root zone. In this model, which has a field capacity of 150 mm, water is added by rainfall and depleted by evapotranspiration. 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, the Hororata recharge was recalculated using a field capacity of 50 mm. The field capacity selected responded to differing soil characteristics in areas of Canterbury.

17. Since much of the Canterbury Plains has generally free-draining soils overlying gravels, and overland flow is rarely, if ever, observed, I assumed 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.

18. To represent the lower part of the catchment the annual recharge data for Lincoln, calculated with a capacity of 100 mm, were also used.

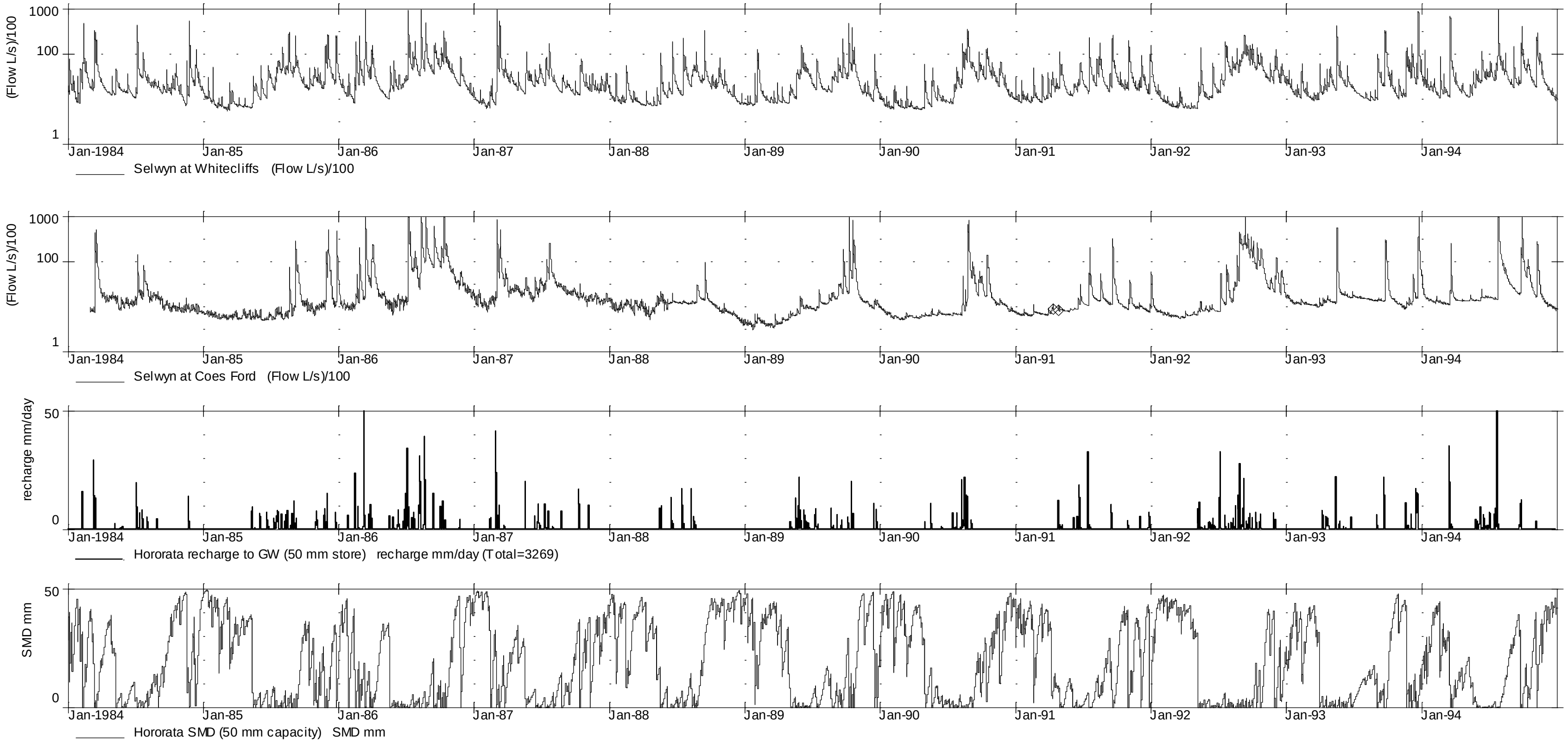

Figure 2: **Data used for 1984-1993**. Top panel, flow recorded at Whitecliffs; second panel, flow recorded at Coes Ford; third panel, daily recharge estimates; fourth panel, daily soil moisture deficits. Note the use of logarithmic scales on the top two panels.

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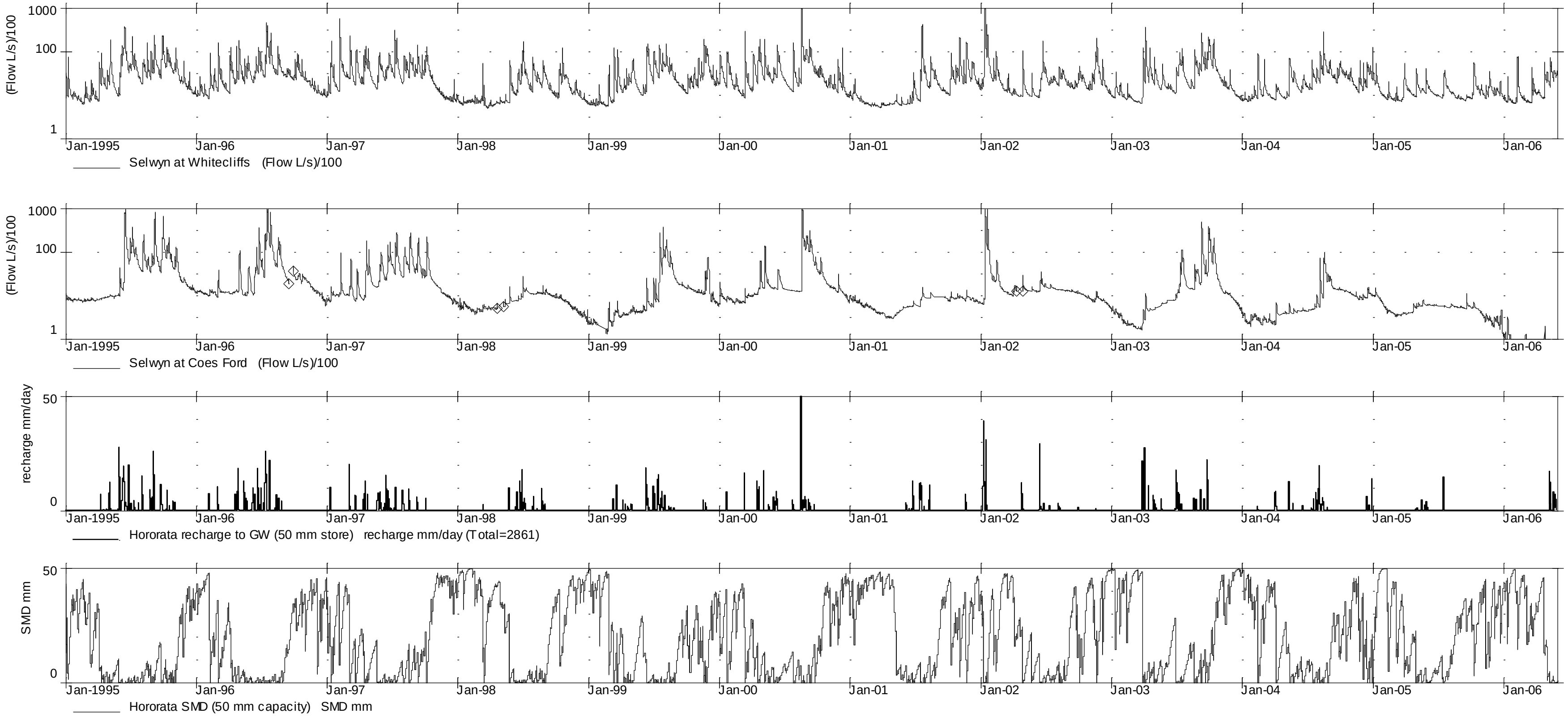

Figure 3: **Data used for January 1995 to May 2006**. Top panel, flow recorded at Whitecliffs; second panel, flow recorded at Coes Ford; third panel, daily recharge estimates; fourth panel, daily soil moisture deficits. Note the use of logarithmic scales on the top two panels and that the Coes Ford flows for January-May 2006 fall below the log scale minimum of 100 L/s.

Inspection of the data

19. 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 flows are plotted with logarithmic scales which give emphasis to low flows. The following features are apparent from study of these plots:

    (a) 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.

    (b) While the Whitecliffs record shows many freshes, only the higher flows continue down the mainstem of the river to be recorded at Coes Ford.

    (c) Recharge varies considerably from year to year and mostly occurs in winter months. Recharge was particularly low over 2001-2005.

    (d) The soil moisture deficit data have a strong seasonal pattern and are at the minimum of 0 mm when recharge occurs.

    (e) 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 low.

20. 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.

21. Recharge was expressed as total recharge over the calendar year. Calendar year totals were used because they aggregate the mainly winter recharge into single numbers. Averages of annual recharge for Hororata and Lincoln were used in subsequent calculations.

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

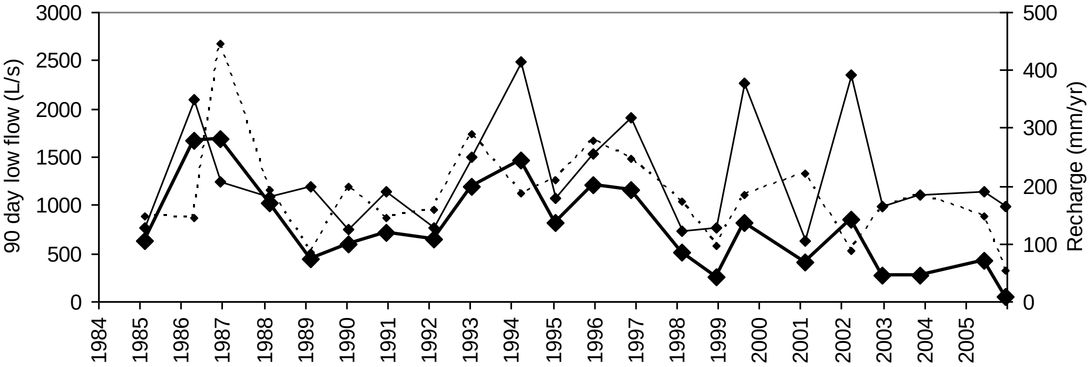

Figure 4: **Low flows and recharge**. Observed 90-day annual minimum flows for Whitecliffs (light line) and Coes Ford (heavy line), and average of annual Hororata and Lincoln recharge (dashed line, scale on right).

Analysis

23. Over the large area of the Canterbury Plains portion of the catchment (Figure 1), it is difficult to characterise the groundwater level for the catchment. However, Environment Canterbury have a selection of groundwater level records. One record, is given by the levels recorded by an Environment Canterbury monitoring well located at Charing Cross, 12 km southeast of Darfield (Figure 1). These levels do show relatively high levels in the 1950s (Figure 5). The annual recharge data for Hororata (50 mm soil moisture storage) and Darfield (for 150 mm soil moisture storage), and Lincoln (100 mm soil moisture storage) are also plotted on Figure 5. 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.

24. Study of the plots in Figures 4 and 5 indicated that a simple modelling approach using data on an annual basis might be useful. The model proposed is shown in Figure 6. The groundwater storage in the plains portion of the catchment is represented as a box with the groundwater surface shown as a sloping dashed line. In this representation, the

groundwater storage is fed by Whitecliffs flows and recharge, and depleted by unknown amounts of pumping and discharge as recorded at Coes Ford.

25. A multiple linear regression fitted to the data in Figure 4 yielded 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.

$$CF = 3.29*RC + 0.479*WC - 448 \quad (R^2 = 0.737, \quad SE = \pm 250) \quad \text{(Equation 1)}$$

26. The linear regression model shows how much of the year to year variation of the Coes Ford low flows can be attributed to year to year variations in the Whitecliffs low flows and the year to year variations in the annual groundwater recharge. The quantity R^2, the coefficient of determination, is the proportion of the variance of the Coes Ford annual low flows explained by the regression relationship: SE is the standard error of estimate. The observed and predicted values are shown in Figure 7.

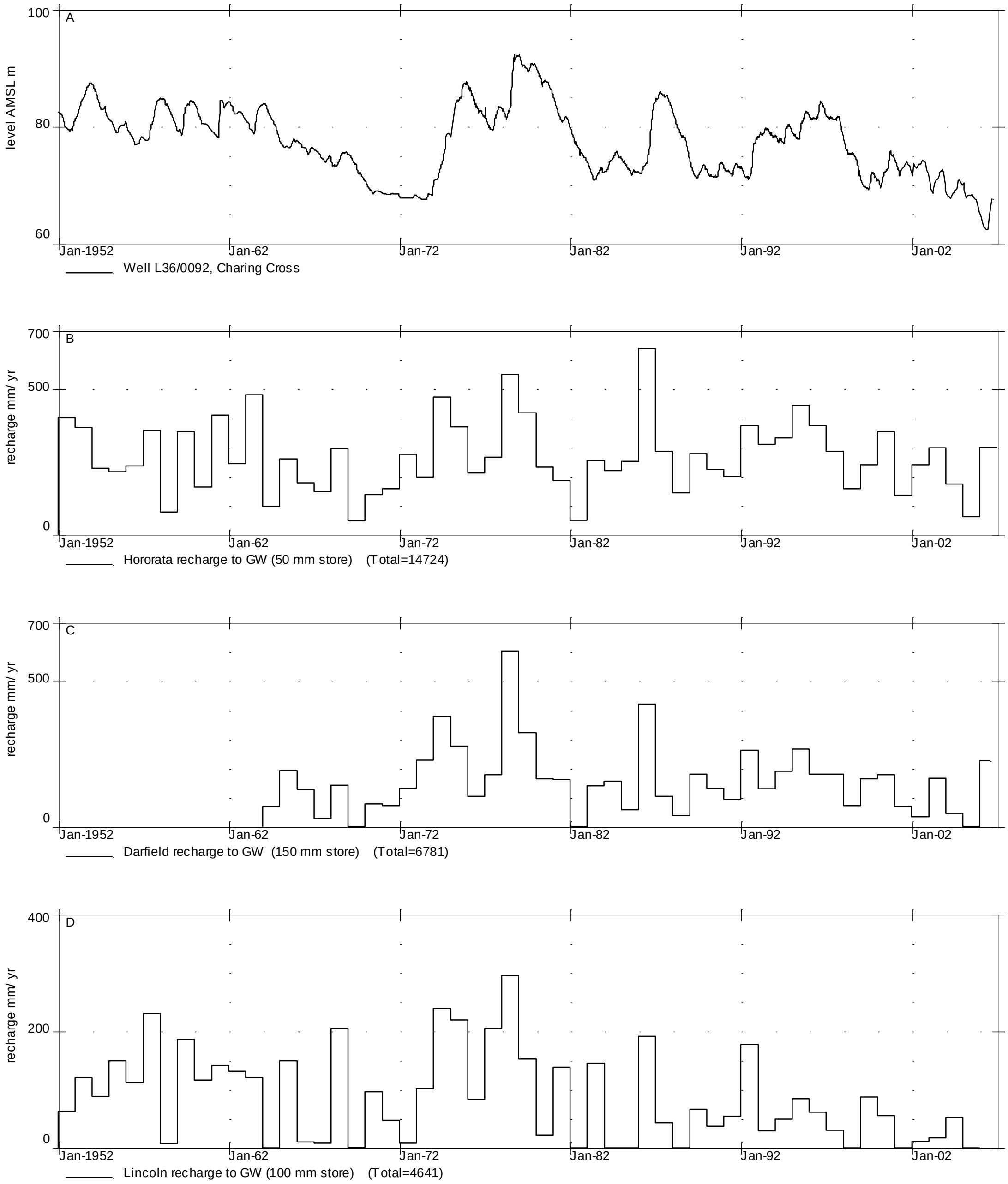

Figure 5: **Comparison of groundwater level at a well and annual recharge**. Plot A, levels recorded in Environment Canterbury's monitoring well at Charing Cross; Plots B, C and D are annual estimates of recharge for Hororata, Darfield and Lincoln respectively. Soil moisture storage capacities of 50 mm, 150 mm and 100 mm are assumed for Hororata, Darfield and Lincoln respectively.

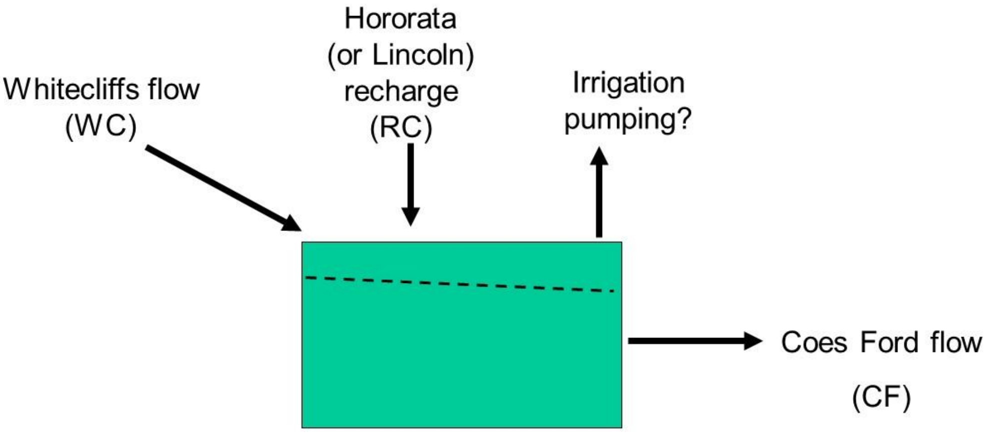

Figure 6: **Conceptual model of lower Selwyn hydrology**. WC is Whitecliffs low flow; RC is recharge; CF is Coes Ford low flow. The dashed line across the box indicates the unknown groundwater level. The uptake by irrigation pumping was not recorded over the study period.

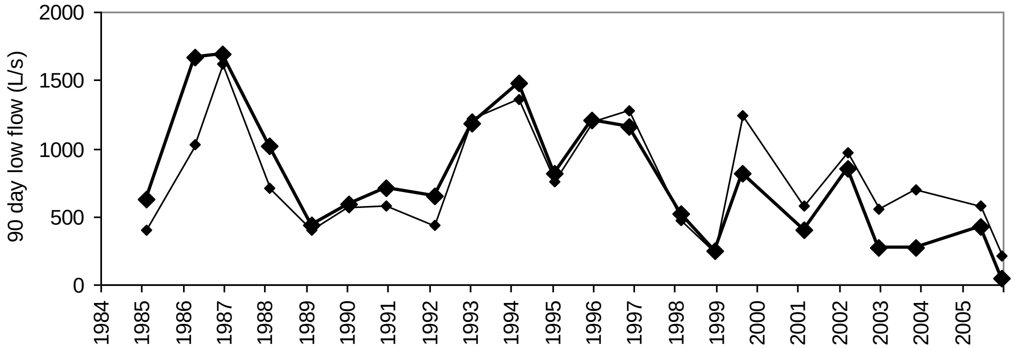

Figure 7: **Observed (heavy line) and predicted (light line, using Equation 1) 90-day annual minimum flows for Coes Ford**.

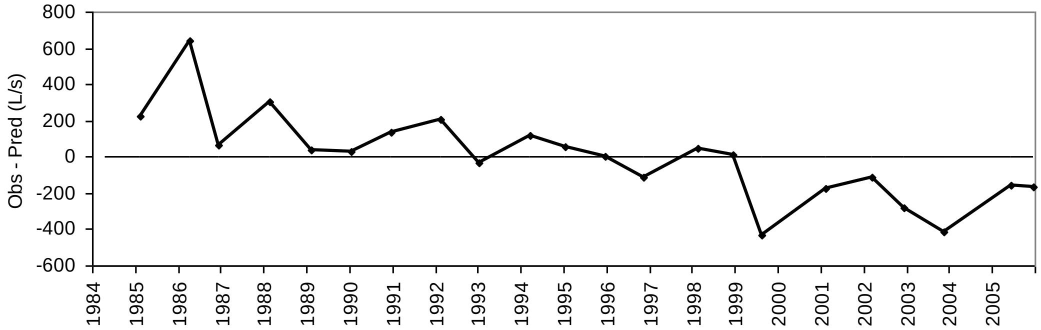

Figure 8: **Differences between observed and predicted in Figure 7.**

27. When residual errors from this regression (ie observed minus predicted Coes Ford flows) were examined, they were found not to be random as required by linear regression theory, but showed a clear, approximately linear, trend to decrease (Figure 8). Since climate variation is accounted for by the recharge data and the Whitecliffs low flows, this trend is attributed to other factors.

28. 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.

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

29. In this case the R^2 value is increased substantially and SE is much reduced. Predictions from this equation are compared with observed values in Figure 9. These predictions provide very good estimates of the 90-day low flows at Coes Ford and the residual errors for the regression 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.

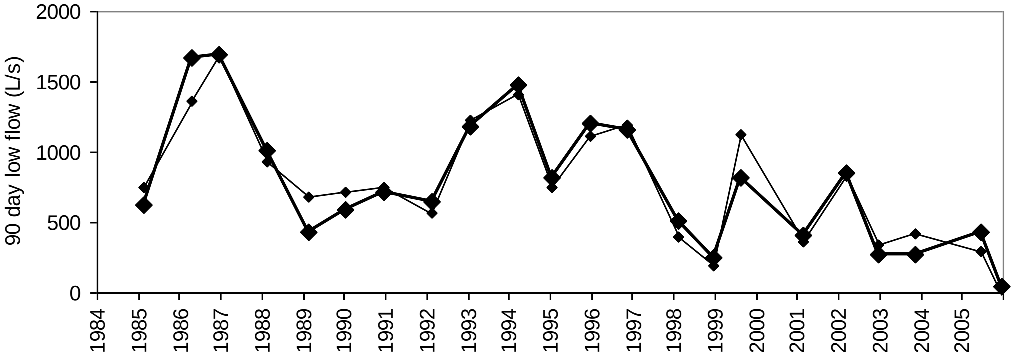

Figure 9: **Observed (heavy line) and predicted (light line, using Equation 2) 90-day minima for Coes Ford.**

Discussion

30. The trend evident in Figure 8, and included in Equation 2, implies the low flows at Coes Ford decreased at a rate of about 32 (ie 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 latter period 1998-2006 were accounted for by the recharge data, the decrease must have occurred over and above the effect of the recent dry years.

31. One potential reason for the decrease is increases in irrigation abstractions from groundwater. However, it was difficult to quantify the irrigation abstractions because they were not measured directly. Data on irrigated area and irrigation use would be needed to directly evaluate this alternative. However, the trend term in the equation is consistent with increased abstraction from groundwater for irrigation over the period of recording.

32. From these results, it is possible that if enhanced recharge to groundwater occurs due to irrigation with water from the proposed Central Plains Irrigation Scheme, low flows in the lower Selwyn/Waikirikiri may be enhanced through recharge.

33. This is only a proposition and it needs careful consideration. A first step would be to examine the robustness of these results in the light of the data that have accumulated since 2006.

Conclusions

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

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

36. Since low rainfall in some years was quantified by the recharge data, the decrease observed is likely to be due to other causes. The trend is consistent with increased pumping for irrigation.

37. The robustness of these results in the light of the data that have accumulated since 2006 needs to be confirmed.

38. It is possible that if enhanced recharge to groundwater occurs due to irrigation with water from the proposed Central Plains Irrigation Scheme, low flows in the lower Selwyn/Waikirikiri may be enhanced.

Acknowledgements

39. The report draws on material by the author and J. Schmidt titled “Decreases in low flows in the Selwyn River?” and published in the New Zealand Journal of Hydrology V46(2), p63-72.

Alistair McKerchar

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